BMI/ONWI/C-308

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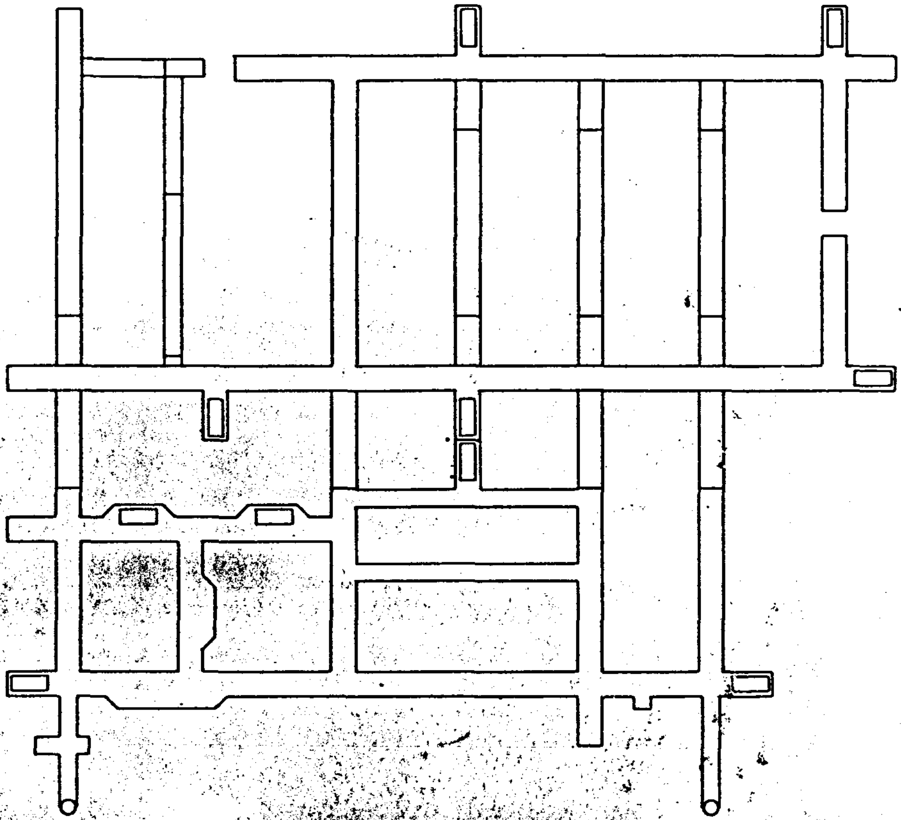
DRAFT SHAFT STUDY PLAN FOR AN EXPLORATORY SHAFT FACILITY IN SALT



BMI/ONWI/C--308

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Prepared for

OFFICE OF NUCLEAR WASTE ISOLATION

Submitted by

GOLDER ASSOCIATES
Redmond, Washington

in association with

SHANNON & WILSON, INC.
SLOPE INDICATOR COMPANY

CONTRACT No. E512-09900
March 1987
WBS 6.9.4.2
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DISCLAIMER

BMI/ONWI/C-308

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GOLDER ASSOCIATES, INC.
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Seattle, Washington

and

SLOPE INDICATOR COMPANY
Seattle, Washington

March 1987

MASTER

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WBS: 6.9.4.2

TECHNICAL STATUS

This technical report is being archived in advance of DOE technical review because of Congressional shutdown of the Salt Repository Project. Because of project termination, DOE has expedited the report clearance process to ensure availability of project data. A summary of the review status of this report is attached.

FOREWORD

This Study Plan has been prepared to document the currently proposed program of testing and monitoring for the Exploratory Shafts (ESs) at the Deaf Smith County salt site. Because of the continually evolving designs of the Exploratory Shaft Facility (ESF) and of the geologic repository, and the incomplete status of numerous program components that directly affect the completion of the Shaft Study Plan, it is not possible to prepare a definitive plan at this time. However, because of the impact that the shaft testing and monitoring program will have on design and construction, it is necessary to prepare a document to enable other program contractors to make an initial evaluation of the impact of the program on design and construction scheduling. It is also necessary to document the testing and monitoring program to enable a technical evaluation of its suitability and completeness.

The site characterization activities described in the Study Plan have been developed based on an evaluation of currently identified information needs. However, site characterization requirements will ultimately be defined by the Site Characterization Plan which is currently being prepared. While it is anticipated that the Shaft Study Plan will generally address the requirements defined in the Site Characterization Plan, it cannot be finalized until these requirements are known.

The preliminary Title I design for the ESs used for developing the testing and monitoring program was the most current and complete design available at the time. However, the general arrangement of the linings, as well as design details, are currently under review. This may result in a complete change in the general arrangement for the shafts, with corresponding changes in monitoring and testing locations. The Study Plan presents the general level of testing and monitoring proposed for the shafts regardless of the final layouts. Detailed instrument array installation drawings have been prepared only for representative areas of the shafts because of the current status of the design. A complete set of detailed drawings will be prepared when the shaft layout is finalized.

The layout of the instrumentation installed from the shafts has been designed on the basis of a synthetic geotechnical database developed for the ESF site from available geological, geotechnical, and hydrological information. Since this information generally comes from boreholes drilled at some distance from the site, some variations are expected between the synthetic database and actual field conditions. However, the synthetic database provides a common set of reference data to which the shafts and shaft instrumentation can be designed, although it is recognized that instrumentation will ultimately be installed based on actual field conditions. Title I drawings were prepared prior to publication of the synthetic data base. Several inconsistencies therefore exist in the document as a result of incorporating both the synthetic data base and Title I design.

Data management requirements for the program will ultimately be defined in a program Data Management Plan, which is currently being developed by ONWI. Details of the data management strategy for the underground testing program cannot be developed until the program Data Management Plan is available. Similarly, no Field Management Organization has currently been developed, so the Field Project Organization for the Underground Testing Contractor has been developed independently.

Preanalyses will be performed to assist in the design of a variety of geomechanical, thermomechanical, and geohydrological instrumentation. The purpose of the preanalyses is to provide a realistic estimate of the ranges of responses to be measured by the instrumentation so that appropriate instrument ranges and accuracies can be specified. Currently, only very limited preanalysis has been performed. The preanalysis section of the Study Plan therefore generally discusses the preanalysis requirements rather than the results of preanalysis. Preanalysis results will be incorporated into subsequent versions of the Study Plan and will be used for instrumentation design as they become available.

EXECUTIVE SUMMARY

This draft Shaft Study Plan describes a program of testing and monitoring in the Exploratory Shafts of a candidate high-level nuclear waste repository site in Deaf Smith County, Texas. The purpose of the program is to assist with site characterization in support of a determination of site suitability for development as a repository, for preparation of licensing documentation, and to provide information in support of repository design and performance assessment evaluations.

The program includes a variety of geological, geophysical, geomechanical, thermomechanical, and geohydrological testing and monitoring. The program is presented as a series of separate studies concerned with geological, geomechanical, and geohydrological site characterization, and with evaluating the mechanical and hydrological response of the site to construction of the shafts. The various studies, and associated test or monitoring methods, are shown in Table ES-1. The procedure used in developing the test program has been to initially identify the information necessary to satisfy (1) federal, state, and local requirements, and (2) repository program requirements. These information requirements have then been assessed to determine which requirements can be addressed wholly or in significant part by monitoring and testing from within the shafts. Test methods have been identified to address specific information requirements.

The components of the shaft study program are described individually. Initially, the test rationale discusses why the test is performed, and what information the test is expected to provide. The type of test or tests that will be performed, the test location within each shaft, site-dependent requirements of the test layout, and scheduling of the test relative to construction activities are then discussed. The emphasis in the test descriptions is on facility-dependent aspects of the test program, since details of test procedures have been developed separately. The data collection system, which forms an integral part of the test program, is discussed in conjunction with each test method. Details of the instrument performance requirements, and of the data monitoring requirements, are presented following the descriptions of the individual tests.

The Study Plan has been developed, based on currently available interpretations of site conditions and the current ESF design, to be as site-specific as possible. Where current data have limited the level of detail of design of the monitoring and testing program, these limitations have been noted along with a discussion of requirements for additional data.

Table ES-1. At-Depth Studies

Study	Testing or Monitoring Method
Geology	Geologic Mapping Core Logging
Shaft Mechanical and Thermal Response Study	Convergence Monitoring Multiple Position Borehole Extensometer Monitoring Embedment Stress Cell Monitoring Bitumen Pressure Cell Monitoring Rebar VWSG Monitoring Steel Liner Welded VWSG Monitoring Embedded Concrete VWSG Monitoring Piezometric Monitoring Jointmeter Monitoring Rock Bolt Monitoring Shaft and Rock Mass Temperature Monitoring
Mechanical and Thermal Properties Study	Absolute Stress Measurement NX Borehole Jack Testing Seismic Velocity Study Large Diameter Core Sampling Thermal Conductivity Testing
Shaft Seal Study	Groundwater Inflow Monitoring Permeability Testing Cross-hole Tracer Testing Formation Fluid Sampling Piezometric Monitoring
Shaft Construction Support Study	Blast Vibration Monitoring Rock Bolt Pull-out Testing

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1.0 INTRODUCTION

This Shaft Study Plan (SSP) has been prepared in support of the requirement for detailed site characterization of the Deaf Smith County candidate repository site in salt, and describes the site characterization and facility performance (i.e., geomechanical, thermal, hydrological) monitoring program to be performed from within the shafts of the Exploratory Shaft Facility (ESF). Section 1.1 discusses the programmatic background to the plan, Section 1.2 presents the scope and purpose of the plan, Section 1.3 discusses previous studies pertinent to this plan, and the organization of the document is given in Section 1.4.

1.1 BACKGROUND

The Nuclear Waste Policy Act (NWPA) of 1982 has established a federal mandate and schedule for high-level nuclear waste (HLW) disposal in a deep geologic repository. In this Civilian Radioactive Waste Management (CRWM) program, various federal agencies have the following responsibilities:

- The U.S. Environmental Protection Agency (EPA) has established environmental standards for HLW disposal (40 CFR Part 191)
- The U.S. Nuclear Regulatory Commission (NRC) will determine that compliance with EPA's long-term performance criteria, as well as other criteria related to health and safety, will be reasonably assured; a formal licensing process and technical criteria have been established by NRC (10 CFR Part 60)
- The U.S. Department of Energy (DOE) will select and investigate potential sites, and design, construct, operate and decommission the repository, as approved by NRC through the licensing process; siting guidelines have been established (as required by NWPA) by DOE (10 CFR Part 960). Within DOE, this overall mission will be carried out by the Office of Civilian Radioactive Waste Management (OCRWM).

The President, as required by the NWPA, has approved the recommendation of three candidate repository sites for detailed site characterization. The Deaf Smith County Site, Texas, is one of the three sites to be characterized. A Site Characterization Plan (SCP) will be submitted to the NRC, with semi-annual updates, to report site investigation activities, identify unresolved issues, and prepare methods for their adequate resolution. Site characterization will include laboratory testing, surface-based field investigations, and subsurface-based field investigations from within an ESF at the candidate repository site. The detailed site characterization program will support selection of a site for development as a repository, preparation of a license application for the selected site, and repository design.

1.2 PURPOSE AND SCOPE

This Shaft Study Plan describes that part of the Salt Repository Project (SRP) underground testing program which will be carried out within the two shafts constructed to provide access to the Deaf Smith County, Texas, Exploratory Shaft Facility (ESF). The shaft testing program has been designed to satisfy an appropriate subset of the underground testing information requirements currently contained in the Underground Test Plan (Golder Associates, 1986a). The requirements will eventually be quantitatively defined in the Site Characterization Plan which will become the "parent" document to the Shaft Study Plan. The relationship of this plan to the overall hierarchy of documents associated with underground testing within the ESF in salt is shown in Figure 1-1.

The purpose of this plan is to present the information needs to be satisfied by this study, describe the program designed to address these information needs, present the rationale for performing particular tests, provide a concise description of the test performance (often by reference to supporting test procedures), and indicate test locations, durations, and schedules.

The broad objectives of shaft instrumentation and monitoring include:

- To provide site characterization data/information required for preparation of an Environmental Impact Statement (EIS) and, if the site is selected for a repository, data/information required in a License Application (LA) to the NRC

- To provide confirmation of the Repository and ESF design by monitoring the performance of designed shaft components

- To provide data/information required by an ESF maintenance plan designed to assure the 100 year design life of the permanent ESF structures

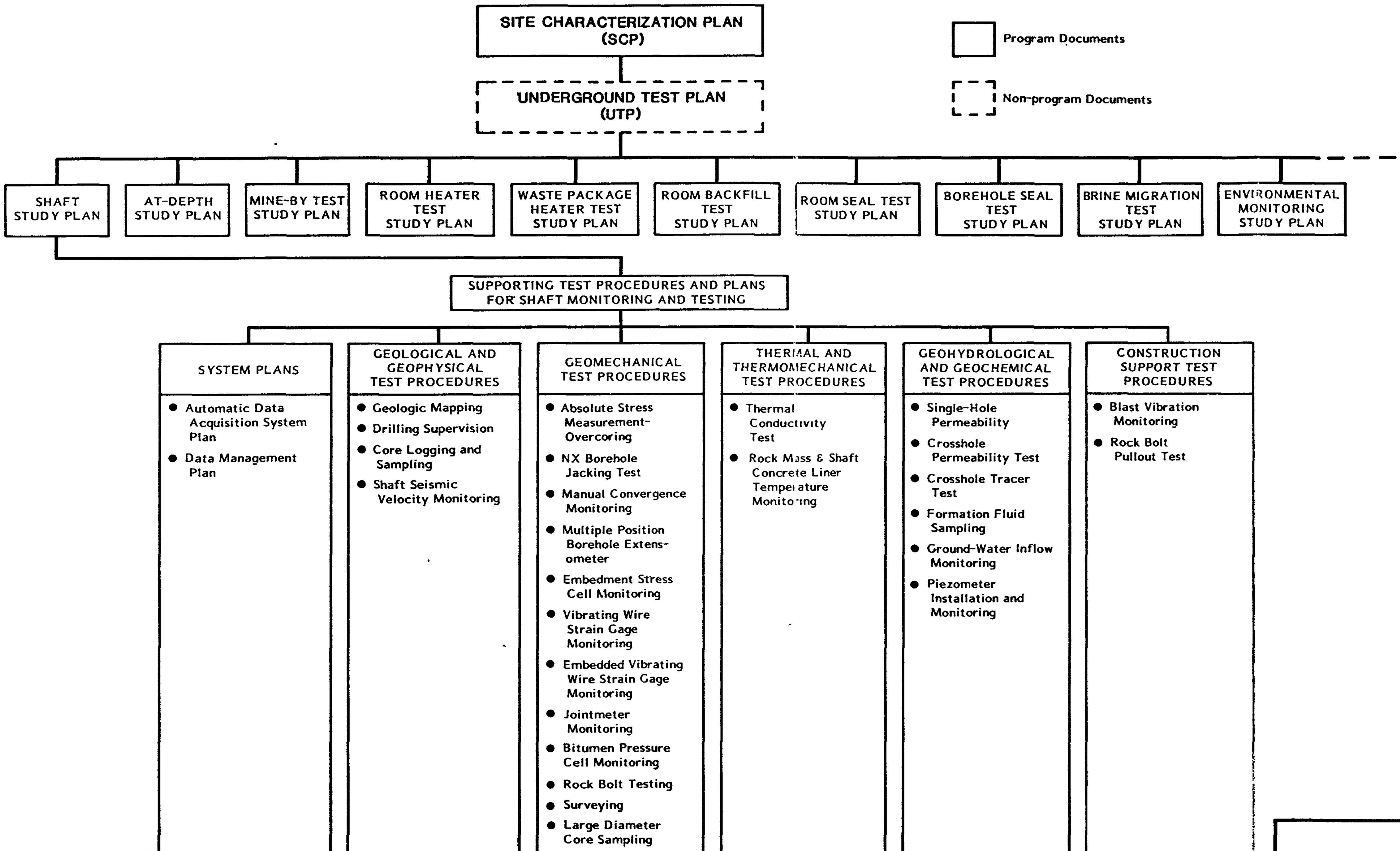
- To provide documentation of as-built conditions for those ESF facility components which will be incorporated into the repository.

The program proposed to meet these broad objectives includes:

- Shaft Geology Study: consisting of geologic mapping of the shaft walls and geological/geotechnical logging of core recovered during instrument installation and testing

- Shaft Mechanical Response Study: consisting of monitoring of the shaft lining, foundation/support ring/seal, shaft station, and shaft bottom plug mechanical responses to external ground-water and rock mass loads

- Shaft Mechanical/Thermal Properties Study: consisting of geomechanical testing (e.g., absolute stress measurement, borehole jack testing, seismic velocity surveying) and thermomechanical testing (e.g., thermal conductivity testing)



Shaft Study Program

Figure 1-1

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- Shaft Seal Study: consisting of geohydrological characterization testing at operational seal locations, geohydrological characterization and testing of the "construction-affected zone" at proposed decommissioning seal locations, and monitoring the performance of the operational seals

- Shaft Construction Support Study: consisting of blast vibration monitoring and rock bolt testing.

Future updates of this Study Plan will reflect any changes that may better define the information needs to be satisfied by underground testing at the Deaf Smith County site. These changes may result from additional site-specific information from on-going site characterization activities, modification to the design of the At-Depth Facility (ADF), future definition of the licensing strategy (i.e., identification of those components/processes of the repository system for which credit will be taken in performance evaluations), and quantitative sensitivity studies to be addressed by underground testing.

1.3 PREVIOUS STUDIES

Site characterization testing from, and performance monitoring of, underground openings in salt or salt-like rocks, have been performed in connection with mining, energy storage, and HLW disposal activities. This information has been used in designing the program of testing and monitoring described in this Study Plan. The HLW disposal test programs at Lyons, Kansas; Avery Island, Louisiana; Asse Mine, Federal Republic of Germany; and the Waste Isolation Pilot Plant (WIPP) near Carlsbad, New Mexico, are of particular interest and have been briefly summarized in the Underground Test Plan (Golder Associates, 1986a).

In addition to field test programs, a number of documents have been prepared previously which describe various aspects of the overall waste disposal program relevant to this Study Plan. These include:

- Environmental Assessment (EA), prepared by the Department of Energy (DOE), May 1986. This document evaluates the suitability of the Deaf Smith County site for a mined geologic repository in accordance with DOE guidelines.

- Mission Plan, prepared by the DOE, June, 1985. This describes the overall goals, objectives and strategy for the disposal of spent nuclear fuel and high-level waste. The plan presented is designed to comply with the requirements of the NWPA; it contains an evaluation of information required by the NWPA.

- Draft Underground Test Plan (UTP), Revision 1, prepared by Golder Associates, February 1986, which presents the rationale for the proposed suite of tests and describes the tests at a conceptual level. This includes descriptions of the repository system and site conditions. Information needs are identified from regulatory requirements since the Site Characterization Plan was not available at the time this document was prepared. The test program schedule and quality assurance programs are also addressed.

- Site Characterization Plan (SCP) to be prepared by the Office of Nuclear Waste Isolation (ONWI). This plan will provide the basis for identifying the number and type of tests and analyses to be performed during site characterization.

1.4 ORGANIZATION OF THE SHAFT STUDY PLAN

The shaft study plan has been divided into nine (9) chapters and three (3) supporting Appendices:

Chapter 2.0 provides the shaft study background and design information including: geological and geohydrological site conditions based on information contained in the Salt Repository Program (SRP) synthetic data base (ONWI, 1986a); a summary of the proposed shaft design and construction sequence excerpted from Parsons Brinkerhoff/PB-KBB's Exploratory Shaft Facility (ESF) Draft Final Design Report (PB/PB-KBB, 1986); and the proposed construction schedule.

Chapter 3.0 discusses the regulatory, repository design, and ESF design confirmation information requirements and the information requirements that will be addressed by the shaft instrumentation and testing program.

Chapter 4.0 presents the shaft testing and monitoring program. This includes: an overview of the proposed test methods and the explicit relationship between test methods and information needs; a summary of the site Automatic Data Acquisition Systems (ADAS) and shaft ADAS sub-system; a summary of construction contractor support requirements; individual test/method descriptions grouped by technical study (e.g., geology, mechanical response, mechanical/thermal properties, geohydrologic properties, shaft seal, and construction support); definition of the design basis for shaft instrumentation; and data collection and ADAS monitoring requirements associated with the overall shaft testing/monitoring program.

Chapter 5.0, Data Management, describes the shaft data management packages, references the document where data management strategy and data reporting procedures are described in detail, and provides a brief description of these activities.

Chapter 6.0, Schedules and Milestones, describes the way in which the testing and monitoring program will be integrated with the construction activity and other concurrent testing activities. The schedule of the testing program is presented, and key milestones of the program and associated studies are identified.

The project organization and the qualifications of individuals assigned to specific tasks are discussed in Chapter 7.0, Organization and Management. The handling, transportation, and storage of samples, and the proposed health and safety requirements, are also described.

Chapter 8.0 describes the Quality Assurance program under which the shaft testing and monitoring will be performed. The level of detail presented in this section reflects the importance assigned to Quality Assurance procedures for the instrumentation and testing program.

The references cited in the Study Plan are listed in Chapter 9.0.

The results of a preliminary preanalysis for mechanical response monitoring are presented in Appendix A. Preanalyses required prior to thermal conductivity probe testing, facility thermal response monitoring, and hydrological testing are also discussed.

Appendix B provides representative examples of designs and specifications for the instrument array configurations and equipment for the Shaft Mechanical and Thermal Response Monitoring. Complete designs and specifications for this monitoring will be prepared when the shaft layout is finalized.

Appendix C describes the testing and laboratory studies required in direct support of the shaft testing and monitoring program, including pre-and post-analysis of underground tests.

2.0 SITE DESCRIPTION AND EXPLORATORY SHAFT DESIGN

The Deaf Smith County site is located in the north-central part of Deaf Smith County, in the southern High Plains of the Texas Panhandle as shown in Figure 2.1. The High Plains province is nearly flat, relatively undissected table land. Surface drainage is poorly integrated and is controlled by small, shallow lake basins (playas) and some sharply defined ephemeral streams (draws). A playa about 0.6 mile (1 km) in diameter and 20 ft (7 m) deep is located in the west-central part of the site. A second playa, about 1.3 miles (2.1 km) in diameter and 40 ft (12 m) deep, straddles the site boundary in the southeast. Most surface runoff is diverted into the playas, except in the northern part of the site where it drains into an unnamed tributary to North Palo Duro Creek. In the vicinity of the site, the land surface slopes gently to the east. Elevations on the site range from 3,985 to 4,065 ft (1,215 to 1,239 m) above sea level (DOE, 1986).

The site lies within the Palo Duro Basin, which is underlain by basement Precambrian crystalline rocks. Above the Precambrian sequence, marine sandstones and shallow marine carbonates are overlain by approximately 6,560 ft (2,000 m) of Permian clastic, evaporite, and carbonate rocks. Overlying the Permian deposits is approximately 1,000 ft (300 m) of Mesozoic and Cenozoic terrestrial deposits.

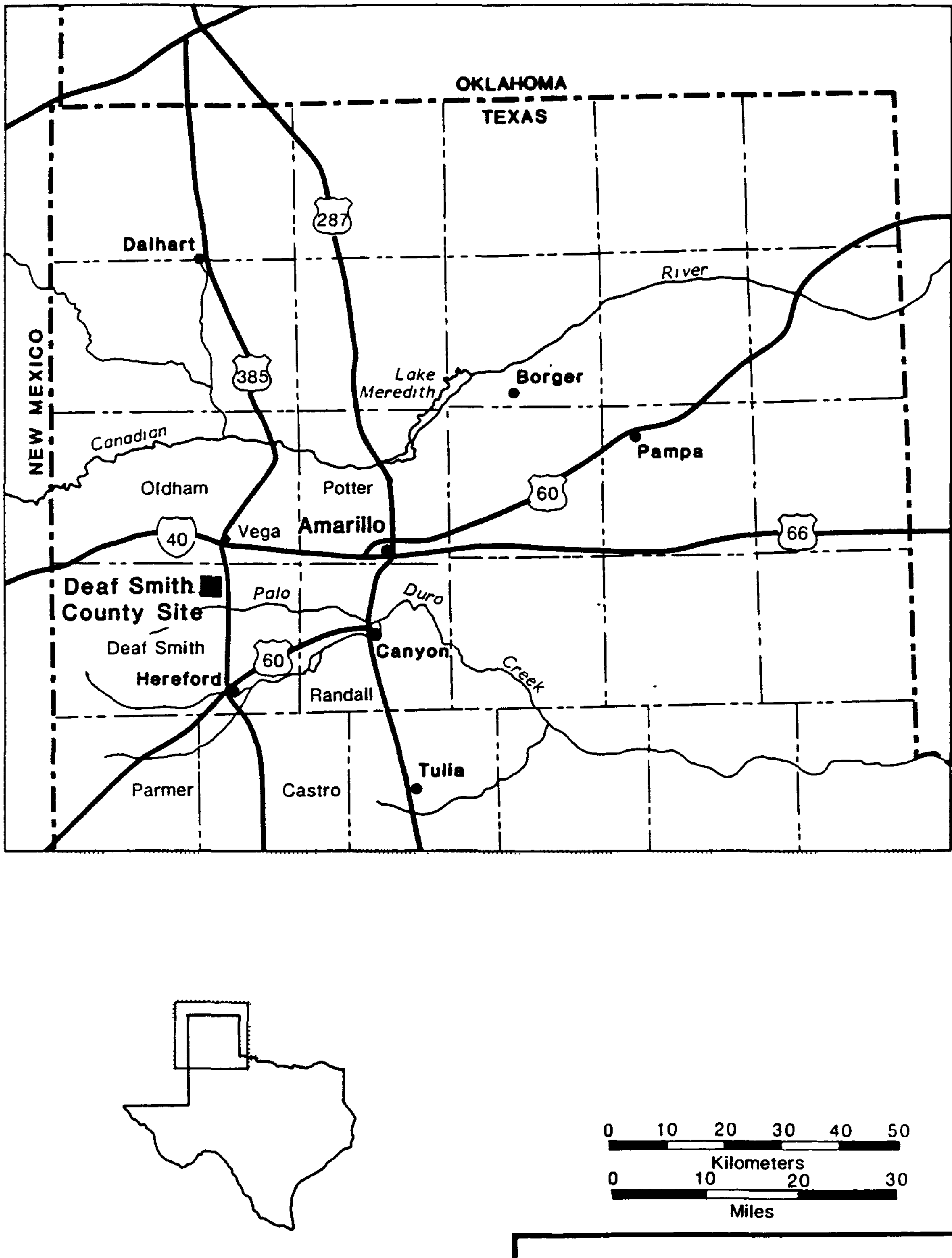
The Mesozoic and Cenozoic formations form a major hydrostratigraphic unit which can be characterized as a fresh water flow system containing important and heavily used aquifers. The Permian strata generally form a shale and evaporite aquitard of low overall permeability which is not considered to have potential as a source of water for any use. The bottom strata of the Permian sequence and all underlying sedimentary strata form an extensive underpressurized brine aquifer system of moderate to high permeability. There is a downward hydraulic gradient through the Permian strata.

No borings have been drilled into the Permian strata at the site because of the need to limit penetrations of the strata. Data from the closest boreholes to the site have been used to develop a synthetic database (Synthetic Geotechnical Reference Data for the Deaf Smith Site, ONWI, 1986a) which will be used for all design parameters until more specific data are available from drilling, development, and testing at the site.

The Exploratory Shafts are planned to be constructed from the ground surface to within the Unit 4 salt horizon of the Lower San Andres Formation. The depth to the top of this unit is about 2,371 ft (723 m), and the host salt sequence is assumed to be 161 ft (49 m) thick.

2.1 SUBSURFACE CONDITIONS

The geological and geohydrological conditions at the Deaf Smith County site will be primarily determined by analysis of core logs and tests carried out in vertical boreholes drilled as part of the Surface Based Test Program. The significant subsurface conditions to be characterized by the Shaft Study



Locality Map of Deaf Smith County Site

Figure 2-1

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Program include stratigraphy/lithology of strata penetrated by the shafts and soil/rock and hydrostatic pressures which will bear on the shaft linings. Other geological and geohydrological data, such as formation fluid density and permeability, are required for performance assessment and individual test design and preanalysis.

2.1.1 Geology

The Deaf Smith County site is located within the Palo Duro Basin in the Texas Panhandle. The basin is underlain and bounded by Precambrian crystalline basement rocks. Above the Precambrian sequence, discontinuous Cambrian, Ordovician, and Mississippian strata, and continuous Pennsylvanian shallow marine clastic and carbonate rocks are overlain by approximately 6,560 ft (2,000 m) of Permian clastic, evaporite, and carbonate rocks. Overlying the Permian deposits are 985 to 1,970 ft (300 to 600 m) of Mesozoic and Cenozoic terrestrial deposits. The sedimentary rocks within the site area are nearly flat-lying (DOE, 1986a).

Site-specific subsurface geologic information will not be available until completion of the Engineering Design Boreholes (EDBHs) to be drilled along the centerline of each of the Exploratory Shafts. The available subsurface geologic information comes from the analysis of well data within a 3,900 square mile (10,000 square kilometer) area around the site. The closest borehole to the site (J. Friemel No. 1 well) is located about 3 miles (4.8 km) south of the site. The estimated stratigraphy at the Deaf Smith County site is given in Table 2-1, and is based on the Synthetic Geotechnical Design Reference Data Hypothetical Core Log at ESF Location (ONWI, 1986a). These synthetic data are based on nearby well data and on descriptions of core from the J. Friemel No. 1 well.

The generalized stratigraphic column at the site, shown in Figure 2-2, is also based on the Synthetic Geotechnical Design Reference Data Hypothetical Core Log at ESF Location (ONWI, 1986a). The near-surface non-evaporite section consists of the Blackwater Draw Formation, Ogallala Formation, Dockum Group, and Dewey Lake Formation. This section is underlain by an evaporite section consisting of the Alibates, Salado, Yates, Upper and Lower Seven Rivers, Queen/Grayburg, and Upper and Lower San Andres Formations. The candidate host rock is the Unit 4 salt horizon of the Lower San Andres Formation.

The Ogallala Formation consists of silty sands, some clays, and basal gravels and sands. Below a 5- to 10-ft (1.5- to 3-m) thick caliche layer near the top of the formation, the unit is unconsolidated or variably cemented, with cementation increasing with depth. Porosity and permeability are generally high (DOE, 1986a). Below the Ogallala Formation, the Dockum Group and the Dewey Lake Formation consist of lithified gravels, sands, silts, and clays. Portions of the Dockum Group are poorly lithified. Running sands are present in the Ogallala and Dockum, and plastic or water-sensitive shales occur within or below the Dewey Lake Formation (Parsons Brinckerhoff/PB-KBB, 1983).

Table 2-1. Estimated Stratigraphy at the Deaf Smith County Site[a,b]

(Page 1 of 3)

Geologic Unit	Elevation of Top[c] from MSL (ft)	Depth to Top from Ground Surface (ft)	Thickness (ft)	Lithology[d]
Blackwater Draw Formation	4,033	0	65	Topsoil overlying loess.
Ogallala Formation	3,968	65	275	Reddish-tan silty sand, some clay; unconsolidated to cemented; caliche caprock; gravel and sand base.
Dockum Group	3,693	340	621	Red-brown and gray-green siltstone and claystone with beds of sandstone.
Dewey Lake Formation	3,072	961	74	Blue-green and red-brown siltstone and claystone.
Alibates Formation	2,998	1,035	32	Light gray to purple dolomite with siltstone/claystone at top.
Salado Formation	2,966	1,067	67	Red-brown siltstone with some gypsum; anhydrite at base.
Yates Formation	2,899	1,134	65	Interbedded red-brown siltstone and claystone.
Upper Seven Rivers Formation	2,834	1,199	130	Thin bed of gray anhydrite and red-brown claystone/siltstone overlying halite and interbedded halite, siltstone/claystone, and anhydrite.

Table 2-1. Estimated Stratigraphy at the Deaf Smith County Site[a,b]

(Page 2 of 3)

Geologic Unit	Elevation of Top[c] from MSL (ft)	Depth to Top from Ground Surface (ft)	Thickness (ft)	Lithology[d]
Lower Seven Rivers Formation	2,704	1,329	194	Interbedded halite, claystone/mudstone, salty sandstone, salty claystone/mudstone, and siltstone, with base of halite and anhydrite.
Queen/Grayburg Formation	2,510	1,523	180	Interbedded silty sandstone, claystone/mudstone, and siltstone, with siltstone and claystone at base.
Upper San Andres Formation	2,330	1,703	474	Massive beds of halite interbedded with claystone, siltstone, anhydrite, and sandstone. Interbedded anhydrite, halite, dolomite, and shale at the base.
Lower San Andres Unit 5	1,856	2,177	194	Upper section massive halite interbedded with red-brown siltstone/claystone and gray anhydrite; lower section alternating beds of bluish gray anhydrite, black claystone, and grayish brown dolomite.
Lower San Andres Unit 4	1,662	2,371	250	Massive halite with varying amounts of mudstone and anhydrite. Dolomite and limestone with anhydrite and shale beds at the base.

Table 2-1. Estimated Stratigraphy at the Deaf Smith County Site[a,b]

(Page 3 of 3)

(a) The location is assumed to be N 411,161, E 1,710,436 (Texas coordinate system, north zone) which is the location of a proposed engineering design borehole (EDBH).

(b) All tabulated thicknesses, depths, and elevations are estimates based on the Synthetic Geotechnical Design Hypothetical Core Log at ESF Location (ONWI, 1986(a)). The depths to the top of the corresponding lithologic units as shown on the sample description column of this core log may vary by several feet. Actual conditions are not known. It would constitute a misuse of this information to proceed with the expectation that conditions at this site location are exactly as estimated; however, variations between thicknesses presented in this table and those found at the site are expected to be similar to variations in thickness between program wells.

(c) Ground-surface elevation at the site location specified in Note 1 is 4,033 $\pm$ 2 ft above mean sea level (USGS, 7.5-Minute Topographic Series, Vega South Quadrangle, Texas, 1966).

(d) Lithologic descriptions are based on the Synthetic Geotechnical Design Hypothetical Core Log at ESF Location (ONWI, 1986(a)).

Source: ONWI (1986(a))

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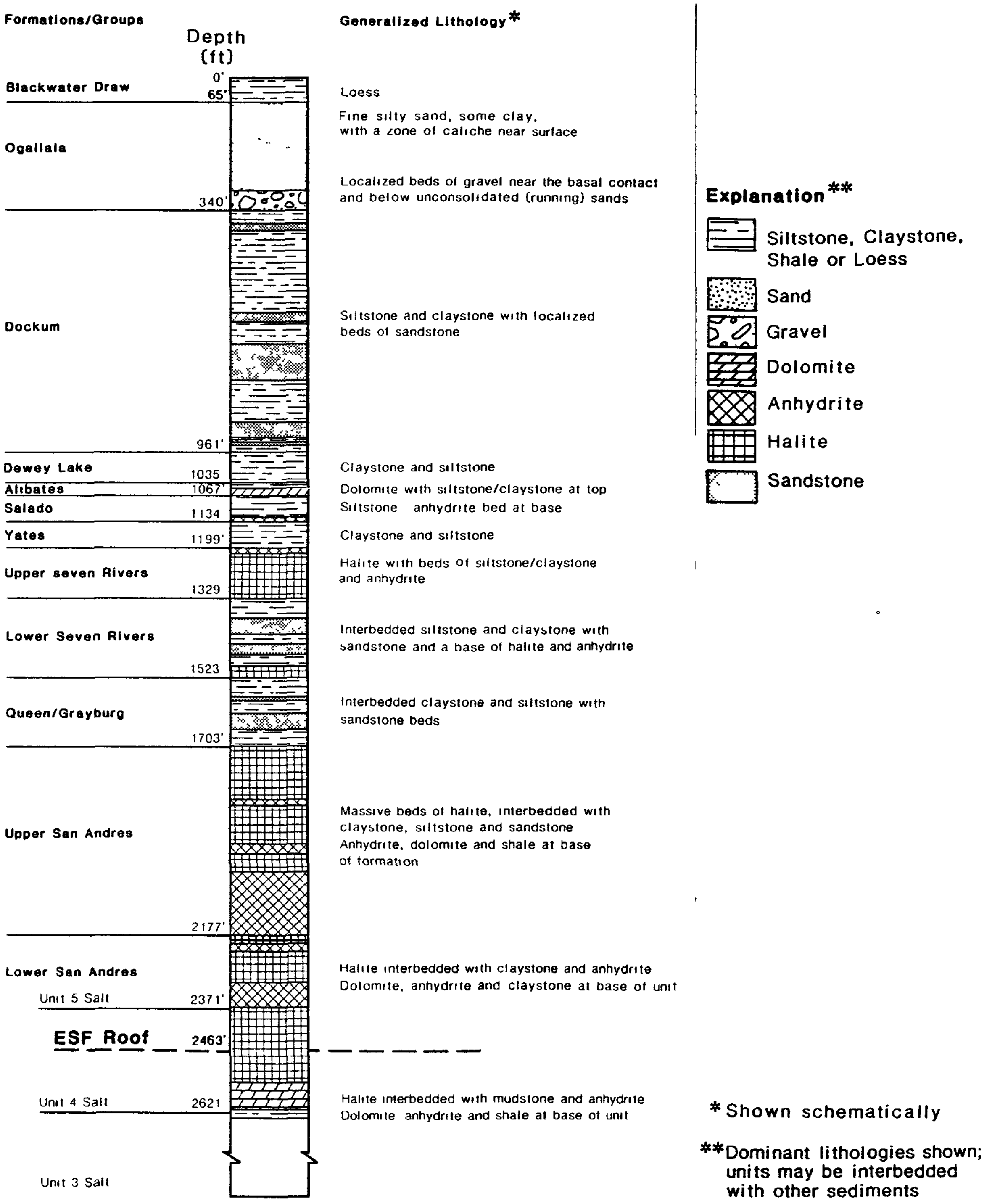

Source: Modified from Synthetic Geotechnical Design Reference Data (ONWI, 1986 (a))

Generalized Stratigraphic Column at the Deaf Smith County Site

Figure 2-2

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The Alibates Formation is composed of moderately strong dolomite and weak siltstone/claystone (ISRM classification) (DOE, 1986a), and forms a low-permeability zone between the upper aquifers and the salt-bearing rocks below. From the base of the Alibates Formation to the top of the Queen/Grayburg Formation, the units are predominantly interbedded saline clastics and evaporites. Locally, these units have been subjected to fracturing associated with paleodissolution and collapse, especially within the upper portion of the Salado Formation (DOE, 1986a). Fracture fillings include halite, anhydrite, or gypsum. The Queen/Grayburg Formation is composed predominantly of weak to strong sandstone, siltstone, and mudstone, and is a low-permeability unit.

The San Andres Formation above the proposed host horizon contains both salt and non-salt rocks. The anhydrites are strong to very strong rocks and have porosities which are typically less than 1 percent. The dolomites are classified as strong rocks and have porosities ranging from 2.5 to 15 percent. The salt rocks are weak to medium strong and essentially nonporous (DOE, 1986a).

Five salt cycles have been identified in the Lower San Andres Formation. The Unit 4 salt is being considered as a potential repository host horizon. At the Deaf Smith County Site, the Lower San Andres Unit 4 (LSA4) is expected to be approximately 250 ft (76 m) thick and is assumed to comprise about 161 ft (49 m) of bedded halite with interbeds and seams of mudstone and anhydrite, which is underlain by about 88 ft (27 m) of dolomitic limestone, dolomite, and anhydrite with thin shale beds (ONWI, 1986a).

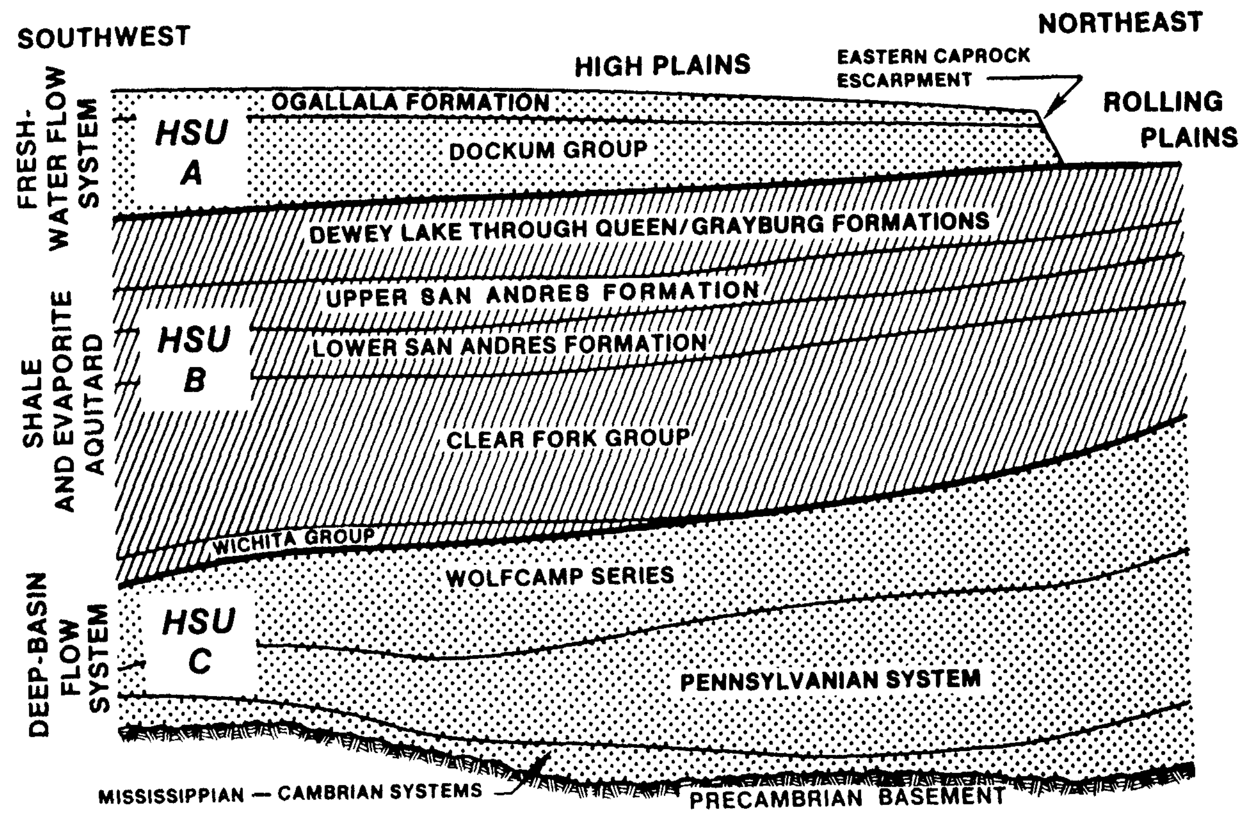
Geologic anomalies such as gas or brine pockets, collapse zones, faulted or fractured zones, or abrupt lateral facies changes are not anticipated at the site. The broad, uninterrupted depositional environment and the uneventful tectonic history subsequent to deposition argue against the presence of such anomalies, and none has been encountered in the near-site wells drilled to date. Fractures have been noted in cores obtained from the host rock, particularly in the mudstone interbeds. These fractures are typically filled with salt; no open fractures have been observed in any of the DOE wells.

2.1.2 Geohydrology

In the absence of site-specific data, hydrogeological conditions at the Deaf Smith County site have been inferred on the basis of existing information, principally the Synthetic Geotechnical Design Reference Data (ONWI, 1986a), and a range of earlier studies discussed below.

On a regional scale, the geohydrology of the Palo Duro Basin has been viewed by Bassett et al., (1981) and subsequent workers as a flow system consisting of three main hydrostratigraphic units (HSUs), as illustrated in Figure 2-3:

1. HSU A - Shallow freshwater flow system: This covers near-surface formations from Triassic to Quaternary and includes the main freshwater aquifers of the region, the Ogallala and the Dockum.



Source: Modified from Bair et. al. (1985)

Generalized Hydrostratigraphic Cross Section of the Palo Duro Basin

Figure 2-3

2. HSU B - Shale and evaporite aquitard: All the underlying Permian strata except the Wolfcamp are included in this grouping. They are composed predominantly of thick sequences of shales, siltstones, carbonates, and evaporites, giving a low overall permeability to the unit.

3. HSU C - Deep basin flow system: Older formations from the Cambrian through the Wolfcamp constitute an extensive brine aquifer system that acts as a basal underdrain to the overlying succession. The transmissive carbonates and granite-washes are more permeable than HSU B and so ground water in this unit is able to drain under the influence of lower potentials in the northeast at a faster rate than it can be recharged (Senger and Fogg, 1983).

The host horizon (LSA 4 salt) lies in the upper half of HSU B at a depth of 2,371 to 2,532 ft (723 to 772 m). One of the ESF shafts may be as deep as 2,670 ft, sufficient to penetrate the LSA 4 basal sediments.

The presence and distribution of groundwater in the various formations at the site is shown schematically on a tentative formation pressure diagram (see Figure 2-4). Site-specific geohydrologic parameter values have been ascribed on a formational basis (ONWI, 1986a) for ESF and repository design purposes. Table 2-2 includes a summary of parameter values relevant to geohydrologic studies in the shafts.

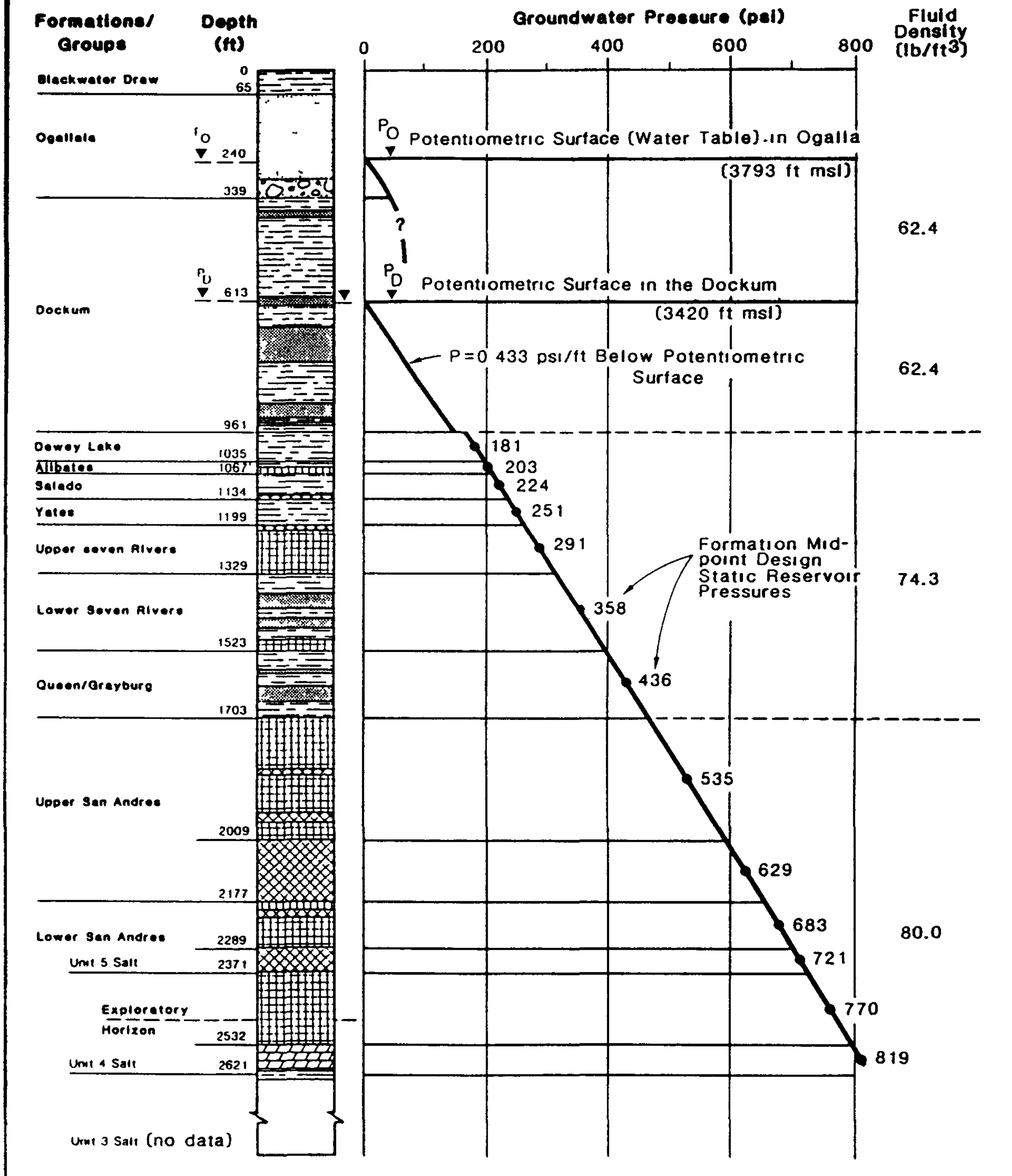
2.1.2.1 Shallow Freshwater Flow System (HSU A)

HSU A consists of the Blackwater Draw and Ogallala formations, and the Dockum Group. Generally, groundwaters in HSU A are young and have relatively low mineral contents (up to 1,500 mg/L). The recharge areas for these aquifers are in eastern New Mexico, and flow directions are southeast in the Ogallala and east in the Dockum (ONWI, 1986). Horizontal hydraulic gradients may be modified locally by ground-water withdrawal.

Blackwater Draw. The shallow Blackwater Draw formation is unsaturated and is not considered to be of any geohydrologic significance to the Shaft Study.

Ogallala. A substantial thickness of the Ogallala formation is unsaturated, the uppermost potentiometric surface being cited at 240 ft (73 m) depth. The saturated thickness of the Ogallala is therefore about 99 ft (30 m) at the site. The Ogallala constitutes one of the main freshwater aquifers in the High Plains, and was extensively pumped during post-war development in the area. The potentiometric surface is estimated to have declined by about 80 ft at the site during this period of sustained withdrawal (SWEC, 1984).

Dockum Group. In Deaf Smith County, extensive usage is made of groundwater from the Dockum Group. Permeable zones within the Dockum exhibit poor lateral continuity, making regional identification and stratigraphic correlation of water-yielding zones problematic. Two formations, locally known as the Chinle and the Santa Rosa (Bair, 1986), constitute the primary ground-water yielding zones within the Dockum, but typical elevations for



Source. Modified from Synthetic Geotechnical Design Reference Data

Note Discontinuity at Dockum/Dewey Lake Interface Results from Assumed High Fluid Density (74.3 lb/ft3) Above the Queen/Grayburg.

Tentative Ground-water Pressure Variation with Depth at the Deaf Smith County Site

Figure 2-4

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Table 2-2. Shaft Study Plan
Selected Geohydrologic Design Parameters

Formation	Thickness (ft)	Permeability (md)	Hydraulic Conductivity (gpd/ft^2) Horizontal	Vertical	Anisotropy (Kh/Kv)	Transmissivity[e] (gpd/ft)	Pressure[c] (psia)	Estimated Shaft Inflow (ft^3/d)	Specific Storage (ft^{-1})	Storativity[e]	Average Porosity (%)
Blackwater	65	-	-	-	-	-	-	-	-	-	-
Ogallala	275	12300	224	-	-	22400	3793 ft	-	-	-	16.1
Dockum[a]	621	5200	94	-	-	8742	3420 ft	-	-	-	24
Dewey Lake	74	5.3E-03	6.9E-05	1.8E-05	3.8	5.1E-03	181	2.1	9.43E-07	7.0E-05	19
Alibates	32	1.8	2.3E-02	2.2E-04	104.5	7.4E-01	203	160	4.48E-07	1.4E-05	19
Salado	67	5.1E-03	6.6E-05	1.7E-05	3.9	4.4E-03	224	2.9	4.05E-07	2.7E-05	12.8
Yates	65	5.4E-03	7.0E-05	1.9E-05	3.7	4.6E-03	251	4.1	6.67E-07	4.3E-05	22
USR	130	9.5E-03	1.2E-04	1.6E-05	7.5	1.6E-02	291	12.5	3.31E-07	4.3E-05	15.4
LSR	194	1.8	2.3E-02	9.7E-06	2371.1	4.5	358	1566	6.24E-07	1.2E-04	20
Q/G	180	0.3	3.9E-03	1.1E-05	354.5	0.7	436	344	2.12E-07	3.8E-05	6
USA (U)	306	7.1E-02	1.2E-03	4.8E-05	25.0	3.7E-01	535	240	1.79E-07	5.5E-05	2.2
USA (L)	168	8.6E-03	1.4E-04	9.7E-06	14.4	2.4E-02	629	36.3	1.28E-07	2.2E-05	3.5
LSA 5 (U)	112	1.1E-02	1.8E-04	3.4E-05	5.3	2.0E-02	683	35.2	1.42E.07	1.6E-05	0.6
LSA 5 (L)	82	7.9E-03	1.3E-04	8.2E-06	15.9	1.1E-02	721	19.3	1.86E-07	1.5E-05	3.2
LSA 4 (U)	161	1.3E-02	2.2E-04	7.5E-05	2.9	3.5E-02	770	63.1	1.78E-07	2.9E-05	1
LSA 4 (L,b)	71	5.0E-02	8.3E-04	4.6E-04	1.8	5.9E-02	819	3.2	1.38E-07	9.8E-06	5

Source: Synthetic Geotechnical Design Reference Data

Notes: (a) All parameters for the Dockum are based on the 93-ft thick Santa Rosa sandstone unit

(b) Thickness of LSA 4 Lower section excludes 18 ft of shale

(c) Elevation of potentiometric surface above MSL given for Ogallala and Dockum

(d) Shaft inflow is instantaneous rate for full formation thickness one day after instantaneous total penetration by unlined shaft

(e) Calculated using data contained in ONWI, 1986a.

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these formations at the site are not available. Ground-water level data for the Dockum (ONWI, 1986a) indicate a potentiometric surface 373 ft (114 m) below the Ogallala potentiometric surface (see Figure 3-4), indicating that the upper siltstones and claystones of the Dockum form an effective aquitard below the Ogallala. Consequently, at the Deaf Smith County site, the upper 274 ft (83.5 m) of the Dockum will be variably saturated, with conditions in individual sandstone beds ranging from dry to saturated but probably unconfined (unpressurized). Below 613 ft (187 m) depth, the Dockum should be saturated, but the presence of discrete sandstones interbedded with siltstones and claystones suggests a complex hydrostatic profile exists with a possibly discontinuous vertical pressure gradient. The lower Dockum consists mostly of siltstones and claystones which probably permit only limited leakage of freshwater into the underlying Permian sequence.

2.1.2.2 Shale and Evaporite Aquitard (HSU B)

The lithological characteristics of the formations from the Dewey Lake through to the Wichita Group (predominantly siltstones, mudstones and evaporites, with some carbonates and sandstones) combine to produce a substantial thickness of low-permeability sediments above and below the host horizon. On a regional scale, hydrodynamic studies (Bair, 1986) tend to support the concept of hydraulic connectivity across the full HSU B sequence, at least down to very low overall values of salt hydraulic conductivity (i.e., when K_v is greater than 9.3×10^{-17} m/s, equivalent to a permeability of 10^{-8} md).

Dewey Lake. Siltstones and claystones of the Dewey Lake formation are hydrologically similar to those in the lower Dockum. Permeability is low and the formation is expected to yield only minor quantities of water. No direct information on groundwater salinity is available. High salinity comparable to brine from the Queen/Grayburg (TDS of 309 g/L) is assumed for design purposes (ONWI, 1986); however, the hydrogeological setting would suggest only moderate mineralization (TDS less than 20 g/L).

Alibates. The Alibates formation consists of siltstone overlying dolomite, both being described as "hard" (ONWI, 1986(a)). The dolomite is ascribed a moderate permeability of 2.9 md and constitutes a potential source for groundwater inflow during shaft construction. No direct information on groundwater salinity is available. High salinity comparable to brine from the Queen/Grayburg is assumed for design purposes (ONWI, 1986a); however, the hydrogeological setting suggests only moderate mineralization.

Salado. The Salado contains some gypsum and anhydrite interbedded with predominant siltstone. The low permeability and presence of evaporites suggests moderately high mineralization of groundwater (TDS of 20 to 50 g/L), although brine salinity is assumed for design purposes.

Yates. The Yates is composed of low-permeability siltstones and claystones that probably inhibit downward movement of fresher groundwaters from the overlying argillaceous strata into the evaporite sequence below. The geophysical log from J. Friemel No. 1 Well (SWEC, 1984c) indicates relatively high neutron porosities (generally between 30 and 40 percent) for the Yates and all overlying strata, consistent with their predominantly clastic nature.

Upper Seven Rivers. The Upper Seven Rivers is predominantly evaporitic, being composed of an estimated 72 percent salt, with the remainder being mostly siltstone/claystone, either disseminated or as discrete stringers. Neutron porosities in the Seven Rivers formations range from high values for the clastic rocks, to low values for the evaporites. Evaporites predominate in underlying strata through to the Lower San Andres Unit 3, and neutron porosities are generally less than 5 percent. As the uppermost salt-bearing horizon, ground-water salinity can be expected to be high and is probably similar to that sampled from the Queen/Grayburg.

Lower Seven Rivers. Core is not available from the Lower Seven Rivers so its lithology has been based largely on geophysical logs (DOE, 1986a). The formation consists of claystones and siltstones (52 percent), sandstone (30 percent), and evaporites (18 percent). The sandstone is ascribed a permeability of 5.9 md (ONWI, 1986a) and is responsible for the high ground-water inflow estimate shown in Table 2-2.

Queen/Grayburg. The lithology of the Queen/Grayburg is similar to the Lower Seven Rivers, and includes sandstone beds with similar shaft inflow potential. However, the permeability quoted for this formation (0.3 md) is based on a pumping test in the J. Friemel No. 1 well (Wilton et al., 1986) and is lower than that calculated on the same basis for the LSR (22 md). Ground water sampled from the Queen/Grayburg formation (ONWI, 1986) is highly mineralized brine (TDS equals 309 g/L).

Upper San Andres. The upper 306 ft of the Upper San Andres is nearly 80 percent salt, with a further 20 percent anhydrite. Low porosity (less than 5 percent) and very low permeabilities (less than 0.1 md) are characteristic of these strata and each underlying salt cycle within the San Andres. The potential for groundwater movement in the upper sections of each unit is very small, and probably limited to low-permeability argillaceous interbeds. The lower sections of each unit reflect different depositional conditions, with carbonates and anhydrites present. Any mobile groundwater is likely to be saturated brine (TDS of about 400 g/L).

Lower San Andres Unit 5. The upper section is predominantly salt, with characteristics similar to those described for the Upper San Andres formation. The lower section is mostly gypsum and anhydrite, but does contain some thin discrete layers of dolomite and claystone/mudstone. Dolomite is ascribed a permeability of 0.05 md, and these layers may constitute the closest transmissive zones above the ADF.

Lower San Andres Unit 4. The host horizon lies within the salt strata in the upper section of the Lower San Andres Unit 4. Its lithology is described in detail in the Synthetic Data Base (ONWI, 1986). At the base of the deepest proposed shaft, the LSA 4 dolomite can also be considered potentially transmissive, the permeability for this stratum being determined from a pumping test conducted in J. Friemel No. 1 Well (Wilton et al., 1986) as 0.05 md.

2.2 SURFACE FACILITIES

The exploratory shaft surface facilities will be located on a 46-acre (19 ha) site with maximum dimensions of 1,280 ft (390 m) by 1,745 ft (532 m). Detailed surface facility descriptions presented in ONWI (1986a), DOE (1986a), and Parsons Brinckerhoff/PB-KBB (1986a) are illustrated in Figure 2-5.

Access and ventilation to the ADF will be provided by two 12-ft (3.7 m) inside diameter shafts approximately 2,500 ft (763 m) deep, located 525 ft (160 m) apart. The western shaft (Shaft 1) will serve as the ventilation intake and service shaft. The eastern shaft (Shaft 2) will be the exhaust ventilation and mucking shaft. During construction, an area of approximately 6 acres (2.4 ha) between the shafts will be available for fabrication and other construction-related activities. An additional area of approximately 5 acres (2 ha) will be available west and north of Shaft 1 for additional storage.

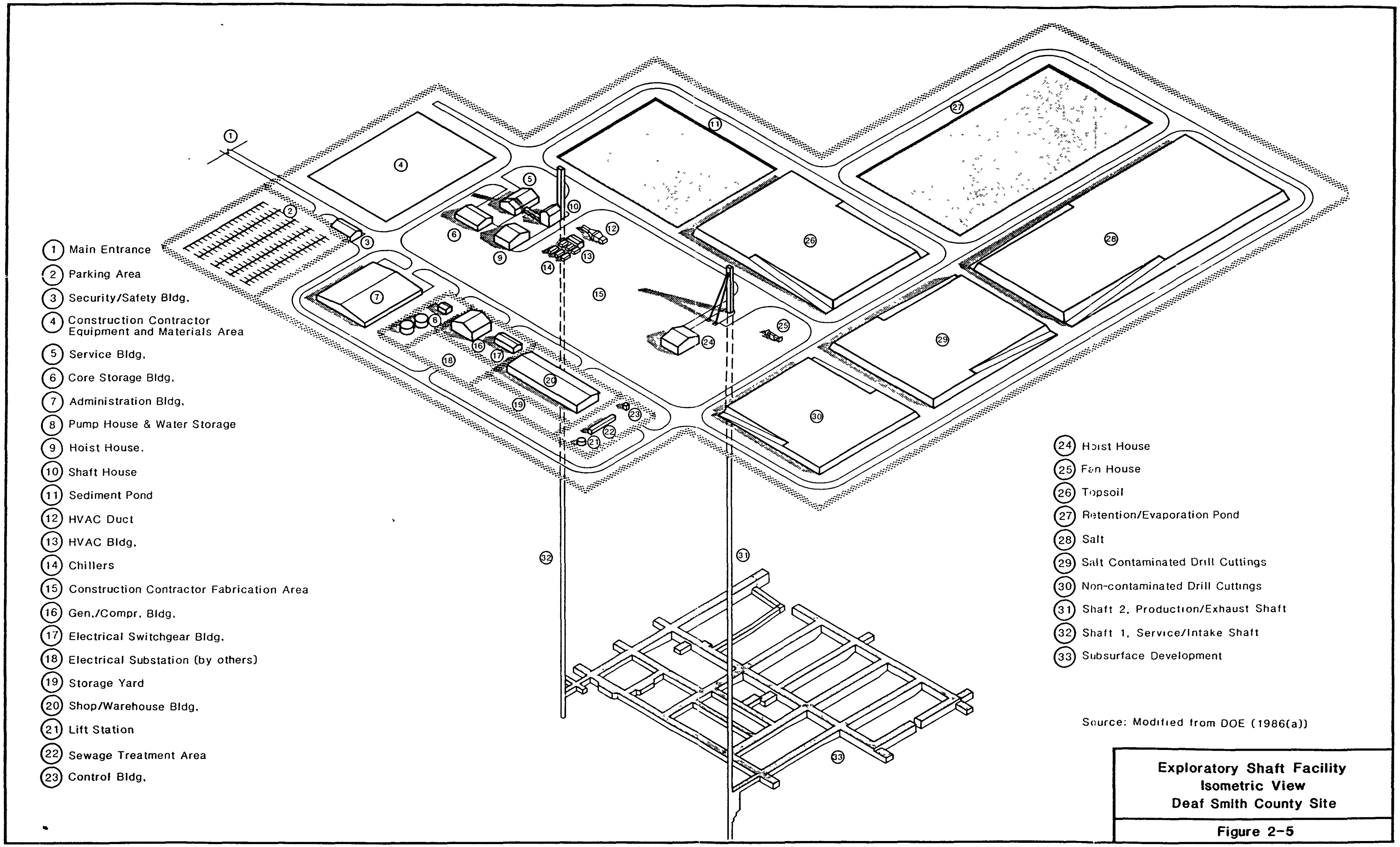
The shaft area will include structures to accommodate hoists, shaft houses, fans, and air conditioning units. Support buildings provided for site contractors will consist of trailers, or pre-engineered, modular, or prefabricated structures equipped with all necessary utilities. Space allocated to the Underground Testing Contractor (UTC) will include office and administrative space; Automatic Data Acquisition System (ADAS) and computing rooms; equipment storage, fabrication, repair, calibration, and testing facilities; and temporary sample storage facilities. Some of these facilities may be located off-site to minimize site disturbance and on-site activities.

Utilities provided at the surface will include potable and fire water supplies; connections to off-site and underground communications and data recording systems; clean, dry compressed air for machinery and instrumentation use; and electrical power. Primary power will be provided through an electrical substation linked to off-site commercial electric power at 4,160 V or higher. Standby power to all safety equipment and instrumentation, security systems, and instrumentation systems will be supplied by on-site emergency diesel generators integrated into the power grid. Uninterruptible power will be provided to critical equipment and instrumentation, and to the data acquisition systems.

2.3 SHAFT DESIGN SUMMARY

The Exploratory Shaft Facility (ESF) will consist of the two shafts and approximately 5,000 ft (1,524 m) of horizontal excavations which form the At-Depth Test Facility as shown in Figure 2-5. The current subsurface layout has been designed by the ESF A/E, Parsons Brinckerhoff/PB-KBB. The design process has been described in preliminary program documents (Parsons Brinckerhoff/PB-KBB, 1986a) and is summarized below.

The design of the ESF shafts has been based on the functional design criteria supplied by the Office of Nuclear Waste Isolation (ONWI, 1986b) and the existing geotechnical data base which consists of information obtained



Exploratory Shaft Facility
Isometric View
Deaf Smith County Site

Figure 2-5

WBS 6.9.4.2

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from boreholes outside the proposed repository block. Changes to the base conceptual design will occur as site-specific information is obtained from the Engineering Design Boreholes (EDBHs), which are currently planned to be drilled on the centerline of each shaft. It must be noted that the reference shaft design is the Title I design and does not include modifications which are currently (3/87) being prepared by Parsons Brinckerhoff/PB-KBB based on the SRP synthetic data base. Any conflicts which exist as a result of using this approach will be resolved in future planned updates to this study plan.

2.3.1 Functional Criteria for Design

Functional Criteria for Design (FCD) have been developed by ONWI (ONWI, 1986b) to provide technical direction for the development of Detailed Design Criteria, and hence the basis of satisfying the ONWI mission and OCRWM program objectives. Functional Criteria for Design for the ESF and support facilities have been summarized by Parsons Brinckerhoff/PB-KBB (1986a) in the Final Preliminary Design Report. Those criteria related to the shaft and shaft seals are given below.

- The composite shaft liners shall be watertight.
- Composite shaft liners and seals shall be designed to prevent the vertical migration of water between the major aquifers.
- If the optional composite shaft liner (i.e., portion below the Dockum) is not installed, the Title II design will be altered to include suitable water control.
- Components such as shaft lining seals which cannot be replaced by normal maintenance procedures will be designed for a 100-year life. Future licensing requirements will probably result in redefinition of criteria so that design at this time will be flexible to the extent that a minimum of redesign will be required to upgrade the elements.
- The ESF shafts shall be excavated and structurally lined using methods and materials based upon conventional shaft construction technology (i.e., drill and blast) for the shaft diameter and depths under consideration. Specifically, both shaft diameters shall be 12 ft finished, with the shaft depths ranging between 2,200 to 3,200 ft, to be determined on a site-specific basis.
- The shafts will provide access to the reference repository horizon to permit in situ testing of the salt to satisfy the following information needs:
  - Demonstration of the capability to adequately seal penetrations into the salt
  - Demonstration of the constructibility and confirmation of the ESF design.

- The design will minimize any adverse impacts which the facility may cause to the environment and any damage to the site should it be found suitable for a repository.

- An important parameter in the design process will be the health and safety of the public and of the workers.

- The design process will consistently employ sound engineering principles and practices.

- The ESF will be designed in accordance with applicable Federal, State, and local regulations, as well as applicable national consensus codes and standards.

- The exploratory shafts and related surface and subsurface facilities will be designed to be economical and reliable in construction, operation, and maintenance.

2.3.2 Geotechnical Data Base

The shaft design is based on existing geotechnical data obtained from surface exploration programs and associated laboratory testing. Information presented below is compatible with the ESF Final Preliminary Design Report (Parsons Brinckerhoff/PB-KBB, 1986a).

2.3.2.1 Hydraulic Pressures

For design calculation purposes, the various formations are considered to be saturated and hydraulically connected with the water table at a depth of approximately 200 ft. Table 2-3 presents the estimated hydrostatic loading conditions.

Initial in situ testing has indicated that the deeper formation (e.g., Wolfcamp) may be underpressured, leading to a downward hydraulic gradient. This condition does not affect the shaft design.

2.3.2.2 Ground Pressures

Three different modes of ground behavior have been incorporated in the design:

- Ground pressures for the Ogallala and Dockum formations were calculated assuming soil-like behavior.

- Ground pressures for other non-salt formations were calculated assuming rock-like behavior (e.g., based on rock quality).

Table 2-3. Total Pressures for Lining Design

Formation	Description	DEPTH (feet)		PRESSURES (psi)			
		Top	Bottom	Soil	Rock	Hydrostatic	Total
Ogallala	Sands, silts, clays, gravels caliche	0	200	49	-	-	49
Ogallala	Same	200	360	86	-	69	155
Dockum	Siltstone, shale, sandstone	360	960	287	-	329	616
Dewey Lake	Siltstone, shale	960	1,015	-	167	358	525
Alibates	Anhydrite, dolomite	1,015	1,060	-	134	381	515
Salado	Shale, siltstone	1,060	1,135	-	125	420	545
Yates	Siltstone, sandstone, shale	1,135	1,195	-	190	452	642
Upper 7 Rivers	Shale, siltstone, anhydrite, halite	1,195	1,335	-	207	524	731
Lower 7 Rivers	Same	1,335	1,520	-	231	621	852
Queen/Grayburg	Salt, siltstone	1,520	1,765	-	266	748	1,014
Upper San Andres	Shale, anhydrite, silt-stone halite	1,765	2,285	-	337	1,019	1,356
Lower San	Halite	2,285	2,375	-	*	*	*
Andres Unit 5	Basalt anhydrite, shale	2,375	2,475	-	365	1,118	1,483
Lower San Andres	Halite	2,475	2,635	-	*	*	*
Andres Unit 4	Basal anhydrite, shale	2,635	2,720	-	396	1,246	1,642

(After Parsons Brinckerhoff/PB-KBB, 1986a)

*Salt strata could develop full lithostatic pressure.

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- Ground pressures in the salt formations were assumed to be lithostatic (e.g., isotropic and equal to the overburden). This condition will be designed for by overexcavating and backfilling with compressible material so that the shaft lining will not experience full lithostatic loading during its design life.

Table 2-3 summarizes the loading conditions assumed for the design.

2.3.2.3 Seismic Design Input

The seismic stability analysis for the final shaft liner is based on the following design input

• Expected peak acceleration	0.1 g
• Expected peak velocity	3 in/sec
• Expected peak displacement	3.5 in
• Expected maximum seismic pressure surcharge	525 psi.

2.3.3 <u>Shaft Construction Method</u>

Geotechnical conditions at the Deaf Smith County site have indicated the need for ground stabilization prior to excavation in the Ogallala and Dockum formations. Options for ground stabilization were reviewed by the facility designer during preliminary design, and freezing was selected. The proposed procedure for shaft construction, incorporating freezing, is shown in Figure 2-6 and described below:

- An Engineering Design Borehole (EDBH) will have previously been cored along the centerline of each shaft

- Drill freeze, temperature, and relief boreholes and freeze ground to required depth (based on EDBH data)

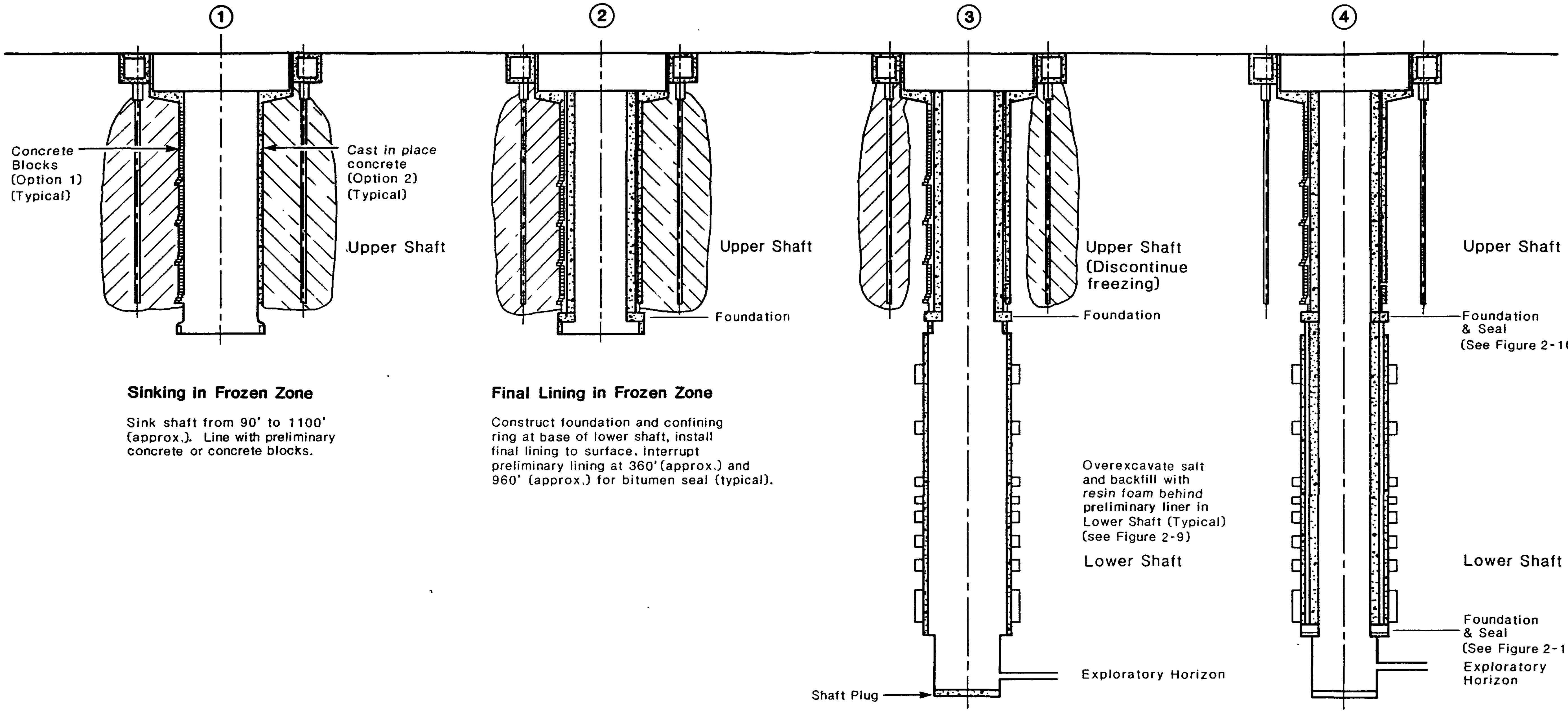
- Excavate, using conventional drill and blast methods, and install preliminary liner in upper shaft section (Figure 2-6, Step 1)

- Construct foundation/support ring and final lining in upper shaft (Figure 2-6, Step 2)

- Discontinue freezing operations and sink/preliminary line to planned base of shaft. Complete shaft stations and connecting drift between two shafts (Figure 2-6, Step 3).

A decision will be made, based on the EDBH, with respect to final lining the lower shaft. If a final lining is required, the following procedure will be carried out prior to shaft connection:

- Construct foundation/support ring and final lining in lower shaft to location of upper shaft seal. Install upper shaft seal and complete final lining (Figure 2-6, Step 4).



Sinking in Frozen Zone

Sink shaft from 90' to 1100' (approx.). Line with preliminary concrete or concrete blocks.

Final Lining in Frozen Zone

Construct foundation and confining ring at base of lower shaft, install final lining to surface. Interrupt preliminary lining at 360' (approx.) and 960' (approx.) for bitumen seal (typical).

Sinking Below Frozen Zone

Discontinue freezing operations. Sink shaft and line with preliminary concrete to within 80' (approx.) of facility horizon.

Final Lining (if required)

Construct foundation & Lower Shaft seal, install final lining and Upper Shaft seal. Abandon freeze holes by removing brine from pipes, perforating pipes and filling with cement grout. Install rockbolts & wiremesh below liner to facility horizon. Excavate exploratory station, install concrete shaft plug. Shaft connection then excavated.

Source: Compiled from PB/PB-KBB
Table I Drawing (PB/PB-KBB, 1986(a))

Shaft 1 and 2 Construction/ Lining Sequence Deaf Smith County Site

Figure 2-6

WBS 6.9.4.2

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2.3.4 Shaft Lining Design

The shaft design incorporates an evaluation of the support contribution provided by three principal components:

- The strata surrounding the shaft
- The preliminary shaft liner
- The final shaft liner.

The shaft liner design assumes uniform horizontal pressures corresponding to anticipated hydrostatic conditions and ground pressures (see Table 2-3). Provisions have also been made for additional loads resulting from seismic events and non-uniform pressures due to grouting, subsidence, and thermal effects.

The proposed shaft profile, including possible final lining in the lower shaft, is shown in Figure 2-7.

2.3.4.1 Preliminary Lining

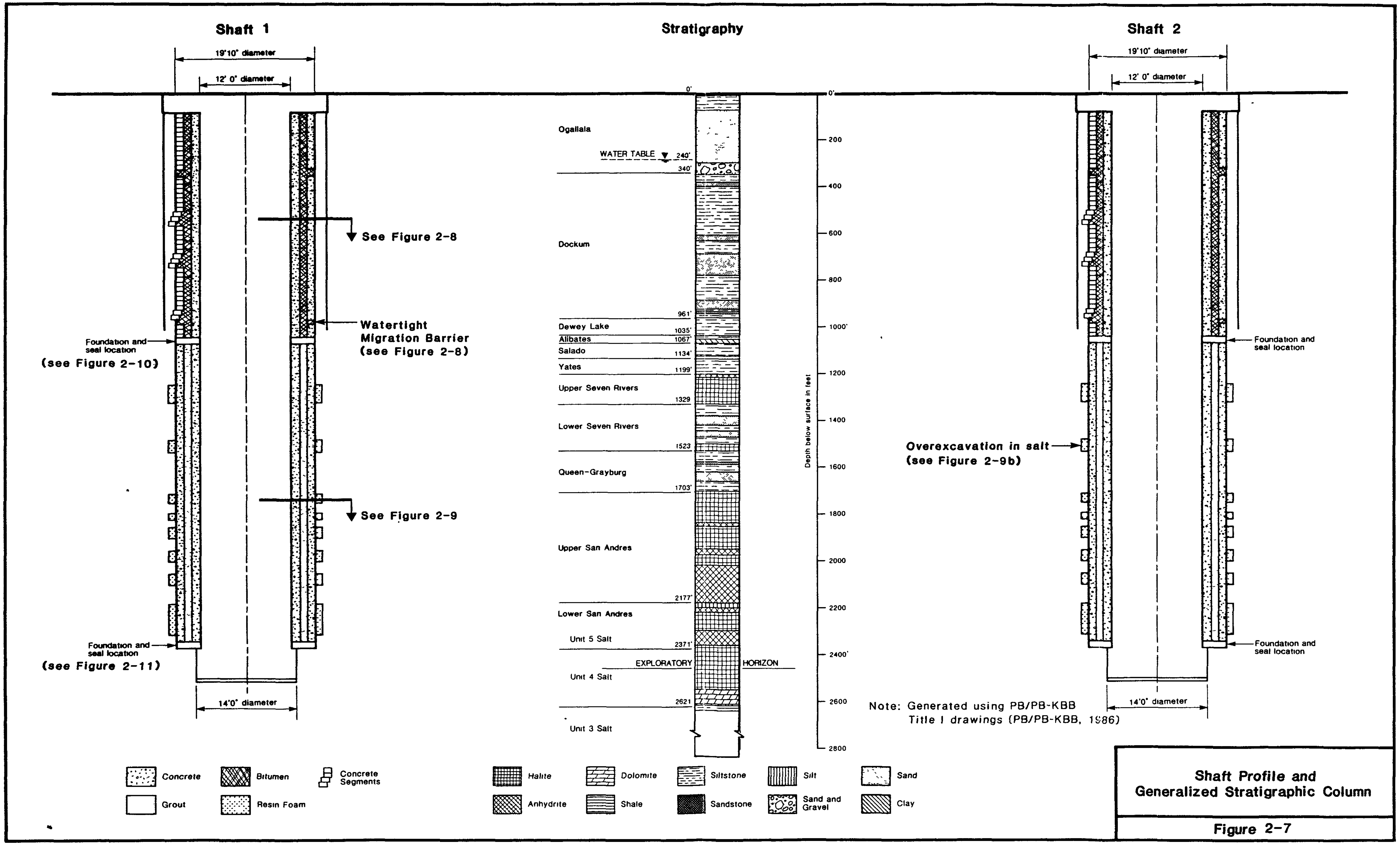
The primary objective of the preliminary lining is to provide ground support during shaft sinking and final lining installation. A maximum ground pressure of 200 psi has been assumed as a basis for calculating support requirements throughout the shaft length. This design limit assumes that the preliminary lining is not watertight and that potentially higher ground pressures will be controlled by overexcavating in salt strata and by careful sequencing of the excavation/lining process in frozen ground.

The timing of preliminary lining installation is of particular importance in the upper shaft, as convergence of the frozen ground must be controlled to prevent excessive deformation of the freeze holes. Allowable freezewall convergence will be determined, during final design, based on data obtained from the EDBH.

Preliminary lining options in the upper shaft include concrete block or cast-in-place concrete. Cast-in-place concrete is specified for the lower shaft. Details of the preliminary lining, including options, are provided on Figure 2-8 and Table 2-4..

2.3.4.2 Final Lining

The primary objectives of the final lining are to provide permanent shaft wall support and a watertight lining system. Total design loads therefore incorporate fully developed hydrostatic pressures and anticipated maximum ground pressures. The potential for lithostatic load development in salt horizons has been provided for by overexcavating in the salt strata and backfilling with a compressible material. Some concern exists with regard to the potential for higher lining loads due to swelling pressures or inward displacement of non-salt strata sandwiched between overexcavated salt beds.



Shaft Profile and Generalized Stratigraphic Column

Figure 2-7

WBS 6.9.4.2

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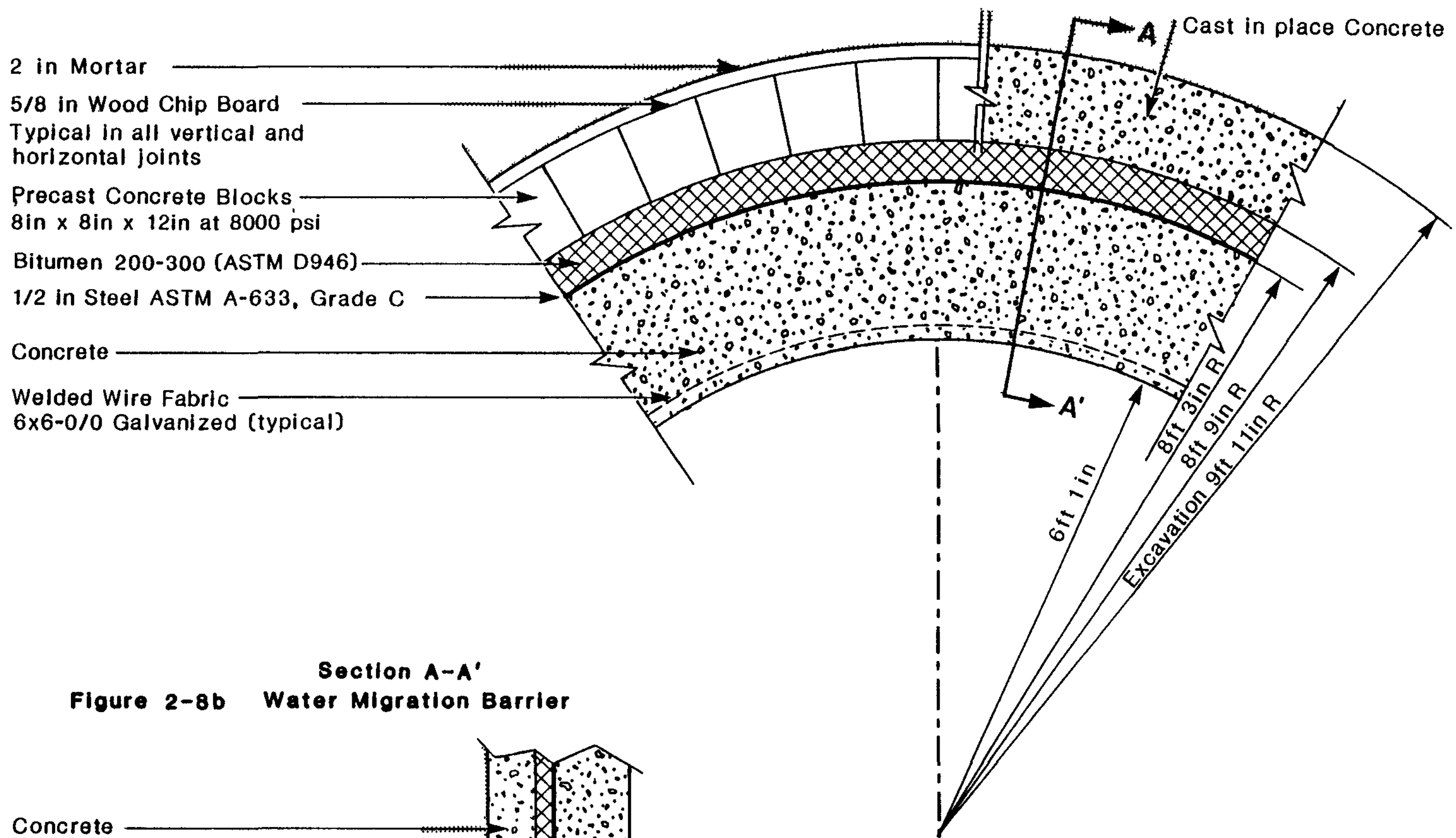
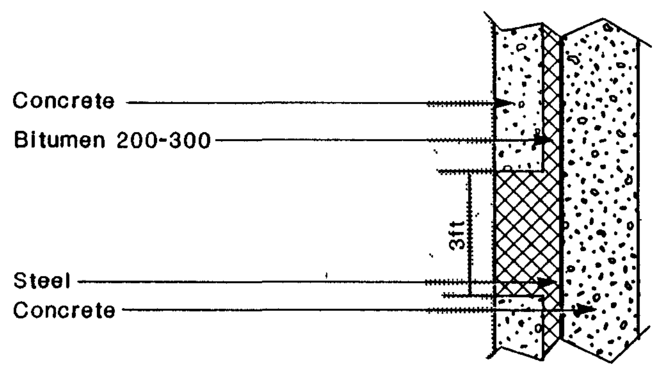
Figure 2-8a Section Through Upper Shaft Lining



Section A-A'
Figure 2-8b Water Migration Barrier



Note: Modified from PB/PB-KBB, 1986 (a)

Plan and Section Through the Upper Shaft Lining

Figure 2-8

Table 2-4. Shaft Lining Details

Depth[1] Interval (ft)	Preliminary Concrete (in)	Bitumen 200-300 (in)	Outer Steel (in)	Concrete (in)	Concrete Strength (psi)	Inner Steel (in)
0 - 1,150	14	6-8	0.5	25.5	6,000	--
		Sanded Cement Grout (in)				
1,150 - 1,470	10	4	0.625	25.5	6,000	--
1,470 - 1,710	10	4	0.625	25.5	8,000	--
1,710 - 2,135	10	4	0.625	24.75	8,000	1.00
2,135 - 2,250	10	4	0.625	24.5	8,000	1.25
2,250 - 2,350	10	4	0.625	24.25	8,000	1.375
2,350 - 2,475	10	4	0.625	24	8,000	1.625

[1]Modified from Parsons Brinckerhoff/PB-KBB, 1986(a).

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These potentially disruptive conditions will be evaluated by monitoring stresses and displacements within the lining system, as described in Section 4.4.

The final lining will be a composite structural liner consisting of an outer steel shell with loadbearing concrete to a depth of approximately 1,710 ft (518 m), with the addition of an inner steel liner from 1,710 ft (518 m) to approximately 80 ft (24 m) above the test facility horizon (see Table 2-4 for final shaft lining dimensions). Bitumen has been specified to fill the annulus between the outer steel liner and preliminary lining in the upper shaft, while cementitious grout has been specified for the lower shaft (see Figures 2-8 and 2-9).

2.3.5 Shaft Foundations and Support Rings

Shaft foundations are required to support the final shaft lining. One foundation will be located in the Alibates formation at an approximate depth of 1,050 ft (320 m) and has been designed to support the upper shaft lining. A second foundation will be located in the Lower San Andres Unit 5 basal sediments and has been designed to support the lower lining.

The magnitude of potential foundation pressures dictates the need for confinement of the strata immediately underlying each foundation installation. Confinement is provided by a reinforced concrete support ring which has been designed to withstand in situ ground and hydrostatic pressures, as well as loads transferred through the respective foundations.

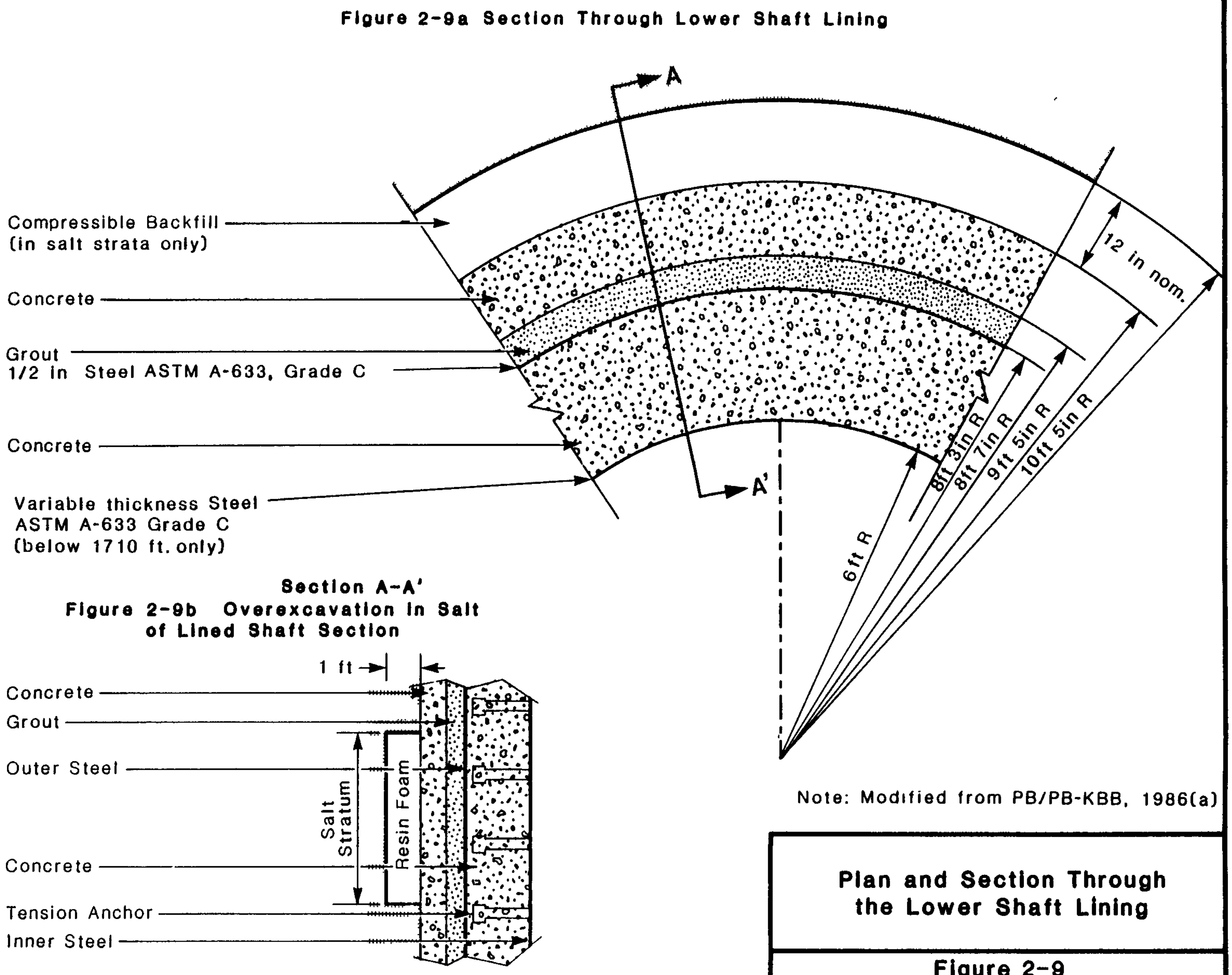
Proposed foundation and support ring layouts are shown in Figures 2-10 and 2-11.

2.3.6 Shaft Sealing

Shaft sealing requirements are guided by the need to provide a dry shaft under the anticipated in situ hydrological conditions. Two types of sealing have been provided for in the shaft design.

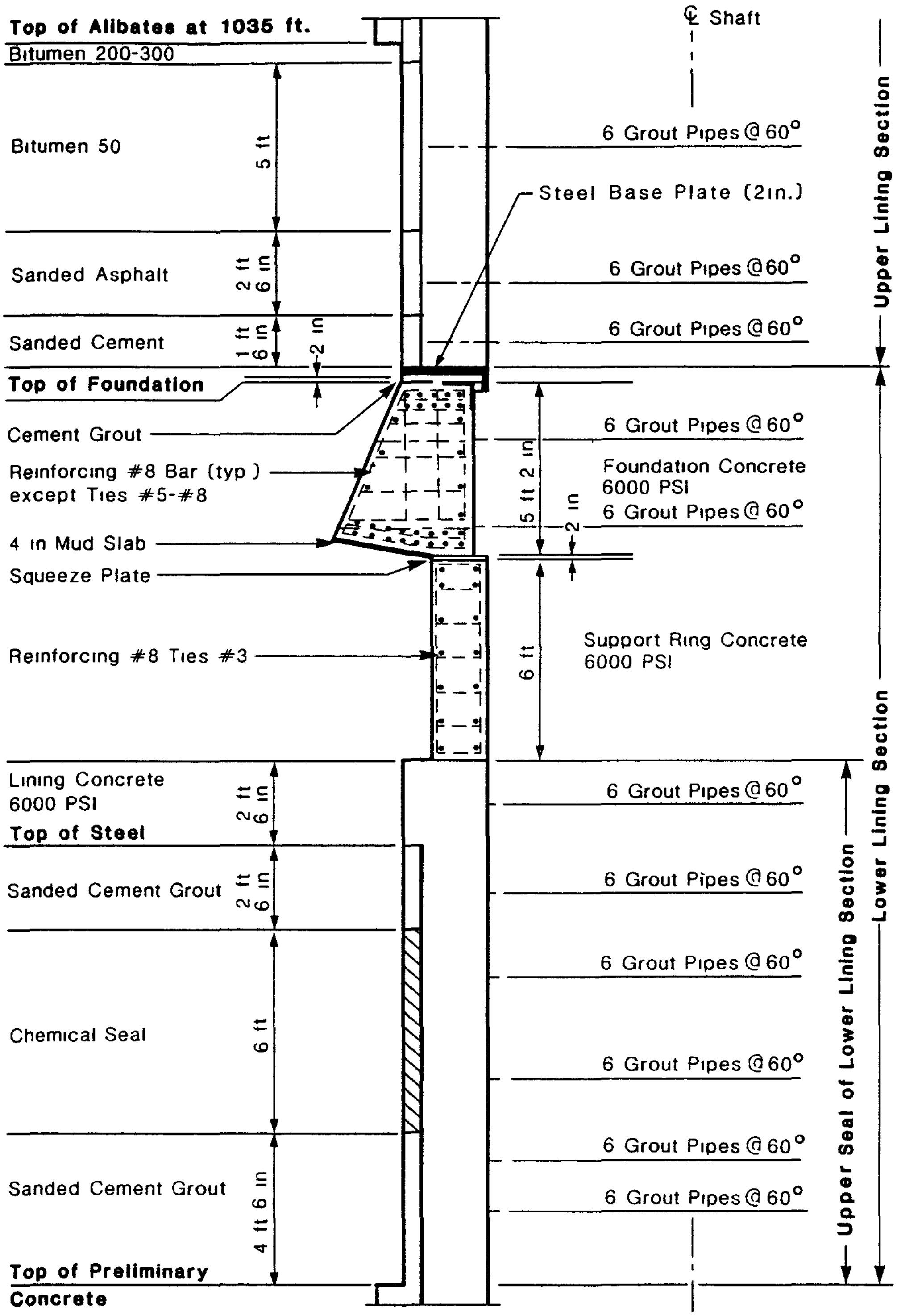
2.3.6.1 Chemical Seals

Chemical seals have been proposed to prevent groundwater migration along the rock/lining interface at the two foundation locations. The current design involves placement of a polymeric sealing compound between the rock and outer steel liner immediately below the upper foundation support ring and immediately above the lower foundation. The polymer material expands on contact with water, and the developed swelling pressure seals against further water migration. Current design concepts include provision for relief holes to enable control of swelling pressures.



Plan and Section Through the Lower Shaft Lining

Figure 2-9



Note. Modified from PB/PB-KBB, 1986(a)

Upper Foundation Support Ring and Chemical Seal (not to scale)

Figure 2-10

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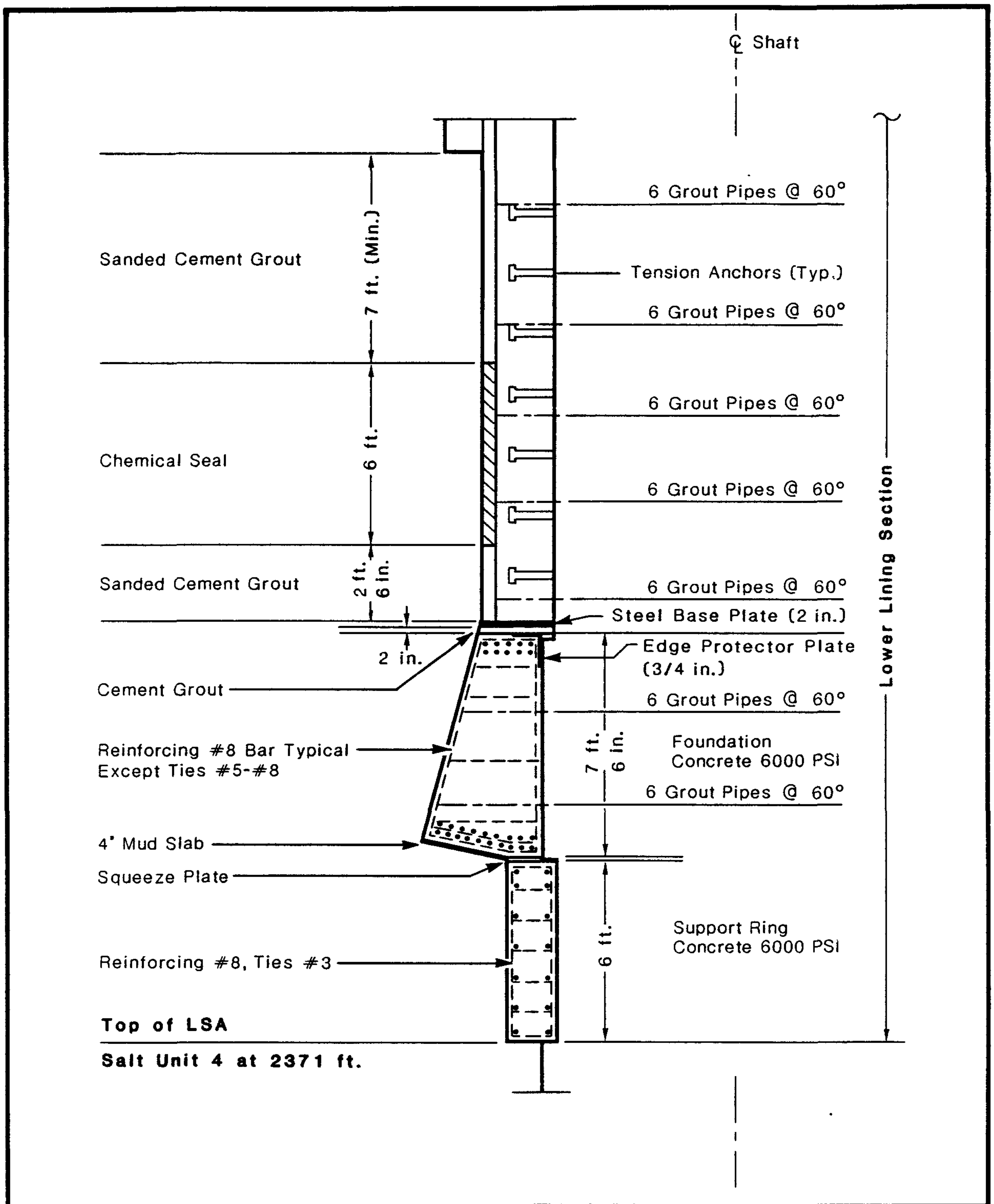

Note: Modified from PB/PB-KBB, 1986(a)

Lower Foundation, Support Ring and Chemical Seal (not to scale)

Figure 2-11

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2.3.6.2 Continuous Bitumen/Grout Sealing

Two materials have been proposed to minimize groundwater migration along the rock/liner interface throughout the shaft length. A 6-in (150-mm) annulus of bitumen will be placed between the preliminary and final lining in the upper shaft to prevent fluid migration following thawing of the frozen ground. Bitumen "windows" will be placed in the preliminary lining to prevent cross-flow between major aquifer systems following thawing of the freezewall. Bitumen is well suited to this application as its viscous nature will ensure continuous sealing during thawing of the freeze wall when ground deformations are expected.

Cementitious grout has been specified to fill the corresponding annulus in the lower shaft.

2.3.7 Unlined Shaft, Shaft Stations, and Shaft Bottom Plus

The unlined portion of the lower shaft will be sunk conventionally at a diameter of 14 ft (4.3 m) to allow for salt creep. Rock bolts and wire mesh are currently planned for ground support in this section of the shaft and in the breakout for the shaft station. A 17 ft (5.2 m) thick shaft bottom plug, able to resist full lithostatic uplift pressure, will be installed in the base of the shaft.

2.4 SHAFT CONSTRUCTION SUMMARY

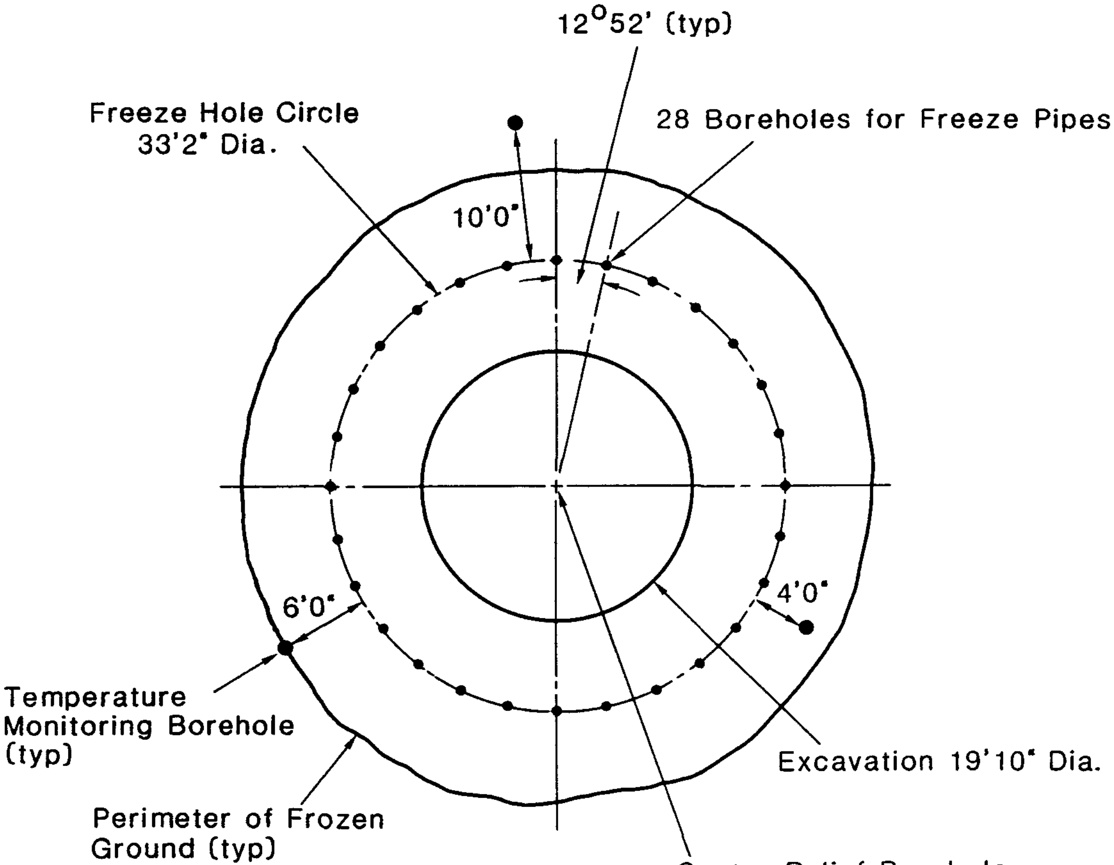
Details of the shaft construction procedure are provided as background for the integration of testing/monitoring and shaft construction activities. This framework also provides the basis for estimating the schedule for the integrated shaft testing program.

2.4.1 Site Preparation and EDBH Drilling

The precise location of the EDBH(s) will be influenced by the needs of shaft freezing contractor and the need to provide geotechnical information representative of the actual shaft alignment. Current plans involve coring along the centerline of each shaft with geophysical and geohydrological testing of the completed boreholes.

2.4.2 Ground Freezing and Shaft Collar Construction

The proposed ESF freezing program will involve drilling 28 freeze holes, 3 temperature monitoring boreholes, and a centerline relief borehole to a depth of approximately 1,000 ft (305 m); this proposed layout is shown in Figure 2-12. Ground freezing will involve circulating calcium chloride brine through the freeze pipes and monitoring the in situ response using the temperature sensors in the monitoring boreholes and the centerline relief borehole. Approximately 45 days of freezing will be required prior to initial ground breaking with an estimated additional 35 days required to completely close the freeze wall to the required depth.



Note: Modified from PB/PB-KBB, 1986(a)

Layout of Freezeholes Around Each Shaft

Figure 2-12

WBS 6.9.4.2

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The first construction activity following ground breaking involves the excavation and lining of the shaft collar to a depth of approximately 90 ft (27.4 m). A plan and section through the shaft collar is included in Figure 2-13 to illustrate the restrictions to routing instrumentation leads and ADAS (Automatic Data Acquisition System) conduits.

2.4.3 Sinking and Preliminary Lining in the Upper Shaft

The construction headframe and hoist will be installed during the ground freezing period, and a multi-deck work stage or galloway will be installed following shaft collar excavation. The galloway is the operational center for the shaft construction and provides facilities for storing excavation and lining supplies, power and other utility centers, deployment of drilling and mucking equipment, and provides access to multiple shaft levels for construction and instrumentation purposes.

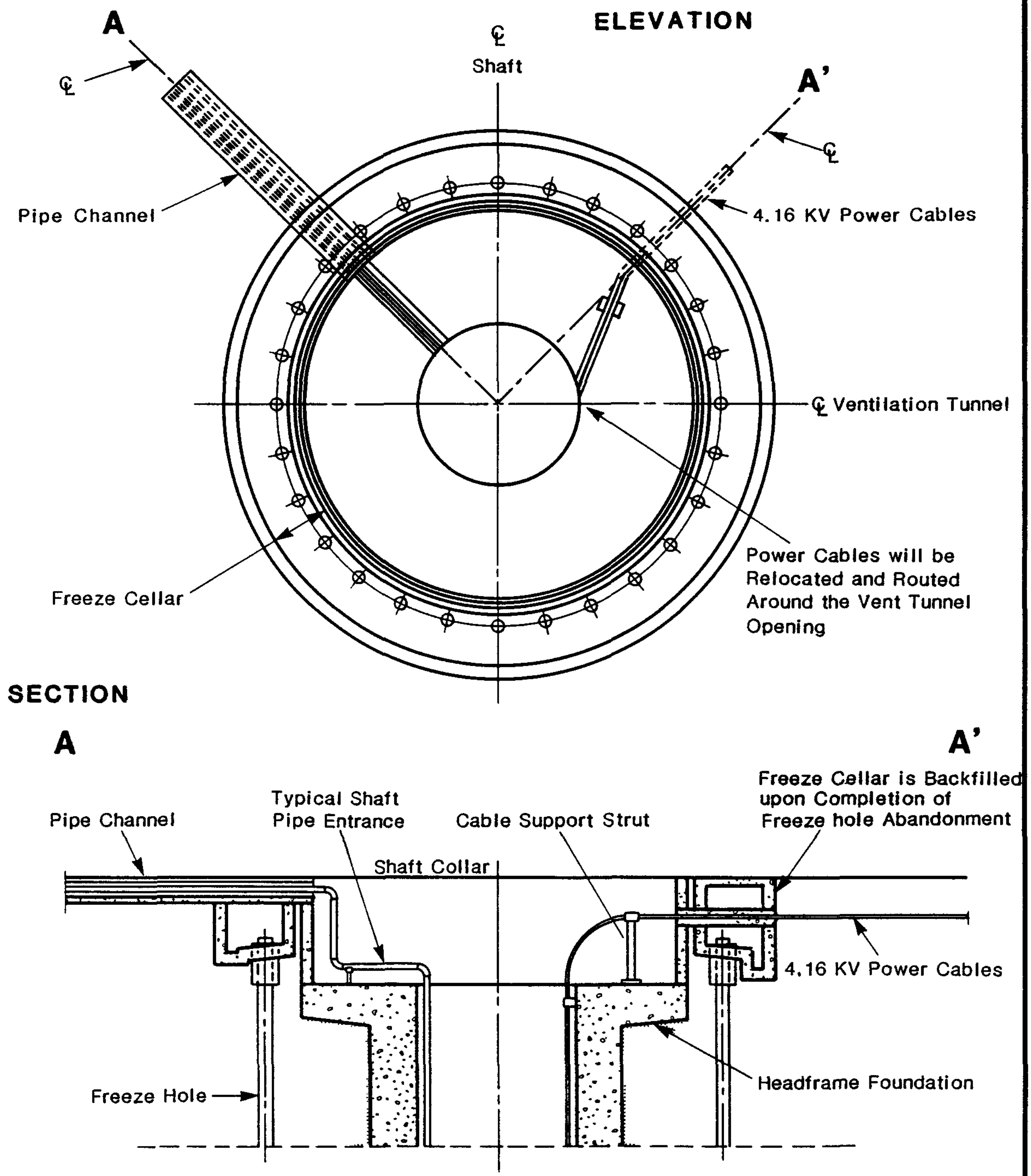
Shaft excavation will be accomplished using conventional drill-and-blast mining methods, which involves:

- Drilling small diameter vertical holes from the shaft bottom using a predetermined pattern. The holes are then loaded with explosives and the round is detonated. In the frozen zone, the possibility of blast damage to the freeze holes is minimized by using a drill pattern which restricts fragmentation to the inner shaft core; the remaining rock is then excavated to A-line (i.e., the design diameter) using hand-held pneumatic tools.

- The broken rock or "muck" is loaded into mucking buckets and hoisted to the surface.

- If necessary, temporary support consisting of rock bolts and wire mesh is installed followed by the preliminary concrete lining. It should be noted that current planning incorporates short, unsupported excavation heights (generally less than 15 ft (5 m)) and no systematic rock reinforcement prior to preliminary lining installation is planned.

The preliminary lining will be installed a short distance behind the excavation face based on convergence monitoring of the shaft walls and estimates of allowable shaft wall deformations as previously discussed. Optional use of either cast-in-place concrete or pre-cast concrete blocks is provided for in the preliminary design. The cast-in-place concrete option will involve placing concrete behind forms set on a kerb ring located above the shaft bottom. The length of concrete pour will be determined based on concrete strength gain and allowable freezewall deformations. The precast concrete block option will involve placement of rows of concrete blocks around the shaft perimeter. Each block and row will be separated by squeeze plates to provide yield during freezewall deformation. Coupling between the outside of each concrete block and the shaft wall is obtained by placing mortar at the interface.



Note: Modified from PB/PB-KBB, 1986(a)

Plan and Section Through Shaft Collar Showing Proposed Axes for Ventilation and Utility Penetration

Figure 2-13

A schematic presentation of the shaft sinking activity, illustrating the use of the galloway, is shown in Figure 2-14. Current plans involve sinking the upper shaft, in 8 ft (2.4 m) rounds, to a depth of approximately 1,100 ft (335 m). The dimensions of the excavation and lining details are provided in Figures 2-8 and 2-9 and Table 2-4.

2.4.4 Foundation Construction and Permanent Liner Installation in the Upper Shaft

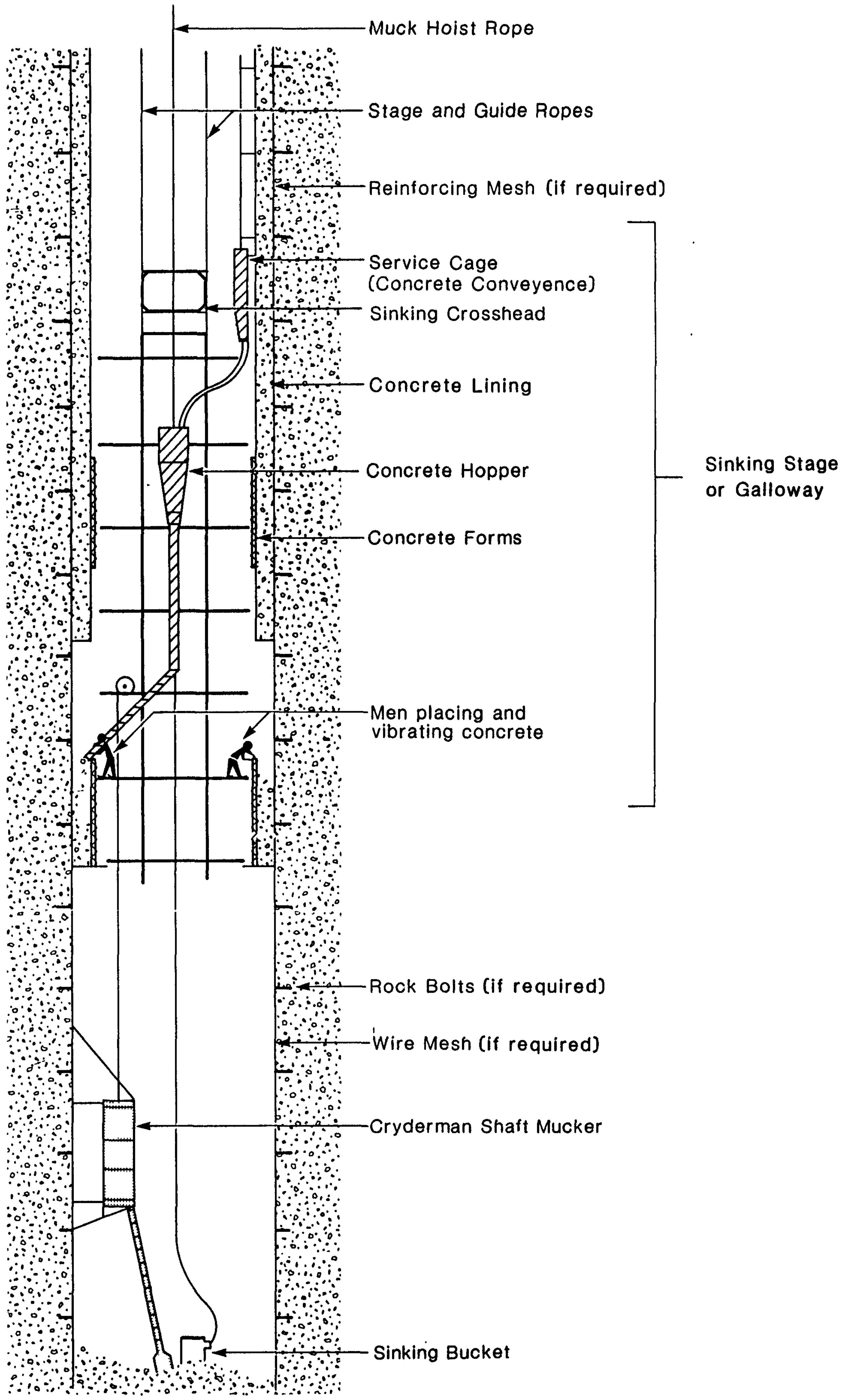
The installation sequence of the final shaft lining is as follows (Parsons Brinckerhoff/PB-KBB, 1986a):

- Excavate and install foundation support ring
- Excavate and install lining foundation. Carry out repairs of disturbed strata surrounding the foundation if required
- Assemble steel liner base level base plate and grout
- Assemble steel liner segments. Align steel column and weld. The galloway allows simultaneous assembly, welding, and inspection work.
- Pour concrete in increments compatible with the steel progress. The outside steel membrane is kept ahead of the inside concrete form work to allow simultaneous work to be carried out.
- Place the bitumen seal material in intervals compatible with the steel and concrete progress.

A schematic of the final lining installation process, illustrating the functional requirements of the galloway, is shown in Figure 2-15. Final lining details are provided in Figure 2-8 and Table 2-4.

2.4.5 Sinking to the Lower Foundation Location

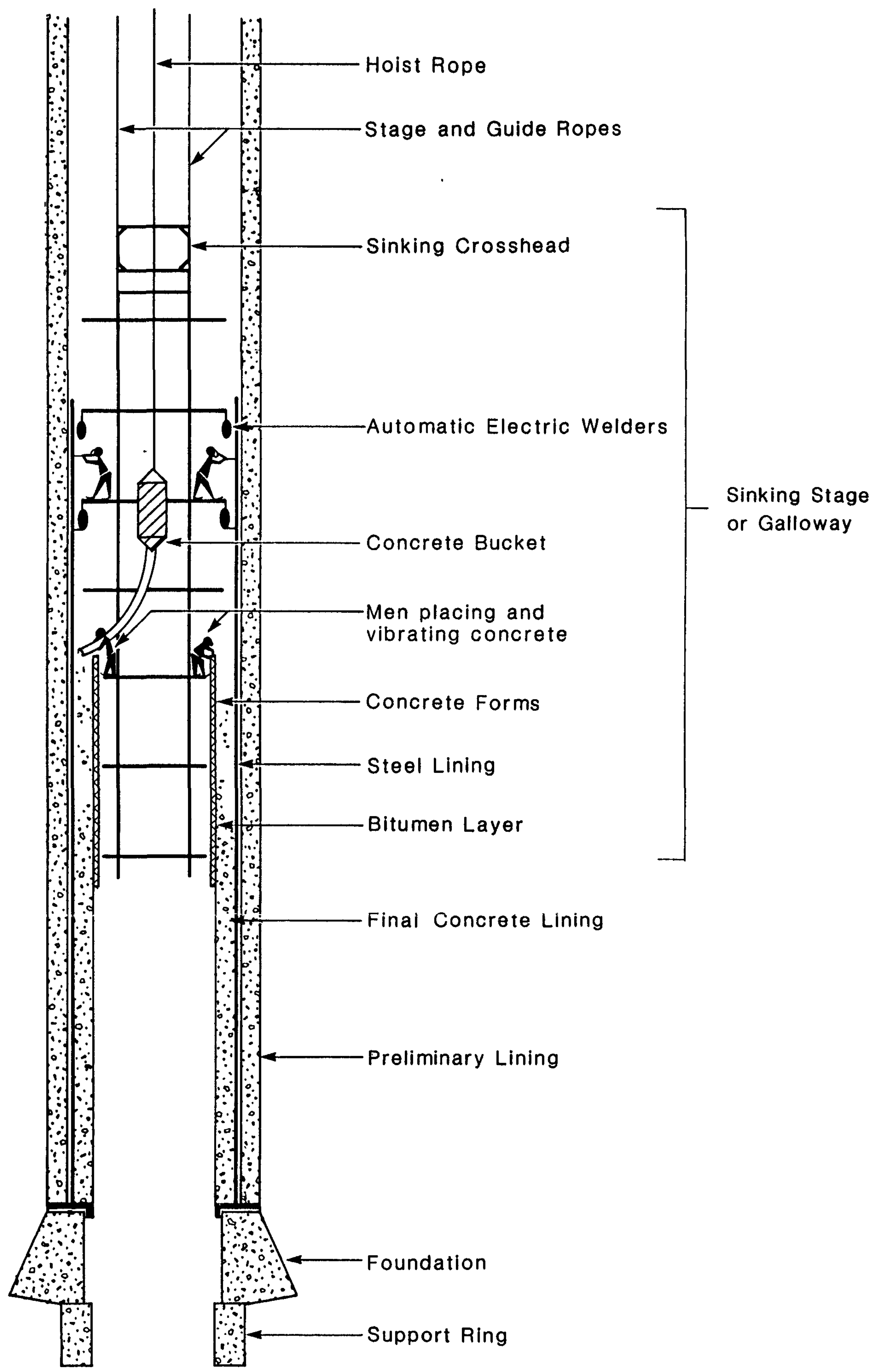
Excavation of the lower shaft will begin following completion of the final lining in the upper shaft. The conventional sinking cycle will involve drill-and-blast excavation and placement of a cast-in-place preliminary concrete lining. As noted previously, the bedded salt strata will be overexcavated to prevent the transfer of lithostatic ground pressures to the lining system (see Figure 2-9). The cavity created by overexcavation will be backfilled with a compressible resin foam.



Source: Modified from Parsons Brinkerhoff/PB-KBB (1986)

Schematic of Sinking and Preliminary Lining Process

Figure 2-14



Source: Modified from Parsons Brinkerhoff/PB-KBB (1986)

Schematic Showing Steel Installation and Final Concrete Lining

Figure 2-15

2.4.6 Foundation Construction and Permanent Liner Installation in the Lower Shaft

If a final lining is required in the lower shaft, the construction sequence will involve installation of the lower shaft foundation and support ring, installation of the lower shaft seal, construction of the final lining to just below the upper shaft foundation, and installation of the upper shaft seal.

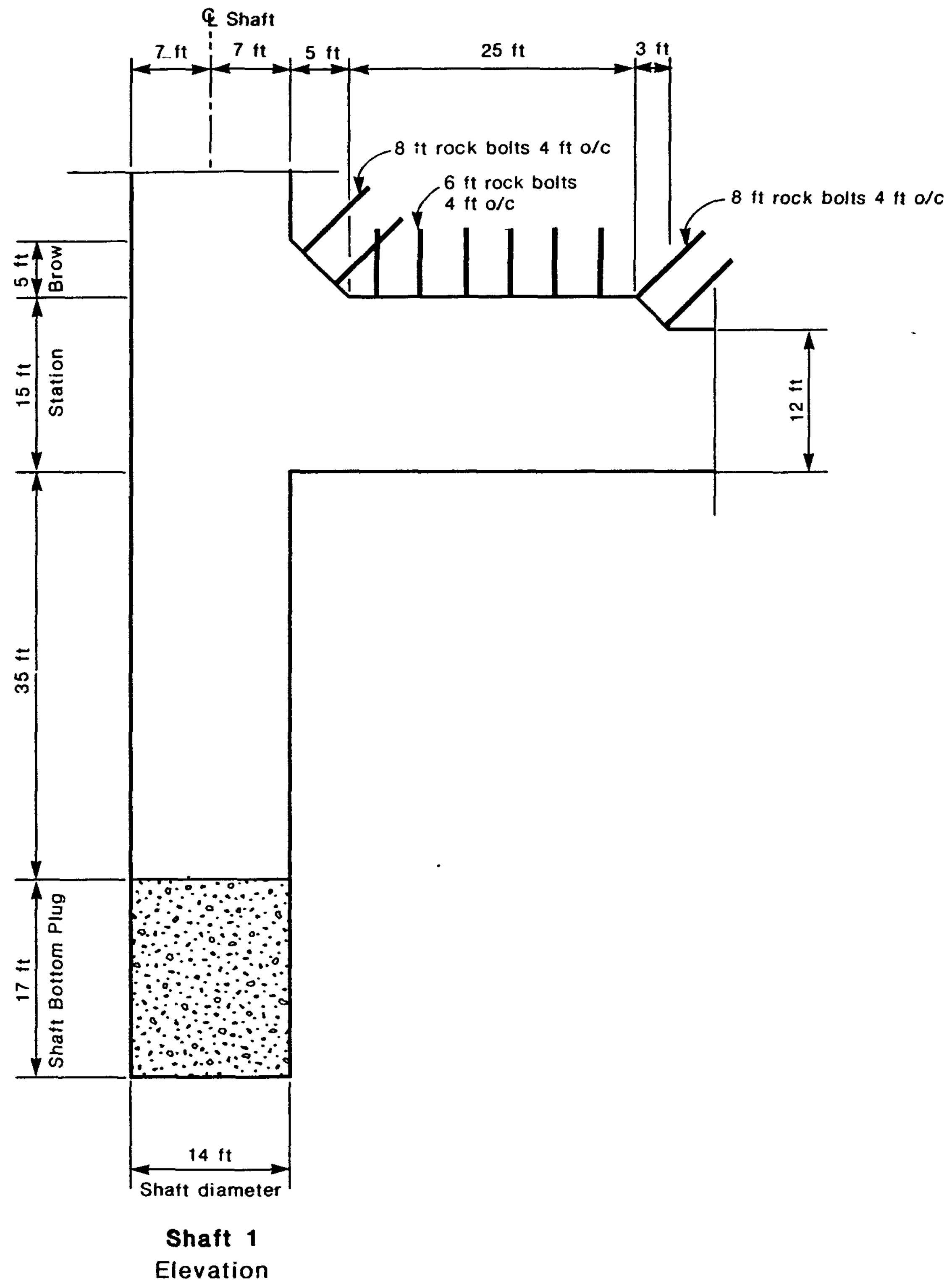
The installation sequence for the final lining construction in the lower shaft is as follows:

- Excavate and install foundation support ring
- Excavate and install lining foundation. Carry out repairs of disturbed strata surrounding the foundation if required
- Assemble steel liner base level base plate and grout
- Carry out repairs of disturbed strata at chemical seal location if required
- Assemble steel liner segments. Align steel column and weld. The outside steel membrane is kept ahead of the inside steel membrane to allow simultaneous work to be carried out.
- Pour concrete in increments compatible with the steel progress.
- Place sanded cement grout between rock and final liner in intervals compatible with the steel and concrete progress.
- Install the chemical seals by placing the chemical seal and sanded cement grout as shown on Figures 2-10 and 2-11. Grout pipes, preinstalled in the shaft liners, are used to pressurize the seal.

2.4.7 Shaft Completion

Conventional sinking of the remaining shaft section will begin following completion of the lining installation in the lower shaft. The shaft will be sunk, using rock bolts and wire mesh for ground support, to the test horizon. The actual location of the test horizon will be selected based on the results of the EDBH and detailed geologic mapping. Approximately 50 ft (15 m) of drift will be mined to form the shaft station breakout prior to continuation of shaft sinking activities (see Figure 2-16). After shaft station breakout completion, the shaft will be mined to approximately 30 ft (9 m) above the top of the basal sediments of LSA4 where a 17-ft (5.2 m) thick concrete plug will be installed.

Subsequent construction activities involve mining of the connecting airway between the two shafts. This operation will be described in the At-Depth Study Plan (Golder Associates, 1987a).



Shaft Station and Shaft Bottom Plug Construction Detail

Figure 2-16

WBS 6.9.4.2

843-1040-102/15

2.4.8 Shaft Outfitting

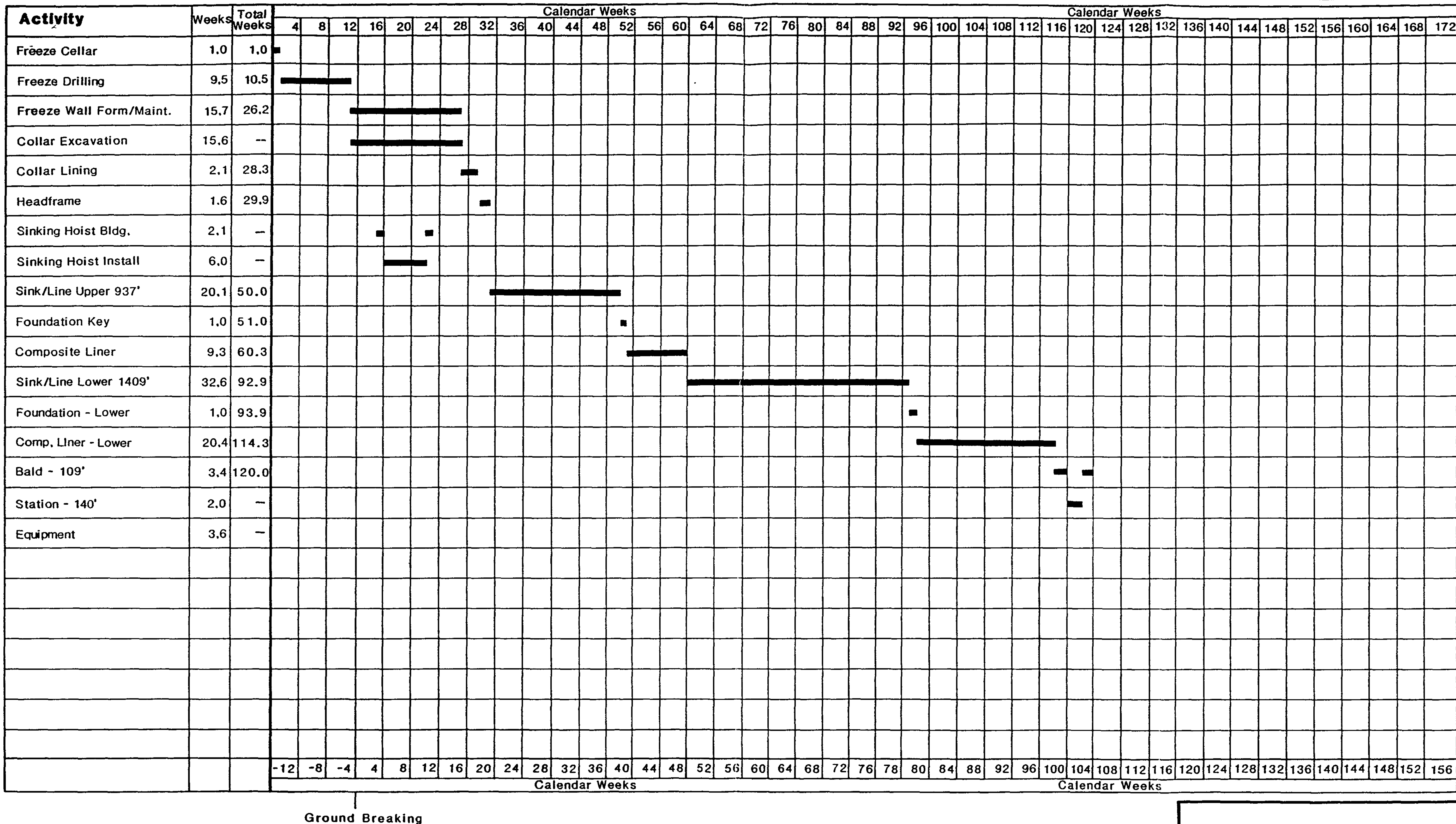
Outfitting of the ESF shaft consists of installation of steel sets to carry the conveyance guides, and utilities such as compressed air pipes, dewatering pipes, potable water pipes, and power supply cables. Shaft No. 1 will accommodate the main service cage operating in balance with a counter weight. Shaft No. 2 will accommodate a single, unbalanced personnel cage and will serve as a ventilation exhaust shaft, an emergency evacuation shaft, and intermittently as a limited-capacity muck hositing shaft.

2.5 SHAFT CONSTRUCTION SCHEDULE

The estimated shaft construction schedule, exclusive of instrument installation and in situ testing, is shown in Figure 2-17. Note that ground breaking has been selected as the reference "start" time for testing schedule estimation purposes.

The schedule has been estimated, based on the Title I drawings, by the Construction Manager and was presented as comments (Parson/Redpath, 1986) to the Shaft Study Plan Scoping Document.

This Table has not been altered to reflect detailed changes resulting from data contained in the Synthetic Geotechnical Data Base (ONWI, 1986a) and must be considered provisional at this stage. Any required changes will be made by the Construction Manager based on detailed Title II design and will be presented in future updates to the SSP.



Source: Modified from Parsons/Redpath Comments on Shaft Test Plan Scoping Document (Parsons/Redpath, 1986)

Shaft Construction Schedule

Figure 2-17

WBS 6.9.4.2

843-1040-102/39

3.0 STUDY RATIONALE AND INFORMATION REQUIREMENTS

The program presented in this Shaft Study Plan (SSP) represents part of the overall site characterization and testing program for developing the information necessary to satisfy (1) federal, state, and local requirements, and (2) repository program requirements, as discussed in Sections 3.1 and 3.2, respectively. The various requirements are compiled in terms of information needs and are briefly described in Section 3.3.

3.1 FEDERAL, STATE, AND LOCAL REQUIREMENTS

Federal, state, and local requirements result in a specific set of issues which must be resolved. To resolve these issues, a relevant information base must be developed, i.e., the "information requirements." This program of monitoring and testing to be performed in the Exploratory Shafts (ES) is a part of the overall program necessary to develop the information base required for regulatory issue resolution. The relevant issues addressed by this study are discussed in Section 3.1.1, and the associated information requirements in Section 3.1.2.

3.1.1 Regulatory Issues

It is necessary at license application (LA) to demonstrate that the regulatory requirements (as specified in the Nuclear Waste Policy Act and in 10 CFR Part 60, and thereby by reference in 40 CFR Part 191, 10 CFR Part 960, 10 CFR Part 20, and 30 CFR Chapter I) either have been met or can be expected (with reasonable assurance) to be met in the future. A hierarchy of performance issues, which comprehensively describes repository system processes in increasing levels of detail, has been previously developed in the Underground Test Plan, Figures A-1 through A-6 and Table A-2 (Golder Associates, 1986a). In this hierarchy, each issue is completely defined by a set of sub-issues at the next level of detail. Determination of compliance with each of the regulatory performance requirements necessitates that a specific set of performance issues be resolved; the set of issues related to each regulatory performance requirement has been previously identified in the Underground Test Plan, Table A-1. Hence, by resolving the entire set of performance issues, compliance with all of the regulatory performance requirements can be determined; however, due to the hierarchal form of the issues, only the most detailed issues need be resolved independently.

The testing and monitoring program described in this SSP will, in general, only partially address some of these issues; other programs required for complete issue resolution include surface-based field testing (including remote sensing and borehole testing), laboratory testing, testing and monitoring in the At-Depth Facility (ADF), and major subsurface model/design validation testing (including for example the mine-by test, waste package heater tests, etc.). Those performance issues which can be addressed, wholly or in significant part, by the program outlined in this SSP are listed in the left-hand column of Table 3-1. Other performance issues which are not significantly addressed herein have been abbreviated and designated as being

Table 3-1 Types of Information Required from Testing/Monitoring in the Exploratory Shafts to Resolve Performance Issues

INFORMATION REQUIREMENTS / PERFORMANCE ISSUES[a]

SITE CHARACTERISTICS ASSESSMENT[b]

PERFORMANCE ISSUES[a]	Geology	Stratigraphy/Lithology	Structure	Tectonic Activity	Man-Made Disturbance[NA]	Geomechanics	In Situ Stress	Strength	Deformation Moduli	Dynamic Properties	Creep/Fusing	Density	Hardness	Index Properties	Thermomechanics	In Situ Temperature	Thermal Conductivity	Specific Heat	Thermal Expansion	Geohydrology	In Situ Hydraulic Pressure	Hydraulic Conductivity	Porosity	Specific Storage	Dispersivity/Diffusion	Brine Migration [NA]	Geochemistry	Geochemistry	Hydrochemistry	Adsorption	Alteration/Solubility
I. PRECLOSURE PERFORMANCE ISSUES																															
A. HEALTH AND SAFETY HAZARDS[d] (preclosure)																															
1. On-Site Health and Safety Hazards[d] (preclosure)																															
a. On-site radiation hazards[d] (preclosure) [NA]																															
b. On-site non-radiation hazards[d] (preclosure)																															
i. On-site underground non-radiation hazards[d] (preclosure)																															
(1) Design, construction and maintenance of underground openings[e] (preclosure)																															
(a) Constructability of shafts and the underground facility[e] [shafts only]		●	●	●			●	●	●		●	●	●	●		●	●	●			●	●		●				●	●		●
(b) Maintenance requirements for underground openings[e] [shafts only]		●	●	●			●	●	●		●	●		●		●	●	●	●									●	●		●
(c) Sealability of boreholes and shafts[e] (preclosure) [shafts only]		●	●	●	○		●									●					●							●	●		●
(2) Performance of non-radiation safety-related design structures, systems and components[e] [shafts only]		●	●	●			●	●	●		●	●				●	●	●	●		●	●		●				●	●		●
(3) Stability of underground openings[d] (preclosure) [shafts only]		●	●	●			●	●	●	●	●			●																	
(4) Water-inflow to underground openings[d] (preclosure) [shafts only]		●	●	●	○		●				●										●	●		●				●	●		●
(5) Air content in underground working areas[d] [shafts only]		●																										●	●		
(6) Noise in underground working areas[d] [shafts only]																															
(7) Other on-site underground non-radiation hazards[d] (preclosure) [shafts only]																															
ii. On-site surface non-radiation hazards[d] (preclosure) [NA]																															
2. Off-Site Health and Safety Hazards[d] (preclosure) [NA]																															
B. COSTS [shafts only]		●	●	●	○		●	●	●	●	●	●	●	●		●	●	●	●		●	●	●	●	●	○		●	●	●	●
II. POST-CLOSURE PERFORMANCE ISSUES																															
A. WASTE PACKAGE RADIONUCLIDE RELEASE (post-closure) [NA]																															
B. RADIONUCLIDE TRANSPORT AT ROOM SCALE (post-closure) [NA]																															
C. RADIONUCLIDE TRANSPORT AT SHAFT SCALE (post-closure)																															
1. Physical Transport of Radionuclides at Shaft Scale (post-closure)																															
a. Advective transport of radionuclides at shaft scale (post-closure)																															
i. Base groundwater flow at shaft scale (post-closure)																															
(1) Base groundwater flow in shaft/borehole seals[f] (post-closure)																					●										

DESIGN/MODEL VALIDATION

PERFORMANCE ISSUES[a]	Shaft	Construction Procedures	Properties of Liner, Operational Seal & Constr. Affected Zone:	- Strength	- Deformation Moduli	- Creep/Fusing	- Dynamic Properties	- Density	- Thermal Conductivity	- Specific Heat	- Salt/Air Heat Transfer Coeff.	- Thermal Expansion	- Hydraulic Conductivity	- Porosity	- Specific Storage	- Dispersivity/Diffusion	Mechanical Response	Thermal/Thermomechanical Response	Hydrologic Reponse	Radionuclide Transport	Hydrochemical/Geochemical Response	Room [NA]	Emplacement Hole [NA]	Waste Package [NA]	Shaft, Room, Emplacement Hole, and Borehole Backfill/Seals [NA]	Repository Operating Systems [NA]	Repository Operations [NA]
I. PRECLOSURE PERFORMANCE ISSUES																											
A. HEALTH AND SAFETY HAZARDS[d] (preclosure)																											
1. On-Site Health and Safety Hazards[d] (preclosure)																											
a. On-site radiation hazards[d] (preclosure) [NA]																											
b. On-site non-radiation hazards[d] (preclosure)																											
i. On-site underground non-radiation hazards[d] (preclosure)																											
(1) Design, construction and maintenance of underground openings[e] (preclosure)																											
(a) Constructability of shafts and the underground facility[e] [shafts only]		●					●										●		●		●	○				○	
(b) Maintenance requirements for underground openings[e] [shafts only]		●		●	●	●		●	●	●		●					●	●			●	○				○	○
(c) Sealability of boreholes and shafts[e] (preclosure) [shafts only]		●		●	●	●							●				●		●		●	○					
(2) Performance of non-radiation safety-related design structures, systems and components[e] [shafts only]		●		●	●	●	●	●	●	●	●	●	●		●		●	●	●		●	○			○	○	
(3) Stability of underground openings[d] (preclosure) [shafts only]		●		●	●	●	●										●					○			○		
(4) Water-inflow to underground openings[d] (preclosure) [shafts only]		●				●							●		●				●		●	○			○		
(5) Air content in underground working areas[d] [shafts only]		●																			●	○	○		○	○	
(6) Noise in underground working areas[d] [shafts only]		●																				○	○		○	○	○
(7) Other on-site underground non-radiation hazards[d] (preclosure) [shafts only]																											
ii. On-site surface non-radiation hazards[d] (preclosure) [NA]																											
2. Off-Site Health and Safety Hazards[d] (preclosure) [NA]																											
B. COSTS [shafts only]		●		●	●	●	●	●	●	●		●	●	●	●	●	●	●	●	●	●	○			○	○	○
II. POST-CLOSURE PERFORMANCE ISSUES																											
A. WASTE PACKAGE RADIONUCLIDE RELEASE (post-closure) [NA]																											
B. RADIONUCLIDE TRANSPORT AT ROOM SCALE (post-closure) [NA]																											
C. RADIONUCLIDE TRANSPORT AT SHAFT SCALE (post-closure)																											
1. Physical Transport of Radionuclides at Shaft Scale (post-closure)																											
a. Advective transport of radionuclides at shaft scale (post-closure)																											
i. Base groundwater flow at shaft scale (post-closure)																											
(1) Base groundwater flow in shaft/borehole seals[f] (post-closure)		●																	●						●		

SITE CHARACTERISTICS ASSESSMENT[b]

INFORMATION REQUIREMENTS / PERFORMANCE ISSUES[a]	**Geology**	Stratigraphy/Lithology	Structure	Tectonic Activity	Man-Made Disturbance[NA]	**Geomechanics**	In Situ Stress	Strength	Deformation Moduli	Dynamic Properties	Creep/Fusing	Density	Hardness	Index Properties	**Thermomechanics**	In Situ Temperature	Thermal Conductivity	Specific Heat	Thermal Expansion	**Geohydrology**	In Situ Hydraulic Pressure	Hydraulic Conductivity	Porosity	Specific Storage	Dispersivity/Diffusion	Brine Migration [NA]	**Geochemistry**	Geochemistry	Hydrochemistry	Adsorption	Alteration/Solubility
(2) Base groundwater flow at shaft scale (excluding shaft/borehole seals) (post-closure)																					●	●									
ii. Significant perturbations on groundwater flow at shaft scale (post-closure)																															
(1) Dissolution/alteration at shaft scale (post-closure) [in rock only]												●				●	●	●			●	●						●	●		●
(2) Thermomechanical effects at shaft scale (post-closure) [in rock only]							●	●	●	●	●	●		●		●	●	●	●		●	●									
(3) Thermohydrology at shaft scale (post-closure) [in rock only]												●				●	●	●			●	●									
(4) Other significant perturbations on groundwater flow at shaft scale (post-closure) [in rock only]																															
b. Dispersion of radionuclides at shaft scale (post-closure) [in rock only]																							●		●						
c. Diffusion of radionuclides at shaft scale (post-closure) [in rock only]																							●		●						
d. Other significant physical radionuclide transport processes at shaft scale (post-closure) [in rock only]																															
2. Chemical Transport of Radionuclides at Shaft Scale (post-closure)																															
a. Solubility (and precipitation) of radionuclides at shaft scale (post-closure) [in rock only]												●				●	●	●										●	●		●
b. Sorption of radionuclides at shaft scale (post-closure) [in rock only]																												●	●	●	●
c. Other significant chemical radionuclide transport processes at shaft scale (post-closure) [in rock only]																															
3. Other Significant Radionuclide Transport Processes at Shaft Scale (post-closure) [in rock only]																															
B: RADIONUCLIDE TRANSPORT THROUGH THE SITE[g] (post-closure)																															
1. Physical Transport of Radionuclides Through the Site[g] (post-closure)																															
a. Advective transport of radionuclides through the site[g] (post-closure)																															
i. Base groundwater flow through the site[f,g] (post-closure)		●	●		○																●	●	●								
ii. Significant perturbations on groundwater flow through the site[g] (post-closure)																															
(1) Dissolution at or near the site[g] (post-closure)																					●	●						●	●		●
(2) Tectonics at or near the site[g] (post-closure)		●	●	●			●	●	●	●	●										●	●									
(3) Erosion or deposition at or near the site[g] (post-closure)		●	●																		●										

DESIGN/MODEL VALIDATION

INFORMATION REQUIREMENTS / PERFORMANCE ISSUES[a]	**Shaft**	Construction Procedures	Properties of Liner, Operational Seal & Constr. Affected Zone:	- Strength	- Deformation Moduli	- Creep/Fusing	- Dynamic Properties	- Density	- Thermal Conductivity	- Specific Heat	- Salt/Air Heat Transfer Coeff.	- Thermal Expansion	- Hydraulic Conductivity	- Porosity	- Specific Storage	- Dispersivity/Diffusion	Mechanical Response	Thermal/Thermomechanical Response	Hydrologic Reponse	Radionuclide Transport	Hydrochemical/Geochemical Response	**Room** [NA]	**Emplacement Hole** [NA]	**Waste Package** [NA]	**Shaft, Room, Emplacement Hole, and Borehole Backfill/Seals** [NA]	**Repository Operating Systems** [NA]	**Repository Operations** [NA]
(2) Base groundwater flow at shaft scale (excluding shaft/borehole seals) (post-closure)		●											●						●								
ii. Significant perturbations on groundwater flow at shaft scale (post-closure)																											
(1) Dissolution/alteration at shaft scale (post-closure) [in rock only]		●						●	●	●			●					●	●		●				○		
(2) Thermomechanical effects at shaft scale (post-closure) [in rock only]		●		●	●	●	●	●	●	●		●	●				●	●	●						○		
(3) Thermohydrology at shaft scale (post-closure) [in rock only]		●						●	●	●			●					●	●						○		
(4) Other significant perturbations on groundwater flow at shaft scale (post-closure) [in rock only]																											
b. Dispersion of radionuclides at shaft scale (post-closure) [in rock only]		●												●		●				●					○		
c. Diffusion of radionuclides at shaft scale (post-closure) [in rock only]		●												●		●				●					○		
d. Other significant physical radionuclide transport processes at shaft scale (post-closure) [in rock only]																											
2. Chemical Transport of Radionuclides at Shaft Scale (post-closure)																											
a. Solubility (and precipitation) of radionuclides at shaft scale (post-closure) [in rock only]		●						●	●	●								●			●				○		
b. Sorption of radionuclides at shaft scale (post-closure) [in rock only]		●																			●				○		
c. Other significant chemical radionuclide transport processes at shaft scale (post-closure) [in rock only]																											
3. Other Significant Radionuclide Transport Processes at Shaft Scale (post-closure) [in rock only]																											
B: RADIONUCLIDE TRANSPORT THROUGH THE SITE[g] (post-closure)																											
1. Physical Transport of Radionuclides Through the Site[g] (post-closure)																											
a. Advective transport of radionuclides through the site[g] (post-closure)																											
i. Base groundwater flow through the site[f,g] (post-closure)																											
ii. Significant perturbations on groundwater flow through the site[g] (post-closure)																											
(1) Dissolution at or near the site[g] (post-closure)																											
(2) Tectonics at or near the site[g] (post-closure)		●															●		●								
(3) Erosion or deposition at or near the site[g] (post-closure)																											

Table 3-1 (cont.)

SITE CHARACTERISTICS ASSESSMENT [b]

INFORMATION REQUIREMENTS / PERFORMANCE ISSUES [a]	Geology: Stratigraphy/Lithology	Structure	Tectonic Activity	Man-Made Disturbance[NA]	Geomechanics: In Situ Stress	Strength	Deformation Moduli	Dynamic Properties	Creep/Fusing	Density	Hardness	Index Properties	Thermomechanics: In Situ Temperature	Thermal Conductivity	Specific Heat	Thermal Expansion	Geohydrology: In Situ Hydraulic Pressure	Hydraulic Conductivity	Porosity	Specific Storage	Dispersivity/Diffusion	Brine Migration [NA]	Geochemistry: Geochemistry	Hydrochemistry	Adsorption	Alteration/Solubility
(4) Surface hydrology at or near the site[g] (post-closure)	●	●	●	○													●									
(5) Excavation of the underground facility	●	●		○													●	●		●						
(6) Thermomechanical effects at the site[g] (post-closure)	●	●	●	○	●	●	●	●	●	●		●	●	●	●	●	●	●								
(7) Thermohydrology at the site[g] (post-closure)	●	●		○						●			●	●	●		●	●	●	●						
(8) Post-closure activities at or near the site[g] (post-closure)	●	●		○													●			●			●	●		
(9) Other significant perturbations on groundwater flow through the site[g] (post-closure)																										
b. Dispersion of radionuclides through the site[g] (post-closure)																			●		●					
c. Diffusion of radionuclides through the site[g] (post-closure)																			●		●					
d. Other significant physical radionuclide transport processes through the site[g] (post-closure)																										
2. Chemical Transport of Radionuclides Through the Site[g] (post-closure)																										
a. Solubility (and precipitation) of radionuclides through the site[g] (post-closure)										●			●	●	●								●	●		●
b. Sorption of radionuclides through the site[g] (post-closure)																							●	●	●	●
c. Other significant chemical radionuclide transport processes through the site[g] (post-closure)																										
3. Other Significant Radionuclide Transport Processes Through the Site[g] (post-closure)																										

DESIGN/MODEL VALIDATION

INFORMATION REQUIREMENTS / PERFORMANCE ISSUES [a]	Shaft: Construction Procedures	Properties of Liner, Operational Seal & Constr. Affected Zone:	- Strength	- Deformation Moduli	- Creep/Fusing	- Dynamic Properties	- Density	- Thermal Conductivity	- Specific Heat	- Salt/Air Heat Transfer Coeff.	- Thermal Expansion	- Hydraulic Conductivity	- Porosity	- Specific Storage	- Dispersivity/Diffusion	Mechanical Response	Thermal/Thermomechanical Response	Hydrologic Reponse	Radionuclide Transport	Hydrochemical/Geochemical Response	Room [NA]	Emplacement Hole [NA]	Waste Package [NA]	Shaft, Room, Emplacement Hole, and Borehole Backfill/Seals [NA]	Repository Operating Systems[NA]	Repository Operations [NA]
(4) Surface hydrology at or near the site[g] (post-closure)																										
(5) Excavation of the underground facility	●																	●			○			○		
(6) Thermomechanical effects at the site[g] (post-closure)																										
(7) Thermohydrology at the site[g] (post-closure)																										
(8) Post-closure activities at or near the site[g] (post-closure)																										
(9) Other significant perturbations on groundwater flow through the site[g] (post-closure)																										
b. Dispersion of radionuclides through the site[g] (post-closure)																										
c. Diffusion of radionuclides through the site[g] (post-closure)																										
d. Other significant physical radionuclide transport processes through the site[g] (post-closure)																										
2. Chemical Transport of Radionuclides Through the Site[g] (post-closure)																										
a. Solubility (and precipitation) of radionuclides through the site[g] (post-closure)																										
b. Sorption of radionuclides through the site[g] (post-closure)																										
c. Other significant chemical radionuclide transport processes through the site[g] (post-closure)																										
3. Other Significant Radionuclide Transport Processes Through the Site[g] (post-closure)																										

NOTES:

[a] Issues hierarchy (modified and abbreviated here in non-applicable areas) was developed and presented in the Underground Test Plan (Golder Associates, 1986), Figures A-1 through A-6 and Table A.2.

[b] Site characteristics will be assessed only in the zone around the shafts. Site characteristics elsewhere will be addressed by other programs (e.g., surface-based field testing, at-depth testing, etc.).

[d] Hazards will be a function of site characteristics and design.

[e] Design features will, to a large extent, determine the hazards. However, in addition, they may also mitigate or remedy the consequences of hazards which do occur. Such design features must be implemented and maintained in order to be effective.

[f] "Base groundwater flow" through a component considers the flux and particle velocity as a function of (1) the conditions of the component at closure, and (2) the pre-construction flow system.

[g] The portion of the "site" of interest in this case is the zone adjacent to the shafts, but outside the construction-affected zone.

[NA] Not applicable

● Information required to resolve performance issues and addressed by Shaft Study Program.

○ Information required to resolve performance issues but not addressed by Shaft Study Program.

not applicable [NA]. This is not to say that these other performance issues are unimportant, only that they will not be significantly addressed by this SSP, but by other testing programs which are not within the scope of this SSP.

As detailed in Table 3-1, the relevant performance issues can be categorized in terms of preclosure and postclosure:

- Relevant preclosure issues are related primarily to:

  - the constructability, maintenance requirements, and stability of the shafts and shaft liner systems

  - water inflow and the sealability of the shafts and shaft liner systems

  Other relevant preclosure issues are related to:

  - the performance of non-radiation safety-related shaft structures, systems, and components

  - air quality and noise levels in the shafts

  - costs associated with the shafts.

- Relevant postclosure issues are related primarily to:

  - ground-water flow (i.e., the base flow and significant perturbations to that flow) at the shaft and to a lesser extent site scales; the perturbations to ground-water flow might be due to dissolution/alteration, thermomechanical or thermohydrological effects, or, for the site, tectonics, erosion/ deposition, surface hydrology, excavation, or postclosure activities.

  - transport of radionuclides at these same scales; processes of significance to radionuclide transport include primarily advection, dispersion, diffusion, solubility and sorption.

Other performance issues which will not be addressed by the program described in this SSP, but by other testing programs, primarily include (see UTP - Tables A-2 through A-5):

- Off-site, surface, and underground facility preclosure performance

- Postclosure engineered system release, considering waste package radionuclide release

- Radionuclide transport at the room scale (postclosure)

- Ground-water flow (both base flow and perturbations in that flow) and radionuclide transport (considering dispersion, diffusion, solubility, and sorption, as well as advection) in shaft decommissioning seals and backfill.

3.1.2 Performance-Related Information Requirements

Resolution of the performance issues identified in Section 3.1.1 generally requires performance predictions to a specific, minimum level of confidence. This might be done in one of several ways:

- Demonstration, in which a component of the repository system is constructed under similar conditions, and the measured/observed results are extrapolated to the proposed repository system.

- Empirical analysis, in which past experience in similar conditions is quantified in a correlational (rather than theoretical) manner, and then the appropriate factors are assessed and used to estimate performance.

- Numerical analysis, in which conceptual and then numerical models are developed to represent the pertinent system processes (in a theoretical way), and then the appropriate system parameters are assessed and input into the models to estimate performance.

For each of the above methods, uncertainty (or probability) analyses can be used to determine the level of confidence in the predictions. By performing sensitivity/trade-off studies, the level of confidence required in each of the components of the analysis to produce a given level of confidence in the performance prediction (and thus resolve the performance issue) can be determined. The type of information and level of confidence required to adequately resolve the relevant performance issues are termed the "information requirements." These information requirements refer to the total information base required, including currently available, relevant information. The set of information requirements is not, however, unique because a variety of information types contribute to issue resolution and different combinations of information can be used to resolve the various performance issues.

The information requirements for resolving each of the most detailed performance issues by each of the resolution methods (where applicable) has been previously identified in the Underground Test Plan (UTP), Tables A-3 through A-5, and summarized in Table A-6 (Golder Associates, 1986a). Due to the lack of quantitatively defined performance goals and sensitivity/trade-off studies (i.e., performance allocation), the information requirements were defined only qualitatively, based on subjective assessments. Until a performance allocation is quantitatively defined, these information requirements cannot be rationally quantified (i.e., the required level of confidence defined).

Once the information requirements have been established, the pertinent available information can be assembled, e.g., from completed generic studies, from the completed portions of the surface-based test program (including limited boreholes drilled from the surface), and from completed laboratory testing. The additional information needed to supplement that currently available and thereby satisfy the information requirements can then be identified. These "information needs" will then be the focus of additional testing.

The available relevant information and, hence, the additional information needed have also been previously identified and summarized in the UTP, Table A-6. Because of the current preliminary and qualitative nature of the information requirements, the information needs are similarly preliminary and qualitative.

Based on the above, the types of information required to adequately resolve each of the pertinent performance issues (Section 3.1.1) have been summarized in Table 3-1. Only those performance issues and those information requirements to be addressed wholly or in significant part by the Shaft Study Program are considered; other information requirements which are not significantly addressed by this test program have been abbreviated and designated as being not applicable [N/A]. Similar to the performance issues, these other information requirements will be addressed by other testing programs which are not within the scope of this SSP.

As detailed in Table 3-1, the relevant information requirements consist primarily of:

- The assessment of geological characteristics (i.e, stratigraphy/lithology and structure) in the vicinity of the ESs, as well as the assessment of specific mechanical (i.e., in situ stress, deformation moduli, dynamic properties, and index properties), thermal/thermomechanical (i.e., in situ temperature and thermal conductivity), and hydrological (i.e., in situ hydraulic pressure) characteristics of the undisturbed rock in the vicinity of the ES and of the construction-affected zone around the shafts

- The validity of specific response models (i.e., primarily mechanical and hydrologic), applied at the shaft scale (excluding shaft decommissioning seals and backfill).

Other relevant information requirements which will be addressed only in a supplemental way (e.g., by providing samples for laboratory testing or by observing performance of the ESF shafts) include:

- Tectonic activity

- Other mechanical (i.e., strength, creep/fusing, density, and hardness), thermomechanical (i.e., specific heat, salt/air heat transfer coefficient, and thermal expansion), geohydrological (i.e., hydraulic conductivity, porosity, specific storage, and diffusion), and chemical (i.e., geochemistry, hydrochemistry, adsorption, and alteration/solubility) properties of the undisturbed rock in the vicinity of the ES and of the construction-affected zone around shafts

- The validity of other response models (i.e., thermal/thermomechanical and chemical) applied at the shaft scale (excluding shaft decommissioning seals/backfill)

- The effectiveness of shaft construction procedures.

Information requirements which are not addressed by the program described in this SSP, but by other testing programs, primarily include (see UTP - Table A-6):

- Past man-made disturbance at the site

- Dispersivity and brine migration of the undisturbed rock in the vicinity of the ES and of the construction-affected zone around the shafts

- Properties of the room and emplacement hole subsystems (including the construction-affected zones), and of the shaft decommissioning seals/backfill

- The validity of any response models applied at the room and waste package (emplacement hole) scales, or applied to the shaft decommissioning seals/backfill, and the validity of radionuclide transport models applied at the shaft scale

- The effectiveness of construction procedures for the room, emplacement holes, and backfill and seals at the shaft, room, emplacement hole, and borehole scales

- The effectiveness of repository operating systems and procedures.

The above information requirements, in conjunction with relevant information requirements from all other sources, will be discussed in more detail in Section 3.3.

3.2 REPOSITORY PROGRAM REQUIREMENTS

In addition to federal, state, and local requirements (Section 3.1), the repository program has its own requirements for repository design, and for design and operation of the Exploratory Shaft Facility (ESF) itself, as discussed in Sections 3.2.1 and 3.2.2, respectively.

3.2.1 Repository Design Requirements

A matrix of repository design activities and information requirements has been previously identified by the repository A/E (Fluor, 1986a and b). The relevant repository design issues addressed wholly or in part by this SSP are discussed in Section 3.2.1.1, and the associated information requirements in Section 3.2.1.2.

3.2.1.1 Repository Design Issues

Demonstrating compliance with the regulatory requirements will require both a suitable site and adequately designed engineered subsystems for the repository. The site subsystem is fixed; however, the engineered subsystems may be designed according to the operating conditions and requirements. Conditions which affect design of the engineered subsystem also generally affect performance, so that the information needed for repository design is primarily a subset of that needed to determine compliance with the regulatory requirements, and the repository design issues are, in general, a subset of the performance issues.

The activities associated with design of the repository (i.e., the repository design issues) have been previously identified by the repository A/E (Fluor, 1986a) and are listed across the top of Table 3-2. These design activities have been categorized in terms of shafts, underground facilities, surface facilities, and decommissioning, of which only the first and last are relevant to the Shaft Study Program. The other design activities, i.e., related to the underground facilities, entry backfill and bulkheads, borehole backfill and seals, and surface facilities, have been abbreviated and designated as being not applicable [NA]. These design activities will not be significantly addressed by the program described in this SSP, but by other testing programs (e.g., At-Depth Study Program [Golder Associates, 1987a]).

3.2.1.2 Repository Design Related Information Requirements

As discussed in Section 3.2.1.1, specific information is required to design the repository, prior to resolving the performance issues and determining compliance with the regulations. The information required for each design activity has been previously identified and discussed in detail by the repository A/E (Fluor, 1986a and b), as summarized in Table 3-2. The set of information requirements has been categorized in terms of near-surface field data, at-depth field data, laboratory data, natural phenomena, geologic processes, and baseline environmental conditions, of which only specific near-surface field data (specifically, engineering geology description), at-depth field data, natural phenomena (specifically at-depth air temperature/humidity), and baseline environmental conditions (specifically at-depth water quality/quantity) are relevant to this SSP.

Table 3-2. Repository Design Information Requirements to be Addressed by Testing/Monitoring in the Exploratory Shafts.

INFORMATION REQUIREMENTS \ REPOSITORY DESIGN ACTIVITIES		SHAFTS												OTHER		DECOMMISSIONING				
		Excavation Procedures	Ground Control	Groundwater Control	Lining Design	Creep/Swell Effects	Operational Seals	Shaft Siting	Shaft Collar	Shaft Stations	Seismic Design	Performance Monitoring	Hoist/Head Frame	Underground Facilities [NA]	Surface Facilities [NA]	Entry Backfill [NA]	Entry Bulkheads [NA]	Shaft Backfill	Shaft Seals	Borehole Backfill/Seals [NA]
1. Field Data, Near Surface (<300')																				
1.1 TOPOGRAPHIC	[NA]	○	○		○			○	○				○	○	○	○	○	○	○	○
1.2 INFRASTRUCTURE/UTILITIES	[NA]			○				○							○					
1.3 SOIL CHARACTERISTICS	[NA]	○	○	○	○	○		○	○	○	○	○	○		○					
1.4 ENGINEERING GEOLOGY																				
1.4.1 Engineering Geology Description		●	●	●	●	●		●	●	●	●	●	●		○	○	○	●	●	○
1.5 HYDROLOGY	[NA]	○	○	○	○	○		○	○		○	○			○				○	
2. Field Data, at Depth (>300')																				
2.1 ENGINEERING GEOLOGY																				
2.1.1 Engineering Geology Description		●	●	●	●	●	●	●		●	●			○		○	○	●	●	○
2.1.2 Structural Configuration								●			●			○						
2.1.3 Cavities		●	●	●			●	●		●				○						
2.2 HYDROGEOLOGY																				
2.2.1 Hydrogeologic Parameters		●	●	●	●	●	●					●		○					●	○
2.2.2 Flow Velocities & Gradients							●	●				●		○					●	○
2.2.3 Hydraulic Pressures		●	●	●	●		●					●		○					●	○
2.2.4 Fluid Properties				●			●												●	○
2.2.5 Brine Content and Migration Rate in Salt				●								●		○						
2.2.6 Disturbed Rock Hydrogeology							●												●	
2.3 THERMAL																				
2.3.1 Rock Temperature				●	●	●	●					●		○					●	○
2.3.2 Thermal Conductivity/Specific Heat				●	●	●	●							○					●	○
2.3.3 Thermal Expansion				●	●	●	●							○					●	○
2.4 GEOMECHANICAL																				
2.4.1 In Situ Dynamic Properties		●	●		●		●			●	●			○						
2.4.2 Rock Joint Parameters		●	●	●	●		●			●	●			○					●	
2.5 ROCK STRESS																				
2.5.1 In Situ Stress		●	●		●	●	●			●	●			○					●	○
2.5.2 Stress near Shaft/Boreholes			●		●	●	●			●		●							●	○
2.5.3 Stress near Underground Openings	[NA]													○			○			
2.5.4 Stress in Pillars	[NA]													○						
2.5.5 Stress near Emplacement Holes	[NA]													○						

● Repository design information requirements addressed by the SSP.

○ Repository design information requirements not addressed by the SSP.

Table 3-2. (cont.)

REPOSITORY DESIGN ACTIVITIES / INFORMATION REQUIREMENTS	SHAFTS												OTHER		DECOM-MISSIONING				
	Excavation Procedures	Ground Control	Groundwater Control	Lining Design	Creep/Swell Effects	Operational Seals	Shaft Siting	Shaft Collar	Shaft Stations	Seismic Design	Performance Monitoring	Hoist/Head Frame	Underground Facilities [NA]	Surface Facilities [NA]	Entry Backfill [NA]	Entry Bulkheads [NA]	Shaft Backfill	Shaft Seals	Borehole Backfill/Seals [NA]
2.6 DISPLACEMENTS																			
2.6.1 Shaft Convergence	●	●		●	●	●		●	●		●							●	
2.6.2 Underground Opening Convergence [NA]				○	○	○			○		○		○		○	○		○	
2.6.3 Emplacement Hole Convergence [NA]													○						
2.6.4 Rick Deformation around Openings	●	●		●	●	●		●	●		●		○			○			
2.7 OTHER																			
2.7.1 Ground Control Systems		●							●		●		○		○	○		●	
2.7.2																			
2.7.3 Instrument Durability		●	●	●	●	●		●	●	●	●		○		○	○	●	●	○
2.7.4																			
2.7.5 Operational Seal Material Response	●		●	●	●	●					●								
2.7.6 Equipment Performance	●		●								●		○		○	○	●	●	○
2.7.7 Friction Coefficients for Emplacement [NA]													○						
2.7.8 Salt Plug Coring Performance [NA]													○						
2.7.9 Water-Bearing Strata Treatment	●	●	●	●		●	●	●			●						●	●	
2.7.10 Rock Weathering		●			●								○						
2.7.11 Rock Parameters for HVAC [NA]													○						
2.8 WASTE ISOLATION SEALS AND BACKFILLS [NA]	○	○	○	○	○					○	○		○		○	○	○	○	○
3. Laboratory Data[a] [NA]	●	●	●	●	●	●		●	●	●	●		○	●	○	○	●	●	○
4. Natural Phenomena																			
4.1 AIR TEMPERATURE/HUMIDITY																			
4.1.1 Surface Air Temperature/Humidity [NA]													○	○					
4.1.2 At-Depth Air Temperature/Humidity	●			●				●			●		○						
4.1.3 Frost Penetration [NA]								○				○		○					
4.2 RAINFALL/SNOWFALL [NA]	○		○											○					
4.3 FLOODS [NA]			○				○				○	○		○					
4.4 WIND [NA]	○						○					○		○					
4.5 TORNADO [NA]												○		○					
4.6 EARTHQUAKE[b] [NA]	○	○		○			○	○	○	○	○		○	○		○		○	
5. Geologic Processes [NA]											○		○	○			○	○	○
6. Baseline Environmental Conditions																			
6.1 AIR/NOISE [NA]													○	○					
6.2 WATER QUALITY/QUANTITY																			
6.2.1 Surface Water Quality/Quantity [NA]			○				○	○						○					
6.2.2 At-Depth Water Quality/Quantity	●		●			●													

NOTE:
Modified from Fluor, 1986(a), with those portions unrelated to testing/monitoring in the exploratory shafts abbreviated and designated as not applicable [NA] and shown as open circle.

[a]Samples will be obtained in the exploratory shaft for laboratory testing.

[b]Some supplementary information relevant to seismic response will be generated by monitoring/testing in the exploratory shafts

Other types of information (e.g., laboratory data, earthquakes, and geologic processes) will be addressed by the program discussed in this SSP in only a supplementary way; i.e.:

- Samples will be obtained for laboratory testing

- Underground testing will address some of the information requirements currently identified under laboratory testing

- Some supplementary information will be generated by monitoring/ testing in the ES which is relevant to assessing seismic response and geologic processes, although this is not the express purpose of the tests, and other tests (e.g., surface-based testing) will provide better information.

Surface, near-surface, and backfill and seal related information will not be addressed by this SSP and have been abbreviated and designated as being not applicable [NA].

The repository design information requirements, as specified by the repository A/E (Table 3-2), are a mixture of data, parameters (e.g., thermal conductivity), measured or predicted responses (e.g., shaft convergence), and design (e.g., ground control systems). As such, they do not coincide directly with the performance-related information requirements in Section 3.1.2, which consist of either parameters or models that describe the response; however, they are generally consistent. In some cases, the identified repository design information requirements are much broader than the performance-related information requirements and approach the level of performance issues, while in other cases they are much narrower and approach the level of methods for obtaining the information. These differences are reconciled in Section 3.3.

3.2.2 ESF Design Confirmation and Maintenance Requirements

Regardless of the repository-related issues, the ESF itself must also perform adequately. It is therefore necessary to confirm that the assumptions made for ESF design are valid.

The information needed to accomplish this has been identified by the ESF A/E (Parsons-Brinckerhoff/PB-KBB, 1986a). The relevant issues are discussed in Section 3.2.2.1, and the pertinent information requirements in Section 3.2.2.2.

3.2.2.1 ESF Design Confirmation and Maintenance Issues

In addition to providing information applicable to repository design, it will be necessary to confirm ESF design for operational reasons, e.g., safety. This will entail confirming that:

- The actual as-built geological, geotechnical, geohydrological, and geochemical conditions correspond to those assumed for ESF design, which will be based primarily on laboratory and surface-based testing, including boreholes such as the EDBH

- The engineered system, i.e., the interaction of the site and the shafts, linings, and seals, is performing as anticipated.

The ESs, as potential components of a repository, are to be designed for a 100-year life. To ensure such a life, a shaft maintenance plan has been proposed by the ESF designer (Parsons-Brinckerhoff/PB-KBB, 1986a), as summarized in Table 3-3. This plan consists of monitoring certain aspects of ES system performance and implementing, if necessary, repair and replacement action.

Because the design concepts for the ESF and the repository shafts are intended to be similar, and in fact the ESs are intended to be incorporated in the repository, the confirmation of ESF design assumptions and the monitoring of ESF performance are primarily a subset of the activities required for repository shaft design (see Section 3.2.1.1). No other design confirmation issues have been identified. Again, confirmation of ADF design assumptions, the monitoring of ADF performance, and the evaluation of ESF equipment and procedures, although important, will <u>not</u> be addressed by this SSP, but by other testing programs which are not <u>within</u> the scope of this SSP.

3.2.2.2 ESF Design Confirmation and Maintenance Information Requirements

As discussed in Section 3.2.2.1, a specific set of information is required to confirm ESF design and implement a maintenance program, regardless of the information required for repository design or licensing. The specific types of information required have been previously identified and discussed in a preliminary fashion by the ESF A/E (Parsons-Brinckerhoff/PB-KBB, 1986). These information requirements have been summarized in Table 3-4.

Information requirements related to the ADF, although important, will <u>not</u> be addressed by the program presented in this SSP, but by other testing programs which are not within the scope of this SSP.

Table 3-3. Shaft Maintenance Plan

FACTORS AFFECTING SHAFT LIFE, METHODS OF DETECTION, AND REPAIR/REPLACEMENT ACTIONS [PB/PB-KBB, 1986 (a)]

Mechanism	Result of Mechanism	Effect on Shaft	Effect Monitoring Locations	Monitoring Methods and Devices	Repair and Replacement Action
Mining extraction	Movement of formations relative to one another resulting from: o ground subsidence o mining induced seismicity. Changes in local aquifer characteristics resulting from subsidence.	Development of shear stresses and/or nonuniform stress distribution in lining; tilt of shaft axis, buckling; shaft convergence, out-of-roundness; and micro-seismicity, water migration behind lining. Geo/hydrochemistry; pore pressures; and changes in electrical potential	Shaft, shaft pillar, subsurface workings, and ground surface.	Optical survey methods, plumblines,and tiltmeters; strain gages; stressmeters, joint meters, and pressure cells; micro-seismic arrays. Piezometers, potentiometers, and geo/hydrochemical sampling.	Local liner reinforcing; liner repairs and replacement; excavation in unlined section; inner liner placement; cathodic protection adjustment pressure grouting, seal replacement.
Localized salt dissolution in salt bearing formations	As above.	As above.	As above.	As above.	As above.
Areal groundwater drawdown	Settlement resulting from soil consolidation.	As above	As above	As above.	As above.
Tectonic (seismic) activity	Uplift/subsidence and/or movement of formations relative to one another (i.e., faulting).	As above	As above.	As above	As above.
Excess in situ stress ($K_o > 1.0$)	Increased rate and magnitude of formational loading; non-uniform directional loading.	Development of excess stress, and/or nonuniform stresses in lining; shaft convergence out-of-roundness; buckling of lining; and changes in electrical potential.	Shaft and pillar	Strain gages, stress meters jointmeters, pressure cells convergencemeters, borehole extensometers and potentiometers.	As above.
Excess salt and/or non-salt rock creep	Increased rate and magnitude of creep loading.	As above.	As above.	As above.	As above.
Geochemical changes	Changes in water chemistry; changes in electric potential; changes in stress of lining, and degradation of polymer seal material.	Corrosion of lining steel, and deterioration of cemetitious and polymer (seal) materials	Shaft and surface cathodic protection monitoring stations, shaft.	Piezometers, water collection ports, potentiometers, strain gages jointmeters, pressure cells; convergencemeters; and acoustic transmitters/receivers, ultrasonic inspection.	Adjust cathodic protection; grouting liner repairs and replacement, seal replacement.
Thermal changes from: o ambient conditions o construction conditions o ventilation conditions o repository operations	Nonuniform stresses resulting from thermally induced uplift from repository operations, stress changes, changes in local aquifer.	Buckling of lining, out-of-roundness; tilt of shaft axis. Increased corrosion of steel shell and deterioration of cementitious and polymer (seal) materials. Water migration behind lining.	Shaft, shaft pillar, subsurface workings and ground surface.	Thermistors, strain gages, jointmeters, pressure cells, convergence meters, stressmeters, acoustic transmitters/receivers, optic survey methods, plumblines, tiltmeters, and potentiometers.	As in items 1 and 7 above.
Erosion by ventilation	Creation of uneven, irregular steel surface. Pitting of lining.	Reduction in lining thickness, shaft increased corrosion, changes in lining stress.		Visual inspection, strain gages, acoustic transmitters/receivers, stress meters, calibration coupons. Ultrasonic inspection.	Adjust ventilation, apply/repair internal corrosion protection, install protective shields.

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Table 3-4. ESF Design Confirmation and Maintenance Information Requirements

CHARACTERISTICS THAT CONTROL ESF SHAFT DESIGN AND MUST BE CONFIRMED:

- Stratigraphy, including:
  - Depth and thickness of stratigraphic units penetrated by the shaft (especially the Alibates and other potential seal strata).
- Structure/Tectonics, including:
  - Faulting
  - Lineament and joint trend
  - Seismic intensity data
  - Uplift, subsidence, and folding.
- Rock Characteristics, including:
  - Geomechanical properties (including creep rates)
  - In situ stress
  - Ambient thermal gradient for the full shaft length
  - Presence of highly fractured zones (especially from the base of the Alibates to the top of the Queen Grayburg Formations)
  - Distribution and amount of mudstone in Unit 4 salt
  - Nature of contact between the Ogallala Formation and the Dockum Group.
- Hydrostratigraphy, including:
  - Water flow horizon
  - Fluid from shale, siltstone, mudstone, dolomite, limestone, and anhydrite formations within the broadly defined aquitard from the Dockum to the top of Unit 4 salt
  - Fluid flow from any salt/non-salt contacts, as well as from the salt itself
  - Vertical fluid flow characteristics through aquitards below the Dockum
  - Pore pressure and fluid characteristics around shaft.
  - Hydrogeologic conditions in strata underlying the ADF horizon.

Table 3-4. ESF Design Confirmation and Maintenance Information Requirements (Page 2 of 3)

- Geochemistry, including:
  - Rock and fluid composition.

<u>ASPECTS OF SHAFT SYSTEM PERFORMANCE THAT MUST BE CONFIRMED:</u>

- Mechanical Response - Total mechanical response of the lining system (including preliminary and final linings and seals) and the interaction of the lining system and surrounding wall rock, in representative non-salt sections as well as in salt sections, especially throughout the length of the preliminary lining, including:
  - Convergence of the shaft diameter in response to ground and water pressures
  - Total pressure on the lining
  - Stresses and strains in the lining
  - Buildup of stress if the in situ creep is greater than that observed in a small-scale borehole or laboratory testing (i.e., greater than that allowed for by overexcavation).
  - Tilt and axial deformation
  - Slippage at rock/preliminary lining interface, as well as between the preliminary and final linings
  - Rock mass deformations and stress conditions during shaft sinking
  - Mechanical forces and resulting reactions of the two shaft foundation rings
  - Effects of regional seismic activity on the shaft and pertinent structures.
- Thermal Response, including:
  - Temperature of lining and rock
  - Thermal-induced stresses in the lining due to concrete curing and cooling
  - Temperature in shaft, as well as stresses resulting from thermal changes
  - Ventilation temperature differentials.

Table 3-4. ESF Design Confirmation and Maintenance Information Requirements (Page 3 of 3)

- Hydrological Response, including:
  - Uplift pressures on/in shaft bottom plug
  - Hydraulic pressures
  - Moisture content in the airstream of both shafts
  - Water inflow.
- Geochemical Response, including:
  - Changes in geochemistry of wall rock or formation fluids
  - Changes in lining thickness, surface integrity, and associated stress changes.
- Specifically in Unlined Portions of the Shaft:
  - Convergence of shaft diameter due to long-term salt deformation (i.e., creep)
  - Heave of shaft bottom.
- Specifically in Shaft Seals:
  - Pressure changes within the shaft chemical seals
  - Overall integrity of seal material with time.
- Specifically During Construction:
  - Ice wall creep in shaft excavation, relative to: (a) freeze pipe deformation, and (b) support pressure
  - Thawing of ice wall relative to freeze hole abandonment schedule requirements and compliance to applicable regulations.

[Derived from Parsons-Brinckerhoff/PB-KBB, 1986]

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3.3 SUMMARY INFORMATION REQUIREMENTS FROM SHAFT STUDY

Information requirements to be addressed by the program described in this SSP have been developed from three primary sources. The correlation between the various sets of information requirements is discussed in Section 3.3.1, and the various sets are then compiled into a single comprehensive set of information requirements and presented in Section 3.3.2.

3.3.1 Correlation of the Various Sets of Information Requirements

Different sets of information requirements which will be addressed by the program given in this SSP have been identified for: resolving the relevant performance issues, and thereby determining compliance with the regulatory requirements (Section 3.1, Table 3-1); repository design (Section 3.2.1, Table 3-2); and confirming pertinent ESF design (Section 3.2.2 Table 3-4). These different sets of relevant information requirements have been identified at different levels of detail, but they are generally consistent, e.g.:

- The relevant performance-related information requirements (Table 3-1), discussed in Section 3.1, are expressed at a relatively broad, but consistent, level of detail. They have been discussed in considerably more detail in the UTP (Golder Associates, 1986a), albeit qualitatively, in terms of the relevant conditional parameters (e.g., scale, temperature, etc.) which must be considered and of the appropriate location and number of samples or tests.

- The relevant repository design information requirements (Table 3-2), discussed in Section 3.2.1, are expressed at a variety of levels of detail, ranging from test data to predicted performance. They have been discussed in greater detail by the repository A/E (Fluor, 1986a and b), generally in terms of what information is required, why it is required, when it is required, and how it should be obtained, although in most cases not where information should be obtained from or how much is required. Generally, the most detailed level of the repository design information requirements are more detailed than the performance-related information requirements, and fit within one of the broader performance-related categories.

- The relevant ESF design confirmation/maintenance information requirements (Table 3-4), discussed in Section 3.2.2, are expressed at a variety of levels of detail, similar to the repository design information requirements. In many cases, the appropriate locations of samples/tests are discussed together with why the information is required and how it should be obtained, but not when it is required. Again, all of these ESF information requirements fit within the broader categories of the performance-related information requirements.

Hence, the identified performance-related information requirements are comprehensive with respect to relevant performance issues (and hence the regulatory requirements), repository design, and ESF design confirmation/maintenance. The identified repository design and ESF design confirmation/maintenance information requirements provide some specific details regarding the otherwise relatively broad categories of performance-related information requirements. A comprehensive development of the information requirements at this level would require performance allocation, i.e., sensitivity studies to determine the influence of various parameters of each of the subsystem components on system performance; assessment of the relative effectiveness in achieving or defining various parameter values; and trade-off studies to determine the optimum combination of achievable parameter values. Although such performance allocations have not yet been quantitatively assigned, the relative significance of each of the parameters and the relative effectiveness in addressing each have been subjectively assessed and implicitly used to determine the appropriate set of detailed information requirements. These detailed information requirements, which are subject to change as performance allocation is quantitatively defined, are summarized in the following section. They have been categorized in the same terms as the relevant performance-related information requirements, with the specific details provided by the relevant repository design and ESF design confirmation/maintenance information requirements noted. Hence, all of the previously identified relevant information requirements (Sections 3.1 and 3.2) have been incorporated.

3.3.2 Detailed Information Requirements

Based on subjective assessments, each of the information requirements to be addressed wholly or in significant part by the Shaft Study Program is described in detail in this section, categorized most broadly in terms of site characteristic assessment in the zone around the shafts (Section 3.3.2.1) and design/model validation (Section 3.3.2.2).

The program of monitoring and testing in the ES is only one component of site characterization and will not, in general, completely satisfy the set of information requirements identified herein. Rather, it will complement and supplement other programs of site characterization, e.g., surface-based testing, laboratory testing, testing and monitoring in the ADF, and major subsurface testing such as the Mine-By Test, Waste Package Heater Test, etc., in satisfying these information requirements.

The information requirements addressed by the program described in this SSP relate primarily to characterization of the physical and chemical properties of the site in the near vicinity of the ES, including both the undisturbed and construction-affected conditions, and the validation of specific design and performance models relevant to the scale of the shaft. Model validation will enable the reliable prediction of performance at locations where the site characteristics/parameters differ from those in the ES, providing the relevant characteristics are determined by site investigations and testing, and the general physical/chemical behavioral regimes are similar. These site investigations/testing away from the ES might consist of relatively simple methods used in surface boreholes or during repository construction, which have been correlated with the more sophisticated methods used in the ES. Such correlative testing allows for the reliable extrapolation of characterization throughout the repository site, of which the ES is only a small part.

3.3.2.1 Site Characteristic Assessment in the Zone Around Shafts

A major subset of the information requirements to be addressed by this program of testing and monitoring in the ES relates to the characteristics of the site in the zone around the shafts, especially: the potential repository horizon (LSA4) and the proximate strata; shaft operational seal locations (Alibates and basal sediments of LSA5); and potential shaft decommissioning seal locations, e.g., basal anhydrite of Salado-Tansill and Upper Seven Rivers Formations, the Queen-Grayburg shale, the Upper San Andres Formation (shale and anhydrite), and LSA5 salt cycle. These characteristics can be categorized generally in terms of geology, geomechanics, thermomechanics, geohydrology, and geochemistry. As detailed in Table A-6 of the UTP, many of the response characteristics are not a unique value but a relatively complex function of various conditions such as stress, temperature, strain rate, and stress/strain and temperature history; in addition, these response characteristic may be anisotropic, scale dependent, and time dependent, and may vary spatially. Although these complexities are important, they have not been explicitly identified below but are implied. This program of testing and monitoring in the ES will address only some of these complexities, with additional information provided by other testing programs.

Geology: The characteristics which broadly but comprehensively describe the site geology (setting and processes) in the zone around the ES include stratigraphy/lithology, structure, tectonic activity, and man-made disturbance [NA].

- Stratigraphy/Lithology

  Depth, thickness, orientation and lithologic description of stratigraphic units, including nature of stratigraphic contacts, down through LSA4, with particular reference to:

  - Number and character of non-salt interbeds, e.g., clay or anhydrite layers

  - Anomalies, impurities, and strata composition, e.g., halite with interbedded siltstone, in terms of nature, percentage of major and minor components, and contacts between components (i.e., tight or loose), especially the distribution and amount of mudstone in LSA4

  - Contact between the Ogallala Formation and Dockum Group

  - Petrofabric description, including rock induration, lithification, cementing materials, grain texture, and grain size distribution

[Note: Also determined down through LSA2 from surface-based geology program and in basal sediments of LSA5 through LSA2 from at-depth program.]

- Structure

  Physical and spatial characteristics (including variability) of geologic structure in units down through LSA4, with particular reference to:

  - Faulting, in terms of magnitude and type of displacement and time history, as well as in terms used for other discontinuities

  - Folding

  - Discontinuities (jointing, fracturing, bedding, lithologic contacts, etc.) in terms of origin (natural vs. induced), orientation, density (spacing), persistence (length), shape, planarity, surface roughness, apparent aperture, and description of infilling material and alteration, especially of the highly fractured zones from the base of the Alibates to the top of the Queen-Grayburg Formation (not including fracturing caused by blasting)

  - Solution features, brine products, and cavities, in terms of location, size, distribution, frequency of occurrence, and degree of interconnection

  [Note: Also determined down through LSA2 from surface-based geology program and in basal sediments of LSA5 through LSA2 from at-depth program.]

- Tectonic Activity

  Ongoing geologic processes (including active regional faulting), in terms of seismic events.

  [Note: Determined primarily from surface-based program supplemented by at-depth program.]

Geomechanics: The characteristics which broadly but comprehensively describe the geomechanical setting and behavior of the zone around the ES include in situ stress, strength, deformation moduli, creep/fusing, dynamic properties, density, hardness, and index properties.

- In Situ Stress

  In situ undisturbed rock stress in non-salt rocks down through LSA4

[Note: Also determined (at least partially) in salt in formations down through LSA2 from surface-based program and the at-depth program, and in basal sediments of LSA5 and LSA4 from at-depth program.]

- Strength

  [Note: Intact rock and discontinuity strengths in salt and nonsalt units down through LSA4 (or LSA2, if required) determined from laboratory program; rock mass strength in LSA4 determined from at-depth program.]

- Deformation Moduli

  Deformation moduli of nonsalt units down through LSA4.

  [Note: Intact rock deformation moduli in salt and nonsalt units down through LSA4 (or LSA2, if required) determined from laboratory program; rock mass deformation moduli in basal sediments of LSA5 and in LSA4 determined from at-depth program.]

- Creep/Fusing

  [Note: Intact rock creep and fusing in salt (or other rocks, if required) down through LSA4 (or LSA2, if required) determined from laboratory program; rock mass creep/fusing rates in LSA4 determined from at-depth program.]

- Dynamic Properties

  Dynamic properties (e.g., seismic shear and compression wave velocities, and dynamic and shear moduli), down through LSA4.

  [Note: Also determined in formations down through LSA4 (or LSA2, if required) from laboratory program and from surface-based program, and in basal sediments of LSA5 and LSA4 from at-depth program.]

- Density

  [Note: Density of rock determined in formations down through LSA2 primarily from laboratory program, supplemented (in terms of index testing) by geophysical borehole logging in surface-based program and at-depth program.]

- Hardness

  [Note: Hardness (i.e., abrasion and total hardness) of rock intersected by the ES determined in formations down through LSA4 primarily from laboratory program, supplemented in terms of index testing by core logging in both surface-based program and at-depth program.]

- Index Properties

  Index properties (e.g., results of point load tests, Brazilian tensile tests, Schmidt hammer, porosity, and soundness) for rock down through LSA4.

  [Note: Determined primarily in formations down through LSA4 (or LSA2, if required) from laboratory and from surface-based programs, and in basal sediments of LSA5 and LSA4 from at-depth program.]

Thermomechanics: The characteristics which broadly but comprehensively describe the thermomechanics setting and behavior of the zone around the ES include in situ temperature, thermal conductivity, specific heat, and thermal expansion.

- In Situ Temperature

  [Note: Determined in formations down through LSA2 from surface-based program, and in basal sediments of LSA5 through LSA2 from at-depth program.]

- Thermal Conductivity

  Thermal conductivity of rock down through LSA4.

  [Note: Intact rock thermal conductivity in formations down through LSA2 determined from laboratory program; rock mass thermal conductivity in LSA4 determined from at-depth program.]

- Specific Heat

  [Note: Intact rock specific heat in formations down through LSA2 determined from laboratory program; rock mass specific heat in LSA4 determined from at-depth program.]

- Thermal Expansion

  [Note: Intact rock thermal expansion in formations down through LSA2 determined from laboratory program; rock mass thermal expansion in LSA4 determined from at-depth program.]

Geohydrology: The characteristics which broadly but comprehensively describe the geohydrologic setting and behavior of the zone around the ES include in situ hydraulic pressure, hydraulic conductivity, porosity, specific storage, dispersivity/diffusion, and brine migration [NA].

- In Situ Hydraulic Pressure

  In situ undisturbed hydraulic pressure down through LSA4.

  [Note: Also determined in formations down through LSA2 from surface-based program, and in basal sediments of LSA5 through LSA2 from at-depth program.]

- Hydraulic Conductivity

  Hydraulic conductivity of rock at decommissioning and operational seal locations.

  [Note: Hydraulic conductivity for rock (especially discontinuities, including geologic unit interfaces) also determined in formations down through LSA2 from surface-based program and in basal sediments of LSA5 through LSA2 from at-depth program, both supplemented by laboratory program.]

- Porosity

  [Note: Porosity (in terms of total, interconnected, and effective or kinematic) of rock determined in formations down through LSA2 by laboratory program and in LSA4 through LSA2 (especially discontinuities, including geologic unit interfaces) from at-depth program.]

- Specific Storage

  [Note: Specific storage of rock determined in formations down through LSA2 from surface-based program and in basal sediments of LSA5 through LSA2 from at-depth program.]

- Dispersivity/Diffusion

  [Note: Dispersivity (i.e., mechanical dispersion associated with flow path tortuosity) for rock in LSA4 through LSA2 from at-depth program; diffusion (i.e., molecular diffusion through connected porosity) for rock in LSA4 through LSA2 determined from laboratory program and in LSA4 from at-depth program].

<u>Geochemistry</u>: The characteristics which broadly but comprehensively describe the geochemical setting and behavior of the zone around the ES include geochemistry, hydrochemistry, adsorption, and alteration/solubility.

- Geochemistry

  Geochemistry of rock down through LSA4.

  [Note: Geochemistry (specifically rock composition and gas analysis) of geologic units down through LSA2 determined primarily from laboratory program and in basal sediments of LSA5 through LSA2 from at-depth program, with particular reference to:

  - rock chemical composition and mineralogy

  - fracture and pore infillings, including clays, alteration products, organics

- rock weathering/alteration

- sulfides, diagenetic changes

- isotopes

- redox potential

- hydrous and nonhydrous phases/dehydration

- mineral stability/transformation

- amount and nature of gas (e.g., based on emanometry), including H_2S, He, CO, CO_2, Cl, SO_2, CH_4, CS_2, Rn, thoron, and "sour" gas, in terms of location, occurrence (pockets or dispersed, also size, number, distribution/frequency, interconnection of gas pockets), and release (continuous or outbursts).]

- Hydrochemistry

  Hydrochemistry, primarily in terms of initial brine content and formation fluid pH and Eh at decommissioning and operational seal locations.

  [Note: Formation fluid composition/properties (viscosity, density, compressibility) and chemical composition/at-depth water quality (degree of salt saturation, cations/anions, pH, SP, Eh/electrical conductance/resistivity, dissolved gasses and environmental isotopes, e.g., deuterium and oxygen-18) of all geologic units, including brine pockets, down through LSA2 determined from laboratory program; initial brine content and formation fluid pH and Eh in basal sediments of LSA5 through LSA2 determined from at-depth program.]

- Adsorption

  [Note: Retardation factor (especially considering sorption) of rock down through LSA2 determined from laboratory program.]

- Alteration/Solubility

  [Note: Alteration (mineral transformation) and solubility (salt or joint infilling dissolution) of rock down through LSA2 determined primarily from laboratory program and in basal sediments of LSA5 through LSA2 from at-depth program.]

3.3.2.2 Design/Model Validation

The other major subset of information requirements besides site characterization relates to design and model validation. The pertinent information requirements to be addressed by this program of testing and monitoring in the ES relate generally to the shaft, but do not address the room; the emplacement hole; the waste package; shaft, room, emplacement hole, and borehole backfill and seals; the repository operating systems; or repository waste operations procedures in any significant way.

The information requirements related to the shaft subsystem (excluding both the site outside the construction-affected zone and the backfill/seals) are categorized in terms of construction procedures, properties, mechanical response, thermal/thermomechanical response, hydrologic response, radionuclide transport, and hydrochemical/geochemical response.

The properties of the rock in the construction-affected zone will tend to be similar to those of the associated undisturbed rock, depending on the nature and amount of disturbance; other properties of the subsystem are related to engineered components (e.g., shaft liner). Not all of these properties will be directly addressed by this SSP, but will be determined in the laboratory on appropriate samples taken from the construction-affected zone.

As detailed in Table A-6 of the UTP, the response models must adequately represent a system which is generally three-dimensional, non-homogeneous, non linear, anisotropic, discontinuous, and rate and history dependent, including changes in stress, temperature, and flow with time. Although these complexities are important, they have not been explicitly identified in the following information requirements. The Shaft Study Program will address only some of these complexities, while the others will be addressed by other testing programs.

Construction Procedures: The effectiveness of shaft construction procedures, ground and groundwater control systems, specifically including blasting practice and rock bolt capacities.

> [Note: Actual ES construction procedures, as well as instrument durability and equipment performance, with particular reference to excavation (including advance rates, drill-and-blast parameters, face and wall stability/closure/heave, bulkhead and seal excavation), ground control methods, and water control (including the freeze zone) will be indirectly addressed by the SSP. Ventilation, trafficability, grout reactivity (chemical or cement), quality control, etc., will be addressed in separate study plans.]

Properties of Shaft Subsystem (including Construction-Affected Zone): Relevant properties of the shaft subsystem (including the construction-affected zone) must be determined, specifically including:

- Strength

  [Note: Strength of construction-affected zone down through LSA4, which is significantly affected by disturbance, determined primarily from laboratory program.]

- Deformation Moduli

  Deformation moduli of construction-affected zone down through LSA4, which are significantly affected by disturbance.

  [Note: Also determined from laboratory program.]

- Creep/Fusing

  [Note: Creep rates of construction-affected zone down through LSA4, which are moderately affected by disturbance, determined primarily from laboratory program.]

- Dynamic Properties

  Dynamic properties (specifically shear and compression wave velocities, dynamic and shear moduli, attenuation/damping, and frequency response) of the construction-affected zone down through LSA4, which are significantly affected by disturbance.

  [Note: Also determined from laboratory program.]

- Density

  [Note: Density of the construction-affected zone down through LSA4, which is not significantly affected by disturbance, determined primarily from laboratory program.]

- Thermal Conductivity

  Thermal conductivity of the construction-affected zone down through LSA4, which is moderately affected by disturbance.

  [Note: Also determined from laboratory program.]

- Specific Heat

  [Note: Specific heat of the construction-affected zone down through LSA4, which is not significantly affected by disturbance, determined primarily from laboratory program.]

- Salt/Air Heat Transfer Coefficient

  [Note: Salt/air heat transfer coefficient, which is a measure of the heat convection from the walls into the ventilation air stream, down through LSA4, determined primarily from laboratory program.]

- Thermal Expansion

  [Note: Thermal expansion of the construction-affected zone down through LSA4, which is significantly affected by disturbance, determined primarily from laboratory program.]

- Hydraulic Conductivity

  Hydraulic conductivity, which is significantly affected by disturbance of construction-affected zone at proposed operational and decommissioning seal locations.

  [NOTE: Hydraulic conductivity of construction-affected zone down through LSA4 also determined from laboratory program.]

- Porosity

  [Note: Porosity (in terms of total, interconnected and effective or kinematic) of construction-affected zone down through LSA4, which is significantly affected by disturbance, determined primarily from laboratory program.]

- Specific Storage

  [Note: Specific storage of construction-affected zone down through LSA4, which is moderately affected by disturbance, is not addressed.]

- Dispersivity and Diffusion Coefficients

  [Note: Dispersivity and diffusion coefficients for the construction-affected zone down through LSA4, which are moderately affected by disturbance, determined primarily from laboratory program.]

Mechanical Response: The mechanical response of the shaft subsystem (including interaction of the construction-affected zone and the shaft liner system) which, as expressed by a model, is a function of strength, deformation moduli, creep/fusing, boundary conditions (i.e., in situ stress), and the shaft liner design. This response includes stress, deformations and closure of the opening, the creation/healing or opening/closing of fractures, and instability, as a function of the construction procedures and design/support system, specifically:

- Stress distribution around the shaft, especially lateral concentrated loads from non-salt beds surrounded by creeping salt, where compressible backfill will permit salt to creep (e.g., lower reaches of Upper San Andres and within LSA5), and also possibly from swelling rock.

- Stresses and strains in the ground support system (e.g., the shaft liner and rock bolts).

- Shaft convergence at the exposed rock surface or liner during and after sinking, in response to ground and ground-water pressures, including:

  - long-term salt deformation, i.e., creep, including rate of creep of over-excavated salt strata, where compressible backfill material is provided behind a concrete lining (e.g, in salt strata overlying LSA4)

  - creep of unlined freeze wall

  - ice wall creep, e.g., relative to (a) freeze-pipe deformation, and (b) support pressure

- Rock deformation/displacement around shafts during and after excavation (e.g., at various distances from the excavation surface to beyond the construction-affected zone).

- Vertical and lateral movement between the preliminary and final linings.

- Mechanical forces and resulting reactions of the two shaft foundation rings, including vertical contact stresses at the shaft foundation concrete/salt interface, and radial and circumferential stresses in the confining ring.

- Tilt and axial deformation of the shaft lining.

- Heave of shaft bottom (if any) during construction.

- Swelling (or shrinkage) strain of concrete in both preliminary and final linings, interface stresses, and elastic moduli of in-place concrete.

- Pressure in shaft lining bitumen layer (with depth).

- Strain (and load) distribution with time after installation, along the length of rock bolts.

- Induced seismicity, resulting from shaft construction (e.g., monitored with a local microseismic monitoring system linked with regional seismograph monitoring).

- Response of shaft and associated structures to seismic loads (e.g., determined by stress changes, strains (transient), and physical visual inspection for cracking), including earthquake-induced effects (effects of regional seismic activity on the shaft and pertinent structures), near-field ground motion, and response spectra.

Thermal/Thermomechanical Response: Thermal/thermomechanical response of the shaft subsystem (including interaction of the construction-affected zone and the shaft liner system), which, as expressed by a model, is a function of thermal conductivity, specific heat/density, salt/concrete/steel-air heat transfer coefficient, and thermal expansion, and the boundary conditions (i.e., in situ temperature, opening/ventilation design, and heat source). This response includes temperature (heat transfer) and thermally induced deformations/fracturing, specifically:

- Temperature distribution around the shaft (within and in rock behind lining)
- Air temperatures in the shaft
- Displacement of the rock and closure of the shaft resulting from thermal changes
- Thermal-induced stresses in the lining due to concrete curing and cooling

Hydrologic Response: Hydrologic response of shaft subsystem (including the interaction of the construction-affected zone and the shaft liner/ seal system), which, as expressed by a model, is a function of hydraulic conductivity, porosity, and specific storage, and the boundary conditions (i.e., in situ hydraulic pressure and opening/dewatering/seal design). This response includes pressures, volume, and velocity of flow, specifically:

- Hydraulic pressure in rock (especially in discontinuities) around shaft, behind the lining near the lining-to-rock contact, and on/in the shaft plug.
- Shaft water inflow (e.g., measured as total initial and steady-state inflow into the shafts during construction), with leakage past seals, and vertical flow through the construction-affected zone between aquifers (especially the Ogallala and Dockum).

Radionuclide Transport [NA]:

[Note: Radionuclide transport (in terms of quantity and velocity) in the shaft subsystem (including the interaction of the construction-affected zone and the shaft liner/seal systems), which, as expressed by a model, is a function of dispersivity, diffusion, solubility, and sorption, as well as of ground water flow and radionuclide source term, determined primarily from laboratory program.]

Hydrochemical/Geochemical Response: Hydrochemical/geochemical response of the shaft subsystem (including the interaction of the construction-affected zone and the shaft liner/seal systems), which, as expressed by a model, is a function of alteration/dissolutioning and of the initial conditions (geochemistry/hydrochemistry). This response includes the degree of alteration and dissolutioning (and thus changes in hydrochemistry) as a function of flow and heating, specifically:

- Mineral transformation/stability (see Alteration/Solubility, Section 3.3.2.1) (e.g., due to brine contamination).

- Changes in geochemistry of wall rock or formation fluids (e.g., due to alternate cycles of drying/wetting, prolonged wetting, seepage, or exposure to outside ventilation air).

- Slake durability and swelling index.

- Concrete/rock interaction and corrosion of ground support systems, including changes in lining thickness, surface integrity, and associated stress changes.

- Release of radon and thoron during mining.

  [Note: Also partially validated by major ES environmental monitoring (e.g., gas monitoring) and by laboratory testing.]

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4.0 SHAFT MONITORING AND TESTING STUDY PROGRAM

The Shaft Monitoring and Testing Study Program has been designed to satisfy the information needs presented in Section 3.0; the relationship between information needs and specific tests is summarized in Section 4.1. To improve the overall understanding of the shaft testing program, an introductory section has been included which summarizes the layout and principle of operation of the Automatic Data Acquisition System (ADAS) and Shaft ADAS components (Section 4.2).

The testing program itself has been divided into five major study areas under which each of the individual test methods is presented.

Section 4.3 presents the Shaft Geology Study including geologic mapping of the shaft walls and logging/sampling of core retrieved from test and instrument boreholes.

Section 4.4 presents the Shaft Mechanical/Thermal Response Study including monitoring hydrostatic pressures adjacent to the shaft; measurement of stresses, strains, and displacements within and between the shaft liner components; monitoring convergence of the shaft walls caused by creep of salt strata; and monitoring temperature in the freezewall, preliminary lining, and final lining to facilitate analysis of instrument readings and, in the upper frozen zone, to characterize the interaction between the rock/soil and preliminary lining during concrete curing and freezewall thawing.

Section 4.5 presents the Mechanical/Thermal Properties Study including measurement of absolute stress and deformation moduli at non-salt candidate decommissioning seal locations; measurement of seismic velocities of strata penetrated by the shafts; large-diameter coring to retrieve samples for the Laboratory Rock Mechanics Program; and thermal conductivity testing.

Section 4.6 presents the Shaft Seal Study including monitoring groundwater inflow to the shafts during and following shaft construction; measuring the geohydrological properties of strata at operational and candidate decommissioning seal locations; monitoring the long term performance of operational shaft seals; and hydrologically characterizing the zone of disturbance and the chemical environment at candidate decomissioning seal locations with time.

Section 4.7 presents the Shaft Construction Support Study consisting of blast vibration monitoring and rock bolt pullout testing.

A summary of the facilities, equipment, and labor to be supplied by the CM and CM subcontractors, in support of testing, is presented in Section 4.8. Shaft instrumentation performance specifications (e.g., measurement range and accuracy) have been estimated and are presented in Section 4.9. ADAS monitoring requirements have been developed from the information presented in Section 4.9 and are presented, along with data collection requirements for activities which cannot be automated, in Section 4.10.

4.1 TEST METHODS AND INFORMATION NEEDS

Table 4-1 summarizes the relationship between the individual test methods and information needs to be satisfied by the Shaft Study Program. Only the information needs that are directly addressed by each test are identified in the table, although many tests will provide supplementary information that may be used to address other needs. The information needs in Table 4-1 have been divided into those required for site characterization and those required for design/model validation. The test methods have been subdivided into five major study areas. The detailed rationale for selecting each test, as well as a summary description of each test method, are provided under the pertinent study area in the following sections.

4.2 AUTOMATIC DATA ACQUISITION SYSTEM

Automatic data acquisition will be used extensively during the shaft monitoring and testing program to facilitate handling large amounts of data that will be generated and to obtain regular, frequent readings from instruments that will not be accessible for long periods of time during both construction and operation. Summary details of the Site and Shaft ADAS are provided here to facilitate understanding of the schedule and sequencing of instrument and ADAS installation.

Instruments associated with short term tests that generate relatively few data will be monitored with portable data loggers. Additionally, portable data loggers may be used to collect data from multiple position borehole extensometers (MPBXs) in overexcavated salt formations, between the time of instrument installation and installing the preliminary liner; the need for these data loggers will be determined at a later date by details of the shaft construction sequence.

The vast majority of instruments will be permanently installed in or behind the shaft liner and will be monitored for at least 3 to 5 years. These instruments will be connected to the Shaft Subsystem of the Automatic Data Acquisition System (ADAS).

4.2.1 Data Loggers

Two types of data loggers, designated Type A and Type B, will be used. The Type A data logger will be used to collect early data from MPBXs prior to completion of the preliminary lining and installation of the Shaft ADAS. This type of data logger will be rated intrinsically safe to comply with the federal gassy-mine regulations 30 CFR 57. A plan will be developed outlining the specific installation and operational details for compliance. The operational capabilities of commercially available equipment that satisfies these regulations are generally limited compared to those of the Shaft ADAS; data logging activities will therefore be limited to the following functions:

- To acquire data on a regularly scheduled basis from a relatively small number of instruments

Table 4.1 Exploratory Shaft Testing Methods to Satisfy Information Needs

SITE CHARACTERISTICS ASSESSMENT[a]

EXPLORATORY SHAFT TESTING METHODS / INFORMATION REQUIREMENTS	Geology: Stratigraphy/Lithology	Geology: Structure	Geology: Tectonic Activity	Geology: Man-Made Disturbance[NA]	Geomechanics: In Situ Stress	Geomechanics: Strength	Geomechanics: Deformation Moduli	Geomechanics: Dynamic Properties	Geomechanics: Creep/Fusing	Geomechanics: Density	Geomechanics: Hardness	Geomechanics: Index Properties	Thermomechanics: In Situ Temperature	Thermomechanics: Thermal Conductivity	Thermomechanics: Specific Heat	Thermomechanics: Thermal Expansion	Geohydrology: In Situ Hydraulic Pressure	Geohydrology: Hydraulic Conductivity	Geohydrology: Porosity	Geohydrology: Specific Storage	Geohydrology: Dispersivity/Diffusion	Geohydrology: Brine Migration [NA]	Geochemistry: Geochemistry	Geochemistry: Hydrochemistry	Geochemistry: Adsorption	Geochemistry: Alteration/Solubility
4.3 SHAFT GEOLOGY STUDY																										
4.3.1 Geological Mapping	●	●																								●
4.3.2 Core Logging*	●	●										●														●
4.4 SHAFT MECHANICAL/THERMAL RESPONSE STUDY																	●									
4.5 MECHANICAL/THERMAL PROPERTIES STUDY																										
4.5.1 Absolute Stress Measurement Overcoring					●																					
4.5.2 Borehole Deformation Testing							●																			
4.5.3 Shaft Seismic Velocity Study	●	●					○	●																		
4.5.4 Large Diameter Core Sampling*	●	●																								●
4.5.5 Thermal Conductivity Testing														●												
4.6 SHAFT SEAL STUDY																										
4.6.1 Groundwater Inflow Monitoring																										
4.6.2 Shaft Operational Seal Testing																	○	○								
4.6.3 Construction-Affected Zone Testing-Decommissioning Seals																	○	○								
4.7 SHAFT CONSTRUCTION SUPPORT STUDY																										
4.7.1 Blast Vibration Monitoring								○																		
4.7.2 Rock Bolt Pullout Test																										

DESIGN/MODEL VALIDATION

EXPLORATORY SHAFT TESTING METHODS / INFORMATION REQUIREMENTS	Shaft: Construction Procedures	Shaft: Properties of Liner, Operational Seal & Constr. Affected Zone: - Strength	- Deformation Moduli	- Creep/Fusing	- Dynamic Properties	- Density	- Thermal Conductivity	- Specific Heat	- Salt/Air Heat Transfer Coeff.	- Thermal Expansion	- Hydraulic Conductivity	- Porosity	- Specific Storage	- Dispersivity/Diffusion	Shaft: Mechanical Response	Shaft: Thermal/Thermomechanical Response	Shaft: Hydrologic Reponse	Shaft: Radionuclide Transport	Shaft: Hydrochemical/Geochemical Response	Room [NA]	Emplacement Hole [NA]	Waste Package [NA]	Shaft, Room, Emplacement Hole, and Borehole Backfill/Seals [NA]	Repository Operating Systems [NA]	Repository Operations [NA]
4.3 SHAFT GEOLOGY STUDY																									
4.3.1 Geological Mapping																			○						
4.3.2 Core Logging*																									
4.4 SHAFT MECHANICAL/THERMAL RESPONSE STUDY				●											●	●	●								
4.5 MECHANICAL/THERMAL PROPERTIES STUDY																									
4.5.1 Absolute Stress Measurement Overcoring															●										
4.5.2 Borehole Deformation Testing			●																						
4.5.3 Shaft Seismic Velocity Study			○		●																				
4.5.4 Large Diameter Core Sampling*																									
4.5.5 Thermal Conductivity Testing							●																		
4.6 SHAFT SEAL STUDY																									
4.6.1 Groundwater Inflow Monitoring																	●								
4.6.2 Shaft Operational Seal Testing											●						●		●						
4.6.3 Construction-Affected Zone Testing-Decommissioning Seals											●						●		●						
4.7 SHAFT CONSTRUCTION SUPPORT STUDY																									
4.7.1 Blast Vibration Monitoring	●				○										●										
4.7.2 Rock Bolt Pullout Test	●																								

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NOTES:

● Test designed to provide significant data for assessing the parameter or response.

○ Test will provide supplementary data for assessing the parameter or response.

* Sampling for laboratory testing; information needs addressed by laboratory testing not shown.

a Site characteristics will be assessed only in the zone around the ES. Site characteristics elsewhere will be addressed by other programs (e.g., surface-based field testing, testing in the ADF etc.)

- To record the collected raw data in battery-backed memory hardware compatible with the ADAS communications system.

The accuracy requirements for Type A data loggers will depend on the type of MPBX sensors ultimately selected. The memory capacity will be sufficient to store all data collected between instrument installation and final connection to the ADAS. The data logger will then be removed to the surface and the memory contents transferred to the ESF data base in the Surface ADAS Center (SAC). The layout of the Type A data logger is illustrated in Figure 4-1.

Type B data loggers will be used to record data generated by tests carried out either during or after shaft construction. This type of data logger will be rated intrinsically safe to comply with the federal gassy mine regulation 30 CFR 57. The general requirements for these portable data loggers include:

- Acquire data on a regularly scheduled basis from a relatively small number of instruments

- Convert raw instrument output into engineering values by using the appropriate calibration factors and algorithms

- Display the data in real time to the test operator on a self contained video display, a hardcopy digital/graphical printout, or an external Video Display Unit (VDU)

- Record the raw data on magnetic tape or disc for future transfer to the project database.

The required accuracy and types of input that must be accepted will be determined by the instruments selected for the pertinent tests, and will be established when detailed test procedures for these activities are finalized. The layout of the Type B data logger is illustrated in Figure 4-2.

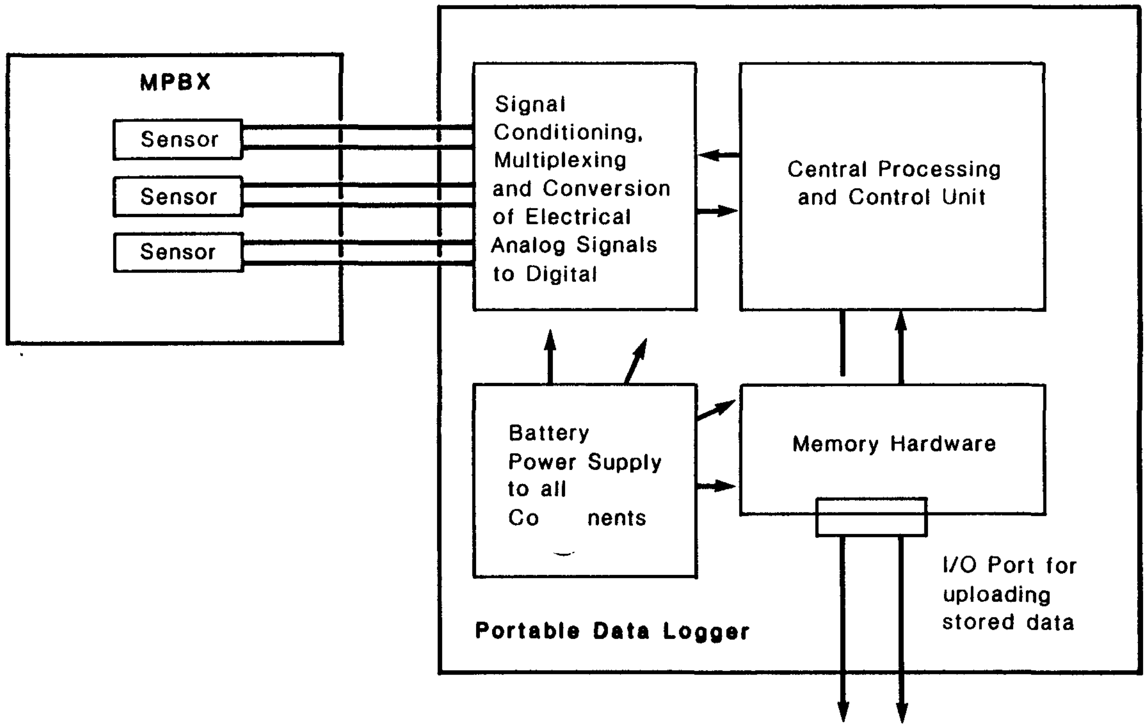
4.2.2 Shaft ADAS Subsystem

4.2.2.1 General Requirements

The ADAS will be installed to monitor those instruments permanently installed in or behind the shaft linings. The general requirements of the Shaft ADAS Subsystem are to:

- Acquire data on a regular basis from as many as 1,900 instruments of several different types and store the data in files for future analysis

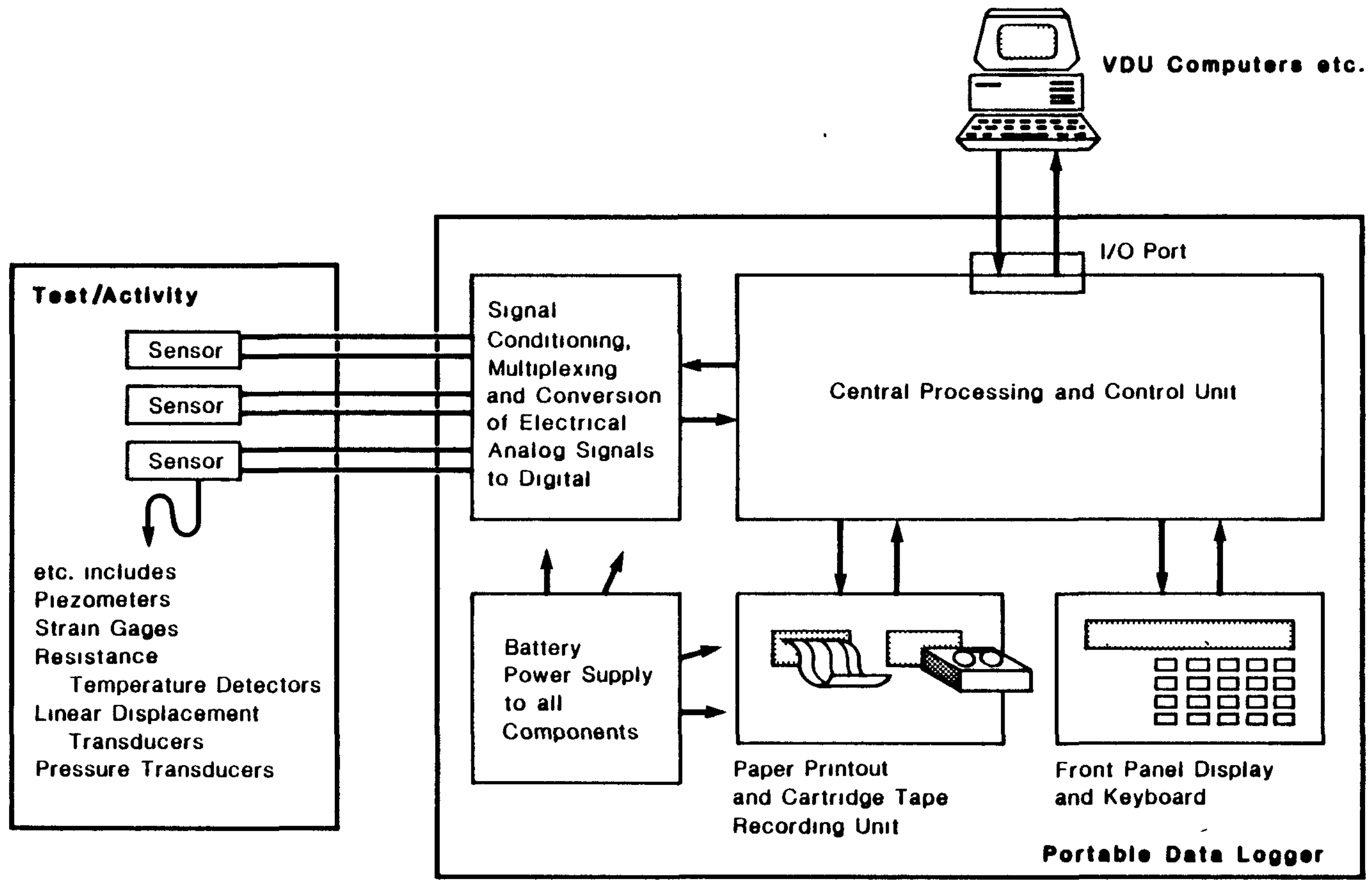
- Convert raw instrument output into engineering values by using appropriate calibration factors and algorithms developed in an earlier phase of the program



Note: Actual number of sensors in MPBX is TBD.

Schematic Layout of Portable Data Loggers (Type A)

Figure 4-1



Schematic Layout of Portable Data Loggers (Type B)

Figure 4-2

- Inspect the calculated results for values that exceed preset alarm limits, and signal the operator that such conditions are present

- Preserve and protect the raw data in controlled-access files with appropriate labeling to provide complete documentation and traceability in conformance with QA requirements

- Provide utilities for managing, reducing, and displaying data to allow real-time evaluation of test results

- Maintain logs and other records of test instrument installation, calibration, maintenance, and wiring

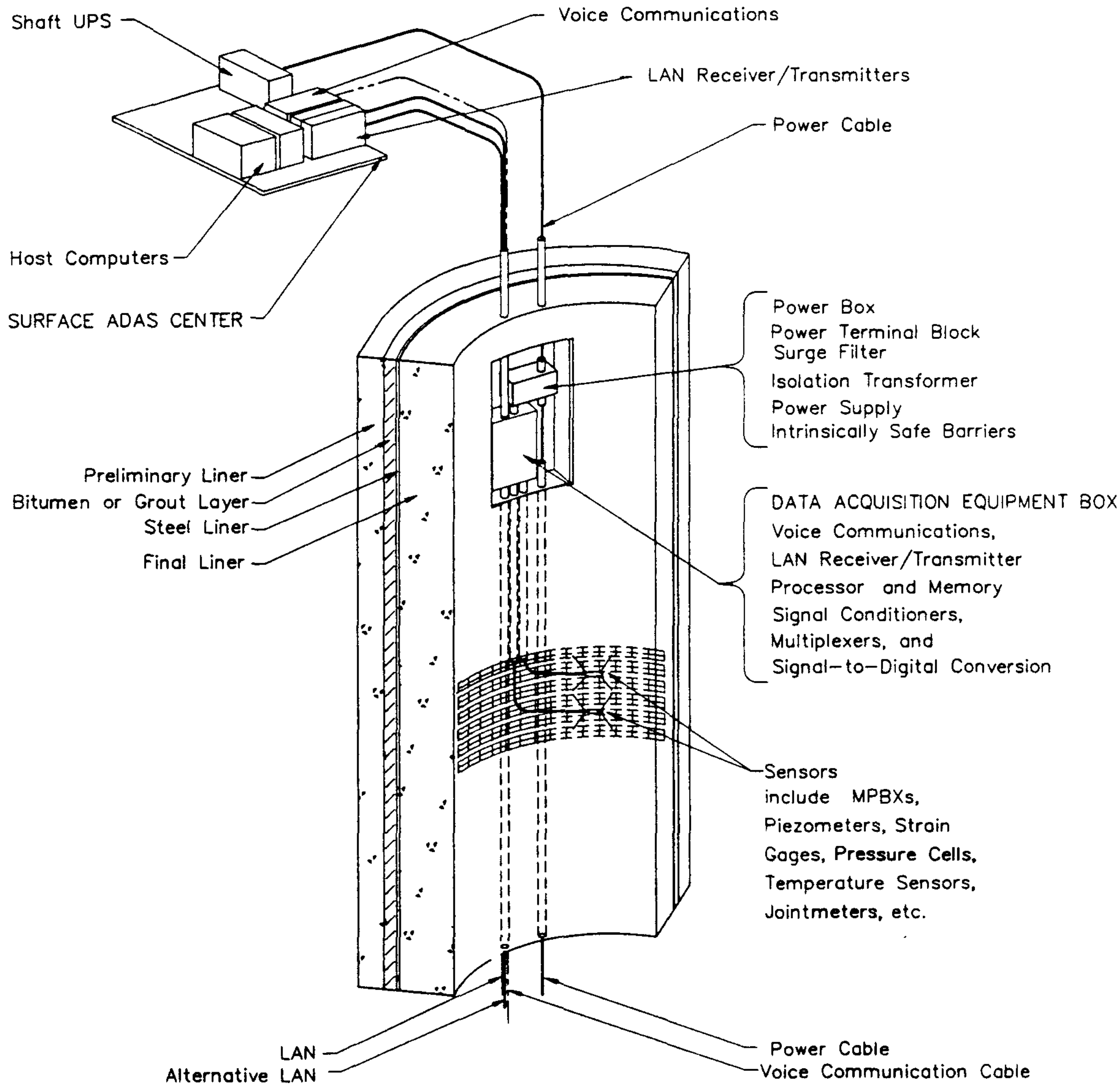
- Provide a highly reliable system so that the loss of data due to the failure of a single system component, at any level, is minimal.

4.2.2.2 System Design

The ADAS for the shafts consists of three major components: the Surface ADAS Center (SAC), the Data Collection Units (DCUs), and the Local Area communications Network (LAN). A schematic diagram of the Shaft ADAS Subsystem is presented in Figure 4-3. A more complete description of the ADAS and details of the location of ADAS components in the Shafts is presented in the Automatic Data Acquisition Plan (in preparation).

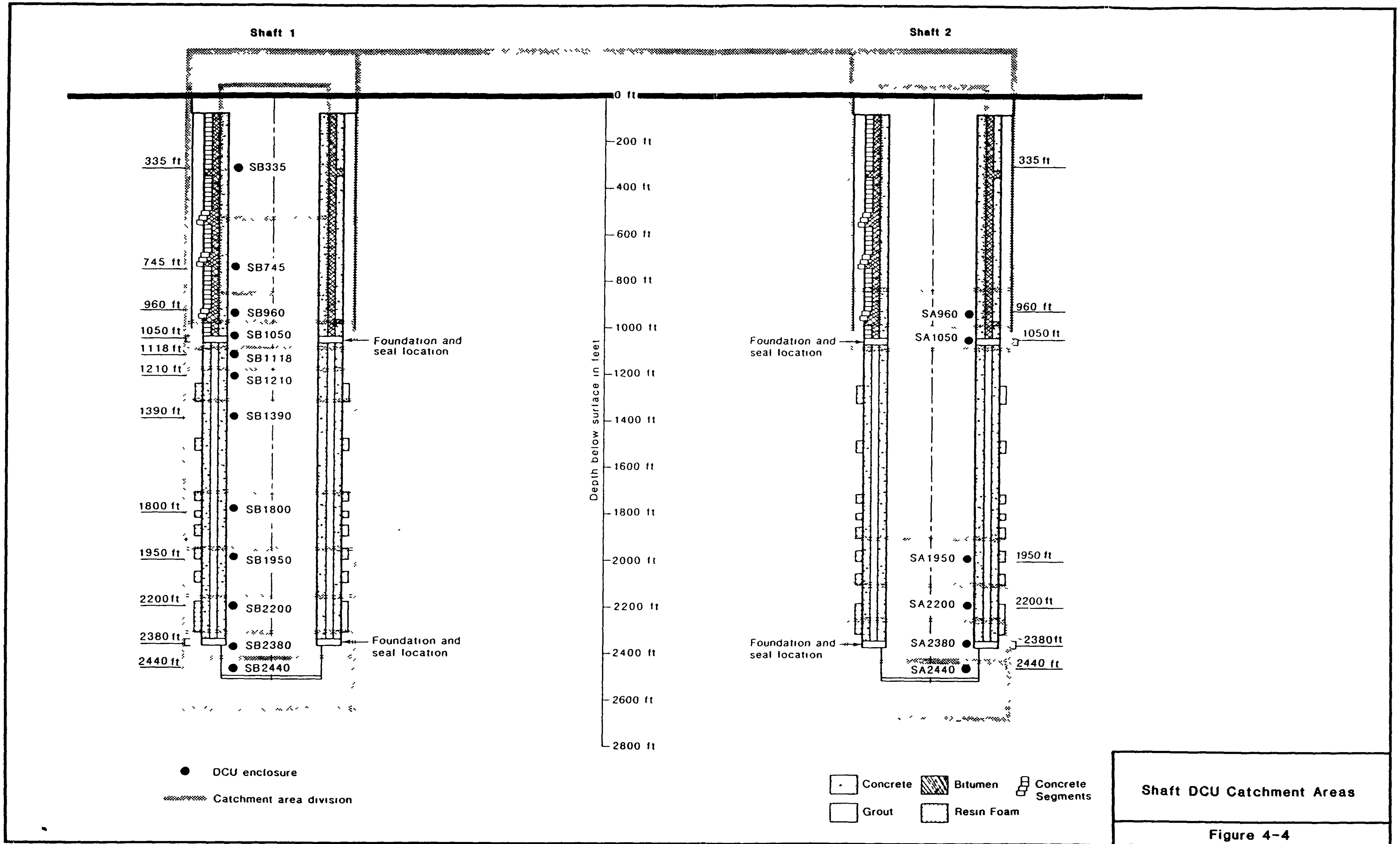
The SAC will be located on the surface. It will be integrated with the Site Computer Center (SCC) and will contain several clean, environmentally controlled rooms for the main computer and associated peripherals such as terminals, printers, plotters, and storage. The main computer will operate the communications network, manage the ESF technical database, provide access to the database for both local and remote users, and provide hardcopy output.

The DCUs will be autonomous, intelligent controllers for collecting data from monitoring instruments. The DCUs will periodically scan the instruments, convert the signals to digital form, store the results, and transmit this information, either automatically or on demand, to the main computer in the SAC via the LAN. The DCUs will also be able to communicate with terminals in other parts of the ADF. All shaft DCUs will be essentially identical. DCUs will be installed in protective enclosures recessed in the shaft liner. The locations and numbering of the DCUs and the area that each DCU will service (the "catchment area") are indicated in Figure 4-4. The advantages of the DCU approach include increasing the measurement accuracy by reducing the length of signal cables, minimizing the amount of shaft wiring needed to connect the instruments to the ADAS (individually routing signal cables from 1,900 instruments to the SAC would be extremely difficult and cumbersome), and providing a convenient and practical method of early data collection from the liners as they are constructed. DCUs will be designed to be as reliable as economically feasible; however, periodic access will be required at least every 90 days for data verification by manual readings, for calibration, and for other maintenance as required for continuous data collection.



Schematic Layout of Shaft ADAS Sub-System

Figure 4-3



Shaft DCU Catchment Areas

Figure 4-4

WBS 6.9.4.2

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The LAN is a distributed communications network consisting of a coaxial cable linking various types of equipment, together with a hardware interface at each communications port (or node), and a software package resident in a master computer that controls the operation of the LAN. The LAN provides a reliable and fast serial data link from each DCU to the SAC with a minimum cable system. This will result in the ADAS having the least impact on shaft construction, shorten the time required for connecting instrument stations to the ADAS, increase the system reliability by minimizing the number of components, and reduce possible ADAS system damage sites. In addition, the LAN is extremely flexible; up to several hundred nodes can be supported by the LAN, and nodes can be added or removed without affecting existing nodes in any way. For the Shaft ADAS Subsystem, the LAN will employ two separate parallel cables, each connected to a DCU to provide redundancy in case of a LAN component failure. The LANs will originate in DCU trailer T11, at the surface, and T1 and T2, in the At-Depth Facility (see Figure 4-5). Communication ports (taps) will be attached to the LANs in the DCUs and at the termination points in the DCU trailers.

4.2.2.3 Wiring System

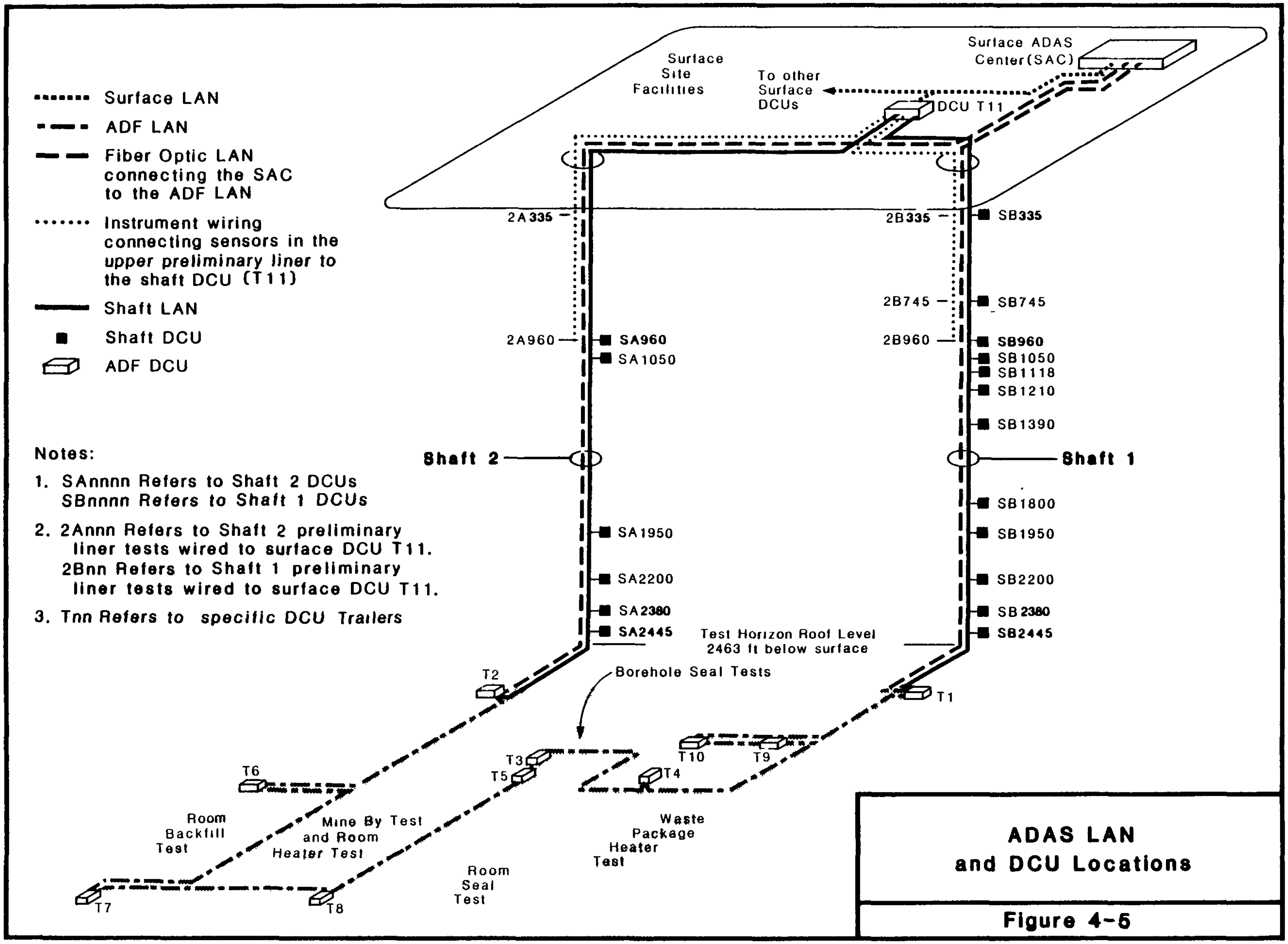
The wiring system will consist primarily of signal cables connecting the instruments with the DCUs and LAN cables connecting the DCUs to the SAC and the at-depth trailers. However, the instruments in the preliminary liner in the frozen zone will all be individually connected to a DCU located at the shaft collar, in order to avoid penetrating the water-tight steel liner in this zone. The wiring system, including the locations of junction boxes and pull boxes is shown in the Appendix B drawings. This system has been designed around the following considerations:

1. To minimize construction impact, instruments will be permanently connected whenever possible, and all wiring and equipment installed in the shaft will be adequately protected from accidental damage.

2. Instrument signal cables will be pre-terminated with electrical connectors to provide fast, reliable connections. These connections will be accessible for wiring changes where required, e.g., for moving DCUs from the preliminary to the final liner in the lower shaft. Wiring connections will be protected from moisture and corrosion due to condensation, water leaks into conduits and junction boxes, and water wicking inside of cables.

3. The number of holes through the final shaft linings will be minimized. This approach has been adopted to maintain the integrity of the water-tight lining and is consistent with a successful instrumentation program. Where sealed penetrations are required, the seal design will be coordinated between the UTC and the ESF A/E to ensure an adequate, workable seal.

4. Instrument cables will be routed to minimize the electrical interference from power cables, communications lines, etc. Radiated and conducted electrical interference generated by the operation of the shaft hoist, lights, shaft communications equipment, and



ADAS LAN and DCU Locations

Figure 4-5

WBS 6.9.4.2

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welding equipment used during construction could interfere with accurate data acquisition. Standards for ADAS signal wiring routing, shielding, and equipment grounding will be developed. The use of fiber optic LAN cables is being investigated.

5. It is desirable to encase all conduits, DCU enclosures, and junction/pull boxes in the shaft liners in order to:

   - Eliminate, during sequential shaft construction phases, the potentially significant conduit and cable disconnect-reconnect problems caused by cables mounted on the surface of the preliminary liner, (i.e., moving cables from behind to the front of steel liner plates as they are installed)

   - Provide physical protection for these components.

4.3 SHAFT GEOLOGY STUDY

Sinking of the exploratory shafts will provide a unique opportunity for a detailed evaluation of the stratigraphy and structure of the sedimentary sequence overlying the candidate repository host horizon. The site and regional geology will be established primarily by surface-based investigations (e.g., drilling, remote sensing). The shaft geology study will complement the surface-based studies by providing information on the continuity and character of the site stratigraphy and structure at a smaller scale than can be evaluated by the surface program. Geologic mapping of the shaft walls will be the principal geology study method, with supporting information from geologic logging of core. Core holes drilled from the exploratory shafts will be for the purpose of installing instrumentation and performing in situ hydrologic and mechanical/thermal properties testing.

4.3.1 Geologic Mapping

4.3.1.1 Rationale

Geologic mapping of the walls of the two exploratory shafts will provide a baseline record of the subsurface geology. Mapping will be oriented toward the collection and presentation of geologic information in an engineering format, which will be needed for analysis of shaft behavior. Mapping will also provide detailed stratigraphic information which will be useful in correlating drillhole data collected as part of the surface-based testing program; this information is essential in developing the conceptual site geologic model which will provide the basis for performance assessments required to determine the suitability of the site for high-level waste disposal. In addition, shaft wall geologic mapping will be required to select and characterize the actual repository horizon and the locations for the shaft operational and decommissioning seals, and to select representative locations for various in situ tests.

4.3.1.2 Method

Geologic mapping of the shaft walls consists of rock description, measurement and description of geologic structures, groundwater inflow observation, and rock mass behavior description. Geologic mapping will be performed in accordance with the Geologic Mapping Procedure (Golder Associates, 1986b).

During mapping, geologic information will be recorded in the field on standardized coding forms. Mapping will typically be done at a scale of 1:120. Selected areas, including final lining foundations, operational seals, and candidate decommissioning seal locations, may be mapped at a scale of 1:12. In addition, photographs of the mapped surfaces of the shaft walls will be taken. Samples will be collected for the purpose of confirming and augmenting rock descriptions.

All geologic data collected as part of this task will be entered in a relational database management system after each mapping shift. This system will have the capability to plot geologic maps at a user-defined scale, based on the coded information. Tables of rock mass ratings, stereographic projections of planar features, and other pertinent geologic data will also be accessible from the database. The computer database can be updated by changing coded information and by adding or subtracting map lines using a digitizer.

At the beginning of each mapping shift, computer-drawn maps plotted from coded data collected during the previous shift will be checked (if shaft wall exposures are available). Additional information may be added directly to the map at that time. Photographic prints made during the previous mapping shift will be available for map editing when mapped exposures are not available for rechecking.

Rock samples will be analyzed by visual means, and optionally by petrographic microscopy, chemical methods, electromagnetic radiation, or other means to be specified by field and supervisory personnel. Independent visual analysis of samples will be conducted in the Field Laboratory by a qualified geologist.

Each shaft wall segment must be geologically mapped before it is covered by the preliminary lining. Total mapping time is estimated to be two to four hours for each 8-ft wall segment. In addition to scheduling time for mapping activities, the Mining Subcontractor (MSC) will also be required to provide support services, utilities and equipment as described in Section 4.8.

4.3.2 Core Logging

4.3.2.1 Rationale

Relatively short (e.g., typically up to 60 ft in length) horizontal holes will be drilled at a number of horizons within the exploratory shafts for instrument installation and thermal/mechanical/hydrological testing. These holes will be cored, and the core will be logged in order to provide detailed geologic characterization of the test zones, improve interpretation of the test results, and assist in defining optimum instrument locations within each borehole. Specifically, hydrologic testing will be performed across shaft operational seals, and mechanical and hydrological testing will be performed at potential shaft decommissioning seal locations. Logging of core from such boreholes will complement the shaft wall geologic mapping and provide a detailed geologic characterization of these areas, which are significant to repository design and performance.

4.3.2.2 Method

Logging of core from boreholes drilled from the exploratory shafts will be performed in accordance with the Core Logging and Sampling Procedure (Golder Associates, 1986c).

Core sample will be carefully removed from the core barrel, placed in protective sleeves, and transported in core boxes to the surface Field Laboratory for detailed logging and photography. Geologic data will be recorded on standard coding forms and will be added to the same relational database management system used for geologic mapping data. This system will allow direct plotting of core logs and will facilitate information retrieval and comparisons with the geologic mapping data.

All exploratory shaft coreholes will be associated with other exploratory shaft studies, and their locations and timing are presented with each relevant study method description later in this document. Required Mining Subcontractor support activities are summarized in section 4.8.

4.4 SHAFT MECHANICAL RESPONSE STUDY

The exploratory shafts will be designed and constructed using the same general methods and principles as those proposed for the repository shafts. An evaluation of the interactions between the shaft lining system and the host rock, of the ground-water and ground pressures imposed on the lining, and of the efficacy of the lining design in supporting the applied loads, is important to confirming both the exploratory shaft performance and the repository shaft design and construction methods. The primary applications of the study therefore include:

- Evaluation of the shaft lining loads, e.g., ground-water pressures, rock/soil pressures, and creep-induced loads, relevant for this combination of shaft design, construction method, and ground conditions. This will include an assessment of special design measures for controlling loads applied to the lining, e.g., overexcavation in salt strata and installation of compressible backfill to control the development of lithostatic ground pressures resulting from salt creep.

- Confirmation of the repository shaft design methodology through evaluating the exploratory shaft performance, and of the suitability of the exploratory shafts for possible incorporation into the repository system. This will include an evaluation of the mechanical performance of the shaft linings, foundations and support rings, chemical seals for ground-water control during the shaft operational life, shaft station rock supports, and the shaft bottom plugs.

- Development of mechanical response information in direct support of shaft construction, e.g., monitoring freezewall convergence during construction to define the timing of placement of the preliminary lining.

- Development of mechanical response information in direct support of shaft operations, e.g., monitoring convergence in unlined salt sections to check on clearances and define any re-excavation requirements.

The shaft mechanical response study will therefore have primary application to the design of the shaft subsystem of the overall engineered repository system. Secondary information will also relate to the nature of the mechanical disturbance to the ground around the shafts, which has application to shaft decommissioning seal designs and to repository performance in isolating the radioactive waste from the accessible environment.

4.4.1 Description

Mechanical response monitoring of the exploratory shafts involves installing instrumentation within and behind the shaft linings to measure soil, rock, and ground-water pressures acting on the linings; the stress, strain, and deformational response of the linings, foundations and support rings, chemical seals, shaft bottom plugs, and rock supports placed in unlined shaft sections, e.g., rock bolts; the deformational response of unlined shaft sections during construction (i.e., prior to lining placement) and of permanently unlined sections of the shafts; the deformational response of salt strata which are mechanically "decoupled" from the shaft lining; and the thermal response of the shaft lining/host rock system for thermomechanical evaluations.

Specific activities include the measurement of:

- Convergence of shaft walls in the freeze zone prior to preliminary lining placement, of shaft walls at operational seal locations prior to seal construction, of shaft preliminary linings prior to final lining installation, of shaft final linings including shaft foundation support rings and operational seals, and of permanently unlined shaft and shaft station walls.

- Stresses and strains within preliminary and final linings at representative locations in salt and non-salt horizons, including operational seals.

- Stress at the shaft lining-rock contact, including foundation support rings.

- Stresses and strains within the foundation support rings.

- Stresses at the shaft foundation-rock contacts.

- Ground-water pressures at the shaft lining-rock contact, including foundation support rings.

- Pressures in the shaft operational chemical seals and in the bitumen layer in the upper shaft.

- Relative movements between lining components at the shaft operational seals, at the upper lining bitumen interface, and at the lower lining cement grout interface in salt strata.

- Deformations within salt strata behind the lower shaft lining, in the lower unlined shaft section, and in the unlined shaft stations.

- Variation of load and strains in rock bolts installed in the unlined shaft section and shaft stations.

- Stresses and ground-water pressures at the shaft bottom plug/rock contact and stresses and strains in the shaft bottom plug itself.

- Temperatures within the freezewall and preliminary and final shaft linings.

Instrumentation for mechanical and thermal response monitoring in the ESF shafts has been selected based on a preliminary evaluation of measurement parameter range and accuracy requirements (see Section 4.9), and the results of a separate instrument evaluation program currently described in Draft Position on Geotechnical Instrumentation in a Salt Repository Environment: Requirements, Performance, Recommendations, and Development Needs (Golder Associates, 1986i). Detailed specifications and installation procedures for the shaft mechanical and thermal response monitoring instrumentation are provided in separate procedures referenced within this Study Plan. The selected shaft instrumentation and monitoring techniques are briefly described below.

- Convergence of the exploratory shaft excavations and concrete lining will be monitored by periodically measuring the distance between diametrically opposed reference points attached to the exposed surfaces. Measurements will be made using portable, manually operated tape extensometers. A permanent automatic non-contacting convergence monitoring system will also be installed if a satisfactory system can be identified with the required accuracy.

- Hydrostatic pressures acting on the shaft liner system will be monitored using sand-packed piezometers installed in the shaft wall prior to concrete placement.

  A sand-packed piezometer consists of a pressure transducer located in a sand pocket between a permeable membrane and an impermeable membrane. The assembly is prepackaged and installed in a shallow recess, excavated by hand in the shaft wall, with the impermeable membrane located towards the inside of the shaft. Both pneumatic and electrical pressure transducers are being considered.

- Changes of tangential and axial stress in the concrete linings and radial stresses in the concrete lining near the lining/rock interface will be measured using Embedment Stress Cells.

  Embedment Stress Cells are hydraulic devices composed of two circular steel plates separated by a small gap and welded together around their perimeter. The interior of this capsule is filled with fluid, generally mercury because of its low compressibility. Any straining of the material in which the cell is embedded deforms the cell and causes a change of fluid pressure that can be measured using an electrical pressure transducer. The response of the pressure transducer will be monitored automatically. The planar geometry of the device restricts measurement to those stresses acting normal to the cell face.

- Bitumen pressure will be monitored using an embedment stress cell set flush with the inside surface of the preliminary lining concrete.

- Radial and tangential stress changes in the chemical seals will be measured using embedment stress cells.

- Axial and tangential strains on the surfaces of the steel linings and tangential strains in the foundation support ring reinforcement will be measured using Vibrating Wire Strain Gages.

  Vibrating Wire Strain Gages (VWSGs) operate on the principle that the change of resonant frequency of a wire tensioned between two anchor points is proportional to the change of length between them. The wire is excited electromagnetically and the frequency response is monitored. VWSGs, spot welded to the surface of the steel liner and installed within small axial holes in re-bar sections, will be monitored automatically.

- Tangential and axial strains within both inner and outer concrete linings will be measured using embedded vibrating wire strain gages set directly in the concrete during concrete placement.

- Measurements of relative movements between the preliminary and final linings will be made using jointmeters.

  A jointmeter consists of a linear displacement transducer that is connected between the linings in order to measure their relative movement. Each of these devices will be monitored automatically. Up to three jointmeters will be required to monitor displacements in three orthogonal directions.

- Radial deformations of selected points within the salt strata around the shaft will be measured using multiple position borehole extensometers (MPBXs).

  An MPBX consists of up to six anchor points fixed to the rock at specified intervals along a borehole, with wires or rods connecting each of these points to linear measuring devices (e.g., LVDTs) in the extensometer head that measure the movements of the anchors relative to the borehole collar. Each of these measuring devices will be monitored automatically.

- Rock bolt loads in point-anchored bolts will be measured using load cells. The load cell will consist of either a strain-gaged steel ring loaded between two bearing plates at the head of the bolt, or a vibrating wire strain gage which is installed within a small-diameter hole drilled along the axis of the bolt. VWSGs will be used to measure strain in either case and will be monitored automatically. In fully bonded rock bolts, measurement of strain, and hence stress, distribution will be made using resistance strain gages bonded to the outer surface of a hollow-core rock bolt.

- Temperatures will be measured using VWTSs (Vibrating Wire Temperature Sensors) embedded in the linings, within short boreholes drilled into the shaft freezewalls, and in boreholes drilled from the lower shaft

  A VWTS consists of a thin steel wire stretched between the two ends of a closed tube of dissimilar thermal expansion (e.g., brass). A change in temperature produces a change in the level of straining in the steel wire and thereby a change in resonant frequency, as previously discussed. VWTSs will be monitored automatically.

4.4.2 Rationale

The basis for the design of the exploratory shaft mechanical and thermal response study derives from the information requirements previously discussed and a consideration of the interactions between the geologic/geohydrologic system and the shaft liner system. Prediction/assessment of the range of stress, strain, and displacement within and between the shaft lining components has been used to assist in instrument selection, location and layout. Final instrument selection will be determined by the range and accuracy of the physical measurement to be made, together with the operating environment and consideration of available instruments; these factors are discussed in Section 4.9. This section discusses the rationale for the location and layout of the instrument arrays used to evaluate the mechanical and thermal response of the ESF shafts.

4.4.2.1 Rationale for Instrumentation Array Locations and Layouts

The layout of mechanical response monitoring instrumentation within the shafts is based on specific design confirmation requirements for each design component, the need to provide information for each designed component representative of the full range of loading conditions, and the requirement to confirm that the results can be reliably extrapolated to other locations. The rationale also addresses the need to provide some redundancy within the monitoring system. Detailed instrument locations and layout within each of the monitoring arrays are given in Appendix B.

4.4.2.1.1 Shaft Foundations and Support Rings. Mechanical response monitoring arrays will be required at each shaft foundation/support ring to monitor:

- Contact stresses at the foundation/rock interface
- Stress transferred to the support ring.

Since the foundation will be heavily reinforced with steel, useful measurements of foundation stress will be very difficult to obtain from instrumentation embedded within this structure. The performance of the instruments would be influenced by localized stress gradients around reinforcing bars, providing readings which would be difficult to interpret. In addition, the stress distributions within the shaft foundations may be relatively complex and potentially unsuitable for analysis. The average vertical loads transferred through the foundation can be determined more reliably by extrapolating from measurements of vertical stress in the final lining, measured immediately above the foundation, and hydrostatic pressure within the bitumen layer (for the upper shaft foundation) at the same elevation. Stresses can also be measured in the mudpack underlying the foundation. Embedment stress cells will be either embedded in the mudpack or set flush against the mudpack, with the cell body in the concrete foundation, depending on mudpack details and construction sequence (see Array Type Ia - Figure 4-6). Two stress cells will be installed at each location to determine the contact stress variation, if any, across the interface.

The less heavily reinforced, laterally loaded foundation support ring is more amenable to analysis, therefore, tangential strains in the reinforcing bars will be measured; strains in reinforcing bars oriented in axial and radial directions need not be measured, as these bars provide secondary reinforcement to the tangentially oriented bars and the tangential strains will provide the most sensitive response to imposed lateral loads. As a backup, embedment stress cells will be installed to measure tangential stress directly in the concrete, being located as far from the rebar as possible.

In addition, the lateral bearing pressure on the support ring will be measured by installing embedment stress cells at the support ring/rock interface. As with the foundation, these instruments should preferably be installed in a 4-in thick mudpack placed at the interface as shown in Figures 4-6 and 4-7. Installation will require careful preparation of the rock wall and placement of the mudpack prior to support ring construction [acceptance of this alternative is subject to approval by the ESF A/E, as redesign of the support ring will be required].

Ground-water pressures acting on the outside skin of the support ring will be monitored using sand-packed piezometers.

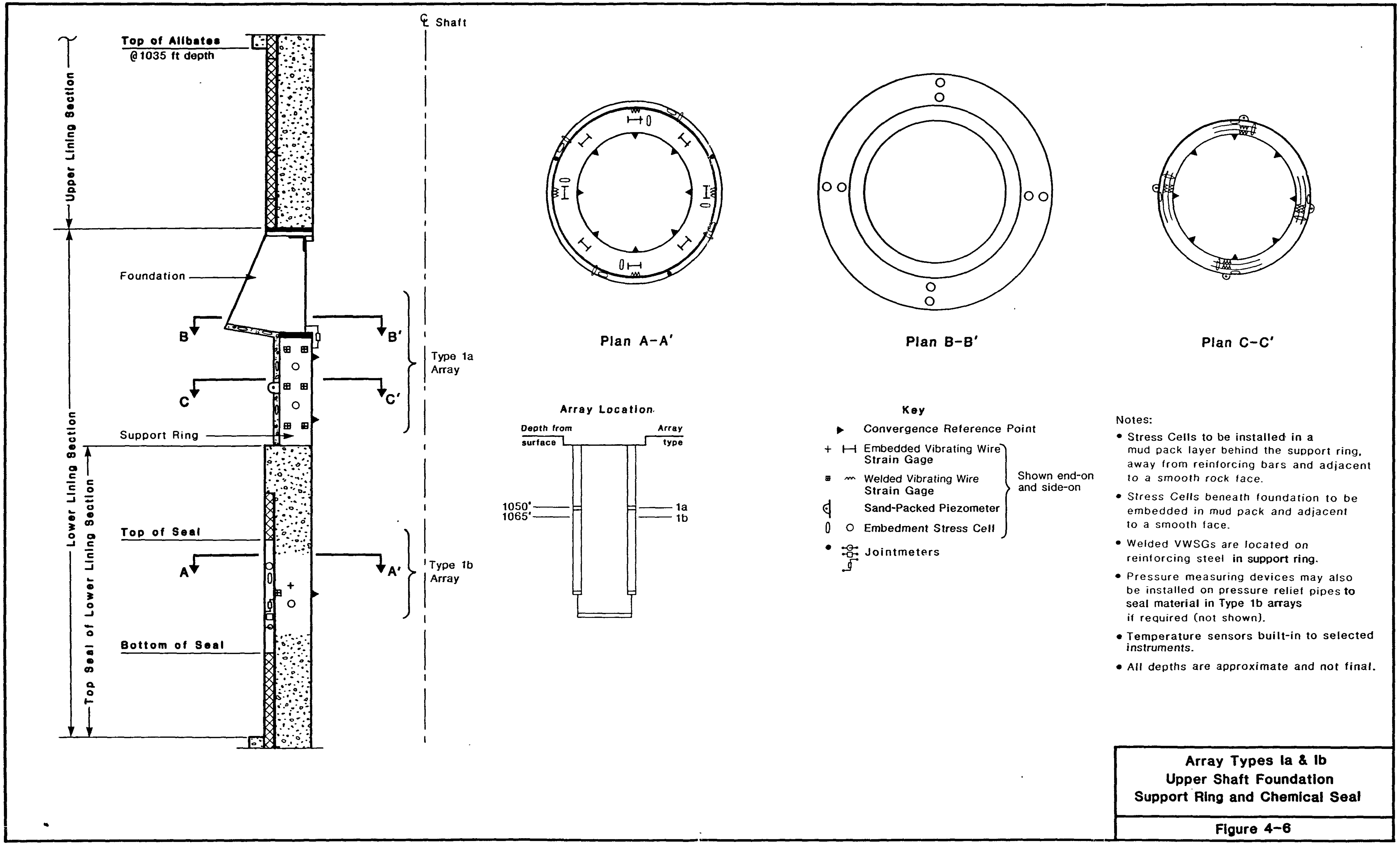
The design of the foundation/support ring interface includes a compressible squeeze plate to prevent direct transfer of axial stress to the support ring. Monitoring of axial displacements at this interface using jointmeters will provide confirmation of squeeze plate design and an indication of axial load transfer (if any).

4.4.2.1.2 Shaft Seals. It is planned to construct two chemical seals, one located just above the lower foundation and one located just below the upper foundation, during placement of the final shaft lining in the lower shaft. Monitoring requirements at the seal locations include:

- Measurement of stress and deformation within the chemical seal material

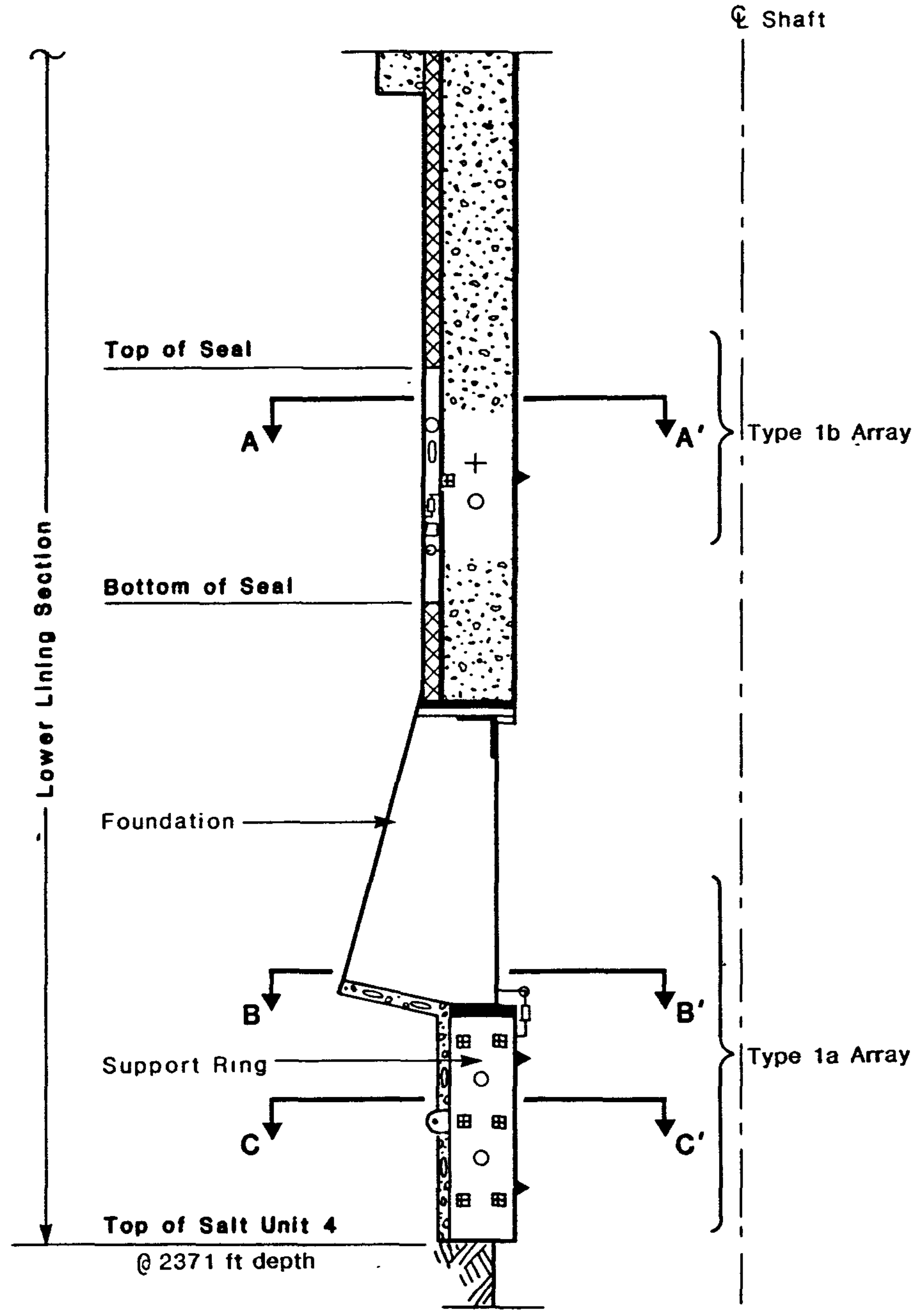
- Measurement of stress and strains in the final lining adjacent to the seal.

The ESF Draft Preliminary Design Report (Parsons Brinckerhoff/PB-KBB, 1986a) describes the Chemical Seal Ring (CSR) material as consisting of a polymeric sealing compound mixed with gravel and placed as a slurry which is

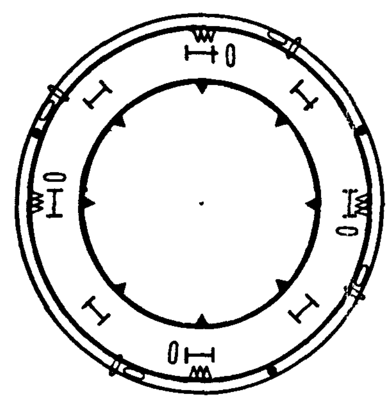


Array Types Ia & Ib
Upper Shaft Foundation
Support Ring and Chemical Seal

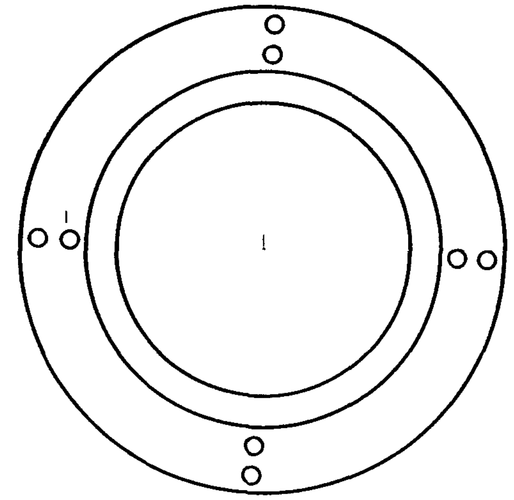
Figure 4-6



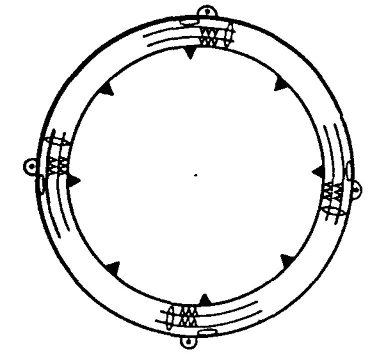
Section through Liner and Foundation System



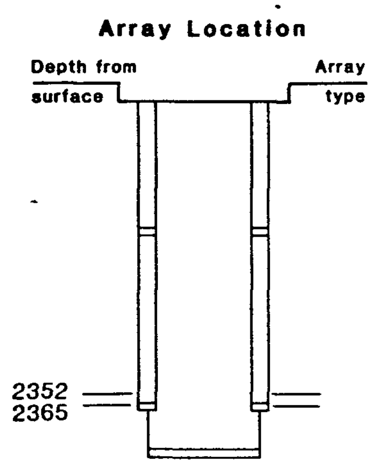
Plan A-A'



Plan B-B'



Plan C-C'



Key

- ▶ Convergence Reference Point
- + ⊢⊣ Embedded Vibrating Wire Strain Gage
- ⊞ ~ Welded Vibrating Wire Strain Gage
- Sand-Packed Piezometer
- 0 ○ Embedment Stress Cell
- • Jointmeters

(Embedded Vibrating Wire Strain Gage, Welded Vibrating Wire Strain Gage, Sand-Packed Piezometer, Embedment Stress Cell: Shown end-on and side-on)

Notes:

- Stress cells in shaft wall need to be installed in a mud pack layer behind the support ring, away from reinforcing bars and adjacent to a smooth rock face.
- Stress Cells beneath foundation to be embedded in mud pack and adjacent to a smooth face.
- Welded VWSGs are located on reinforcing steel in support ring.
- Pressure measuring devices may also be installed on pressure relief pipes to seal material in Type 1b Arrays if required (not shown).
- All depths are approximate and not final.
- Temperature Sensors built-in to selected instruments.

Array Types Ia & Ib
Lower Shaft Foundation
Support Ring and Chemical Seal

Figure 4-7

sufficiently pliable to penetrate into near-field cracks. After emplacement, the slurry hardens to form an elastic solid. Additional qualification of CSR material consistency has been provided by Boughton and Dellinger (1965); when describing the application of CSR to Project Dribble, they note, "Material used in the seal sets up in a rubbery mass somewhat similar in appearance to an art gum eraser."

Both radial and tangential stresses will therefore be measured in the seal material using embedment stress cells. In addition, if the ESF A/E requires that boreholes, drilled at the seal location to initially pressurize the seal, be decommissioned and used as pressure relief holes, then suitable pressure transducers will be installed in each relief borehole.

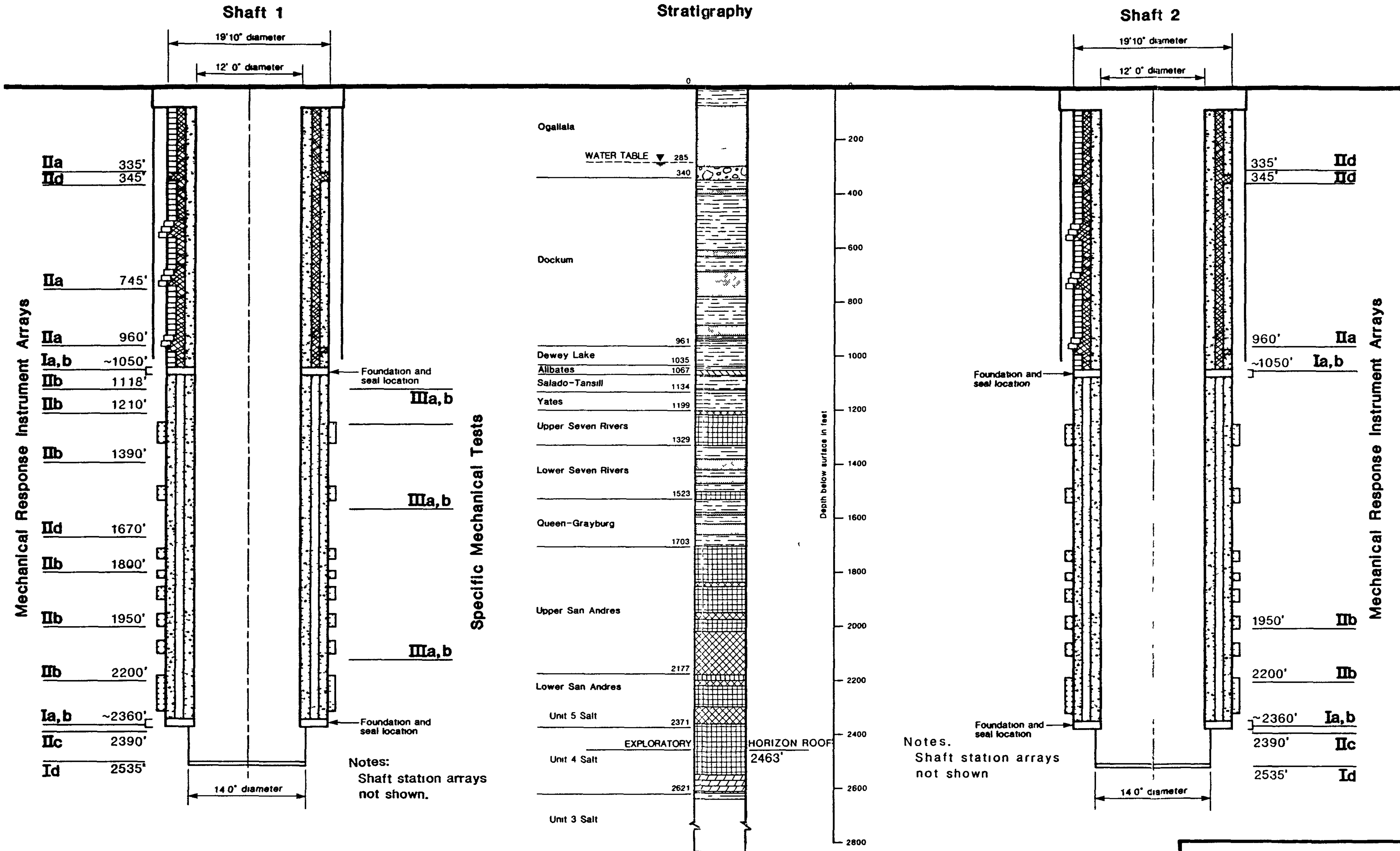
In the presence of water, the polymer seal material will expand and develop swelling pressure which will act on the final liner. Load development will be monitored by measuring tangential stress and strain within the concrete and tangential strain in the steel liner (see Array Type Ib - Figures 4-6 and 4-7). Convergence monitoring will be used to measure movement of the temporarily lined seal section, prior to seal installation, as well as deformation of the final lining. Jointmeters will be installed to monitor radial displacements between the rock and steel liner after seal installation.

4.4.2.1.3 Upper Shaft Lining - Cast-in-Place Concrete Option. Monitoring requirements in the Upper Shaft Lining include:

- Measurement of lining loads caused by creep of the freezewall.
- Monitoring "bitustatic" pressure on both preliminary and final linings.
- Measurement of hydrostatic and lateral earth pressures bearing on the lining, after thawing of the freezewall.
- Monitoring the response of shaft linings to the thawing of the freezewall and to the build-up of hydrostatic and lateral earth pressures.
- Monitoring temperature change in the shaft lining and immediate wall rock to facilitate instrument reading correction and interpretation of mechanical response monitoring results.

Convergence of the freezewall during shaft construction will be monitored to enable optimization of the timing of preliminary lining installation. These convergence data will be input to the database for each of the proposed mechanical response monitoring arrays discussed below.

Mechanical response monitoring arrays will be installed to monitor the response of the preliminary lining during shaft excavation and the response of the composite lining to the build-up of hydrostatic, earth, and bitustatic pressures during final lining construction and subsequent thawing of the freezewall. The location of proposed arrays, in the two shafts, is shown on Figure 4-8.



Source.
Generated from PB/PB-KBB Title I drawing (PB/PB-KBB, 1986)
Synthetic Geotechnical Data Base (ONWI, 1986a)

Concrete | Bitumen | Concrete Segments | Halite | Dolomite | Siltstone | Silt | Sand
Grout | Resin Foam | Anhydrite | Shale | Sandstone | Sand and Gravel | Clay

Ia,b,d Shaft Foundation/Seal/Bottom Plug instrument arrays
IIa,b,c,d Shaft Liner instrument arrays
IIIa Absolute Stress Measurement Test
IIIb Deformation Modulus Test

Instrument Array and Specific Test Locations in the ESF Shafts

Figure 4-8

WBS 6.9.4.2

843-1640-102/25

One mechanical response monitoring array will be located approximately 90 ft (27.4 m) above the upper shaft foundation (see Figure 4-9, Array Type IIa, at a depth of 960 ft [293 m]) so that the maximum hydrostatic and bitustatic loads and liner response to these loads can be measured. This location also satisfies the requirement to monitor the build-up of bitustatic loads during construction and, hence, determination of one part of the upper shaft foundation load. A second mechanical response monitoring array is proposed for the base of the Ogallala formation (Array Type IIa - Figure 4-9 at 335 ft [102.5 m]) to confirm hydrostatic and earth-pressure design assumptions within this formation, and to measure the response of the liners to the imposed loads. A third Type IIa array will provide spatial coverage in the upper shaft and will be located towards the middle of the Dockum formation at a depth of approximately 745 ft (227 m).

One hydrostatic pressure monitoring array will be located in the upper parts of the Dockum formation at an aproximate depth of 345 ft [105 m] to monitor the effectiveness of the bitumen in controlling cross-flow between the Ogallala and Dockum formations (see Section 4.6 Shaft Seal Study and Figure 4-10, Array Type IId). This array will also assist in confirming the site hydraulic gradient and, hence, the shaft lining hydrostatic design loads.

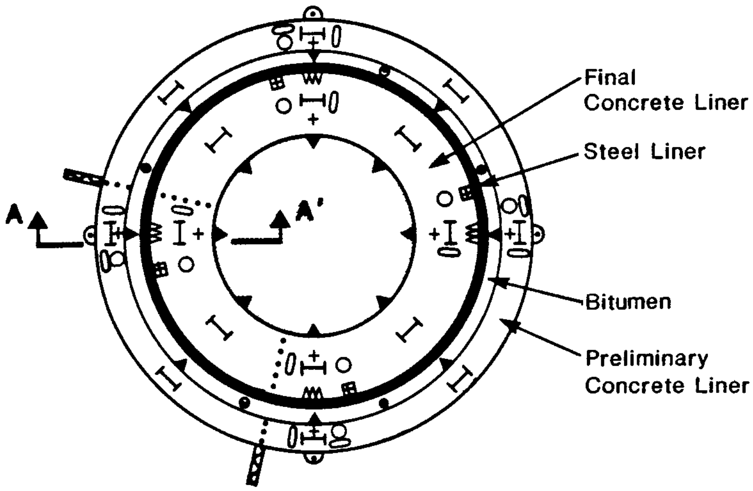
The instrument content of each array is based on the need to monitor:

- The boundary stresses, which include the earth-rock pressure at the preliminary lining/rock interface, the hydrostatic pressures which will develop during thawing, and the bitustatic stresses. The latter must be measured during final liner construction in order to monitor the load on the final lining, and possibly, any effects of segregation of the limestone flour filler in the bitumen with time.

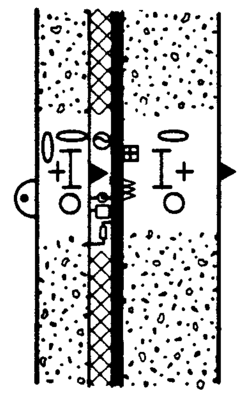
- The response of the shaft liners to the imposed lateral loads. The most sensitive parameters that can be measured to monitor liner response to radial stress changes are the tangential stresses and strains in both concrete liners and tangential strains in the steel liner. Convergence of the lined shaft walls will also be measured.

- Relative movements between the preliminary and final linings. As the bitumen will behave essentially as a viscous fluid, the two lining systems will be mechanically decoupled and relative movements between them may occur. Such displacements may arise due to slip of the unfounded preliminary liner, lateral buckling of the preliminary lining, or sway/buckling of the final liner due to self weight. Relative movements will be measured using jointmeters.

  Overall movement and tilt of the inner liner may be measured using a combination of EDM and/or plumb-line techniques. Details of these conceptual approaches await confirmation of shaft outfitting and headframe configuration.

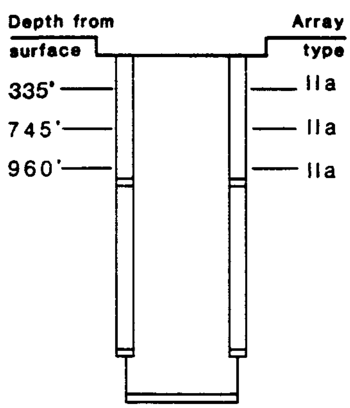


Plan



Section A–A'

Array Location



Key

- 4 Vibrating Wire Temperature Sensors in Borehole
- Vibrating Wire Temperature Sensor in Concrete Liner
- Convergence Reference Point
- Embedded Vibrating Wire Strain Gage
- Welded Vibrating Wire Strain Gage
- Sand-packed Piezometer
- Embedment Stress Cell
- Bitumen Pressure Cell
- Jointmeters

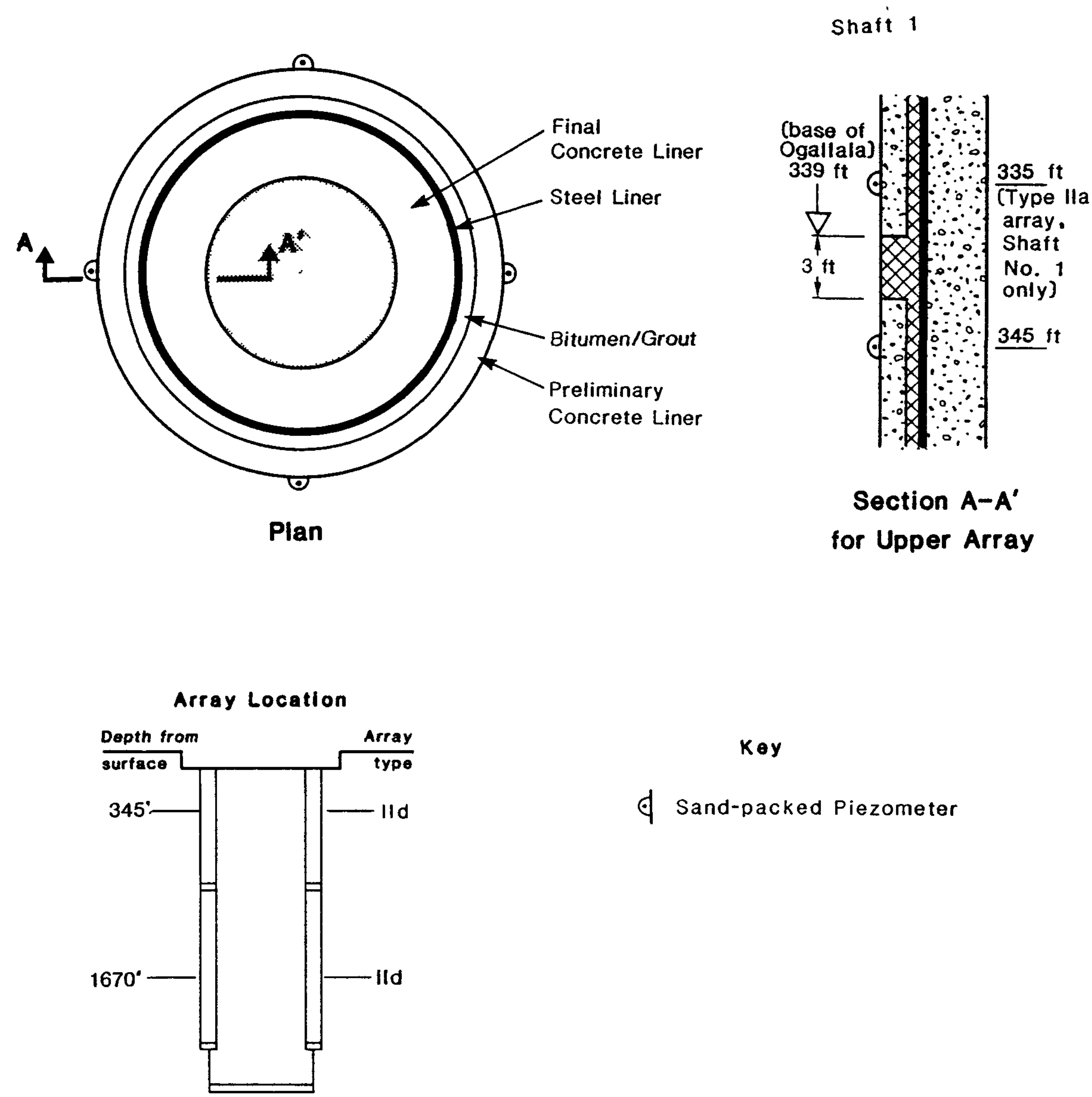
(Shown end-on and side-on)

Notes:

- Axial stress and strain instruments installed in the Preliminary Concrete Liner at 960 ft. only.
- **All depths are approximate and not final.**
- Temperature sensors built-in selected instruments.
- Arrays at 335' and 745' in shaft no No. 1 only.

Array Type IIa
Upper Shaft Lining

Figure 4–9



Notes:

- Piezometer located in upper Array (335 ft depth) incorporated in Type IIa array and shown on Figure 4-9
- **All depths are approximate and not final.**
- Temperature sensors built-in to each instrument.
- Array at 1670' in shaft No. 1 only.

Array Type IId
Hydrostatic Pressure Monitoring

Figure 4-10

- Axial stresses and strains in the final liner, which must support its own weight as a result of decoupling of the final lining by the bitumen annulus. Axial stress and strain measurements are not proposed in general for the preliminary liner as its self weight is expected to be supported by skin friction. Nevertheless, axial stress and strain measuring instruments will be installed in the preliminary liner at the deepest array (Array Type IIa - Figure 4-9 at 960 ft [293 m]) to obtain confirmatory information.

It will not be necessary to monitor movement along the preliminary liner/rock interface as movement at this boundary is considered unlikely while the ground is frozen (e.g., only a very small shear stress is required to support the self weight of the liner). If movement of the preliminary liner occurs after thawing, it can be measured relative to the final liner by the jointmeters installed in the bitumen layer.

4.4.2.1.4 Upper Shaft Preliminary Lining - Precast Concrete Block Option. If the Contractor chooses to build the preliminary liner using precast concrete blocks, minimal or no instruments may be installed in the preliminary lining. Considerable difficulty would be encountered in installing instruments within, behind and/or between blocks, and with routing electrical leads. Interpretation of results would be extremely difficult due to the discontinuous structure. The components of the mechanical response monitoring program that will be used should the contractor select the concrete block option include: monitoring hydrostatic pressures which will develop following freezewall thawing; measurement of freezewall and preliminary liner convergence; monitoring relative movements between the preliminary and final linings; monitoring build-up of bitustatic pressures; and full instrumentation of the final lining.

Convergence of the freezewall, during shaft construction, will be monitored to enable optimization of installation of the precast concrete block lining.

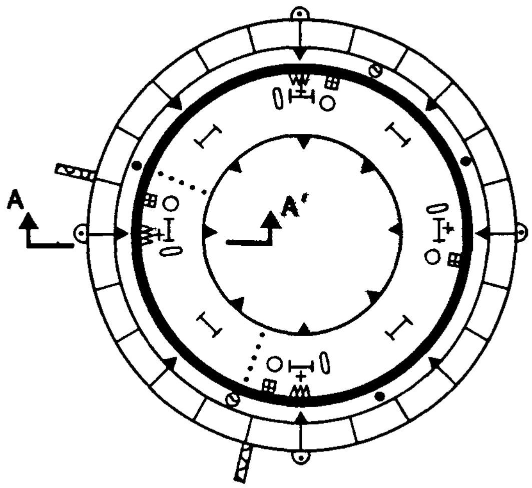
Mechanical response monitoring arrays will be installed to measure displacement of the preliminary lining during shaft excavation and the response of the final lining to the build-up of hydrostatic, earth and bitustatic pressures during final lining construction and subsequent thawing of the freezewall. The location of the proposed arrays is the same as shown for the cast-in-place concrete lining option in Figure 4-9. 4-8.

The instrument layout of each modified Type IIa array for the precast concrete block preliminary lining option is shown in Figure 4-11.

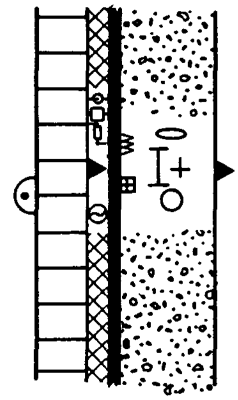
4.4.2.1.5 Lower Shaft Lining. Monitoring requirements in the Lower Shaft Lining include:

- The build-up of hydrostatic and rock pressures on the outside of the lining

- The response of the shaft linings to the external loads

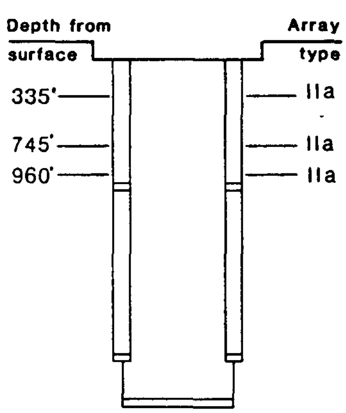


Plan



Section A-A'

Array Locations



Key

- 4 Vibrating Wire Temperature Sensors in Borehole
- • Vibrating Wire Temperature Sensor in Concrete Liner
- ▶ Convergence Reference Point
- + ├┤ Embedded Vibrating Wire Strain Gage
- ▪ /W\ Welded Vibrating Wire Strain Gage
- Sand-packed Piezometer
- 0 O Embedment Stress Cell
- ⊖ *Bitumen Pressure Cell*
- • Jointmeters

(Embedded Vibrating Wire Strain Gage through Embedment Stress Cell: Shown side-on and end-on)

Notes:

- All depths are approximate and not final.
- Temperature sensors built-in to selected instruments.
- Piezometers may be cast into block liner.
- Arrays at 335' and 745' in shaft No. 1 only.

Modified Type IIa Array for Block Liner Option in Upper Shaft

Figure 4-11

- Creep deformation of the salt strata behind the shaft lining

- Response of the lining to external load imposed, through the backfill material, by the creeping salt (if any)

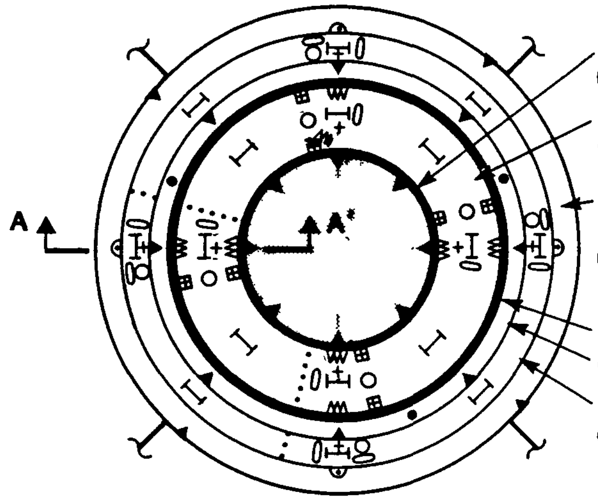
- The build-up of stresses in the shaft liner system imposed by non-salt strata, including the potential effects of swelling (in anhydrites) and lateral loading of the lining by non-salt strata sandwiched between adjacent creeping salt strata (drag loads).

Three instrumentation arrays will be installed in salt strata. The deepest array will be located in the Lower San Andres Unit 5 at a depth of approximately 2,200 ft (670 m) (see Array Type IIb - Figure 4-12) below surface. It is expected that this location will experience the largest amount and rate of creep deformation of any location in the lined shaft section. Two additional arrays will be located to provide both spatial coverage and confirmation that creep rates and deformations can be extrapolated from one elevation to another. These arrays will be located at depths of approximately 1,210 ft (369 m) and 1,800 ft (549 m) see Array Type IIb - Figure 4-12).

Three instrumentation arrays will be installed in non-salt strata in the lower shaft. The potential for large lateral loads applied by non-salt strata subject to drag from unrestrained creep of proximate salt formations is expected to be most severe in strata located at depth in the shaft. Two suitable non-salt strata have been identified immediately above the base of the Upper San Andres formation. The deepest of these is a bed approximately 170 ft (51.8 m) thick, sandwiched between two salt beds. The second stratum is approximately 24 ft (7.3 m) thick, and located at a depth of 1,950 ft (594 m). The latter is expected to provide the most suitable location for monitoring these potentially large lateral concentrated loads (Array Type IIb - Figure 4-12 at 1,950 ft [594 m]).

A second mechanical response monitoring array (Type IIb Array - Figure 4-12) will be located in the Salado formation at an approximate depth of 1,118 ft (341 m). This array will be located to monitor the potential for swelling pressures due to hydration of the anhydrite. It is generally accepted that the Permian anhydrites were initially laid down as gypsum in a saline environment. The gypsum was then converted to anhydrite through loss of the water of hydration in the presence of pressure and heat. Subsequent reduction in pressures and reintroduction of water may cause reconversion of gypsum. During shaft construction, additional water will be introduced to these strata and confining pressures will be reduced, potentially resulting in substantial swelling pressures.

The third non-salt mechanical response monitoring array will provide spatial coverage over the lower shaft section. This array will be located in the siltstone of either the Lower Seven Rivers or the Queen/Grayburg formations. For planning purposes, the location has been identified in the Lower Seven Rivers at a depth of approximately 1,390 ft (424 m) (see Array Type IIb - Figure 4-12).



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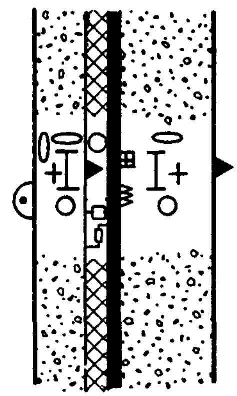
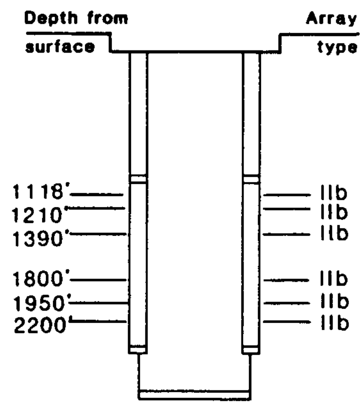


Section A–A'

Array Location



Key

- • Vibrating Wire Temperature Sensor in Concrete Liner
- 6 anchor MPBX with convergence reference point on head
- ▶ Convergence Reference Point
- + ⊢⊣ Embedded Vibrating Wire Strain Gage
- ⊞ ʍ Welded Vibrating Wire Strain Gage
- Sand -packed Piezometer
- 0 ○ Embedment Stress Cell

(Embedded Vibrating Wire Strain Gage through Embedment Stress Cell: Shown end-on and side-on)

- • Jointmeters (radial and vertical)

Notes:

- Extensometers and jointmeters installed only at 1210 ft, 1800 ft and 2200 ft (in salt strata).
- Axial stress and strain instruments installed only at 2200 ft.
- Access to MPBX head to be provided through shaft liner. Penetrations of water tight liner to be designed by A/E.
- All depths are approximate and not final.
- Temperature sensors built-in to selected instruments.
- Arrays at 1118, 1210, 1390, and 1800 ft in Shaft No. 1 only.

Array Type IIb
Lower Shaft Lining

Figure 4-12

WBS 6.9.4.2

843-1040-102/28

As in the upper shaft section, it is necessary to instrument both preliminary and final shaft linings. The preliminary lining must be instrumented to provide information necessary to evaluate interaction of the lining systems and the surrounding rock, and to evaluate the loads being transmitted to the final lining. The final lining must be instrumented to provide confirmation of the design.

The instrument content of each array is based on the need to monitor:

- The boundary loads, which include the contact stresses at the preliminary liner/rock interface and the hydrostatic pressures on the outside of the lining.

- The response of the shaft liners to the imposed lateral loads. The most sensitive parameters that can be measured to monitor liner response to a radial stress field are the tangential stresses and strains in both concrete liners and the tangential strains in the steel liner. Convergence of the lined shaft walls will also be measured.

- In the lower section of the shaft, the space between the preliminary and final liner will be backfilled with cement grout. Therefore, there will not be the same freedom of movement as in the upper shaft. However, as the possibility still exists for debonding of the preliminary liner from the final liner in sections where constraint is minimal (e.g., due to the presence of backfill within salt strata), jointmeters will be included to monitor relative horizontal and vertical displacements at these locations.

- In the salt strata, creep movement must be monitored at several points in the rock in order to evaluate the efficacy of the shaft design methodology for controlling the development of salt lithostatic loads on the shaft lining.

- As in the upper shaft section preliminary lining, the self weight of the liners can be adequately supported by very small skin friction stresses at the boundary between liner components. Since the backfill behind the final liner is cement grout, the final liner is expected to support its own weight and little load is expected to be transferred to the foundation. Axial strains in the concrete and steel liners, and axial stresses in the concrete, will be measured only at the deepest elevation (e.g., at a depth of 2,200 ft (671 m)) in order to obtain confirmatory information.

4.4.2.1.6 Unlined Shaft Section and Shaft Stations. Monitoring requirements in the unlined shaft section and the shaft stations will include:

- Creep deformation of the shaft walls and shaft station excavation

- Load variation and stress distribution within rock bolts installed for ground support.

Three Type IIc instrumentation arrays will be installed in the unlined shaft section (see Array Type IIc - Figure 4-13) at 20 ft (6.1 m) below the lower foundation support ring, 20 ft (6.1 m) above the shaft station roof, and 20 ft (6.1 m) below the shaft station floor. A fourth mechanical response monitoring array will be installed 23 ft (7 m) from the shaft centerline in the shaft station breakout, as shown in Figures 4-14 and 4-15.

Rock bolt load variation and stress distribution will be measured in rock bolts installed from within the shaft and shaft stations. Four rock bolts in each of two rings of construction bolts will be monitored from within the shaft; approximately ten bolts will be monitored from within each shaft station. The proposed location of monitored bolts is shown on Figure 4-15.

4.4.2.1.7 Shaft Bottom Plug(s). Monitoring requirements in the shaft bottom plug will include:

- The buildup of hydraulic and rock pressures on the outside of the plug
- The response of the plug to the external loads.

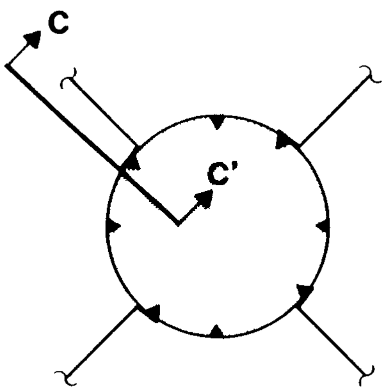
Lateral and vertical contact stresses and hydraulic pressures will be measured at the plug/rock interface. The response of the plug to lateral and vertical stresses will be monitored using vibrating wire strain gages positioned to measure axial and radial strains as shown in Figure 4-14.

A summary of the location of instrumentation arrays is presented in Table 4-2. As the site stratigraphy is not precisely known at this time, the actual location of certain mechanical and thermal response monitoring arrays may change. Furthermore, there is some flexibility associated with the location of arrays which have been positioned to monitor response in specific formations. Possible variations in the location of arrays have been included in Table 4-2 to illustrate the flexibility which already exists, based on the Synthetic Data Base, in positioning arrays. The instrument content of each array is also noted and discussed below.

4.4.2.2 Rationale for Quantity of Instrumentation in Arrays

Instrumentation layouts have been designed to satisfy two prerequisites: that at least one parameter (e.g., tangential strain in the concrete) should be measured at three independent locations around the shaft cross-section, and that every parameter should be measured at both ends of at least one diameter. The rationale for these requirements is as follows:

As a simplifying assumption, the shaft lining may be considered as a long cylinder of homogeneous, isotropic, linear-elastic material that is subjected to a non-uniform (biaxial) radial stress field (e.g., worse-case loading condition). Application of



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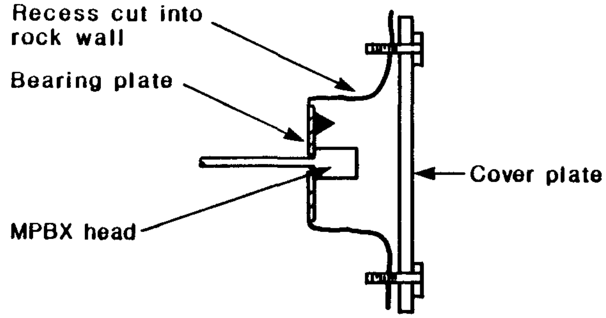
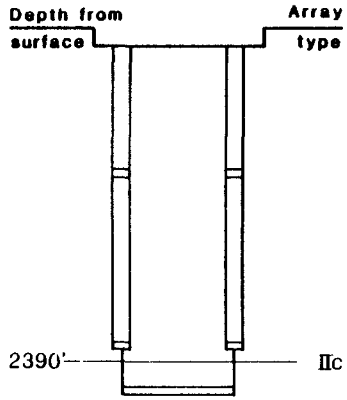


Section C-C'

Extensometer Installation in Salt

Array Location



Key

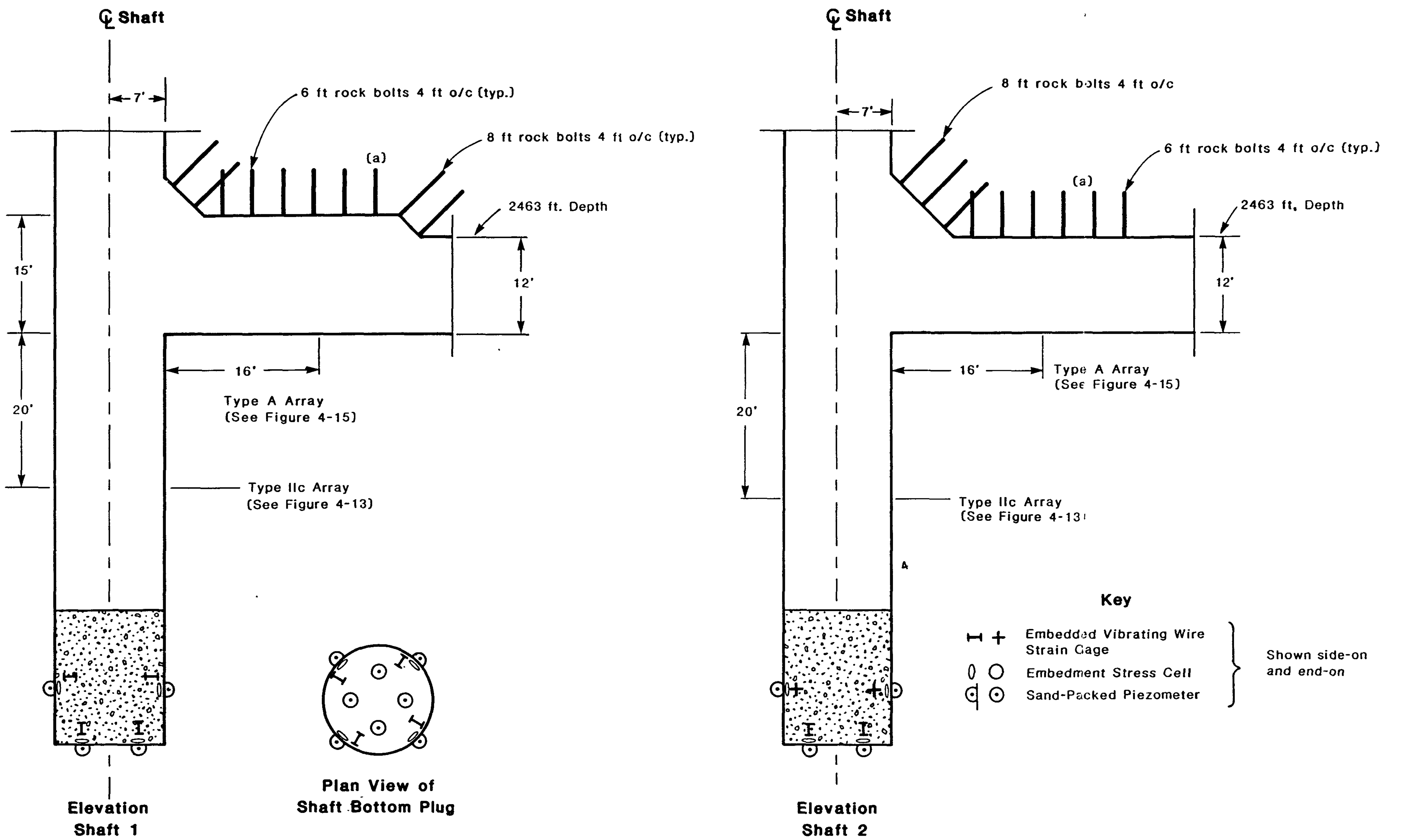
6 anchor MPBX with convergence reference point on head

▶ Convergence Reference Point

Notes:
- All depths are approximate and not final.
- Temperature sensors built-in to each instrument.
- Shaft station arrays not shown.

Array Type IIc – Lower Unlined Shaft Section

Figure 4-13

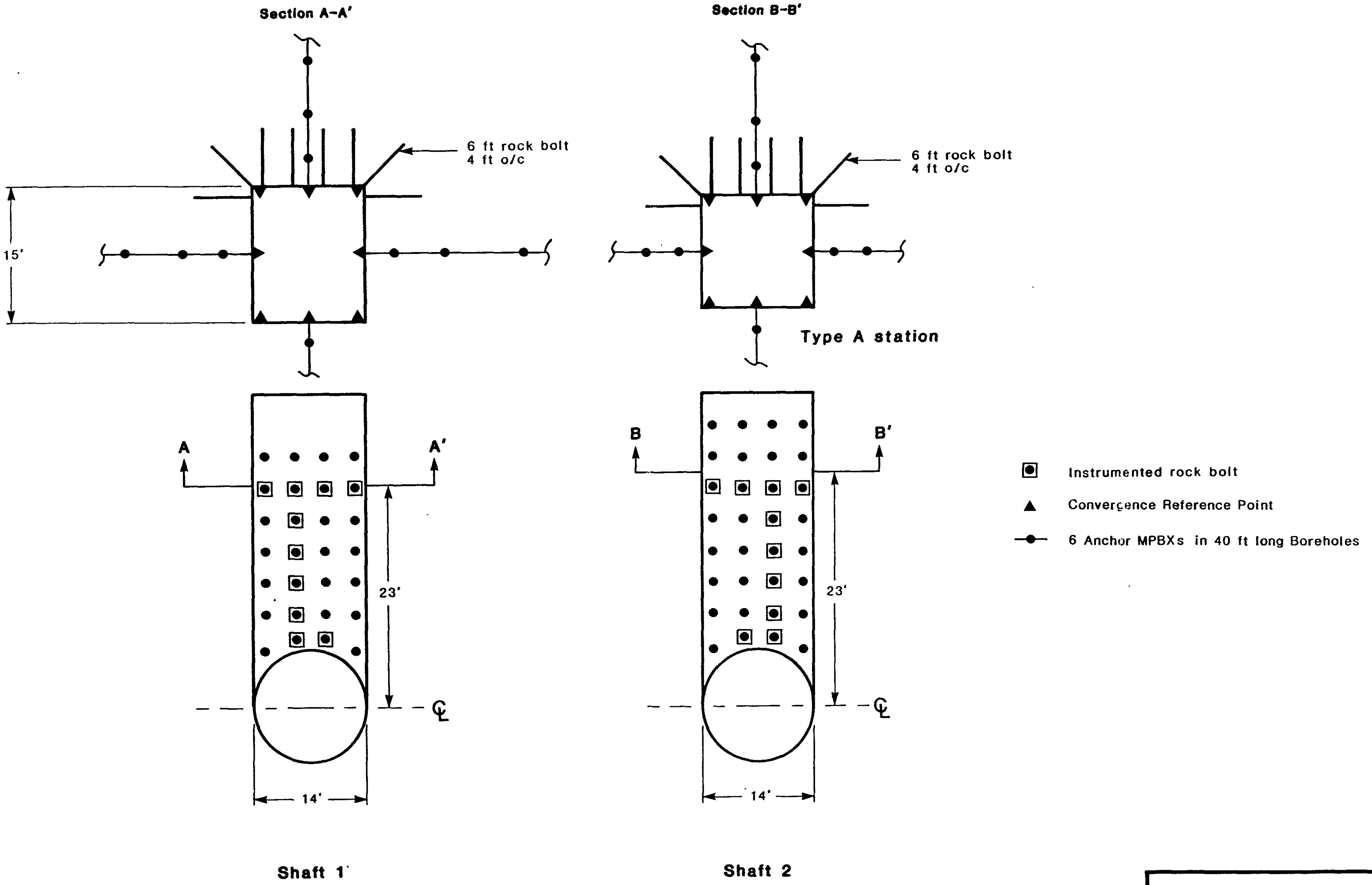


Notes:

- See Figure 4-15 for rock bolt monitoring layout.
- Type 11c station 20ft. (6.1m) above shaft station not shown.
- Temperature Sensors built into selected instruments.

Mechanical Response Monitoring Shaft Station and Shaft Bottom Plug Array

Figure 4-14



Source: Modified from PB/PB-KBB, 1986(a)

Shaft Station Mechanical Response Monitoring Arrays

Figure 4-15

WBS 6.9.4.2

843-1040-102/35

Table 4-2. Summary of Mechanical Response Monitoring Instrumentation in Shaft No. 1

Array Type	Depth[1] ft(m)	Formation	Possible[1] Depth Range, ft(m)	Rationale	Instrument Content of Array									
					CRP	ESC	EVWSG	WVWSG	BPC	JM	VWTS	MPBX	PZ	RLC
II	335 (102)	Ogallala	[NA]	Base of Ogallala	16	16	20	8	2	9	22		4	
IId	345 (105)	Dockum	[NA]	Top of Dockum									4	
IIa	745 (227)	Dockum	± 20 (6)	Spatial distribution of measurement	16	16	20	8	2	9	22		4	
IIa	960 (293)	Dockum/ Dewey Lake	± 20 (6)	Close to Upper Shaft Foundation	16	20	24	8	2	9	22		4	
Ia		Alibates	[NA]	Foundation and Support Ring (MRM)	16	24	0	24		4			4	
Ib		Alibates	[NA]	Seal (MRM)	16	12	8	4		9				
IIb	1118 (341)	Salado	± 5 (2)	Located to monitor swelling pressures	16	12	16	4			16		4	
IIb	1210 (369)	USR	± 50 (15)	Spatial coverage and confirmation of design	20	12	16	4		6	16	4	4	
IIb	1390 (424)	LSR	± 20 (6)	Spatial coverage over lower shaft section	16	12	16	4			16		4	
IId	1670 (509)	Queen/ Grayburg	± 20 (6)	Spatial coverage for hydrostatic pressure monitoring									4	
IIb	1800 (549)	USA	± 20 (6)	Spatial coverage and confirmation of design	20	12	16	8		6	16	4	4	
IIb	1950 (594)	USA	+ 10 (3)	Elastic strata sandwiched between salt beds	16	12	16	8			16		4	
IIb	2200 (671)	LSA5	+ 50 (15)	Greatest rate of creep deformation in lined shaft	20	20	24	16		6	16	4	4	
Ia		LSA5	[NA]	Foundation and support ring (MRM)	16	24	0	24		4			4	
Ib		LSA5	[NA]	Seal (MRM)	8	12	8	8		9				
IIc	2390 (729)	LSA4	± 10 (3)	Spatial coverage within unlined shaft section	8							4		
IIc	2445 (745)	LSA4	[NA]	Monitoring deformation around shaft station	8							4		8

Table 4-2. Summary of Mechanical Response Monitoring Instrumentation in Shaft No. 1
(Continued)

Array Type	Depth ft(m)	Formation	Possible Depth Range, ft(m)	Rationale	Instrument Content of Array									
					CRP	ESC	EVWSG	WVWSG	BPC	JM	VWTS	MPBX	PZ	RLC
Type A	Shaft	LSA4	[NA]	Shaft Station (MRM)	8							4		10
IIc	2495 (761)	LSA4	[NA]	Monitoring Deformation Around Shaft Station	8							4		
Id	Shaft	LSA4	[NA]	Shaft Bottom Plug Uplift Pressure		8	8						6	

Key:
CRP - Convergence Reference Point
ESC - Embedment Stress Cell
EVWSG - Embedded Vibrating Wire Strain Gage
WVWSG - Welded Vibrating Wire Strain Gage
BPC - Bitumen Pressure Cell
JM - Jointmeter
VWTS - Vibrating Wire Temperature Sensor
MPBX - Multiple Position Borehole Extensometer
PZ - Piezometer
RLC - Rock Bolt Load Cell
MRM - Mechanical Response Monitoring
USR - Upper Seven River
LSR - Lower Seven River
USA - Upper San Andres
LSA - Lower San Andres

Note:

[1] - Based on Synthetic Data Base (ONWI, 1986a)

8431040102/SHAFT SP-D/TAB42/387

linear-elastic theory to determine the distribution of stresses and strains in a horizontal plane through the lining introduces three unknown variables, requiring three independent measurements of stress and/or strain to provide a unique solution. Two measurements made on either end of a given diameter are not independent. However, for practical purposes, it is important to measure the parameter at either end of a diameter because the data will provide a means of confirmation (of the measurement) and redundancy should either of the instruments fail. In the present application, it is prudent to introduce slightly more redundancy and data confirmation/ correlation, as the lining will not behave as a homogeneous, isotropic, linear-elastic material. In addition, as far as the performance of the instrumentation is concerned, uncertainties exist with regard to the direct measurement of stress in concrete, and the transformation of measured strains into stress is complicated by changes in the constitutive behavior of the concrete in the long term. Furthermore, the lining is likely to contain spatial variation of material properties that can only be "averaged out" by obtaining sufficient numbers of measurements. Each array has therefore been arranged so that the tangential strain in the concrete and the radial convergence of the lined shaft wall will be measured at each of four equispaced diameters. Confirmatory data will be obtained by measuring stresses on both ends of two orthogonal diameters.

Instruments will be grouped together in clusters in order to minimize the influence of spatial variation of material properties when correlating measurements of stress and strain locally.

In the case of jointmeters, since each installation set will contain three orthogonally oriented jointmeters, only two sets are needed to completely define the relative movements in three dimensions. An additional set of jointmeters has been added in order to provide measurement confirmation and redundancy.

In the case of pressure cells which measure bitustatic pressure, two cells are included in order to provide measurement confirmation and redundancy.

4.4.2.3 Rationale for Instrumentation Layout in Both Shafts

It is essential to install a full set of mechanical response monitoring arrays, as described above, in one of the shafts. However, since the shafts are to be identical in design and construction, and it is generally accepted that there will be minor horizontal variation in stratigraphy and rock mass properties from one shaft to the other, there is no requirement to fully instrument the second shaft. Instrumentation arrays in the second shaft should therefore be located to confirm repeatability (e.g., at the same elevations as in the first shaft) within each design component. As a minimum, instrument arrays will be duplicated at both shaft foundations and support rings (Type Ia array), and operational seals (Type Ib array); at the lowermost elevation in the upper shaft where hydrostatic and bitustatic loads are expected to be greatest (Type IIa array at 960 ft (293 m)); at the lowermost salt and non-salt elevations in the lower shaft (Type IIb arrays at 2,220 ft (671 m) and 1,950 ft (594 m), respectively); at the array elevation in the lower unlined section of the shaft (Type IIc array at 2,390 ft (728 m)); at the Bitumen Seal placed at the Ogallala/Dockum contact (two Type IId arrays, at 335 ft (102 m) and 345 ft (105 m)); and at the shaft station and shaft bottom plug. A summary of the location of instrumentation arrays in the second shaft is presented in Table 4-3.

The comprehensively instrumented shaft ultimately will be the ESF intake shaft, with the exhaust shaft containing confirmation monitoring arrays only. This arrangement results from a requirement to start the At-Depth Facility excavation, to commence from the exhaust shaft station, as early as possible. The instrument array locations for both shafts are given in Figure 4-8.

4.4.3 Method

Installation and monitoring of individual instruments to be installed as part of the Shaft Mechanical and Thermal Response Study are described in separate supporting Technical Procedures supporting this Study Plan. The relevant procedures are:

- Manual Convergence Monitoring Procedure (Golder Associates, 1986d)
- Multiple Position Borehole Extensometer Installation and Monitoring Procedure (Golder Associates, 1986e)
- Strain Monitoring
  - Welded VWSG Installation and Monitoring Procedure (Golder Associates, 1987c)
  - Embedded VWSG Installation and Monitoring Procedure (Golder Associates, 1987d)
  - Rebar VWSG Installation and Monitoring Procedure (Golder Associates, TBDd)
- Stress Change Monitoring
  - Bitumen Pressure Cell Installation and Monitoring Procedure (Golder Associates, 1987e)
  - Embedment Stress Cell Installation and Monitoring Procedure (Golder Associates, 1987f)
- Jointmeter Installation and Monitoring Procedure (Golder Associates, 1987g)
- Piezometer Installation and Monitoring Procedure (Golder Associates, 1986f)
- Rock Mass and Shaft Temperature Monitoring Procedure (Golder Associates, 1986g)
- Drilling Supervision Procedure (Golder Associates, 1986h)

Table 4-3. Summary of Mechanical Response Monitoring Instrumentation in Shaft No. 2

Array Type	Depth[1], ft(m)	Formation	Possible[1] Depth Range, ft(m)	Rationale	Instrument Content of Array									
					CRP	ESC	EVWSG	WVWSG	BPC	JM	VWTS	MPBX	PZ	RLC
IId	335 (102)	Ogallala	[NA]	Base of Ogallala									4	
IId	345 (105)	Dockum	[NA]	Top of Dockum									4	
IIa	960 (293)	Dockum	± 20 (6)	Close to Upper Shaft Foundation	16	20	24	8	2	9	22		4	
Ia		Alibates	[NA]	Foundation and Support Ring (MRM)	16	24	0	24		4			4	
Ib		Alibates	[NA]	Seal (MRM)	16	12	8	4		9				
IIb	1950 (594)	USA	+ 10 (3)	Elastic strata sandwiched between salt beds	16	12	16	8			16		4	
IIb	2200 (671)	LSA5	+ 50 (15)	Greatest rate of creep deformation in lined shaft	20	20	24	16		6	16	4	4	
Ia		LSA5	[NA]	Foundation and support ring (MRM)	16	24	0	24		4			4	
Ib		LSA5	[NA]	Seal (MRM)	8	12	8	8		9				
IIc	2390 (729)	LSA4	± 10 (3)	Spatial coverage within unlined shaft section	8							4		
IIc	2445 (745)	LSA4	[NA]	Monitoring deformation around shaft station	8							4		8
Type A	Shaft Station	LSA4	[NA]	Shaft Station (MRM)	8							4		10
IIc	2495 (761)	LSA4	[NA]	Monitoring deformation around shaft station	8							4		
Id	Shaft Bottom	LSA4	[NA]	Shaft Bottom Plug Uplift Pressure		8	8						6	

Key:
CRP - Convergence Reference Point
ESC - Embedment Stress Cell
EVWSG - Embedded Vibrating Wire Strain Gage
WVWSG - Welded Vibrating Wire Strain Gage
BPC - Bitumen Pressure Cell
JM - Jointmeter
VWTS - Vibrating Wire Temperature Sensor
MPBX - Multiple Position Borehole Extensometer
PZ - Piezometer
RLC - Rock Bolt Load Cell
MRM - Mechanical Responses Monitoring
USR - Upper Seven Rivers
LSR - Lower Seven Rivers
USA - Upper San Andres
LSA - Lower San Andres

Note:
1 - Based on Synthetic Data Base (ONWI, 1986a)

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A majority of the mechanical response monitoring instrumentation will be connected to the Automatic Data Acquisition Systems (ADAS). Several procedures apply to the installation of the ADAS:

- Instrumentation Cable Termination Procedure (Golder Associates, TBDa)
- Shaft DCU Completion Procedure (Golder Associates, TBDb)
- Junction Box Completion Procedure (Golder Associates, TBDc).

The overall methodology for installing the shaft monitoring arrays is described in the following sections, with direct references to each relevant supporting Procedure. Integration with shaft construction operations and support requirements from the Construction Manager are also discussed.

4.4.3.1 Task Sequence

Installation of the Shaft Mechanical and Thermal Response Monitoring arrays requires close cooperation between the Mining Subcontractor (MSC) and the Underground Testing Contractor (UTC). The task sequence, described below, therefore, makes frequent reference to construction procedures previously outlined in Chapter 2.0. The presentation is focused on the needs of the UTC and the currently perceived MSC constraints associated with instrumentation array installation and monitoring. However, the impact of these perceived constraints on cost and schedule have not been fully analyzed and alternative methods may exist which satisfy both MSC and UTC requirements. These alternatives will be evaluated by the UTC, CM, and ESF A/E and incorporated in future, planned updates to this SSP.

The following activities are described within the task sequence for each shaft section:

- Excavation, ADAS hardware installation, and lining to individual target stations. (Two types of target stations are referenced. An instrument array target station includes the instrument array, associated ADAS hardware, and space required for installing wiring and instrument support fixtures. Each target station is referenced by the Instrument Array Elevation [see Tables 4-2 and 4-3]. An ADAS target station includes either a pull-box or DCU and is referenced by the elevation of the base of the unit)
- Installation of instrumentation and ADAS hardware at the target station, connection of instruments to the ADAS, instrument checkout, and preliminary reading
- Completion of construction sequence to the next target station, including integrated installation of ADAS hardware (e.g., conduit and pull-boxes).

During presentation of the Task Sequence, frequent reference is made to drawings contained in Appendix B. For each instrument array target station, there are three principal drawings:

- The Preparation drawing shows the layout of all equipment that will be installed in the shaft and other preparation performed by the MSC at the target station prior to the UTC installing instruments
- The Instrument Array Assembly drawing shows the layout of instruments that will be installed in the shaft lining at the target station
- The Instrument Cable Routing drawing shows where instrument cables will be routed in order to connect instruments to the target station junction and/or DCU box.

4.4.3.1.1 Upper Shaft Installation. The sequence of construction activities in the upper shaft includes sinking and preliminary lining through frozen ground, construction of a foundation support ring and foundation, and final lining. Instrumentation and monitoring requirements include manual convergence and installation of Mechanical and Thermal Response Monitoring arrays and ADAS hardware at the following target stations in each shaft:

Shaft 1	Shaft 2
335' (102 m) - Type IIa	335' (102 m) - Type IId
345' (105 m) - Type IId	345' (105 m) - Type IId
500' (152 m) - Pull Box (Final Lining Only)	
745' (227 m) - Type IIa	500' (152 m) - Pull Box
960' (293 m) - Type IIa	960' (293 m) - Type IIa
Foundation/Support Ring	Foundation/Support Ring

Manual convergence measurements will be made during construction through the freeze zone to monitor closure of the frozen shaft wall. This activity will be performed primarily as a construction support function for defining the timing of the preliminary shaft lining installation and will be conducted using the Manual Convergence Monitoring Procedure (Golder Associates, 1986d).

4.4.3.1.1.1. Preliminary lining in the upper shaft. This lining will be constructed from the shaft collar downwards through the frozen zone containing the major aquifers. It will probably be cast-in-place concrete approximately 14 in (350 mm) thick. The liner will end about 10 ft (3 m) above the upper foundation. The instruments in the final lining upper foundation and support ring will, however, be included in the preliminary lining wiring system for logistical reasons (e.g., conduit routing). The wiring system, including conduits, J-boxes, and wiring, will be embedded in the preliminary concrete lining during construction.

Automatic Data Acquisition System (ADAS) Installation

The installation and wiring method in the preliminary lining of the upper shafts consists of the following steps:

1. 3.5-in (89-mm)-diameter plastic conduits will be installed in the lining starting at the shaft collar and continuing downward in conjunction with lining construction between instrumention array target stations. The number of conduits in different sections of each shaft will be as follows:

   Shaft 1: Fifteen between the shaft collar and 335' (102 m)
   Twelve between 335' (102 m) and 345' (105 m)
   Eleven between 345' (105 m) and 745' (152 m)
   Seven between 745' (227 m) and 960' (293 m)
   Two between 960' (293 m) and the base of the preliminary lining

   (Appendix B: Drawing No. 01-0100A)

   Shaft 2: Eight between the shaft collar and 335' (102 m)
   Eight between 335' (102 m) and 345' (105 m)
   Seven between 345' (105 m) and 500' (152 m)
   Seven between 500' (152 m) and 960' (293 m)
   Two between 960' (293 m) and the base of the preliminary lining

   (Appendix B: Drawing No. 02-0100A)

2. At each target station except 345 ft (105 m), the MSC will provide a block-out for either a junction box or pull box and will install the junction/pull box and will extend the conduit to these block-outs and down through the kerb ring set below the target station, as shown on the Appendix B: target station Preparation drawings.

3. Cables will be pulled from the shaft collar junction boxes, through pull boxes, if required, to the target station junction/pull box. The top deck of the galloway may need to be detached and raised up the shaft to gain access to higher elevations in order to carry out pulling of cables between junction boxes and pull boxes.

4. Instruments will be installed at the target station and the instrument cables will be routed into the junction box through short lengths of conduit, as shown in Appendix B: Instrument Cable Routing drawings. Instruments in the 345' (105 m) target station will be routed directly to the 335' (102 m) junction box through an additional conduit.

5. Inside the junction box, the instrument cables will be connected to the cables previously extended, via pull boxes, from the surface. The instrument cables and extension cables will be prefabricated with in-line miniature connectors that will be plugged together in the junction box to complete the connection of the instrument to

the surface junction box and DCU. All instruments in the target station will be checked out and repaired if required. Each instrument cable connection in the junction box will be protected with sealant-filled heat-shrink tubing after the checkout is completed. At this time, the target station will be fully functional and data will be collected by the ADAS.

6. Forms will be set, the ADAS block-out tubs sealed to the form, and the concrete will be placed.

7. After the forms are removed from around the target station, access will be regained to the ADAS junction box to permit cable termination from instruments that will be installed later in the bitumen layer.

Instrument Installation, Type IIa Array

This sequence of activities covers the installation of the instruments comprising Type IIa arrays during sinking and preliminary lining of the upper shaft. Three arrays will be installed using this procedure at depths of approximately 335, 745, and 960 ft (102, 227, and 293 m) in Shaft No. 1, and one array will be installed at a depth of 960 ft (293 m) in Shaft No. 2.

1. The MSC will excavate to below the instrumentation array elevation and will install the kerb ring at the bottom of the target station. The MSC and CM will be respectively responsible for installing all hardware, including installation of a block-out for the ADAS junction box, indicated on the Appendix B: target station Preparation drawings and for marking bearing lines and the target station horizontal datum.

2. All activities associated with installation of ADAS equipment, including installation of additional conduit and pulling of cables from the surface, will be completed prior to instrument installation. Instrumentation will be transported from the surface and stored on the galloway during ADAS hardware installation.

3. A strip of Tensar Geogrid (or equivalent) plastic mesh, which will support the instrument leads, will be installed around the entire shaft perimeter at the elevation shown on the Appendix B: Instrument Array Assembly Drawings.

4. Four sand-packed piezometers will be the first instruments to be installed in the upper shaft instrument arrays. The installation will require preparation of the rock surface using chipping hammers, installation of the piezometers (see Piezometer Installation and Monitoring Procedure, Golder Associates, 1986f) and routing of the instrument cables to the ADAS junction box.

5. Two 3-to-4-ft (1-to-1.3-m)-long temperature monitoring boreholes will be drilled in mutually perpendicular directions at the locations shown on the Appendix B: Instrument Array Installation drawings. Vibrating Wire Temperature Sensors will be installed

using the Shaft Temperature Monitoring Procedure (Golder Associates, 1986g) and instrument cables will be routed to the ADAS junction box, as indicated in Appendix B: Instrument Cable Routing drawings.

6. Other instrumentation will be suspended from short sections of re-bar preinstalled by the MSC in the shaft wall. Embedded VWSGs and Embedment Stress Cells will be installed using the Embedded VWSG Installation and Monitoring Procedure (Golder Associates, 1987d) and the Embedment Stress Cell Installation and Monitoring Procedure (Golder Associates, 1987f), respectively. All cabling will be fastened to the preinstalled plastic mesh and routed to the ADAS junction box, as indicated in the Appendix B: Instrument Cable Routing drawings.

7. The MSC will install forms ready for concrete placement. Bitumen pressure cells will be installed against the outside (i.e, concrete side) of the formwork using the Bitumen Pressure Cell Installation and Monitoring Procedure (Golder Associates, 1987e). To accomplish this, a small removable window will be installed in the form. Cables from the bitumen pressure cells will be fastened to the preinstalled plastic mesh and routed to the ADAS junction box, as indicated on the Appendix B: Instrument Cable Routing drawings.

8. Instrumentation installation and connection of instrument cables, at the junction box, will proceed concurrently, requiring the use of two galloway decks. Two ADAS electricians, working on the deck above the instrumentation crew, will connect wires at the junction box using the Instrumentation Cable Termination Procedures (Golder Associates, TBDa).

9. Surveys of the installed instrument positions and preinstallation checks will be carried out prior to concrete placement. The UTC will monitor the placement of concrete around the instruments. At the same time, instrument performance during concrete placement will be monitored through the ADAS.

   [Concrete placement may involve the use of nonstandard length formwork to facilitate concrete placement around instruments and instrument cabling. Details of these requirements will be resolved with the CM and A/E and presented in future updates to the SSP.]

10. When the concrete has cured and the formwork has been removed, the CM will re-mark the reference lines and the locations of instruments on the exposed concrete surface. Recesses for convergence reference points will be cut in the concrete at the reference horizon, reference points will be installed, and an initial set of convergence measurements will be made (see Manual Convergence Monitoring Procedure, Golder Associates, 1986d).

11. Embedded instrumentation will be monitored remotely through the ADAS. Periodic measurements of shaft convergence will be made manually.

Instrument Installation, Type IId Array

Type IId arrays will be installed at a depth of approximately 345 ft (102 m) in Shaft No. 1, and depths of approximately 335 ft and 345 ft (102 m and 105 m) in Shaft No. 2.

1. The MSC will excavate to below the instrumentation array elevation and will install the kerb ring at the bottom of the target station. The MSC will be responsible for installing all hardware indicated on the Appendix B: target station Preparation drawings, including installation of a short section of conduit from the 335' (102 m) Type IIa array junction box. The CM will be responsible for marking and labeling bearing lines and the target station horizontal datum.

2. A strip of Tensar Geogrid (or equivalent) plastic mesh will be installed as described in Step 3 of the preceding Type IIa array installation procedure.

3. Four sand-packed piezometers will be installed (see Step 4 of preceeding Type IIa array installation procedure). All cabling will be routed to the junction box above the 335 ft (102 m) level array.

4. Surveying, preinstallation checks, concrete placement, re-marking of reference lines, and instrumentation monitoring will be carried out using Steps 8 through 11 of the preceding Type IIa array installation procedure.

4.4.3.1.1.2 Upper foundation support ring and foundation. The upper foundation support ring and foundation will be constructed when excavation of the shafts has progressed to the required design elevation. The sequence of activities involved in instrumentation installation and ADAS extension is as follows:

Automatic Data Acquisition System (ADAS):

Foundation and support ring instrumentation will be monitored by a DCU mounted on the shaft wall below the support ring. The DCU will be temporarily connected to the ADAS via a LAN installed in the preliminary lining during support ring and foundation construction and final lining in the upper shafts. After completion of the upper shaft final lining, data transmission will be via a LAN installed in the final lining. The installation and wiring method associated with this activity is described below and in the ADAS section of the final lining task sequence.

1. The MSC will sink the shaft to approximately 10 ft (3 m) below the base of the support ring. A temporary concrete liner will be placed below the base of the support ring to provide support for the strata which will eventually house the upper shaft seal.

2. The MSC will install the kerb ring at the base of the support ring, and will install the foundation/support ring DCU and power box. Seven conduits will be routed from the DCU upwards through the kerb ring.

   - Two conduits terminated approximately 2 ft (0.6 m) above the kerb ring, will be used to service the support ring instrumentation.

   - One conduit, terminated flush with the top of the foundation squeeze plate, will service the foundation instrumentation.

   - Two conduits will be routed, during support ring and foundation construction, into the upper shaft final lining to a small junction box located adjacent to the base of the preliminary lining. During final lining installation, LAN and power cables will be routed from the preliminary lining, through watertight penetrations in the outer steel lining, to the final lining junction box. Conduit will then be extended from the junction box up to the 960-ft (293-m) level DCU block-out as shown on the Appendix B drawings and discussed in the final lining task sequence.

   - The two remaining conduits, which will serve the At-Depth LAN cables, will eventually be routed through the 500-ft (152-m) level pull box to the surface.

3. UTC electricians will complete outfitting of the DCU and power boxes ready for LAN and instrument cable termination. The MSC will route temporary LAN and power cables from the preliminary lining as previously described.

Instrument Installation, Type 1a Array

1. The MSC will complete excavation of the shaft and preparation of the shaft walls ready for installation of the foundation support ring and foundation. Sufficient space must be provided, below the support ring, to permit installation of the foundation/support ring DCU.

2. The MSC will install the kerb ring at the base of the support ring and will route seven conduits from below the support ring, upward through the kerb ring as previously described.

3. Instrument array reference bearings and a horizontal datum will be marked, by the CM, on the exposed rock surfaces. The MSC will install all hardware required for instrument installation at the support ring and foundation as shown on Appendix B: target station Preparation drawings.

4. Hand tools will be used to prepare the rock surface against which the embedment stress cells will be placed.

5. Four sand-packed piezometers will be installed at the locations shown on the Appendix B: Instrument Array Assembly drawings using the Piezometer Installation and Monitoring Procedure (Golder Associates, 1986f).

6. Embedment stress cells will be installed, in a specially constructed mudslab, using the Embedment Stress Cell Installation and Monitoring Procedure (Golder Associates, 1987f). Cables from the piezometers and stress cells will be coiled up and protected during installation of the support ring reinforcement.

7. Sections of rebar, containing pre-installed VWSGs, will be installed with the support ring reinforcement (see Rebar VWSG Installation and Monitoring Procedure, Golder Associates, TBDd) at the locations shown on the Appendix B: Instrument Array Assembly drawing.

8. Embedment stress cells will be installed between rebar sections, at the locations shown on the Appendix B: Instrument Array Assembly drawing, using the Embedment Stress Cell Installation and Monitoring Procedure (Golder Associates, 1987f). Cables from all instruments will then be routed down to the Foundation/Support Ring DCU (see Appendix B: Instrument Cable Routing drawings).

9. ADAS Electricians will complete instrument cable connection to the foundation/support ring DCU, using the Instrument Cable Termination Procedure (Golder Associates, TBDa).

10. Surveys of the installed instrument positions and pre-installation checks will be carried out prior to concrete placement. The UTC will monitor the placement of concrete around the instruments. At the same time, instrument performance during concrete placement will be monitored through the ADAS.

11. When the concrete has cured and the formwork has been removed, the CM will re-mark the reference lines and the locations of instruments on the exposed concrete surface. Convergence reference point recesses will be cut in the concrete at the reference horizon, reference points will be installed and an initial set of convergence measurements will be made (see Manual Convergence Monitoring Procedure, Golder Associates, 1986d).

12. The MSC will complete any preparation required at the foundation location as shown on the Appendix B: target station Preparation drawings. Hand tools will be used to prepare the rock surface against which the embedment stress cells will be placed.

13. The specified location for the embedment stress cells to be installed in the 4-in (0.1-m) thick mud slab will be marked on the rock surface.

14. Embedment stress cells will be installed during placement of the mudslab using the Embedment Stress Cell Installation and Monitoring Procedure (Golder Associates, 1987f). Stress cells will be tied to

short lengths of small gage rebar (approximately 3/8-in diameter), previously installed normal to the prepared rock surface. Cables from all instruments will be routed down to the support ring DCU where they will be terminated using the Instrument Cable Termination Procedure (Golder Associates, TBDa).

15. The MSC will complete assembly of the reinforcement, placement of concrete, and installation of construction hardware ready for upper shaft final lining construction. The UTC will monitor the placement of concrete around the instruments. At the same time, instrument performance during concrete placement will be monitored through the ADAS.

16. Jointmeters will be installed across the foundation squeeze plate, using the Jointmeter Installation and Monitoring Procedure (Golder Associates, 1987g), and cables will be routed to the foundation/support ring DCU.

17. Embedded instrumentation and surface-mounted jointmeters will be monitored remotely through the ADAS. Periodic measurements of shaft convergence will be made manually.

4.4.3.1.1.3 Final lining in the upper shaft. The final lining will be constructed from the upper foundation upwards to the shaft collar, and will be completed before any work is started in the lower shaft. The lining will be constructed with an outer steel membrane containing cast-in-place concrete, approximately 25 in (625 mm) thick, and a 6-in (150-mm)-thick bitumen layer placed between the preliminary and final linings.

The plan for the final lining is to collect data via the ADAS by mounting a DCU at each instrumentation station as it is completed. The DCUs will initially be connected to the ADAS through a temporary LAN routed through the preliminary lining and upwards from the foundation. When the final lining is finished, this temporary LAN will be abandoned, the conduit sealed, and new, permanent LAN cables will be installed.

Automatic Data Acquisition System (ADAS) Installation

The installation and wiring method in the final lining of the upper shaft consists of the following steps:

1. Four 3.5-in (89-mm)-diameter conduits will be installed in the lining by the MSC starting at the upper foundation and continuing upward in conjunction with the lining construction between target stations.

   - Two conduits extending from the foundation/support ring DCU will be routed into a small junction box located opposite the base of the preliminary lining on the inside of the final steel liner. LAN and power cables will be routed from the preliminary lining, through watertight penetrations in the steel liner, to the final lining junction box. These penetrations will eventually be decommissioned when the LAN and power cables in the final lining are completed.

- Two conduits servicing the At-Depth LAN cables will be installed on the opposite side of the shaft wall to the Shaft LAN and power conduits, as shown on the Appendix B drawings.

All four conduits will be extended as part of the normal final lining construction process until a target station is reached.

2. Before the steel liner is constructed up past a target station, cables from jointmeters installed in the bitumen layer will be routed to the junction box in the preliminary lining. Each instrument will be checked out through the ADAS before the junction box is prepared for abandonment. The steel liner will then be installed past the target station.

3. At each target station, the MSC will provide a block-out in the final lining concrete for either a DCU and power box or a pull box and will install either a DCU and power box or a pull box inside the block-out. Conduit will be extended from the blockout upwards towards the next target station and downwards to connect with the conduit routed from below.

4. Shaft LAN and power cables will be pulled from the target station below. These cables will be connected to previously installed cables at the lower target station. If necessary, a temporary work platform will have to be installed to gain access to the lower target station in order to carry out pulling of cable assemblies between target stations.

5. ADAS electricians will install DCU and power supply equipment in the DCU and power boxes, respectively. At the same time, the instruments will be installed and instrument cables will be routed into the DCU box through short conduit sections, which will be sealed prior to placing concrete.

6. Each instrument cable will be connected to the DCU, and the instrument will be checked out and repaired as required. At this time the target station will be fully functional and data will be collected by the ADAS.

7. Forms will then be erected, the ADAS block-outs will be sealed to the form, and the concrete will be placed.

8. After the forms are removed from around the target station, access will be regained to the ADAS block-out tubs, and maintenance checks will be made.

LAN and power conduits could alternatively be run on the surface of the final lining, but are embedded to expedite the lower shaft construction schedule by:

- Eliminating the task of conduit installation on the surface of the final lining after lining construction
- Protecting the cables (i.e., avoiding replacement) during later construction and operation phases.

Upon completion of final lining construction, the shaft LAN and power cables exiting from the final lining conduits will be routed to one of the collar junction boxes, and will replace those connected to the preliminary lining. In this step, the "live" shaft LAN and power cables will switch to the final lining. When the galloway returns to the junction box above the upper foundation, the shaft LAN and power cables from the preliminary lining will be disconnected and the penetrations sealed. The preliminary lining conduits and junction boxes will then be filled with moisture-proof sealant to block water migration.

In both shafts, the ADF LAN cables will be pulled through the vacant conduits in the final lining in conjunction with the movement of the galloway from the collar to the upper foundation.

Instrumentation Installation, Type IIa Array

This sequence of activities covers the installation of the instruments comprising Type IIa arrays during construction of the final lining of the upper shaft. Three arrays will be installed using this procedure at depths of approximately 335, 745, and 960 ft (102, 227, and 293 m) in Shaft No.1 and one array at a depth of 960 ft (293 m) in Shaft No. 2.

1. The MSC will complete installation of the outer steel liner to just below the marked instrumentation array elevation. A final set of preliminary lining convergence measurements will be made (see Manual Convergence Monitoring Procedure, Golder Associates, 1986d). Instrumentation and associated installation hardware and equipment will be transported from the surface and stored on the galloway at convenient times during lining installation.
2. The required locations of instruments within the bitumen layer will be marked on the preliminary lining concrete using the reference lines previously marked following preliminary lining instrumentation.
3. Three sets of jointmeters will then be installed using the Jointmeter Installation and Monitoring Procedure (Golder Associates, 1987g). In the case of the vertically oriented jointmeter, for example, this will involve drilling 0.5-in (13 mm) holes through the steel plate at about 18 in (0.45 m) below the top of the lining; installing one end of the jointmeter fixture; marking off the concrete above the steel liner where the second attachment hole will be drilled; drilling this hole in the

preliminary lining concrete and grouting in the fixture bolt; welding protective guard plates onto the back of the steel lining; installing the jointmeter; and routing the instrument cabling to the junction box previously installed in the preliminary lining.

4. Instrument installation and termination of instrument cables, at the preliminary lining junction box will proceed concurrently where possible. The ADAS electricians will complete termination of instrument leads and closure of the junction box prior to advancing the steel lining.

5. The MSC will extend the steel liner up past the target station. The MSC will be responsible for installing all hardware indicated on the Appendix B: target station Preparation drawings, including the target station DCU and power box. The CM will be responsible for marking and labeling instrument array reference bearing lines and the target station horizontal datum on the inside of the steel liner. Instrumentation for the concrete liner will be transported from the surface and stored on the galloway during hardware installation.

6. ADAS electricians will complete outfitting of the DCU and power boxes prior to or during instrument installation.

7. A strip of Tensar Geogrid (or equivalent) plastic mesh, which will support the instrument cables, will be installed around the entire shaft perimeter at the elevation shown on the Appendix B: Instrument Array Assembly drawings.

8. Cables for Vibrating Wire Strain Gages, pre-installed on the inside of the steel liner at the locations shown on Appendix B: Instrument Array Assembly drawings, will be routed to the DCU, as shown on Appendix B: Instrument Cable Routing drawings.

9. Vibrating Wire Temperature Sensors (VWTSs) will be installed using the Shaft Temperature Monitoring Procedure (Golder Associates, 1986g). Embedded VWSGs and Embedment Stress Cells will be suspended from rebar sections installed by the MSC in accordance with the Embedded VWSG Installation and Monitoring Procedure (Golder Associates, 1987d) and the Embedment Stress Cell Installation and Monitoring Procedure (Golder Associates, 1987f). All cabling will be securely fastened to the pre-installed mesh and routed to the DCU.

10. Instrumentation installation and termination of instrument leads at the DCU will proceed concurrently requiring the use of at least two galloway decks. The ADAS electricians will complete termination of instrument leads and closure of the DCU prior to concrete placement using the Instrumentation Cable Termination Procedure (Golder Associates, TBDa), and the shaft DCU Completion Procedure (Golder Associates, TBDb).

11. Surveys of the installed instrument positions and pre-installation checks will be carried out prior to concrete placement. The UTC will monitor the placement of concrete around the instruments. At the same time, instrument performance will be monitored through the ADAS.

12. When the concrete has cured and the formwork has been removed, the CM will remark the reference line and the locations of the instruments on the exposed concrete surface. Permanent convergence reference point recesses will be cut in the concrete at the reference horizon, reference points will be installed, and an initial set of convergence measurements will be made using the Manual Convergence Monitoring Procedure (Golder Associates, 1986d).

13. The UTC will monitor the placement of bitumen behind the outer steel liner. At the same time, jointmeter and bitumen pressure cell performance will be monitored through the ADAS.

14. Embedded instrumentation will be monitored remotely through the ADAS. Periodic measurements of shaft convergence will be made manually.

4.4.3.1.1.4 Upper shaft operational seal (type Ib array) - temporary monitoring. Lower shaft sinking will commence below the upper foundation support ring and will include excavation of the section which will eventually contain the upper shaft operational seal. The following sequence of activities will be performed at this location during the mining cycle.

1. The MSC will complete excavation and lining of the proposed seal zone, including extension of conduit (on the concrete surface) from the DCU and power box block-out; the conduit will be embedded if concrete must be placed up to the finished shaft diameter. The DCU and power box will be installed inside the block-out. A small junction box will be located at the bottom of the conduit opposite the top of the preliminary lining in the lower shaft.

   [Note: An alternative arrangement to embedded conduit may be required here as seal construction will involve removal of concrete placed during shaft sinking. This particular concern will be resolved with the ESF A/E and CM during detailed design of the overall ADAS shaft subsystem.]

2. The MSC will have completed the temporary concrete liner past the operational seal location. When the concrete has cured and the formwork has been removed, temporary convergence reference point recesses will be cut in the concrete at the reference horizon, reference points will be installed, and an initial set of convergence measurements will be made using the Manual Convergence Monitoring Procedure (Golder Associates, 1986d).

3. Manual convergence measurements will be made at approximately weekly intervals following installation for about one month, and then at approximately monthly intervals up to the time of upper shaft seal placement.

4.4.3.1.2 Lower Shaft Installation. The sequence of construction activities in the Lower Shaft includes sinking and preliminary lining, construction of a foundation support ring and foundation, construction of the lower shaft seal, installation of the lower shaft final lining, construction of the upper shaft seal, sinking the shaft bald to the shaft station elevation, excavation and support of the shaft station breakout, sinking the shaft to the required final depth, and installation of a shaft bottom plug. Instrumentation and monitoring requirements include manual convergence and installation of Mechanical and Thermal Response Monitoring arrays and ADAS hardware at the following target stations in each shaft:

Shaft 1

Upper Shaft Seal
1118' (341 m) - Type IIb Array
1210' (369 m) - Type IIb Array
1390' (424 m) - Type IIb Array
1500' (457 m) - Pull Box (Final Lining Only)
1670' (509 m) - Type IId Array
1800' (549 m) - Type IIb Array
1950' (594 m) - Type IIb Array
2200' (671 m) - Type IIb Array
Lower Foundation, Support Ring and Seal
2390' (729 m) - Type IIc Array
2445' (745 m) - Type IIc Array
Shaft Station - Type A Array
2495' (761 m) - Type IIc Array
Shaft Bottom Plug

Shaft 2

Upper Shaft Seal
1500' (457 m) - Pull Box
1950' (594 m) - Type IIb Array
2200' (671 m) - Type IIb Array
Lower Foundation, Support Ring and Seal
2390' (729 m) - Type IIc Array
2445' (745 m) - Type IIc Array
Shaft Station - Type A Array
2495' (761 m) - Type IIc Array
Shaft Bottom Plug

Several mechanical and thermal property tests (see Section 4.5) will also be performed during lower shaft construction, and boreholes for operational and decommissioning seal monitoring will be installed.

4.4.3.1.2.1 Geomechanical and thermal properties tests. The following geomechanical and thermal properties tests will be conducted intermittently with lower shaft excavation and preliminary lining.

1. Absolute Stress Measurement - Overcoring (Section 4.5.1) will be conducted at the following approximate depths in Shaft No. 1:

   - At a depth of 1110 ft (338 m) in the Salado formation
   - At a depth of 1600 ft (488 m) in the Queen/Grayburg
   - At a depth of 2150 ft (655 m) in the Upper San Andres.

2. Deformation Moduli testing will be conducted, using the NX-Borehole Jack (Section 4.5.2) at the following approximate depths in Shaft No. 1:

- At a depth of 1110 ft (338 m) in the Salado Formation
- At a depth of 1600 ft (488 m) in the Queen/Grayburg
- At a depth of 2150 ft (655 m) in the Upper San Andres.

3. Thermal conductivity testing (Section 4.5.5) will be conducted at the following approximate depths in Shaft No. 1:

- In the Lower San Andres, at depths of 2272, 2285, and 2342 ft (693, 697, and 714 m).

4. Large diameter core samples (Section 4.5.4) will be obtained from within both shafts at the locations of the construction seals and above and below the candidate repository horizon. The approximate locations of large diameter core runs, in the lined lower shaft section, are as follows:

- In the Alibates, from 1035 to 1065 ft (316 to 325 m)
- In the LSA5, from 2350 to 2370 ft (716 to 723 m).

4.4.3.1.2.2 Operational and decommissioning seal test boreholes. Test boreholes will be installed and completed (see Section 4.6) at the following locations during lower shaft construction in Shaft No. 1:

- Six 40-ft (12-m)-long boreholes at each operational seal location (approximate elevations of each array of 3 boreholes are 1060, 1070, 2340, and 2355 ft (323, 326, 713, and 718 m))

- Three 40-ft (12-m)-long boreholes at non-salt decommissioning seal locations (e.g., at depths of approximately 1110, 1600, and 2150 ft (338, 488, and 655 m))

- Two 20-ft (6-m)-long boreholes drilled approximately 30 ft (9 m) above each decommissioning seal array.

4.4.3.1.2.3 Preliminary lining in the lower shaft. This lining will be constructed downward from about 15 ft (5 m) below the upper foundation support ring to about 15 ft (5 m) above the lower foundation. When excavating and lining through non-salt strata, the MSC will adopt a construction sequence similar to that and in the upper shaft. In salt strata, the ESF A/E has specified the use of compressible backfill which will be placed behind the preliminary concrete lining during construction. The construction sequence must be modified to accommodate placement of this component and may involve complete excavation (using temporary support if required) of the section between non-salt strata and subsequent construction of the preliminary lining, incorporating placement of the compressible backfill, in an upward direction.

[Note: This method of construction has been assumed for the ADAS hardware and instrumentation installation sequence; however, other construction methods are feasible and may be used (e.g., constructing the preliminary lining downward using embedded steel tendons to support the concrete). The preferred method will be selected by the ESF A/E and CM during detailed design and will be incorporated in future updates to the SSP.]

Automatic Data Acquisition System (ADAS) Installation

The installation and wiring method in the preliminary lining of the lower shafts consists of the following steps:

1. Two 3.5-in (89-mm)-diameter plastic conduits will be installed in the lining starting at a junction box located at the top of the preliminary lining and continuing downward in conjunction with lining construction between instrumentation array target stations. Temporary LAN and power cable connections will be made between this upper junction box and the one installed below the foundation/support ring DCU.

2. At each target station the MSC will install a block-out for a DCU and power box and will mount the DCU and power box inside the block-out and will extend conduit from each block-out upwards to the conduit installed during lining construction and downwards through the kerb ring set by the MSC at the bottom of the section to be lined. In salt strata, the MSC will install an outer concrete form, and may place compressible backfill (resin form) behind the form prior to installing the DCU and power box block-out, DCU and power box, and conduit.

3. Cables will be pulled from higher elevation DCU and power boxes to the station DCU/power boxes. These cables will be connected to previously installed cables at the higher elevation. If necessary the top deck of the galloway will need to be detached and raised up the shaft to gain access to higher elevations in order to carry out pulling of cable assemblies between ADAS boxes.

4. The UTC ADAS electricians will install DCU and power supply equipment in the DCU and power boxes, respectively. At the same time the instruments will be installed and the instrument cables will be routed into the DCU box through short conduit sections which will be sealed prior to placing concrete.

5. Each cable will be connected to the DCU, and the instrument will be checked out and repaired as required. At this time the target station will be fully functional, and data will be collected by the ADAS.

6. Forms will then be set, the ADAS block-out tubs sealed to the form, and the concrete will be placed.

7. After the forms are removed from around the target station, access will be regained to the ADAS block-out tub, and maintenance checks made.

Instrumentation Installation, Type IIb Array

This sequence of activities covers the installation of the instruments comprising Type IIb arrays during sinking and preliminary lining in the lower shaft. Six arrays will be installed at depths of approximately 1118, 1210, 1390, 1800, 1950, and 2200 ft (341, 369, 424, 549, 594, and 671 m) in Shaft No. 1, and two arrays will be installed at depths of 1950 and 2200 ft (594 and 671 m) in Shaft No. 2.

As the construction sequence for non-salt strata differs from that to be used for salt strata, two separate sequences are described.

Type IIb Array - Salt Strata Installation

Three arrays will be installed in salt strata at depths of approximately 1210, 1800, and 2200 ft (369, 549, and 671 m) in Shaft No. 1 and one array will be installed at a depth of 2200 ft (671 m) in Shaft No. 2.

1. The MSC will complete excavation of the shaft to the required target station elevation, including installation of temporary support if required.

2. The CM and MSC will be respectively responsible for marking bearing lines and the target station horizontal datum and for installing all hardware indicated on the Appendix B: target station Preparation drawings, except hardware attached to (or through) the outer wall of the form, which will be installed prior to preliminary lining.

3. The UTC will install temporary convergence reference points at the instrument array reference elevation and will take a preliminary set of convergence measurements using the Manual Convergence Monitoring Procedure (Golder Associates, 1986d).

4. Four equispaced, N-sized boreholes will be drilled normal to the shaft wall at the locations shown on the Appendix B: Instrument Array Assembly drawings. Multiple Position Borehole Extensometers (MPBXs) will be installed in each of the boreholes using the MPBX Installation and Monitoring Procedure (Golder Associates, 1986e). The extensometer head will be recessed in the shaft wall so that it does not project beyond the inside of the preliminary lining. Cables from the MPBX head will be connected to a portable data logger and an initial set of extensometer measurements will be made. Finally, a set of convergence measurement will be made between opposite extensometer heads.

5. The MSC will complete excavation in the salt sequence and will install the kerb ring and concrete forms at the bottom of the shaft, ready for preliminary lining installation. Construction will then proceed upwards; formwork will be installed on the outside of the preliminary lining concrete to contain the compressible backfill. The MSC will complete installation of the outer formwork to the bottom of the preliminary lining located above. A block-out will be inserted over the head of the MPBX during outer formwork installation and will be sealed to the outer form to isolate the head during placement of the compressible backfill. Compressible backfill (resin foam) will be placed behind the outer form. At each instrument array station a block-out will be provided, at the location shown on the Appendix B: target station Preparation drawings, for the instrumentation array DCU and power box. This block-out will be attached to the outer formwork.

6. The UTC will install sand-packed piezometers on the back of the outer formwork during formwork installation using the Piezometer Installation and Monitoring Procedure (Golder Associates, 1986f). Cabling from the piezometers will be routed through a sealed gland in the outer formwork, ready for connection to the DCU.

7. The MSC will install the DCU and power box in the block-out provided and will extend conduit from the block-out upwards to the conduit installed in the preliminary lining above, and downwards through the kerb ring set at the bottom of the shaft. UTC ADAS electricians will complete outfitting of the target station DCU and power box ready for termination of instrument cables. LAN and power cables will be pulled from DCU and power boxes located above, and will be terminated at the target station DCU and power box.

8. Cables from the MPBX heads will be routed through the outside of each previously installed block-out and will be connected to the DCU.

9. The CM will mark reference bearings and the target station horizontal datum on the outer formwork at the target station. The MSC will be responsible for installing all remaining fixtures and hardware required for instrument installation at the target station as shown on the Appendix B: target station Preparation drawings.

10. A strip of Tensar Geogrid (or equivalent) plastic mesh, which will support the instrument cables, will be installed around the entire shaft perimeter at the elevation shown on the Appendix B: Instrument Array Assembly drawings. The mesh will be mounted on the inside of the outer preliminary lining concrete formwork.

11. The MSC will install the compressible backfill and preliminary lining concrete to the bottom of the target station as shown on the Appendix B: Instrument Array Assembly drawings.

12. Embedded Vibrating Wire Strain Gages and Embedment Stress Cells will be tied between support bars previously installed by the MSC using the Embedded VWSG Installation and Monitoring Procedure (Golder Associates, 1987d) and the Embedment Stress Cell Installation and Monitoring Procedure (Golder Associates, 1987f), respectively.

13. Vibrating Wire Temperature Sensors will be installed using the Shaft Temperature Monitoring Procedure (Golder Associates, 1986g). All cabling will be securely fastened to the preinstalled mesh and routed to the ADAS junction box as shown in the Appendix B: Instrument Cable Routing drawings.

14. Instrumentation installation and termination of instrument cables, at the DCU, will proceed concurrently requiring the use of two galloway decks. Two ADAS electricians, working on the deck above the instrumentation crew, will terminate cables at each DCU using the Instrumentation Cabling Termination Procedure (Golder Associates, TBDa).

15. The block-outs over the extensometer head and around the target station DCU and power box will be sealed to the inner concrete form.

16. Surveys of the installed instrument positions and preinstallation checks will be carried out prior to concrete placement. UTC will monitor the placement of concrete around the instruments. At the same time instrument performance will be monitored through the ADAS.

17. When the concrete has cured and the formwork has been removed, the CM will re-mark the reference line and the location of instruments on the exposed concrete surface. Temporary convergence reference point recesses will be cut in the concrete at the reference horizon, reference points will be installed, and an initial set of convergence measurements will be made.

18. A set of convergence measurements will be made between opposite extensometer heads using the Manual Convergence Monitoring Procedure (Golder Associates, 1986d).

19. Embedded instrumentation and extensometers will be monitored remotely through the ADAS. Periodic measurement of shaft convergence will be made manually.

Type IIb Array - Non-Salt Strata Installation

Three arrays will be installed, using this procedure, at depths of approximately 1118, 1390, and 1950 ft (341, 424, and 594 m) in Shaft No. 1 and one array will be installed at a depth of 1950 ft (594 m) in Shaft No. 2. An additional Type IId array will be located at a depth of 1670 ft (509 m) in Shaft No. 1 and is described separately.

1. The MSC will complete excavation of the section incorporating the instrumentation array and will install the kerb ring at the bottom of the target station. The MSC and CM will respectively be responsible for installing all hardware indicated on the Target Station Preparation drawings, including installation of a block-out for the ADAS DCU and power box, and for marking bearing lines and the target station horizontal datum.

2. All activities associated with installation of ADAS equipment, including installation of conduit and routing of LAN and power cables from above, will be completed prior to instrument installation. Instrumentation will be transported from the surface and stored on the galloway during ADAS hardware installation.

3. A strip of Tensar Geogrid (or equivalent) plastic mesh, which will support the instrument cables, will be installed around the entire shaft perimeter at the elevation shown on the Appendix B: Instrument Array Assembly drawings.

4. Four sand-packed piezometers will be installed using the Piezometer Installation and Monitoring Procedure (Golder Associates 1986f). Two sets of Vibrating Wire Temperature Sensors will be installed using the Shaft Temperature Monitoring Procedure (Golder Associates, 1986g). Embedded VWSGs and Embedment Stress Cells will be installed using the Embedded VWSG Installation and Monitoring Procedure (Golder Associates, 1987d), and the Embedment Stress Cell Installation and Monitoring Procedure (Golder Associates, 1987f), respectively. Cables from all instruments will be routed to the target station DCU as shown on the Appendix B: Instrument Cable Routing drawings.

5. ADAS electricians will complete outfitting of the target station DCU and power box during instrumentation installation. Instrument cables will be terminated at the DCU using the Instrument Cable Termination Procedure (Golder Associates, TBDa).

6. Block-outs around the target station DCU and power box will be sealed to the inner concrete form.

7. Surveys of the installed instrument positions and pre-installation checks will be carried out prior to concrete placement. The UTC will monitor the placement of concrete around the instruments. At the same time, instrument performance will be monitored through the ADAS.

8. When the concrete has cured and the formwork has been removed, the CM will remark the reference line and the locations of the instruments on the exposed concrete surface. Permanent convergence reference point recesses will be cut in the concrete at the reference horizon, reference points will be installed, and an initial set of convergence measurements will be made using the Manual Convergence Monitoring Procedure (Golder Associates, 1986d).

9. Embedded instrumentation will be monitored remotely through the ADAS. Periodic measurement of shaft convergence will be made manually.

Instrument Installation, Type IId Array

One Type IId array will be installed at a depth of approximately 1670 ft (509 m) in Shaft No. 1.

1. The MSC will complete excavation of the section incorporating the instrumentation array and will install the kerb ring at the bottom of the target station. The MSC will be responsible for installing all hardware indicated on the Appendix B: target station Preparation drawings, including installation of a section of conduit from the 1390 ft (424 m) Type IIb array DCU. The CM will be responsible for marking and labeling bearing lines and the target station horizontal datum.

2. A strip of Tensar Geogrid (or equivalent) plastic mesh will be installed as described in Step 3 of the preceding Type IIb array installation procedure.

3. Four sand-packed piezometers will be installed (see Step 4 of preceding Type IIb array installation procedure). All cabling will be routed to the junction box above the 1390' (424 m) Type IIb array.

4. Surveying, preinstallation checks concrete placement, re-marking of reference lines, and instrumentation monitoring will be carried out using Steps 5 through 9 of the preceding Type IIb array installation procedure.

4.4.3.1.2.4 Lower foundation support ring and foundation. The lower foundation support ring and foundation will be constructed when excavation of the shafts has progressed to the required design elevation. The sequence of activities involved in instrumentation and ADAS extension is as follows:

Automatic Data Acquisition Systems (ADAS)

Foundation and foundation support ring instrumentation will be monitored by a DCU mounted on the shaft wall below the support ring. The DCU will be temporarily connected to the LAN installed in the preliminary lining during support ring and foundation construction and final lining in the lower shaft. After completion of the lower shaft final lining and upper shaft seal, data transmission will be via a LAN installed in the final lining. The installation and wiring method associated with this activity is described below and in the ADAS section of the final lining task sequence.

1. The MSC will sink the shaft to approximately 10 ft (3 m) below the base of the support ring, to provide room for the support ring DCU.

2. The MSC will install the kerb ring at the base of the support ring, will install the foundation/support ring DCU and power box, and will route nine conduits from the DCU upwards through the kerb ring.

   - Two conduits, terminated approximately 2 ft (0.6 m) above the kerb ring, will be used to service the support ring instrumentation.

   - One conduit, terminated flush with the top of the foundation squeeze plate, will service the foundation instrumentation.

   - Two conduits, terminated approximately 2 ft (0.6 m) above the final lining base plate, will service the Lower Shaft Seal instrumentation.

   - Two conduits will be routed into the upper shaft final lining to a small junction box located adjacent to the base of the preliminary lining. During final lining installation, LAN and power cables will be routed from the preliminary lining, through a water tight penetration in the outer steel lining, to the final lining junction box. Conduit will then be extended from the junction box up to the 2200 ft (671 m) DCU as shown on the Appendix B drawings and discussed in the final lining task sequence.

   - The two remaining conduits, which will serve the At-Depth LAN cables, will eventually be routed through the 1950-ft (594 m) level pull box to eventually connect up with conduits previously installed in the upper shaft final lining.

3. UTC electricians will complete outfitting of the DCU and power boxes ready for LAN and instrument cable termination. The MSC will route LAN and power cables from the preliminary lining as previously described.

Instrument Installation, Type 1a Array

1. The MSC will complete excavation of the shaft and preparation of the shaft walls ready for installation of the foundation support ring and foundation. Sufficient space must be provided, below the support ring, to permit installation of the foundation/support ring DCU.

2. The MSC will install the kerb ring at the base of the support ring and will route nine conduits from below the support ring, upward through the kerb ring, as previously discussed.

3. Instrument array reference bearings and a horizontal datum will be marked, by the CM, on the exposed rock surfaces. The MSC will install all hardware required for instrument installation at the support ring and foundation as shown on Appendix B: target station Preparation drawings.

4. Hand tools will be used to prepare the rock surface against which the embedment stress cells will be placed.

5. Four sand-packed piezometers will be installed at the location shown on the Appendix B: Instrument Array Assembly drawings using the Piezometer Installation and Monitoring Procedure (Golder Associates, 1986f).

6. Embedment stress cells will be installed in a specially constructed mudpack, using the Embedment Stress Cell Installation and Monitoring Procedure (Golder Associates, 1987f). Cables from the piezometers and stress cells will be coiled up and protected during installation of the support ring reinforcement.

7. Sections of rebar, containing pre-installed VWSGs, will be installed with the support ring reinforcement (see Rebar VWSG Installation and Monitoring Procedure, Golder Associates, TBDd) at the locations shown on the Appendix B: Instrument Array Assembly drawing.

8. Embedment stress cells will be installed between rebar sections, at the locations shown on the Appendix B: Instrument Array Installation drawing, using the Embedment Stress Cell Installation and Monitoring Procedure (Golder Associates, 1987f). Cables from all instruments will then be routed down to the foundation/support ring DCU (see Appendix B: Instrument Cable Routing drawings).

9. UTC ADAS electricians will complete instrument cable connection to the foundation/support ring DCU, using the Instrument Cable Termination Procedure (Golder Associates, TBDa).

10. Surveys of the installed instrument positions and pre-installation checks will be carried out prior to concrete placements. The UTC will monitor the placement of concrete around the instruments. At the same time, instrument performance during concrete placement will be monitored through the ADAS.

11. When the concrete has cured and the formwork has been removed, the CM will remark the reference lines and the locations of instruments on the exposed concrete surface. Convergence reference point recesses will be cut in the concrete at the reference horizon, reference points will be installed, and an initial set of convergence measurements will be made using the Manual Convergence Monitoring Procedure (Golder Associates, 1986d).

12. The MSC will complete any preparation required at the foundation location as shown on the Appendix B: target station Preparation drawings. Hand tools will be used to prepare the rock surface against which the embedment stress cells will be placed.

13. The specified location for the embedment stress cells to be installed in the 4-in (0.1 m) thick mud slab will be marked on the rock surface.

14. Embedment stress cells will be installed during placement of the mud slab using the Embedment Stress Cell Installation and Monitoring Procedure (Golder Associates, 1987f). Stress cells will be tied to short lengths of small gage rebar (approximately 3/8-in diameter), previously installed normal to the prepared rock surface. Cables from all instruments will be routed down to the support ring DCU where they will be terminated using the Instrument Cable Termination Procedure (Golder Associates, TBDa).

15. The MSC will complete assembly of the reinforcement, placement of concrete and installation of hardware ready for lower shaft seal construction. The UTC will monitor the placement of concrete around the instruments. At the same time, instrument performance during concrete placement will be monitored through the ADAS.

16. Jointmeters will be installed across the foundation squeeze plate, using the Jointmeter Installation and Monitoring Procedure (Golder Associates, 1987g), and cables will be routed to the foundation/support ring DCU.

17. Embedded instrumentation and surface-mounted jointmeters will be monitored through the ADAS. Periodic measurements of shaft convergence will be made manually.

4.4.3.1.2.5 Lower Shaft Seal. The lower shaft seal will be installed starting above the lower foundation at a distance of approximately 15 ft (5 m). Construction will involve: installation of an outer steel liner; sequential placement of sanded cement grout, chemical seal ring (CSR) material, and sanded cement grout behind the outer steel liner; and placement of inner, cast-in-place concrete and steel liners. The sequence of activities involved in instrumentation installation and ADAS extension is as follows:

Automatic Data Acquisition System (ADAS)

Lower shaft seal instrumentation will be monitored by the DCU located below the lower foundation support ring. The installation and wiring method associated with this activity is described below.

1. The MSC will route six conduits upwards from the final lining base plate, in conjunction with installation of the outer steel liner.

   - Two conduits will be terminated approximately 2 ft above the final lining base plate and will be used to service the lower seal instrumentation.

   - Two conduits will be routed to a small junction box adjacent the base of the preliminary lining. When the outer steel liner has been installed above this level, the LAN and power cables will be routed from the preliminary lining, through watertight fittings in the outer steel liner, to the final lining junction box. LAN and power cables will be routed down to the foundation/support ring DCU and then back up from the DCU into the final lining junction box.

- The two remaining conduits, which will serve the At-Depth LAN cables, will eventually be routed into the 1950-ft (594 m) level pull box.

2. After the UTC has completed installation of the jointmeters at the top of the steel liner, the MSC will route cables from instrumentation installed behind the steel liner in the CSR, through watertight penetrations, to the conduit previously extended from the foundation/support ring DCU.

3. The final lining instrumentation will be installed, each cable will be connected to the DCU hardware, and the instrumentation will be checked out and repaired as required. At this time the target station will be fully functional and data will be collected by the ADAS.

Instrumentation Installation, Type Ib Array

This sequence of activities covers the installation of instrumentation in the seal and in the final lining adjacent to the seal.

1. The MSC will complete installation of the outer steel section of the final lining and placement of the sanded cement grout column to the specified chemical seal bottom elevation. Instrumentation and associated hardware and equipment will be transported from the surface and stored on the galloway at convenient times during lining installation.

2. The CM and MSC will be respectively responsible for marking bearing lines and the target station horizontal datum and for installing all hardware indicated on the Appendix B: target station Preparation drawings.

3. The MSC will construct the final lining so that the outer steel section projects approximately 1 ft (0.3 m) above the marked instrumentation array elevation.

   [Special precautions may be required to protect the Vibrating Wire Strain Gages installed on the inside of the steel liner.]

4. Embedment stress cells will be installed behind the outer steel liner using the Embedment Stress Cell Installation and Monitoring Test Procedure (Golder Associates, 1987f). Jointmeters will be installed using the Jointmeter Installation and Monitoring Procedure (Golder Associates, 1987g).

5. The MSC will route cables from the instrumentation installed behind the outer steel liner, through watertight penetrations in the steel liner, ready for routing to the foundation/support ring DCU. The outer steel liner will be installed to an elevation about 30 ft (9 m) above the instrument array.

6. The CM and MSC will be respectively responsible for marking the instrument array reference bearing lines and horizontal datum on the inside of the outer steel liner and for installing all hardware indicated on the Appendix B: target station Preparation drawings. The MSC will be responsible for extending conduit upwards from the final lining base plate as previously described in the ADAS task sequence.

7. A strip of Tensar Geogrid (or equivalent) plastic mesh, which will support the instrument cables, will be attached to the inside of the outer steel liner at the elevation shown on the Appendix B: Instrument Array Assembly Installation drawings.

8. Embedded Vibrating Wire Strain Gages and Embedment Stress Cells will be installed using the Embedded VWSG Installation and Monitoring Procedure (Golder Associates, 1987d) and the Embedment Stress Cell Installation and Monitoring Procedure (Golder Associates, 1987f), respectively.

9. All cabling will be securely fastened to the plastic mesh and routed to the foundation/support ring DCU.

10. Instrumentation installation and termination of instrument leads at the DCU will proceed concurrently requiring the use of at least two galloway decks. The ADAS electricians will complete termination of instrument leads, prior to MSC installation of the inner steel/concrete liner, using the Instrument Cable Termination Procedure (Golder Associates, TBDa).

11. Surveys of the installed instrument positions, and pre-installation checks will be carried out prior to installing the inner steel liner past the instrument array.

12. The MSC will install the inner steel lining to the elevation shown on the Appendix B: Instrument Array Assembly Drawings. Cables for Vibrating Wire Strain Gages pre-installed on the outside of the inner steel liner will be routed and connected to the DCU.

13. The UTC will monitor the placement of concrete around the instruments. At the same time, instrument performance will be monitored through the ADAS.

14. After the MSC has installed the final lining to the base of the preliminary lining, convergence reference points will be welded to the inside of the inner steel lining and a preliminary set of convergence measurements will be made using the Manual Convergence Monitoring Procedure (Golder Associates, 1986d).

15. The MSC will place the CSR material and upper sanded cement grout. At the same time, the UTC will monitor instrument performance through the ADAS.

16. Embedded instrumentation will be monitored remotely through the ADAS. Periodic measurements of shaft closure will be made manually.

4.4.3.1.2.6 Final lining in the lower shaft. This lining will be constructed upwards from approximately 15 ft (5 m) above the lower foundation to the base of the upper shaft seal zone located approximately 15 ft (5 m) below the upper foundation support ring. The lining will be constructed using a outer steel/concrete/inner steel composite lining from the lower foundation to the 1700 ft (518 m) level. Above the 1700 ft (518 m) level, the lining will consist of an outer steel membrane and an inner concrete liner only. A nominal 4-in thick (100 mm) grout layer will be placed between the preliminary and final linings throughout the lower shaft.

The plan for the final lining is to collect data using the DCUs previously installed in the preliminary lining. The DCUs will initially be connected to the ADAS through a temporary LAN routed through the preliminary lining and foundation. When the final lining is completed, this temporary LAN will be abandoned, the conduit sealed, and new, permanent LAN cables will be installed. The sequence of activities involved in instrument installation and ADAS extension is as follows:

Automatic Data Acquisition System (ADAS)

The installation and wiring method in the final lining in the lower shaft consists of the following steps:

1. Four 3.5-in (89-mm)-diameter conduits will be installed in the lining by the MSC starting at the upper foundation and continuing upwards in conjunction with the lining construction between target stations.

   - Two conduits extended from the foundation/support ring DCU will be routed into a small junction box located opposite the base of the preliminary lining on the inside of the outer steel liner. LAN and power cables will be routed from the preliminary lining, through watertight penetrations in the steel liner, to the final lining junction box. These penetrations will eventually be decommissioned when the LAN and power cables in the final lining are completed.

   - Two conduits servicing the At-Depth LAN cables will be installed on the opposite side of the shaft wall to the Shaft LAN and power conduits, as shown on the Appendix B drawings.

   All four conduits will be extended as part of the normal final lining construction process until a target station is reached.

2. At each target station in the final lining, the UTC ADAS electricians will disconnect preliminary lining instrumentation from the DCU installed in the preliminary lining and will remove the hardware from inside the DCU and power box.

3. The MSC will remove the DCU and power box from the preliminary lining and will install two small junction boxes which will house the temporary LAN and power cable connections, which are required in the preliminary lining prior to final lining completion.

4. The MSC will advance the outer steel liner to just below the top of the block-out in the preliminary lining. The MSC will route individual preliminary lining instrument leads, and cables from jointmeters installed outside of the liner, through watertight penetrations pre-installed in the outer steel liner, ready for connection to the final lining DCU. An 18-in (0.5-m) diameter steel pipe will be inserted through holes pre-installed in the outer, and below 1700 ft, inner steel liner and will be grouted into the preliminary lining around each extensometer head. The outside of the pipe will then be welded to the outer steel liner. A removable, steel cover plate will be installed over the open end of the pipe. This steel block-out will protect the extensometer head during grout placement and will provide a means for access to the extensometer head after final lining completion.

   [Note: Details of the final lining penetrations associated with routing instrument cables and providing access to extensometers, including description and dimensions of the steel pipe noted above, are conceptual and must be designed by the ESF A/E.]

5. The MSC will advance the final lining so that the outer steel liner extends approximately 30 ft (10 m) past the target station and the inner steel and concrete lining is completed to the location shown on the Appendix B: Target Station Preparation drawings.

6. At each target station, the MSC will provide a block-out for either a DCU and power box or a pull box and will install either the DCU and power box removed from the preliminary lining or a new pull box. The MSC will then extend conduit from this block-out upwards towards the next target station and downwards to connect up with the conduit routed from below.

7. Shaft LAN and power cables will be pulled from the target station below. These cables will be connected to previously installed cables at the lower target station. If necessary, a temporary work platform will have to be installed to gain access to the lower target station in order to carry out pulling of cables.

8. UTC ADAS electricians will install DCU and power supply equipment in the DCU and power boxes, respectively. At the same time, the final lining instruments will be installed and preliminary and final lining instrument cables will be routed into the DCU box through short conduit sections, which will be sealed prior to placing concrete.

9. Each cable will be connected to the DCU, and the instrument will be checked out and repaired as required. At this time, the target station will be fully functional and data will be collected by the ADAS.

10. In the case of target stations above 1700-ft (518-m), forms will then be erected, and the ADAS and MPBX block-outs will be sealed to the form. For target stations below the 1700-ft (518-m) level, ADAS and MPBX block-outs will be sealed or welded to reinforced windows provided in the inner steel liner prior to concrete placement. The concrete will then be placed.

Upon completion of the final lining construction, the shaft LAN and power cables exiting from the final lining conduits will be routed to the upper foundation/support ring DCU, and will replace those connected to the preliminary lining. When the galloway returns to the junction box above the lower foundation, the shaft LAN and power cables from the preliminary lining will be disconnected and the penetrations will be sealed. The preliminary lining conduits and junction boxes will then be filled with moisture-proof sealant to block water migration.

In both shafts, the ADF LAN cables will be pulled through the vacant conduits in the final lining in conjunction with the movement of the galloway from the upper foundation to the lower foundation.

Instrumentation Installation, Type IIb Array

This sequence of activities covers the installation of the instruments comprising the Type IIb arrays during construction of the final lining in the lower shaft. Six arrays will be installed using this procedure at depths of 1118, 1210, 1390, 1800, 1950, and 2200 ft (341, 369, 424, 549, 594, and 671 m) in Shaft No. 1, and two arrays will be installed at depths of 1950 and 2200 ft (594 and 671 m) in Shaft No. 2.

1. The MSC will complete installation of the final lining to just below the target station as shown on the Appendix B: target station Preparation drawings. A final set of preliminary lining convergence measurements will be made between recessed convergence points and, in salt sections, between adjacent extensometer heads. Instrumentation and associated installation hardware and equipment will be transported from the surface and stored on the galloway at convenient times during lining installation.

2. The MSC will extend the outer steel liner to approximately 1 ft (0.3 m) above the instrument array reference line previously marked on the preliminary lining concrete. Jointmeters will be installed using the Jointmeter Installation and Monitoring Procedure (Golder Associates, 1987g).

3. The MSC will complete relocation of the target station DCU, including steps 2 thru 7 of the preceding ADAS installation sequence, and will install all hardware shown on the Appendix B: target station Preparation drawings. Instrumentation will be transported from the surface and stored on the galloway during DCU relocation.

4. UTC ADAS electricians will complete outfitting of the DCU and power boxes prior to or during instrument installation.

5. A strip of Tensar Geogrid (or equivalent) plastic mesh, which will support the instrument cables, will be installed around the entire shaft perimeter at the elevation shown on the Appendix B: Instrument Array Assembly drawings.

6. Cables for Vibrating Wire Strain Gages, pre-installed on the inside of the outer steel liner at the locations shown on Appendix B: Instrument Array Assembly drawings, will be routed to the DCU, as shown on the Appendix B: Instrument Cable Routing drawings.

7. Vibrating Wire Temperature Sensors (VWTSs) will be installed using the Shaft Temperature Monitoring Procedure (Golder Associates, 1986g). Embedded VWSGs and Embedment Stress Cells will be suspended from re-bar sections installed by the MSC in accordance with the Embedded VWSG Installation and Monitoring Procedure (Golder Associates, 1987d) and the Embedment Stress Cell Installation and Monitoring Procedure (Golder Associates, 1987f), respectively. All cabling will be securely fastened to the pre-installed mesh and routed to the DCU.

8. Instrumentation installation and termination of instrument leads at the DCU will proceed concurrently requiring the use of at least two galloway decks. The ADAS electricians will complete termination of instrument leads and closure of the DCU using the Instrumentation Cable Termination Procedure (Golder Associates, TBDa) and the shaft DCU completion Procedure (Golder Associates, TBDb).

9. Surveys of the installed instrument positions and pre-installation checks will be carried out.

10. The MSC will then install the concrete formwork or the inner steel liner. Cables for Vibrating Wire Strain Gages preinstalled on the outside of the inner steel liner at the locations shown on the Appendix B: Instrument Array Assembly drawings, will be fitted and routed to the DCU.

11. Above the 1700 ft (518 m) elevation, the ADAS and extensometer block-outs will be sealed against the concrete formwork. Below the 1700 ft (518 m) elevation, ADAS and MPBX block-outs will be sealed or welded to reinforced windows provided in the inner steel liner prior to concrete placement.

12. The UTC will monitor the placement of concrete around the instruments. At the same time, instrument performance will be monitored through the ADAS.

13. Below 1700 ft (518 m), the CM will remark the reference line and the locations of the instruments on the surface of the inner steel liner and the MSC will weld convergence reference points onto the liner at the locations shown on the Appendix B: Instrument Array Assembly drawings.

14. In the case of the shaft section above 1700 ft (518 m), when the concrete has cured and the formwork has been removed, the CM will remark the reference line and the locations of instruments on the exposed concrete surface. Permanent convergence reference point recesses will be cut in the concrete at the reference horizon, reference points will be installed, and an initial set of convergence measurements will be made using the Manual Convergence Monitoring Procedure (Golder Associates, 1986d).

15. Embedded instrumentation will be monitored remotely through the ADAS. Periodic measurements of shaft convergence will be made manually.

4.4.3.1.2.7 Upper shaft seal. The upper shaft seal will be installed between the top of the preliminary lining in the lower shaft and the bottom of the upper foundation. Construction will involve: installation of an outer steel liner; sequential placement of sanded cement grout, CSR material, and sanded cement grout behind the outer steel liner; and placement of an inner cast-in-place concrete liner. The sequence of activities involved in instrumentation and ADAS extension is as follows:

Automatic Data Acquisition System (ADAS)

Upper shaft seal instrumentation will be monitored by the upper foundation/support ring DCU. The installation and wiring method associated with this activity is described below.

1. The MSC will disconnect the LAN and power cables at the junction box below the upper foundation/support ring DCU and will remove the conduit routed from the junction box to the top of the lower shaft preliminary lining. The LAN and power cables will be removed from the temporary lining conduit and the conduit will be sealed. A temporary connection, incorporating "quick disconnects", will then be installed between the LAN and power cables exiting the final lining and the upper foundation/support ring DCU and power box. This temporary connection may be broken during the seal construction cycle if required.

2. The MSC will route four conduits upwards from the top of the final lining, in conjunction with seal construction.

   - One conduit will be routed into the upper foundation support ring DCU.

   - One conduit will be routed into the foundation/support ring power box.

   - The two remaining conduits will be connected to the At-Depth LAN conduits located beneath the upper foundation support ring.

3. After the UTC has completed installation of the jointmeters at the top of the seal section, the MSC will route cables from instrumentation installed behind the steel liner in the CSR, through watertight penetrations, to the upper foundation/support ring DCU. The instrumentation will be checked out and repaired as required.

4. LAN and power cables will be pulled from the DCU and power box below the upper seal and routed to the upper foundation/support ring DCU and power box.

5. The final lining instrumentation will be installed. Each cable will be connected to the DCU, and the instrumentation will be checked out and repaired as required. At this time, the target station will be fully functional and data will be collected by the ADAS.

6. Following seal construction and final lining placement up to the base of the upper foundation support ring, the galloway will be moved to the bottom of the shaft. The shaft LAN and power cables from the preliminary lining in the base of the lower shaft will be disconnected and the penetrations will be sealed. The preliminary lining conduits and junction boxes will then be sealed with moisture-proof sealant to block water migration.

7. In both shafts, the ADF LAN cables will be pulled through the conduits installed in the final lining in conjunction with the movement of the galloway from the upper foundation to the shaft bottom.

Instrumentation Installation, Type Ib Array

This sequence of activities covers the installation of instrumentation in the seal and in the final lining adjacent to the seal.

1. A final set of convergence measurements will be made, at the seal location, using the Manual Convergence Monitoring Procedure (Golder Associates, 1986d).

2. The MSC will complete the ADAS preparations as described in Step 1 of the ADAS task sequence.

3. The MSC will complete installation of the outer steel section of the final lining and placement of the sanded cement grout column to the specified Chemical Seal bottom elevation. Instrumentation and associated hardware and equipment will be transported from the surface and stored on the galloway at convenient times during lining installation.

4. The CM and MSC will be respectively responsible for marking bearing lines and the target station horizontal datum and for installing all hardware indicated on the Appendix B: target station Preparation drawings.

5. The MSC will construct the final lining so that the outer steel section projects approximately 1 ft (0.3 m) above the marked instrumentation array elevation.

   [Special precautions may be required to protect the Vibrating Wire Strain Gages installed on the inside of the steel liner.]

6. Embedment stress cells will be installed behind the outer steel liner using the Embedment Stress Cell Installation and Monitoring Procedure (Golder Associates 1987f). Jointmeters will be installed using the Jointmeter Installation and Monitoring Procedure (Golder Associates, 1987g).

7. The MSC will route cables from the instrumentation installed behind the outer steel liner, through watertight penetrations in the steel liner ready for routing to the foundation/support ring DCU, and will complete the outer steel liner.

8. The CM will be responsible for marking the instrument array reference bearing lines and horizontal datum on the inside of the outer steel liner. The MSC will be responsible for installing all hardware indicated on the Appendix B: target station Preparation drawings and for extending conduit upwards from the final lining as previously described in the ADAS task sequence.

9. A strip of Tensar Geogrid (or equivalent) plastic mesh, which will support the instrument cables, will be attached to the inside of the outer steel liner at the elevation shown on the Appendix B: Instrument Array Assembly drawings.

10. Embedded Vibrating Wire Strain Gages and Embedment Stress Cells will be installed using the Embedded VWSG Installation and Monitoring Procedure (Golder Associates, 1987d and the Embedment Stress Cell Installation and Monitoring Procedure (Golder Associates, 1987f), respectively.

11. All cabling will be securely fastened to the plastic mesh and routed to the foundation/support ring DCU.

12. Instrumentation installation and termination of instrument leads at the DCU will proceed concurrently requiring the use of at least two galloway decks. The ADAS electricians will complete termination of instrument leads, prior to MSC installation of the inner concrete liner, using the Instrument Cable Termination Procedure (Golder Associates, TBDa).

13. Surveys of the installed instrument positions and pre-installation checks will be carried out prior to final lining past the instrument array.

14. The UTC will monitor the placement of concrete around the instruments. At the same time, instrument performance will be monitored through the ADAS.

15. The MSC will place the CSR material and upper sanded cement grout. At the same time, the UTC will monitor instrument performance through the ADAS.

16. After the MSC has installed the final lining to the base of the upper foundation support ring, convergence reference point recesses will be cut in the concrete, reference points will be installed, and a preliminary set of convergence measurements will be made using the Manual Convergence Monitoring Procedure (Golder Associates, 1986d).

17. Embedded instrumentation will be monitored remotely through the ADAS. Periodic measurements of shaft convergence will be made manually.

4.4.3.1.2.8 Unlined shaft section. The construction sequence in the unlined shaft section will involve sinking, using rock bolts and wire mesh for ground support, to a depth of approximately 2475 ft (755 m), construction of the shaft station breakout, sinking to the required shaft bottom design elevation, and placement of the shaft bottom plug. Two non-mechanical response monitoring test activities will be conducted intermittent with shaft construction.

1. Large-diameter (12-in (300 mm)) core samples (see Section 4.5.4) will be retrieved from two locations during shaft sinking:

   - In the LSA4, from 2445-2470 ft (745 to 753 m)
   - In the LSA4, from 2470-2495 ft (753 to 760 m)

2. Rock bolt pullout tests (see Section 4.7.2) will be carried out on a representative number of production bolts installed by the MSC.

The sequence of activities involved in mechanical response monitoring instrumentation installation and ADAS extension is as follows:

Automatic Data Acquisition System

Two DCUs will service instrumentation in the unlined shaft section. The uppermost DCU, installed immediately beneath the lower foundation support ring during support ring construction, will be used to service the Type IIc array located 20 ft (6 m) below the support ring. The other DCU will be located approximately 70 ft (21 m) below the base of the support ring and will be used to service the remaining instrumentation installed during shaft construction. The installation and wiring method associated with this activity is described below.

1. The MSC will install four conduits in the unlined shaft as part of the shaft sinking cycle.

   - Two conduits will be extended from the lower foundation/support ring DCU and power box and will be terminated at the DCU and power box located at the 2440-ft level.

   - The remaining two conduits, which will house the At-Depth LAN cables, will be terminated at a junction box adjacent to the shaft station located at an approximate depth of 2470 ft (753 m).

2. The 2440-ft (744 m) level DCU and power box will be installed and outfitted during installation of the Type IIc Array at the 2445-ft (745 m) level. A prefabricated enclosure, containing the DCU and power box, will be installed on the shaft wall using short bolts grouted into the shaft wall. Cables from instruments installed below the DCU will be routed, via conduits, to the DCU concurrent with instrumentation installation activities. Extension of the At-Depth LAN and power cable conduits, and installation of the junction box at the 2470-ft (753 m) level, will be undertaken as part of the normal shaft sinking cycle.

LAN and power cables will eventually be routed to Trailer DCUs T1 and T2 located in the At-Depth Facility (ADF). This connection will ensure continuous monitoring of shaft instrumentation should a break occur in the LAN installed in the shaft.

Instrumentation Installation, Type IIc Array

This sequence of activities covers the installation of Type IIc arrays in the lower, unlined section of the ESF shafts. Three Type IIc instrumentation arrays will be installed at depths of 2390, 2445, and 2495 ft (729, 745, and 761 m) in each shaft.

1. The MSC will complete excavation of the section incorporating the instrumentation array, to the depth shown on the Appendix B: target station Preparation drawings.

2. Instrument array reference bearing lines and a horizontal datum will be marked, by the CM, on the exposed rock surface. The MSC will mobilize all test equipment and UTC personnel from the surface to the shaft bottom.

3. Four equispaced N-sized boreholes will be drilled normal to the rock surface at the locations shown on the Appendix B: Instrument Array Assembly drawings. Multiple Position Borehole Extensometers (MPBXs) will be installed in each of the boreholes using the MPBX Installation and Monitoring Procedure (Golder Associates, 1986e). The extensometer head will be recessed into the shaft wall and covered with a steel plate for protection. Convergence reference points will be installed on the shaft wall at the locations shown on the Appendix B: Instrument Array Assembly drawings, and a preliminary set of convergence measurements will be made using the Manual Convergence Monitoring Procedure (Golder Associates, 1986d). Cables from the extensometer heads will be routed to the 2380 ft (726 m) level DCU. All other cabling will be routed to the 2440 ft (744 m) level DCU.

Rock Bolt Monitoring

The mechanical response of eight rock bolts located in each shaft, and ten rock bolts in each shaft station, will be monitored using the following procedure:

1. Specially fabricated, hollow rock bolts, containing externally mounted strain gages, will be installed by the MSC using the same bolting pattern and techniques used for normal production bolting.

2. The UTC will install a load cell between two steel plates at the head of each test bolt. Cables from each test bolt installation will be routed by the MSC to the lowermost DCU and will be connected to the ADAS. The instrumentation will be checked out through the ADAS and repaired as required.

3. The MSC will tighten the nut at the end of the test bolt to the designed torque setting.

Shaft Station Instrumentation Installation, Type A Array

This sequence of activities covers the installation of Type A mechanical response monitoring arrays in the shaft stations. One Type A array will be installed in each shaft station at the location shown on the Appendix B drawings.

1. The MSC will excavate and support the shaft station breakout to a depth of approximately 25 ft (8 m). Test bolts will be installed as part of the normal production bolting cycle and will be instrumented using the procedure presented above.

2. Four N-sized boreholes will be drilled normal to the rock surfaces at the locations shown on the Appendix B: Instrument Array Assembly drawings. Multiple Position Borehole Extensometers (MPBXs) will be installed in each of the boreholes using the MPBX Installation and Monitoring Procedure (Golder Associates, 1986e).

The extensometer head will be recessed into the salt strata and covered with a steel plate for protection. Convergence reference points will be installed at the locations shown on the Appendix B: Instrument Array Assembly drawings, and a preliminary set of convergence measurements will be made using the Manual Convergence Monitoring Procedure (Golder Associates, 1986d). Cables from the extensometer heads will be routed to the 2440-ft (744 m) level DCU. UTC ADAS electricians will terminate instrument cables at the DCU using the Instrumentation Termination Procedure (Golder Associates, TBDa).

3. The MSC will complete excavation of the shaft station breakout, and will sink the shaft to the final design depth. One Type IIc array will be installed 20 ft (6 m) below the shaft station, as previously discussed.

Shaft Bottom Plug Instrumentation Installation, Type Id Array

A 17-ft (5-m) thick concrete plug will be installed at the bottom of each shaft. The sequence of activities involved in the installation of a Type Id array in each shaft bottom plug is as follows:

1. The MSC will complete shaft sinking to the specified shaft bottom elevation, including installation of any required ground support and conduit. The CM will be responsible for marking the instrument array reference bearing and a horizontal datum on the exposed shaft walls. The MSC will be responsible for installing all hardware required for instrumentation installation, as shown on the Appendix B: target station Preparation drawings.

2. Hand tools will be used to prepare the rock surfaces ready for piezometer and embedment stress cell installation.

3. Six sand-packed piezometers will be installed at the locations shown on the Appendix B: Instrument Array Assembly drawings using the Piezometer Installation and Monitoring Procedure (Golder Associates, 1986f).

4. Embedment stress cells and Embedded VWSGs will be installed, at the locations shown on the Appendix B: Instrument Array Assembly drawings, using the Embedment Stress Cell Installation and Monitoring Procedure (Golder Associates, 1987f) and the Embedded VWSG Installation and Monitoring Procedure (Golder Associates, 1987d), respectively. Cables from all instruments will then be routed to the 2440-ft (744 m) level DCU, as shown on the Appendix B: Instrument Cable Routing drawings.

5. Installation of instrumentation and termination of instrument cables will proceed concurrently, requiring access to both the shaft bottom and the 2440-ft (744 m) level. UTC ADAS electricians will terminate instrument cables at the DCU using the Instrumentation Cable Termination Procedure (Golder Associates, TBDa).

6. Surveys of installed instrument positions and pre-installation checks will be carried out prior to concrete placement. The UTC will monitor the placement of concrete around the instruments. At the same time, instrument performance will be monitored through the ADAS.

4.4.3.2 Integration with Shaft Sinking and Lining Operations

This section presents an estimate of the time required for ADAS hardware and instrumentation installation at each of the target stations, based on the task sequence previously described. These estimates are integrated, with schedule estimates for other shaft testing and monitoring activities, in Chapter 6.0, Schedule and Milestones.

No estimate has been prepared for installing conduit as part of the shaft sinking activities. It is anticipated that this estimate will be prepared by the CM based on the requirements contained in this Draft Shaft Study Plan. Mechanical response monitoring array installation times have been estimated assuming that:

1. One 8-hour shift will be required to set up the ADAS hardware (either a junction box, DCU and power box, or a pull box), including conduit extensions as noted in the task sequence, and to pull wires between installed boxes during preliminary lining construction and final lining in the upper shaft. An additional six hours will be required during final lining in the lower shaft for removal of DCU and power boxes and for extending preliminary lining instrument cables through the outer steel liner.

2. Two hours will be required to mobilize instrumentation to proposed array locations. Four additional hours will be required to mobilize drilling equipment to the shaft bottom ready for extensometer borehole drilling.

3. The time required to complete target station preparation, prior to instrumentation installation, has been incorporated in the individual instrument installation times, which have been estimated as follows:

   - Eight shift hours to install and check out each extensometer, and four shift hours to install the extensometer block-out during final lining placement.

   - Four shift hours to install eight convergence studs and take a preliminary set of measurements.

   - An average of one shift hour to install and check out vibrating wire temperature detectors (prefabricated string of 3 to 4 VWTSs installed in the concrete liners), embedded and welded VWSGs, embedded stress cells (including stress cells installed in the bitumen layer), rock bolt load cells, and sand-packed piezometers where access is unrestricted. An average of 1.5

shift hours has been assigned when installing these instruments behind steel liners (e.g., during final lining construction).

- An average of four shift hours to install and check out a string of three to five vibrating wire temperature sensors in the frozen shaft wall.

- An average of 1.5 shift hours to install and check out one jointmeter.

One shift hour involves two crews, each consisting of two trained technicians, working for one hour.

4. Two ADAS technicians will be terminating instrument leads at previously established junction or DCU boxes while instruments are being installed. An additional eight-hour shift will be required to complete this activity following the completion of instrumentation installation at Type Ia, Ib, IIa, and IIb arrays. An additional four shift hours will be required to complete this activity following the completion of instrumentation installation at Type A, Id, IIc, and IId arrays.

5. After completion of lining past the target station, four hours will be required for re-marking reference lines, completion and check-out of ADAS junction box or DCU, and demobilizing UTC personnel. At Type IId arrays, demobilization time is estimated at two hours.

6. In the unlined section, six hours will be required to complete surveys of installed instruments and demobilize test personnel and drilling equipment.

7. Contingencies corresponding to 50 percent and 30 percent have been respectively assigned to installations in the upper and lower shafts.

The estimated duration of mechanical response monitoring activities is summarized in Tables 4-4 and 4-5 for each array and each shaft. These estimates are used, in conjunction with schedule estimates for other shaft testing activities, to develop the overall shaft schedule in Chapter 6.0.

Table 4-4. Mechanical Response Monitoring Array Installation Schedule - Shaft No. 1

Section	Liner	Instrum. Array Type	Target Station Depth	ADAS Setup (hrs)	Mobe (hrs)	Install Instrum. (hrs)	ADAS Comp. (hrs)	Demobe (hrs)	Contin-gent (hrs)	TOTAL (hrs)	TOTAL (days)	MPBX	Conv Ref Pts	Embed VWSG	Weld VWSG	Embed Stress Cell	Bitmn Press Cells	Rock Bolt L.C.	Joint-meter	VWTS	Piezos
				ESTIMATED DURATION OF ACTIVITY								INSTRUMENT QUANTITIES									
UPPER SHAFT	PRELIM LINER	IIa	335 ft	8	2	29	8	4	26	77	3.2		8	8		8				14	4
		IId	345 ft		2	4	4	4	7	21	0.9										4
		IIa	745 ft	8	2	29	8	4	26	77	3.2		8	8		8				14	4
		IIa	960 ft	8	2	37	8	4	30	89	3.7		8	12		12				14	4
		Ia	1050 ft	8	2	66	8	4	44	132	5.5		16		24	24			4		4
	FINAL LINER	IIa	960 ft	8	2	51	8	4	36	109	4.5		8	12	8	8	2		9	10	
		IIa	745 ft	8	2	51	8	4	36	109	4.5		8	12	8	8	2		9	10	
		Pull Box	500 ft	8	2	0	0	2	6	18	0.8										
		IIa	335 ft	8	2	51	8	4	36	109	4.5		8	12	8	8	2		9	10	
			TOTAL UPPER SHAFT	64	8	317	60	34	246	739	30.8	0	64	64	48	76	6	0	31	72	20
LOWER SHAFT		Ib	1060 ft		2	4		2	2	10	0.4		8								
	PRELIM LINER	IIb	1118 ft	8	2	26	8	4	14	62	2.6		8	8		8				6	4
		IIb	1210 ft	8	6	60	8	6	26	114	4.8	4	12	8		8				6	4
		IIb	1390 ft	8	2	26	8	4	14	62	2.6		8	8		8				6	4
		IId	1670 ft		2	4	4	2	4	16	0.7										4
		IIb	1800 ft	8	6	60	8	6	26	114	4.8	4	12	8		8				6	4
		IIb	1950 ft	8	2	26	8	4	14	62	2.6		8	8		8				6	4
		IIb	2200 ft	8	6	68	8	6	29	125	5.2	4	12	12		12				6	4
		Ia	2360 ft	8	2	66	8	4	26	114	4.8		16		24	24			4		4
		Ib	2350 ft	8	2	51	8	4	22	94	3.9		8	8	8	12			9		
	FINAL LINER	IIb	2200 ft	14	2	69	8	4	29	126	5.3		8	12	16	8			6	10	
		IIb	1950 ft	14	2	36	8	4	19	83	3.5		8	8	8	4				10	
		IIb	1800 ft	14	2	45	8	4	22	95	4.0		8	8	8	4			6	10	
		Pull Box	1500 ft	8	2	0	0	2	6	18	0.8										
		IIb	1390 ft	14	2	22	8	4	15	65	2.7		8	8	4	4				10	
		IIb	1210 ft	14	2	31	8	4	18	77	3.2		8	8	4	4			6	10	
		IIb	1118 ft	14	2	22	8	4	15	65	2.7		8	8	4	4				10	
		Ib	1060 ft	8	2	48	8	4	21	90	3.8		8	8	4	12			9		
	UNLINED SHAFT	IIc	2390 ft		6	36	4	6	16	68	2.8	4	8								
		IIc	2445 ft	8	6	44	4	6	20	88	3.7	4	8					8			
		Type A	2475 ft		6	46	4	6	19	81	3.4	4	8					10			
		IIc	2495 ft		6	36	4	6	16	68	2.8	4	8								
		Id	2555 ft		2	22	4	4	10	42	1.7			8		8					6
			TOTAL LOWER SHAFT	172	74	847	144	100	404	1740	72.6	28	180	128	80	136	0	18	40	96	38
			TOTAL	236	92	1164	204	134	650	2479	103.4	28	244	192	128	212	6	18	71	168	58

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Table 4-5. Mechanical Response Monitoring Array Installation Schedule - Shaft No. 2

Shaft	Liner	Instrum. Array Type	Target Station Depth	ESTIMATED DURATION OF ACTIVITY: ADAS Setup (hrs)	Mobe (hrs)	Install Instrum. (hrs)	ADAS Comp. (hrs)	Demobe (hrs)	Contin-gent (hrs)	TOTAL (hrs)	TOTAL (days)	INSTRUMENT QUANTITIES: MPBX	Conv Ref Pts	Embed VWSG	Weld VWSG	Embed Stress Cell	Bitmn Press Cells	Rock Bolt L.C.	Joint-meter	VWTS	Piezos
UPPER SHAFT	PRELIM LINER	IId	335 ft	8	2	4	4	4	11	33	1.4										4
		IId	345 ft		2	4	4	4	7	21	0.9										4
		IIa	960 ft	8	2	37	8	4	30	89	3.7		8	12		12				14	4
		Ia	~1050 ft	8	2	66	8	4	44	132	5.5		16		24	24			4		4
	FINAL LINER	IIa	960 ft	8	2	51	8	4	36	109	4.5		8	12	8	8	2		9	10	
		PULL BOX	500 ft	8	2	0		2	6	18	0.8										
			TOTAL UPPER SHAFT	40	12	162	32	22	134	402	16.8	0	32	24	32	44	2	0	13	24	16
LOWER SHAFT	PRELIM LINER	Ib	~1060 ft		2	4		2	2	10	0.4		8								
		PULLBOX	1500 ft	8	2	0		2	4	16	0.7										
		IIb	1950 ft	8	2	26	8	4	14	62	2.6		8	8		8				6	4
		IIb	2200 ft	8	2	105	8	4	27	117	4.9	4	12	12		12				6	4
	FINAL LINER	Ia	~2360 ft	8	2	66	8	4	26	114	4.8		16		24	24			4		4
		Ib	~2350 ft		2	51	8	4	19	84	3.5		8	8	8	12			9		
		IIb	2200 ft	14	6	69	8	4	30	131	5.5		8	12	16	8			6	10	
		IIb	1950 ft	14	2	36	8	4	19	83	3.5		8	8	8	4				10	
		PULL BOX	1500 ft	8	2	0		2	4	16	0.7										
		Ib	~1060 ft	8	2	48	8	4	21	90	3.8		8	8	4	12			9		
	UNLINED SHAFT	IIc	2390 ft		6	36	4	6	16	68	2.8	4	8								
		IIc	2445 ft	8	6	44	4	6	20	88	3.7	4	8					8			
		Type A	2475 ft		6	46	4	6	19	81	3.4	4	8					10			
		IIc	2495 ft		6	36	4	6	16	68	2.8	4	8								
		Id	2555 ft		2	22	4	4	10	42	1.7			8		8					6
			TOTAL LOWER SHAFT	84	50	551	76	62	247	1070	44.6	20	108	64	60	88	0	18	28	32	18
			TOTAL	124	62	713	108	84	381	1472	61.4	20	140	88	92	132	2	18	41	56	56

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4.5 MECHANICAL/THERMAL PROPERTIES STUDY

Characterization of the mechanical and thermal properties of the strata overlying the candidate repository horizon will be undertaken primarily through laboratory testing of core samples recovered from the surface-based drilling program. Information of this type is required for both shaft design and for thermomechanical performance modeling of the response of the repository block to the thermal loading imposed by the emplaced waste. Construction of the exploratory shafts will provide the opportunity for in situ mechanical/thermal property evaluations to complement the information developed from surface-based and laboratory testing. The methods to be applied to this study include absolute stress measurements within the specific non-salt strata which are candidate repository decommissioning seal horizons, borehole deformation modulus testing of the same strata, small strain deformation modulus testing of the stratigraphic sequence overlying the repository horizon through seismic wave velocity determinations within each stratum, large-diameter core recovery in specific horizons for special laboratory mechanical property testing, and thermal conductivity testing of critical strata in the near vicinity of the repository horizon.

4.5.1 Absolute Stress Measurement - Overcoring

4.5.1.1 Rationale

The virgin state of stress is a fundamental boundary condition for thermomechanical analyses of the repository system, including the site response to excavation and thermal loading. It is therefore important to define the initial undisturbed stress state at the site for both salt and non-salt strata. Evaluation of the state of stress within salt strata is relatively complex and will be undertaken within the At-Depth Facility. The exploratory shafts will provide access for in situ stress determinations in representative non-salt strata overlying the repository horizon. The undisturbed in situ stress in representative non-salt strata at the site will assist in understanding the general character of the site virgin stress conditions by complementing those measured or inferred in the salt materials.

The effects of shaft excavation on the surrounding rock, including the nature of the associated stress redistributions, are particularly important to the design of seals which will be placed in the shafts during decommissioning. Absolute stress measurements at the candidate non-salt horizons for decommissioning seals will therefore be used to define both the stress redistributions caused by shaft sinking (near field) and the virgin stress state (far field) within these strata.

4.5.1.2 Method

Absolute stress measurements will be performed using the U.S. Bureau of Mines Borehole Deformation Gage (BDG) to measure the change in three diameters of a small borehole as it is stress-relieved by overcoring. Elastic theory is employed to relate the measured displacements to the pre-existing stress at the measurement location. The BDG will be used because it is rugged, reusable, relatively quick and easy to use, and has a substantial and well-proven track record. The absolute stress measurements will be performed in accordance with USBM Borehole Deformation Gage Absolute Stress Measurement Test Procedure (Golder Associates, 1986j).

A 6-in (0.15-m) -diameter hole will be drilled into the rock mass to approximately 10 in (0.25 m) from the proposed test location. A small-diameter (1.5 in (0.037 m)) smooth-walled corehole will then be drilled coaxially approximately 24 in (0.6 m) further into the rock mass. The cleaned hole will then be inspected for discontinuities or unwanted depressions and a suitable test location identified. The BDG, which measures the change of hole diameter in three equally spaced directions normal to the hole axis, will be inserted into the hole so that the measurement plane is about 10 in (0.25 m) from the small hole collar. The orientation of the gage in the hole will be measured. The larger hole will then be drilled concentrically to the same depth as the smaller hole using a thin-walled core barrel, relieving the stresses within the resulting annulus of rock. The resulting change of shape and size of the smaller hole is measured by the BDG.

Elastic theory will be used to calculate the in situ stresses from the measured deformations. The magnitude of Young's Modulus for the material, which is necessary for this calculation, will be determined by testing the annulus of rock, immediately after recovery from the drillhole, in a standard field biaxial testing apparatus. The procedure and equipment for the biaxial test are also described in USBM Borehole Deformation Gage Absolute Stress Measurement Procedure (Golder Associates, 1986j). Determinations of the value of Poisson's Ratio for the rock will be performed in a separate laboratory test.

The number of measurements made in a single borehole are insufficient to determine the three-dimensional stress tensor, which requires test data from three non-parallel boreholes in the same rock formation. The deepest measurement location in each hole will be about 55 ft (16.8 m) from the shaft wall so that the error in the calculated virgin stress state due to the influence of the excavation is expected to be less than a few percent. The planned hole directions, inclinations, and measurement depths are summarized in Table 4-6. The overcore test cycle will be repeated at approximately 10 intervals along each borehole in order to characterize the distribution of stress around the excavation.

The duration of the absolute stress measurement program at each candidate non-salt decommissioning seal location has been estimated as follows:

- Approximately one eight hour shift will be required to mobilize equipment to each test location (i.e., elevation in the shaft)
- Each overcore test cycle (i.e., drill to the next measurement depth and test) will require one eight-hour shift

Table 4-6. Absolute Stress Measurement (Overcoring) Borehole Specifications and Measurement Intervals

Host Strata	Hole Number	Collar[b] Depth Below Surface, ft (m)	Bearing[a]	Inclination Upward	Final Hole Depth, ft (m)
Salado	1	1110 (340)	60°	4°	55 (16.8)
	2	1110 (340)	0°	4°	55 (16.8)
	3	1110 (340)	-60°	4°	55 (16.8)
Queen/Grayburg	1	1600 (490)	60°	4°	55 (16.8)
	2	1600 (490)	0°	4°	55 (16.8)
	3	1600 (490)	-60°	4°	55 (16.8)
Upper San Andres	1	2150 (660)	60°	4°	55 (16.8)
	2	2150 (660)	0°	4°	55 (16.8)
	3	2150 (660)	-60°	4°	55 (16.8)

[a] Bearing is referenced to the line connecting the centers of the two shafts, with 0° for each shaft in the direction away from the other shaft.

[b] Depths are provisional and must be confirmed based on detailed analysis of the Synthetic Data Base core log and discussions with the Seal Designer. Ultimately, depths will be based on the EDBH core log.

Measurement Intervals. In each hole, one test will be typically performed in each of the following intervals (distances measured from the rock/concrete interface). These depths are a guide only; final test locations will be determined in the field, based on inspection of the small diameter core.

Test 1	0.4 ft - 1.7 ft	(0.1 m - 0.5 m)
Test 2	1.7 ft - 4 ft	(0.5 m - 1.2 m)
Test 3	4 ft - 7 ft	(1.2 m - 2.1 m)
Test 4	7 ft - 10 ft	(2.1 m - 3.1 m)
Test 5	10 ft - 18 ft	(3.1 m - 5.5 m)
Test 6	18 ft - 26 ft	(5.5 m - 7.9 m)
Test 7	26 ft - 34 ft	(7.9 m - 10.4 m)
Test 8	34 ft - 42 ft	(10.4 m - 12.8 m)
Test 9	42 ft - 50 ft	(12.8 m - 15.2 m)
Test 10	53 ft - 55 ft	(16.2 m - 16.8 m)

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- Approximately one shift will be required to grout the three completed boreholes at each elevation

- Approximately one shift will be required to demobilize or move to the next test location.

It is therefore estimated that approximately 32 days will be required to perform the complete stress measurement program at the three locations within the shaft.

The instrumentation and equipment are described in detail in the procedure for this test. The Construction Manager will be required to provide access to the test location, and possibly a work platform (see Section 4.5.6) sufficient to accommodate drilling equipment, stress measurement equipment, drilling and test personnel, and recovered rock core. Further test support requirements are summarized in Section 4.8.

4.5.2 Deformation Moduli Testing - NX Borehole Jack Testing

4.5.2.1 Rationale

The deformational properties of the repository block rock mass constitute basic input to thermomechanical analyses of the repository system. The complex time-dependent behavior of the salt materials will be evaluated by laboratory testing and borehole closure monitoring within the candidate host horizon. The effects of non-salt interbeds, including low strength argillaceous seams, will be studied by observing the deformational response of the ESF openings, which will also be used to validate the independently derived salt material models. The deformational properties of the non-salt materials will be evaluated/inferred by a combination of methods which include both rock material testing and rock quality assessments for empirically incorporating the effects of geologic structure on rock mass deformability. Rock material properties will be studied by laboratory testing, and this database will be complemented by a limited program of in situ borehole-scale deformation testing in specific non-salt strata.

The deformational properties of the candidate non-salt strata for shaft decommissioning seals are of importance to seal design. Borehole deformation testing, using a directional borehole jack, will therefore be performed in these strata, at the same locations previously noted for absolute stress measurements.

4.5.2.2 Method

The borehole jacking test is used to estimate in situ deformation moduli appropriate to a scale on the order of borehole size by applying a directional loading to the walls of the borehole, measuring the resulting deformations, and using elastic theory to interpret/reduce the data. The test is relatively easy and rapid to perform, and will be performed in accordance with NX Borehole Jack Procedure (Golder Associates, 1986k).

Jacking tests will be performed in N-sized (3-in (76-mm)-diameter) boreholes, diamond-drilled with a double-tube core barrel to obtain continuous core. To ensure correct contact between the loading platens of the jack and the wall of the borehole, the allowable deviation of the borehole diameter from the nominal value of 3.000 in (76.20 mm) is limited to a few thousandths of an inch; consequently, a reaming shell mounted behind the bit will be used during drilling. The borehole will be washed clean of drill cuttings.

The borehole jack consists of two curved steel platens, which are expanded outward against opposing 90^{0} sectors of the borehole wall by hydraulic pistons. This arrangement applies a directional loading which allows the anisotropy of deformation modulus to be evaluated by changing the orientation of the jack. During the tests, pressure will be applied with a hand-operated pump and will be measured using a Bourdon pressure gage and electrical pressure transducer mounted on the pump manifold. The change in borehole diameter will be measured by two LVDTs located in the jack itself which sense the separation between the loading platens.

The jack will be placed at the desired depth and orientation using flush-coupled casing with orientation marks transferred from section to section. Following hydraulic pump and readout equipment connection, a small pressure will be applied to the jack to seat the platens firmly against the borehole wall. The pressure will then be raised incrementally to either the maximum jack capacity (10,000 psi (70 MPa)) or, in soft and/or low strength rock, to a predetermined value. At each increment, borehole deformation will be measured. The maximum pressure will be held constant for a period of time to provide a qualitative indication of any time-dependent rock behavior (i.e., creep). The pressure will then be decreased, with borehole deformation measured as before. Several loading cycles will be performed to evaluate the degree of any permanent rock deformation. When the test is completed, the platens will be retracted and the jack will be rotated 90^{o}. The same testing sequence will then be performed in this new orientation. Following completion of this second test, the jack will be moved along the borehole to the next test location, and the entire process repeated.

The planned hole directions, inclination, and measurement depths for each test location are summarized in Table 4-7. The tests will be performed in each of two holes at each test location, with five to seven tests performed in each 30-ft (9.2-m) hole.

It is estimated that three days will be required at each of the three test station locations to complete the above program. The test holes will be subsequently be reamed to H size (3.91-in- (99-mm-) diameter) and used for hydrological testing of the construction-affected zone at the candidate decommissioning seal locations.

The instrumentation and equipment are described in detail in the test procedure. The Construction Manager will be required to provide access to the test location, and possibly a work platform (see Section 4.5.6) sufficient to accommodate drilling equipment, test equipment, drilling and test personnel, and recovered rock core. Further test support requirements are summarized in Section 4.8.

Table 4-7. Borehole Deformation Testing Hole Specifications

Host Strata	Hole Number	Collar[b] Depth Below Surface, ft (m)	Bearing[a]	Inclination Upward	Hole Depth, ft (m)
Salado	1	1110 (340)	10°	4°	30 (9.2)
	2	1110 (340)	100°	4°	30 (9.2)
Queen/Grayburg	1	1600 (490)	10°	4°	30 (9.2)
	2	1600 (490)	100°	4°	30 (9.2)
Upper San Andres	1	2150 (660)	10°	4°	30 (9.2)
	2	2150 (660)	100°	4°	30 (9.2)

[a] Bearing is referenced to the line connecting the centers of the two shafts, with 0° for each shaft in the direction array from the other shaft.

[b] Depths are provisional and must be confirmed based on detailed analysis of the Synthetic Data Base core log and discussions with the Seal Designers. Ultimately, depths will be based on the EDBH core log.

Measurement Intervals. Borehole jacking tests will be conducted at 4 to 6 ft (1.2 to 1.8 m) intervals along the length of the hole. Exact test locations will be determined in the field, based on inspection of recovered core.

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4.5.3 Shaft Seismic Velocity Survey

4.5.3.1 Rationale

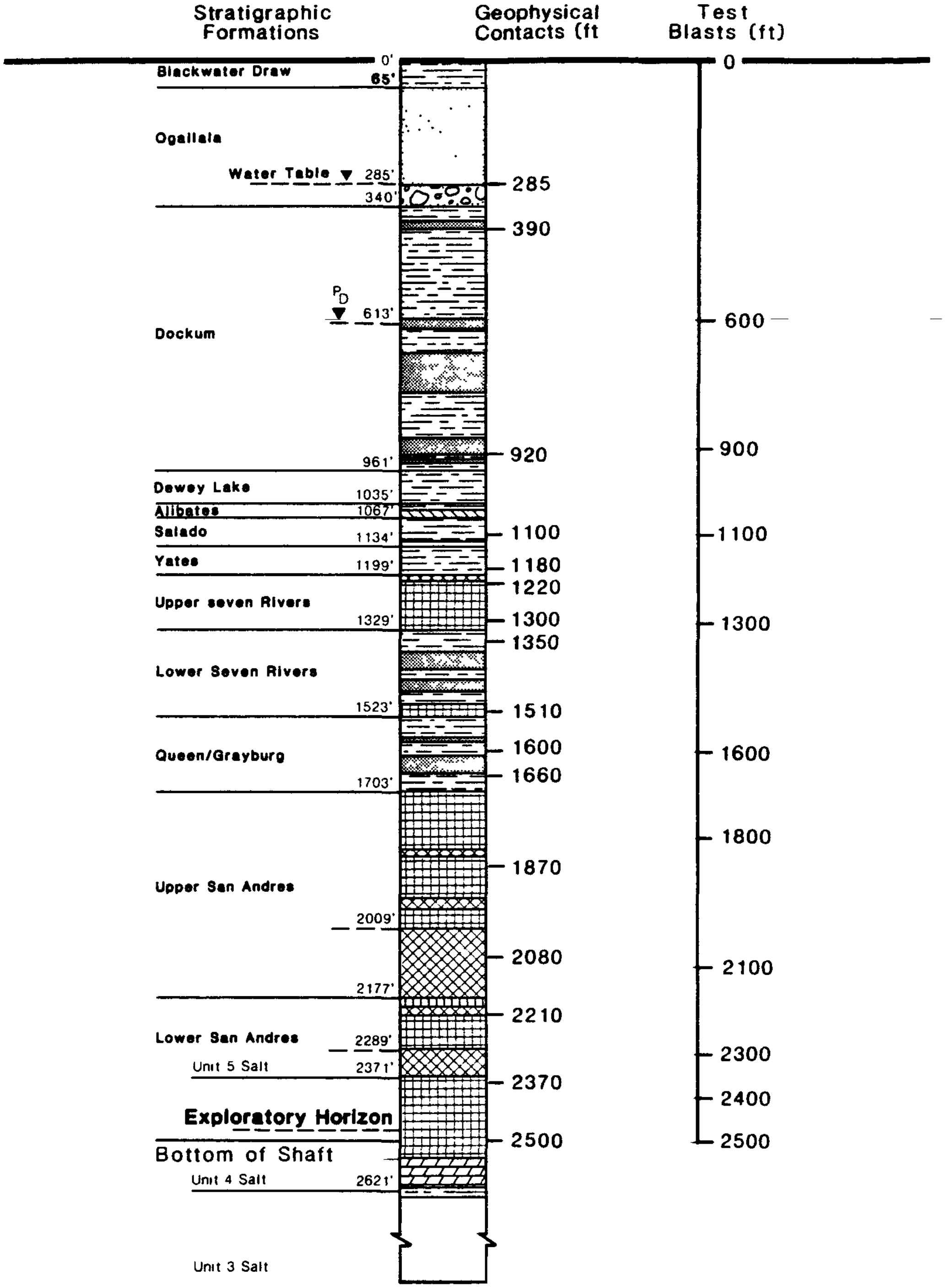
During shaft sinking, the construction blast vibration levels will be monitored to ensure that structural and instrumentation vibration limits are not exceeded. A secondary use of the construction blast energy and shaft seismometers will be the measurement of seismic velocities for each of the major stratigraphic units overlying the repository horizon. This information will complement seismic velocities determined from borehole logging and borehole seismic surveys (e.g., Vertical Seismic Profiling) performed as part of the surface-based site characterization program. Seismic velocity data will be used to define engineering properties of the rocks overlying the repository horizon, and particularly the small strain deformation modulus values. This information will form part of the overall database required to define the deformability properties of the rock mass. As noted previously (section 4.5.2.1), the rock mass deformability properties constitute basic input required for thermomechanical analyses of the repository system.

Construction blasts will permit the determination of compression wave velocities only. At specified intervals during shaft construction, test blasts consisting of single shots will be detonated in order to enable identification of shear and secondary wave forms. These test blasts may also enable an evaluation of seismic wave attenuation characteristics for input to seismic design analyses.

4.5.3.2 Method

Seismic velocities in each of the major stratigraphic units will be calculated from travel time measurements of the first arrival compression wave at each three-component seismometer of a strategically located seismometer string in each shaft. Where single-shot test blasts are employed, first arrival shear waves and seismic wave attenuation characteristics may also be determined. The test is essentially a by-product of blast vibration monitoring during shaft construction and will be performed in accordance with Shaft Blast Vibration Monitoring Procedure (Golder Associates, 1986l).

A string of nine seismometers will be used in each shaft to monitor the construction blasts. All seismometers will be connected to the same seismograph recording system so that they will be on the same time base for accurate travel time determinations. The two lowermost seismometers will be positioned relatively close to the blast for vibration monitoring. The remaining seven seismometers will be positioned at or adjacent to stratigraphic or geophysical contacts identified from shaft mapping and the EDBH. These contacts are identified in Figure 4-16, which also shows the proposed locations for the single-shot test blasts.



Generalized Stratigraphic Column
at the Deaf Smith County Site

Sources: Modified from ONWI (1986)

Seismometer Monitoring Locations, Stratigraphical and Geological Contacts, and Test Blast Locations

Figure 4-16

The individual seismometers will be fastened to the shaft lining by cast-in-place brackets and connected to the seismograph recording system with a shielded seismic conductor cable. The seismometer locations will be adjusted on about a weekly basis, depending on specific conditions and the rate of shaft advance.

The instrumentation and equipment, together with the required range and accuracy of the individual measurements, are described in detail in the test procedure. The Construction Manager will be required to cast the seismometer brackets in the shaft lining and string the shielded seismic conductor cable during construction as discussed in Section 4.8.

4.5.4 Large-Diameter Core Sampling

4.5.4.1 Rationale

As part of site characterization activities, an extensive rock mechanics laboratory testing program will be conducted. This work will characterize the physical, hydrologic, mechanical, thermal, and other properties of both salt and non-salt rock types at the Deaf Smith site. This information is basic input to repository design, performance assessment, model validation, interpretation of results from large-scale in situ tests, and other major aspects of site evaluation. A detailed description of this program is presented in the Preliminary Rock Mechanics Laboratory Investigation Plan (ONWI, 1987a). Most testing will be performed on 4-in- (102-mm-) diameter core samples from the EDBHs, as well as stratigraphic and hydrologic boreholes that are part of the Surface Based Test Program. However, in certain instances, larger samples are necessary to overcome the limitations, inherent in conventional-size samples, on measuring scale-dependent properties. The Rock Mechanics Plan has identified (1) direct shear testing of discontinuities encountered in the shaft, (2) triaxial compression testing of 4-in- (102-mm-) diameter cores drilled from large diameter cores, (3) large-scale creep tests, and (4) hydrofracturing studies as instances where larger samples are required.

4.5.4.2 Method

Large-diameter (12-in (305-mm)) core will be obtained by drilling from the bottom of the shaft using a single tube thin-walled core barrel about 5 ft (1.5 m) long with a diamond or tungsten carbide bit, depending on the type of rock being drilled. In salt and mudstones susceptible to swelling, air will be used to cool the bit and remove cuttings; this approach will minimize sample disturbance. In dolomites and limestones, water may be used as the circulation fluid to allow faster drilling and eliminate the dust problem. Core will be removed using a lifting tool similar to the core barrel, but with inward-pointing teeth, a lifter spring, or some other mechanism at the lower end to grab and hold the core. Drilling activities will be supervised in accordance with Drilling Supervision Procedure for the Exploratory Shaft Facility (Golder Associates, 1986h).

When large-diameter core sampling is required, the bottom of the shaft will be excavated to 6 ft (1.8 m) above the start of the core run; this is necessary because blast-damaged rock immediately below the shaft bottom is too disturbed to provide useful results. Although normal shaft excavation may involve benching, it will be necessary to have the shaft bottom at a single elevation for this activity. When mucking is completed, the drill will be lowered to the shaft bottom and bolted firmly into the rock. The first 6 ft (1.8 m) will be drilled and the core discarded. The next 20 ft (6.1 m) of core will be recovered for laboratory testing, in runs about 4 ft (1.2 m) long. If the core breaks in the barrel, shorter runs may be required. When the core is removed from the lifting tool, it will be logged, marked with identification and elevation information, wrapped in foil or plastic, coated with paraffin, boxed, and transported to the surface for storage. When the entire 20 ft (6.1 m) of core has been recovered, the drill and associated equipment will be demobilized.

Large-diameter core samples will be obtained in both shafts at the locations of the construction seals and above and below the candidate repository horizon. The Rock Mechanics Plan requires 12-in (305 mm) diameter core drilled vertically from the shaft bottom to obtain suitably sized samples in the orientation of interest. A total of approximately 200 ft (61 M) of this large diameter core will be required, 100 ft (30 m) in each shaft. Equal footages of both salt and non-salt strata will be sampled. Depths and rock types are summarized in Table 4-8; this information is based on the synthetic stratigraphic column for the site, and exact locations for each sampling run will be determined from EDBH data.

The duration of large-diameter core drilling and sampling has been estimated (Stafford, 1986) on the basis of one shift each for mobilizing and demobilizing equipment, and an average drilling rate of about 10 ft (3 m) per shift. Suitable derating factors have been applied. Using these assumption, approximately six days will be required in each shaft for Large Diameter Core Sampling.

The Construction Manager will be required to provide a relatively smooth, level shaft bottom as discussed above, together with transportation for equipment and recovered core to and from the shaft bottom. Further test support requirements are discussed in Section 4.8.

4.5.5 Thermal Conductivity Testing

4.5.5.1 Rationale

The distribution and anisotropy of thermal conductivity is required, in conjunction with specific heat, virgin rock temperatures, and thermal inputs, to predict the transient temperature distributions associated with waste emplacement in the repository. The thermal characteristics of the site materials are important to a wide range of repository design and performance issues. At the repository scale, the thermal characteristics of the materials above and below the repository horizon will influence the rate of transfer of heat from the disposal horizon and, hence, for a given thermal loading, control the temperatures developed. This information is important

Table 4-8. Locations For Large Diameter Core Sampling

Location	Formation	Rock Type	Depth, ft (m)[a]
Upper Construction Seal	Alibates	Siltstone/ Dolomite	1035-1065[b] (316-325)
Lower Construction Seal	Lower San Andres Unit 5	Anhydrite/ Salt	2350-2370 (716-723)
Repository Horizon Overlying Zone	Lower San Andres Unit 4	Salt	2445-2470[b] (745-753)
Repository Horizon Underlying Zone	Lower San Andres Unit 4	Salt	2470-2495[b] (753-760)

[a] Based on synthetic stratigraphic column; exact locations to be determined from EDBH data.

[b] May require two drill rig set ups, with some shaft excavation in between.

Note: These locations will be sampled in each shaft.

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to issues such as the rate of closure of backfilled rooms and consolidation of emplaced fill, and the nature and magnitude of deformation of the overlying strata (e.g., surface heave, ground cracking). The lower thermal conductivities of non-salt strata in the relatively near vicinity of the repository level will be of particular significance.

Thermal properties of the site materials will be evaluated by extensive laboratory testing. Thermal conductivity testing in situ is required to provide comparative values for the laboratory data obtained from possibly disturbed samples. The exploratory shafts provide the opportunity for accessing critical strata above the repository horizon and performing in situ thermal conductivity tests to complement the laboratory-determined information.

4.5.5.2 Method

Thermal conductivity values will be measured in situ using a borehole thermal probe. A constant power level is supplied to the probe, which is in close thermal contact with the surrounding rock, and the thermal conductivity of the rock is inferred from the transient thermal response of the probe. Conductive heat transfer is assumed. The method is a relatively inexpensive and rapid in situ test and tests a volume of material which is typically larger than that tested in the laboratory. The test will be performed in accordance with Thermal Conductivity Test Procedure (Golder Associates, 1986m).

Thermal probe tests will be performed in E-sized (1.5 in. (38 mm) diameter) holes drilled with a double-tube core barrel to obtain continuous core. It is essential to characterize the homogeneity and potential anisotropy of the tested zone in order to ensure meaningful reduction of the data. The probe will be inserted into the hole at the required measurement location, constant power will be applied to the probe, and the temperature rise will be monitored. The rate of temperature rise in the probe is related to the thermal conductivity of the surrounding rock, i.e., more highly conductive rock will transfer heat from the probe more quickly and lower the rate of temperature rise. Following test completion, the probe will be moved to the next measurement location.

The planned hole directions, inclinations, and measurement depths for each test location are summarized in Table 4-9. The tests will be performed in two holes at each test location, with five tests performed in each 50-ft (15.2-m) hole. The test horizons identified in Table 4-9 are representative non-salt strata of the Lower San Andres 5 formation. Because of their low thermal conductivity relative to the salt units, and their relatively close proximity to the repository horizon, these strata are of principal concern. Test boreholes will be essentially horizontal in order to investigate thermal conductivity in the vertical direction, as this will be the major direction of heat flow away from the repository, due to its very large lateral extent and relative thickness. It is recognized that bedded, sedimentary strata may have different vertical and horizontal thermal conductivities, and that the measured thermal conductivities will be a composite of these values. The degree of anisotropy will be investigated in the laboratory, and the in situ

Table 4-9. Thermal Conductivity Testing Borehole Specifications

Host Strata	Rock Type	Hole Number	Collar Depth Below Surface,[a] ft (m)	Bearing[b]	Inclination Upward	Hole Depth, ft (m)
Lower San Andres	Dolomite	1	2272 (693)	0°	4°	50 (15.2)
	Dolomite	2	2272 (693)	90°	4°	50 (15.2)
	Anhydrite	3	2285 (697)	0°	4°	50 (15.2)
	Anhydrite	4	2285 (697)	90°	4°	50 (15.2)
	Anhydrite (c)	5	2342 (714)	0°	4°	50 (15.2)
	Anhydrite (c)	6	2342 (714)	90°	4°	50 (15.2)

(a) Exact depths to be determined from EDBH data.

(b) Bearing is referenced to the line connecting the centers of the two shafts, with 0° for each shaft in the direction away from the other shaft.

(c) Stratum is internally inhomogeneous (e.g., containing significant amounts of mudstone). Other strata of the same rock type are internally homogeneous.

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measurements corrected if necessary, on the basis of these results. The minimum stratum thickness that can be tested will be determined by detailed numerical analysis or laboratory testing, but is estimated at this time to be on the order of 6 in (150 mm).

It is estimated that four days will be required for testing at each test location (i.e., for two boreholes at the same elevation in the shaft). This estimate includes three shifts for drilling the boreholes and nine shifts for testing at a rate of just over one test per shift.

The instrumentation and equipment are described in detail in the test procedure. The Construction Manager will be required to provide access to the test location, and possibly a work platform (see section 4.5.6) sufficient to accommodate drilling equipment, test equipment, and drilling and test personnel. Further test support requirements are summarized in Section 4.8.

4.5.6 Integration with Construction Activities

The Seismic Velocity Study will be performed during shaft sinking in order to utilize the construction blasts as seismic wave sources. Large-Diameter Core Sampling will also be performed during shaft construction in order to most conveniently obtain samples in the required orientation. The other mechanical/thermal properties tests can be performed at any time during or after shaft construction without affecting the results. However, it is desirable to perform these tests on the shaft bottom, "in line" with construction, rather than from platforms installed in the shafts after final lining is complete, for the following reasons:

1. A larger working area is available, 20-ft (6.1 m) -diameter versus 12-ft (3.7 m) -diameter less allowance for ventilation and outfitting, allowing greater efficiency in drilling and testing.

2. No penetrations through the final liner will be required.

3. Data will be available earlier.

4. Shaft support crews and utilities will be readily available.

5. No special platforms will be required.

6. Working conditions will be significantly safer.

It is recognized that testing in line with shaft construction places these activities on the critical path and potentially introduces contractual complications. Should budget and/or schedule considerations preclude this approach, the ESF A/E and Construction Manager will need to provide suitable penetrations through the final liner at all borehole locations.

At the present time, it is assumed that all mechanical/thermal properties testing will be performed in Shaft No. 1 (the intake air shaft), with the exception of large-diameter core sampling, which will be conducted in both shafts. This assumption is based on the desire to complete Shaft No. 2 first and allow ADF excavation to begin.

4.6 SHAFT SEAL STUDY

During the operational life of the exploratory and repository shafts, there are requirements for limiting ground-water inflow to the shafts and controlling ground-water movements in the potentially disturbed zone adjacent to the shafts. The exploratory and repository shaft designs will address these issues with a combination of watertight shaft liners through potentially water-bearing ground and shaft operational seals at strategic locations. Since the exploratory shafts will be constructed through the same strata as any future repository shafts and will be designed using similar methodologies, monitoring of the performance of the exploratory shafts in controlling ground-water ingress and migration will confirm both the exploratory shaft design and construction implementation, and the repository shaft design methodology. The shaft seals installed at the Ogallala/Dockum contact will be monitored by permanently installed piezometer arrays as described in Section 4.4. The methods to be applied for evaluating the operational performance of the exploratory shafts include ground-water inflow monitoring in the shafts, and a program of testing and monitoring at each of the installed chemical seals within the Permian strata. This operational seal program will include permeability testing and piezometric monitoring.

At decommissioning, permanent seals will be placed at strategic locations within the repository shafts. These locations are likely to include both salt and non-salt strata, and a total of six candidate decommissioning seal locations have been identified. An important element of these seals is the character and extent of the zone of disturbance of the rock surrounding the engineered seal. Similarly, the hydrochemical environment of the seal is important for evaluating the long-term chemical interactions between the engineered seal materials and the host environment.

The Mechanical Response Monitoring program will provide deformation data which will aid in characterizing the construction-affected zone at salt-decommissioning seal locations. No hydrologic testing will be performed in salt because the salt is expected to creep substantially prior to decommissioning making testing at the ESF stage unrepresentative of probable conditions at decommissioning. A program of hydrologic testing and monitoring will therefore be performed at non-salt decommissioning seal locations. This decommissioning seal construction-affected zone program will include permeability testing, piezometric monitoring, and formation fluid sampling.

4.6.1 Ground-Water Inflow Monitoring

4.6.1.1 Rationale

Ground-water inflow measurements during construction of the exploratory shafts will be used to evaluate potential problems during repository shaft construction and to characterize the efficacy of the shaft sinking method in controlling ground-water ingress. Following exploratory shaft construction, ground-water inflow monitoring will be used to verify that design specifications have been met. These have been tentatively specified as (ONWI, 1986b):

- No inflow in the upper 1100-ft shaft section, i.e., through the Ogallala/Dockum aquifer sequence
- A maximum of 0.3 gpm (58 ft^3/day) in the lower shaft section with no point source to exceed 0.1 gpm (19 ft^3/day). These allowances do not include moisture due to condensation.

Estimates of inflow rates from each formation are provided in the Synthetic Geotechnical Design Data Base (ONWI, 1986a) and reproduced in Table 4-10. The reference does not indicate the method by which these values were derived; however they are believed to be derived from numerical model simulations of 'instantaneous' shaft emplacement in the ambient hydrologic regime. Quoted values represent total inflows from the full unlined thickness of each formation, and may therefore differ substantially from actual flow rates, as only short sections of the shaft will be unlined at any one time.

4.6.1.2 Method

Ground-water inflow may occur in any section of the shaft which does not have a watertight lining on either a temporary or a permanent basis. Substantial inflow rates may be expected while penetrating the Lower Seven Rivers and the Queen/Grayburg formations, where instantaneous inflow rates (after one day) are estimated to be 1566 and 344 ft^3/d, respectively, for the total thicknesses of these formations. The Engineering Design Boreholes may further indicate the potential for ground-water inflow, although probe-holes drilled in advance of the shaft bottom will provide a more direct, advance indication of high-flow zones.

Point inflow monitoring will be carried out where a visible inflow or seepage is observed, using the Ground-Water Inflow Monitoring Procedure (Golder Associates, TBDe). Initial measurements will be taken during geologic mapping of the shaft walls. These measurements will be made manually, using a graduated cylinder and stopwatch, together with auxiliary equipment needed to contain or channel the inflow. Subsequently, point inflow measurements at locations which have no watertight lining on either a temporary or permanent basis will be periodically performed. Inflow monitoring of this type will have a negligible impact on shaft construction or facility operations, although access to relevant sections of the shaft walls will be required for inspection and, where necessary, monitoring.

Table 4-10. Estimated Shaft Inflow Rates[a]

Formation[b]	Instantaneous Flow[c] (ft^3/d)	Steady-State Flow[d] (ft^3/d)
Dewey Lake	2.1	0.34
Alibates	160.0	49.0
Salado	2.9	0.32
Yates	4.1	0.36
Upper Seven Rivers	12.5	1.4
Lower Seven Rivers	1566.0	446.0
Queen/Grayburg	344.0	84.0
Upper San Andres (U)	240.0	57.5
Upper San Andres (L)	36.3	4.87
Lower San Andres 5 (U)	35.2	4.65
Lower San Andres 5 (L)	19.3	2.6
Lower San Andres 4 (U)	63.1	11.0
Lower San Andres 4 (L)	3.2	4.4

Source: Synthetic Geotechnical Design Reference Data, ONWI (1986(a)).

[a] Inflow to 20 ft diameter shaft, presumably over total thickness of each formation.

[b] Letters U and L indicate Upper and Lower sections of these formations, as defined in the Synthetic Geotechnical Design Data Base (ONWI, 1986a).

[c] Flow after each formation is open for one day.

[d] Figures quoted are for "Grid 1" (Grid 1 is not defined in source document).

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Inflows from preliminary lined shaft sections will be monitored manually while access is available, using suitable containment and measuring equipment (e.g., plastic sheeting, caulking, graduated containers, stopwatch). Substantial inflows requiring diversion works (e.g., weep pipes) will be fitted with automatic flow-monitoring devices (e.g., tipping-bucket flowmeters) to permit long-term monitoring.

During construction, it is possible that total inflows could be sufficiently large that they could be estimated from sump pumping rates. If so, this information will be collected as part of the construction monitoring record. Following construction, the design specification will require such low inflows that estimates of the total rate of water ingress to the shafts will require explicit consideration of the moisture balance in the shaft ventilation air. This information will be collected as part of the ESF environmental monitoring program.

Short-term inflow monitoring will be scheduled within the shaft excavation and lining cycle in conjunction with other testing activities (e.g., geologic mapping, mechanical response monitoring, etc.) and will have a negligible impact on the shaft construction schedule. Monitoring ground-water inflow from weep pipes or other similar devices installed to collect flow during construction will also be integrated with the construction activity and will have a minor impact on the shaft schedule.

4.6.2 Shaft Operational Seal Testing

4.6.2.1 Rationale

Shaft operational seals will be installed to separate the major shallow aquifer system from the underlying relatively impermeable Permian strata, and to isolate those sections of the shaft which are fitted with a watertight lining. In addition, operational seals will be installed to prevent cross-aquifer flow within and between the Ogallala and Dockum by using bitumen windows in the primary liner (Parsons Brinckerhoff/PB-KBB, 1986a). The effectiveness of these seals will be assessed by piezometer arrays installed above and below each bitumen window, as described in Section 4.4. There will be no additional testing associated with the bitumen window seals.

Performance testing of the two chemical shaft operational seals will be undertaken to measure the effectiveness of these seals in controlling vertical migration of ground water behind the watertight lining (i.e., check the efficacy of the seal design), and to evaluate the hydrologic integrity of the rock which immediately surrounds the seal. The seal testing program will utilize permeability testing of the seal/rock interface and of the adjacent rock to provide a direct measure of the effectiveness of the seal zone, and long-term piezometric monitoring above and below the seal to measure hydraulic gradients across the seal. Testing of operational seals is planned for shaft No. 1 only.

4.6.2.2 Method

The shaft operational seal testing program will be performed on an array of six H-sized boreholes cored to a depth of approximately 40 ft (12.5 m) into the shaft walls, as shown in Figures 4-17 and 4-18 for the upper and lower seals, respectively. The layout incorporates two sets of three equispaced radial boreholes, with one set above the seal and the other below. Test boreholes will be drilled during shaft construction, either from the shaft bottom during excavation or from the galloway during seal construction. Final lining penetrations will be "built" into the shaft liners to provide access to the test holes following completion of construction activities.

As the drilling of each borehole is completed, a temporary packered piezometer installation will be installed in the hole, in accordance with the Piezometer Installation and Monitoring Procedure (Golder Associates, 1986d). The installation will comprise three measurement intervals separated from each other by inflatable packers as shown in Figures 4-17 and 4-18. If formation fluids do not fill the borehole, synthetic formation fluid chemically compatible with the local pore fluids will be pumped into the borehole as part of piezometer installation. Instrument cables from the four pressure transducers (including one for monitoring packer inflation pressure) and temperature sensors will be connected to the nearest DCU soon after installation. The development of pressure in each response zone will be monitored through the ADAS system until access to borehole locations for permeability testing is scheduled.

Permeability tests will be carried out after completion of the connecting drift between the two shafts, and possibly after completion of At-Depth Facility (ADF) construction. Immediately prior to permeability testing, the ADAS cabling will be disconnected and temporarily removed. The temporary packered piezometer installation will be removed from the borehole and replaced by a guarded straddle packer testing string. Zones isolated by the guarded straddle packer assembly will be tested using the Single Borehole Permeability Procedure (Golder Associates, 1987h). The first zone to be tested will be the deepest 16 ft (5 m) of the borehole. The packers will be inflated at the required depth, and the pressure in the test interval and guard zones will be allowed to rise back towards the ambient levels recorded prior to removal of the temporary packered piezometers. Pressure and temperature transducers will be monitored by a data logger.

Piezometer removal and test string placement will be repeated in the two remaining boreholes at the test level, as described above, using additional equipment sets. This will permit a reasonable time for pressures to be reestablished in each test zone.

A pulse injection test (see Single Borehole Permeabaility Procedure [Golder Associates, 1987h]) will be conducted in the first isolated test section. Depending on the degree of pressure equilibration achieved before testing, the pulse test may need to be repeated at successively higher pressure levels until satisfactory results are obtained. Preliminary on-site analysis will indicate when this is achieved, according to predetermined test operation criteria.

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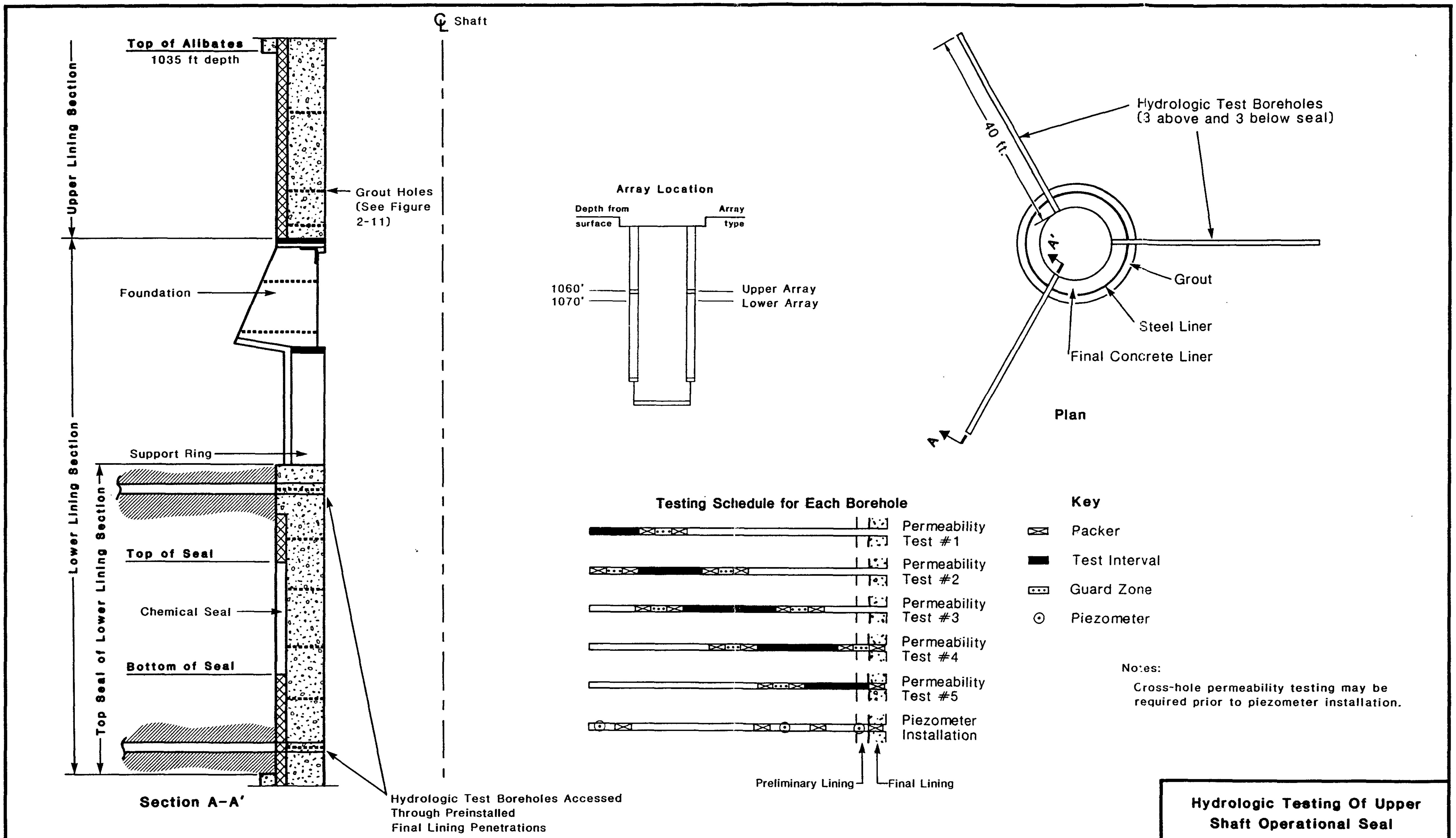

Hydrologic Testing Of Upper Shaft Operational Seal

Figure 4-17

WBS 6.9.4.2

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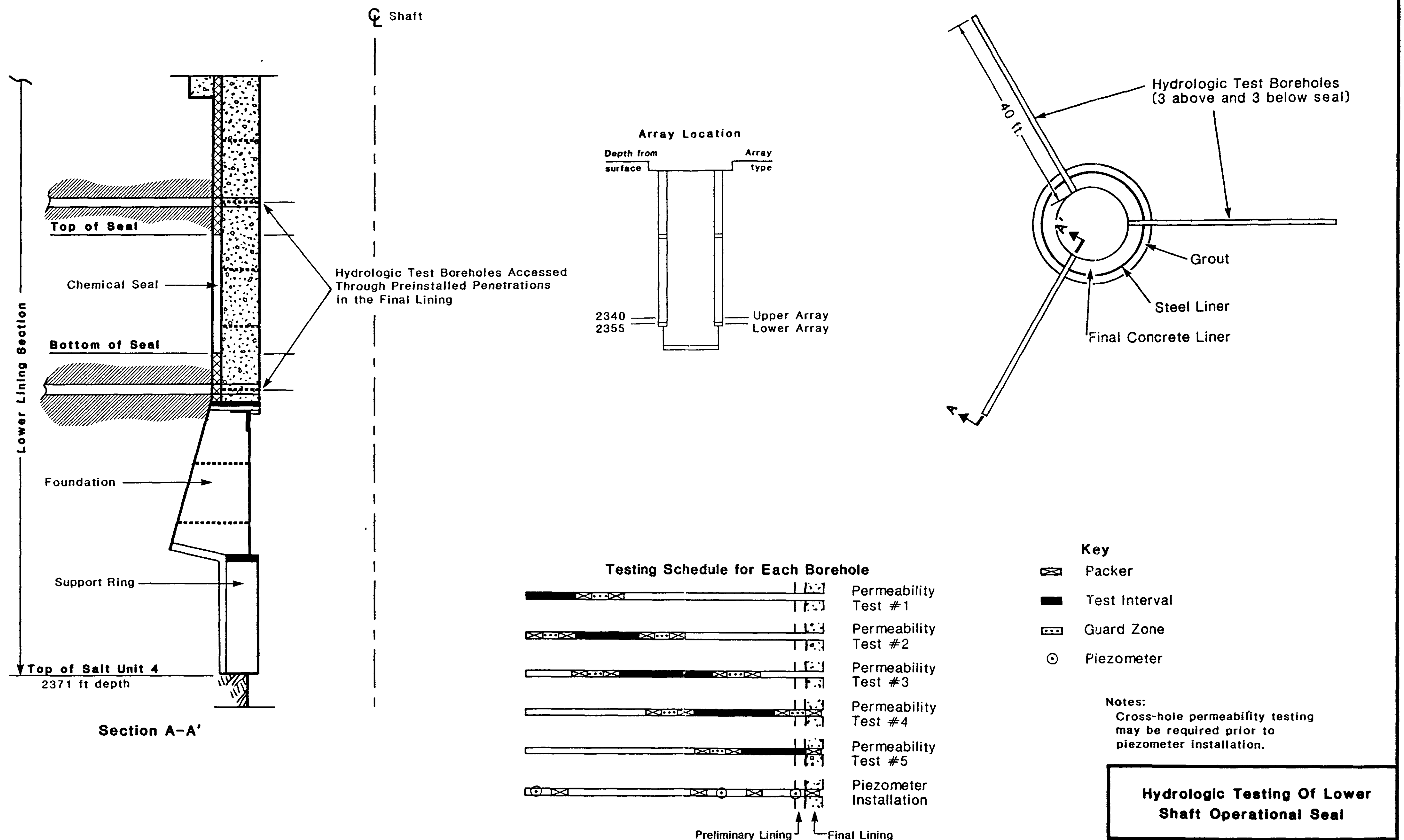

Hydrologic Testing Of Lower Shaft Operational Seal

Figure 4-18

WBS 6.9.4.2

843-1040-102/34

If the intrinsic permeability of the test section is relatively high (> 1 md [0.001 μm^2]), the pulse test will decay substantially in less than one minute and very little data will be obtained. A constant pressure injection test will then be carried out to better characterize the intrinsic permeability of the test zone. Once satisfactory data have been obtained from a selected interval, the test and guard intervals and then the packers will be depressurized and the test string moved back towards the borehole collar to test the next 16-ft (5-m) section of borehole, each test interval overlapping the previous one by 8 ft (2.5 m).

The above procedure will be repeated until profiling of all three holes at each level is complete. Depending on the configuration of the working platform and schedule considerations, the operation will then be repeated at the array of geohydrologic test boreholes below the operational seal. If data indicate high permeability (probably greater than 100 md [0.1 μm^2] but subject to confirmation by sensitivity studies) in rock both above and below the operational seals, then crosshole permeability testing may be required.

Crosshole permeability testing will be carried out between pairs of boreholes in the same axial plane of the shaft, using the upper hole for injection and the lower hole for monitoring (see Crosshole Permeability Test Procedure [Golder Associates, 1987i]). Simultaneous access to both levels will therefore be required. In the unlikely event that significant flowpaths are detected in the crosshole permeability tests, consideration will be given to conducting crosshole tracer tests by adding tracer to the injection hole and simultaneous pumping from the monitoring hole (see Crosshole Tracer Test Procedure [Golder Associates, TBDf]). The tracer will be chosen to be non-reactive with the strata at the foundation level in order to eliminate tracer retardation that could adversely affect test results.

Once all testing at the seals is finished, each borehole will be completed with permanent (non-replaceable) packered piezometer installations, incorporating three response zones separated by packers. These will be reconnected to the ADAS system to allow long-term monitoring of pressures either side of the operational seals.

The planned hole directions, inclinations, and depths for testing each of the shaft operational seals in Shaft No. 1 are shown in Table 4-11, with the test locations shown in Figures 4-17 and 4-18. The estimated schedule for drilling operational seal test boreholes and installing temporary piezometers is as follows:

1. Approximately one shift will be required to mobilize drilling and other equipment to each test location.

2. Approximately one shift will be required to drill each of the three H-sized test holes at each location, for a total time of three shifts at each station.

3. Approximately two shifts will be required to install the piezometers at each station and connect them to the ADAS.

Table 4-11. Operating Seal Hydrologic Test Borehole Specifications and Test Intervals

Host Strata	Hole Number	Depth Below Surface ft (m)	Bearing	Inclination Downward	Final Hole Depth ft (m)
Salado	1	1060 (323)	0°	5°	40 (12)
	2	1060 (323)	+120°	5°	40 (12)
	3	1060 (323)	-120°	5°	40 (12)
	4	1070 (326)	0°	5°	40 (12)
	5	1070 (326)	+120°	5°	40 (12)
	6	1070 (326)	-120°	5°	40 (12)
Lower San Andres Unit 5	1	2340 (713)	0°	5°	40 (12)
	2	2340 (713)	+120°	5°	40 (12)
	3	2340 (713)	-120°	5°	40 (12)
	4	2355 (718)	0°	5°	40 (12)
	5	2355 (718)	+120°	5°	40 (12)
	6	2355 (718)	-120°	5°	40 (12)

Test Intervals: Single borehole permeability test intervals in each hole will typically be:

Test 1 - 24 ft - 40 ft (7.3 - 12.2 m)
Test 2 - 16 ft - 32 ft (4.9 - 9.8 m)
Test 3 - 8 ft - 24 ft (2.4 - 7.3 m)
Test 4 - 0 - 16 ft (0 - 4.9 m)
Test 5 - 0 - 8 ft (0 - 2.4 m)

Piezometer Depths: 2, 20 and 40 ft (0.6, 6.1, and 12.2 m), separated by packers.

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Since the layout for each operational seal incorporates borehole arrays on two levels, this phase of the program will require 4 days at each seal, for a total of 8 days in Shaft No. 1. The time requirements for permeability testing are:

- Approximately two shifts will be required for mobilization and for removal of piezometers from the six boreholes at each location.

- Eighteen shifts will be required for testing at each horizon of three boreholes. This assumes simultaneous testing of the holes with staggered installation and packer repositioning between tests (Each test is estimated to take 20 hours, with 4 hours to reposition and initiate the next test).

- Four shifts will be required to install piezometers in the six boreholes and reconnect to the ADAS.

This will require a total testing time of 14 days at each operational seal location for a total time of 28 days in Shaft No. 1. If crosshole testing is required, the time requirement at each seal location will be extended by up to 8 days. Permeability testing will be performed following construction of the connecting drift between the two shafts, and possibly after ADF construction is completed.

The instrumentation and equipment, together with the required range and accuracy of the individual measurements taken during testing, are described in detail in the referenced procedures. The Construction Manager will be required to provide access to the test location together with a work platform sufficient to accommodate test equipment and test personnel. Further support requirements are summarized in Section 4.8.

4.6.3 Construction-Affected Zone Testing - Decommissioning Seals

4.6.3.1 Rationale

Characterization of the zone of disturbance and of the hydrochemical environment at candidate shaft decommissioning seal locations is an important requirement for design of the repository shaft decommissioning system. The testing program at each potential decommissioning seal location will include permeability testing of both the disturbed and undisturbed rock in order to provide a direct measure of the magnitude and extent of disturbance caused by excavation and how this disturbance changes with time, piezometric monitoring to provide a profile of ground-water pressures adjacent to the exploratory shaft for comparison with undisturbed ambient values, and formation fluid sampling to characterize the hydrochemical environment.

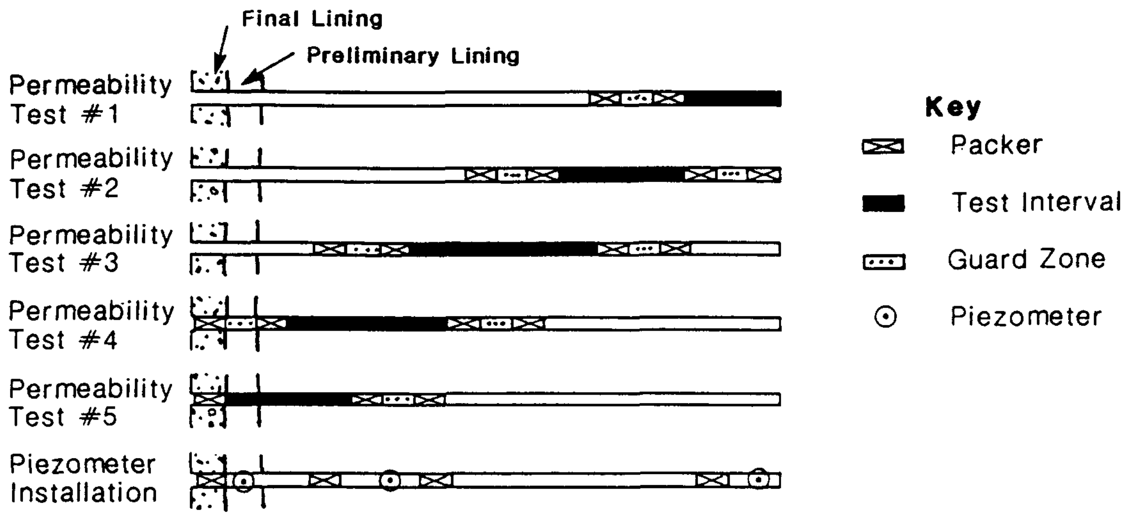
Hydrologic characterization of the construction-affected zone will be restricted to the three prospective seal locations in non-salt strata in the Salado, Queen/Grayburg and Upper San Andres formations. The Environmental Assessment (DOE, 1986a) indicates additional seals in the Alibates as well as three salt strata locations. Testing of the Alibates seal is already covered under Shaft Operational Seal Testing (Section 4.6.2), as the upper shaft foundation and seal spans the full thickness of the Alibates. No hydrologic testing will be performed in salt because the salt is expected to creep substantially prior to decommissioning, with associated fracture healing, making testing at the ESF stage unrepresentative of probable conditions at decommissioning.

4.6.3.2 Method

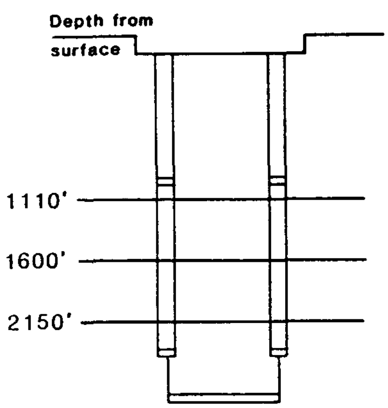
The shaft construction-affected zone testing program will be performed at candidate decommissioning seal locations in Shaft No. 1 using an array of three H-sized boreholes cored to a depth of approximately 40 ft (12.5 m) into the shaft wall, as shown in Figure 4-19. The test boreholes will be inclined about 5 below horizontal and will be drilled during shaft construction, either through the preliminary lining concrete, or before it is placed. Multiple use of the borehole jacking test holes (see Section 4.5.2) will be made at the three relevant test sections, although this will require reaming of the N-sized hole to H-size. Each test borehole will be completed with a temporary packered piezometer installation in accordance with the Piezometer Installation and Monitoring Procedure (Golder Associates, 1986d). The installation will comprise three response intervals separated from each other by inflatable packers as shown in Figure 4-19. Two formation fluid sampling boreholes will be located approximately 30 ft (9 m) above the permeability test and piezometric monitoring boreholes so as to avoid interfering with the piezometric monitoring, and will also be drilled during shaft construction. These boreholes will be N-size and between 10 and 20 ft (3 and 6 m) in length, and will be completed with packer installations forming the inhole component of the formation fluid sampler, in accordance with the Formation Fluid Sampling Test Procedure (Golder Associates, 1987j). Watertight penetrations will be installed through the final lining to provide access for permeability testing, piezometric monitoring, and formation fluid sampling after completion of the exploratory shafts.

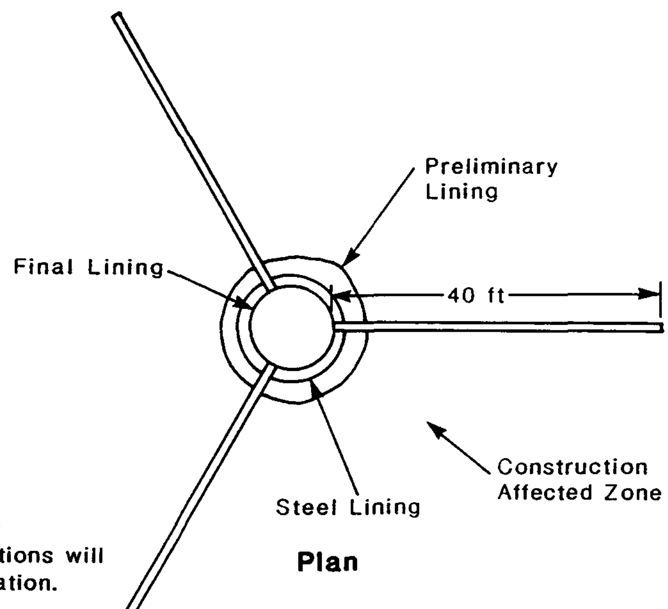
Permeability tests will be carried out after completion of the connecting drift between the two shafts, and possibly after completion of ADF construction. Permeability testing will be carried out as described in Section 4.6.2.2. Typically, five test intervals will be used in each borehole, as listed in Table 4-12. Following permeability testing, each borehole will be completed with a packer string containing three piezometers. These will enable ground-water pressures at various distances from the shaft to be monitored. The packered piezometer system will be removable to permit repeat permeability testing of the holes at a future time. Such testing may be required to assess time-dependent changes in construction-affected zone characteristics.

Separate boreholes will be drilled for installation of formation fluid samplers, as the formations at the decommissioning seal locations will necessarily be of low permeability and thus extended periods may be required to ensure accumulation of sample volumes sufficient for analysis. Samples will be collected and monitored at pressures close to ambient formation pressure (see Formation Fluid Sampling Procedure [Golder Associates, 1987j]), as any loss in pressure may cause chemical changes to occur. Brines in the



Testing Locations





Notes:

- Boreholes will be drilled during shaft construction and final lining penetrations will be installed during final lining installation.
- Formation fluid samplers will be installed in 10-to-20-ft-long boreholes drilled up to 30 ft above each test location.
- All depths are approximate and must be confirmed based on an examination of the Synthetic Data Base core log and discussions with the seal designers.
- Testing to be performed in Shaft No. 1 only.

Hydrologic Testing of the Construction Affected Zone

Figure 4-19

Table 4-12. Decommissioning Seal Hydrologic Test Borehole Specifications and Test Intervals

Host Strata (Lithology)	Hole Number	Depth[a] Below Surface ft (m)	Bearing	Inclination Downward	Final Hole Depth ft (m)
Salado	1	1110 (340)	0°	5°	40 (12)
(Siltstone)	2	1110 (340)	+120°	5°	40 (12)
	3	1110 (340)	-120°	5°	40 (12)
Queen/Grayburg	1	1600 (490)	0°	5°	40 (12)
(Siltsone)	2	1600 (490)	+120°	5°	40 (12)
	3	1600 (490)	-120°	5°	40 (12)
Lower San Andres	1	2150 (660)	0°	5°	40 (12)
(Anhydrite)	2	2150 (660)	+120°	5°	40 (12)
	3	2150 (660)	-120°	5°	40 (12)

Test Intervals: Single-hole permeability test intervals in each hole will typically be:

Test 1 - 24 ft - 40 ft (7.3 - 12.2 m)
Test 2 - 16 ft - 32 ft (4.9 - 9.8 m)
Test 3 - 8 ft - 24 ft (2.4 - 7.3 m)
Test 4 - 0 - 16 ft (0 - 4.9 m)
Test 5 - 0 - 8 ft (0 - 2.4 m)

Piezometer Depths: 2, 20, and 40 ft (0.6, 6.1 and 12.2 m), separated by packers.

[a] Depths are approximate and depend on lithology and eventual design of decommissioning system.

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lower part of the shaft will be at or near saturation with respect to certain chemical species, and precipitation mechanisms are likely to be sensitive to depressurization effects during sampling. Fluid temperatures will be maintained for similar reasons.

Samplers will be located by utilizing shaft geologic mapping results to identify suitable lithologies or permeable features likely to yield adequate sample volumes.

The design of formation fluid samplers will be such that a sample tube will lead from a porous sampling port in the test interval to the pressurized sampling system at the borehole collar. The system will incorporate a removable sample container with integral piston which can maintain sample pressure during sampling and storage. During sampling, the container will be connected to the sample tube, and the pressure behind the piston will be maintained at 7-15 psi (50 to 100 kPa) below test interval pressure in order to induce flow along the sample tube. The system will be thermally controlled and insulated to maintain in situ fluid temperature. When sufficient fluid has collected in the sample container, the sample tube will be closed off by a valve and the pressurized container removed. The piston side of the container will be disconnected from the gas supply and fitted with a pressure gauge for monitoring during transit and storage. Any loss in pressure will be rectified by reconnecting a nitrogen supply and repressurizing the piston.

The estimated schedule for construction-affected zone test borehole drilling is as follows:

1. Approximately one 8-hour shift will be required to mobilize drilling and other test equipment to each test location.

2. Approximately four 8-hour shifts will be required to ream out the two borehole jacking test boreholes, drill an additional H-sized borehole, and complete each borehole with the packer installations.

3. Approximately two 8-hour shifts will be required to drill and complete the Formation Fluid Sampling Borehole.

The estimated schedule for construction-affected zone testing is as follows:

1. Approximately one shift will be required for mobilizing test equipment to each test location.

2. Eighteen shifts will be required for testing at each horizon of three boreholes. This assumes simultaneous testing of the holes with staggered installation and packer repositioning between tests (each test is estimated to take 20 hours, with 4 hours to reposition and initiate the next test).

3. Two shifts will be required to install three piezometers in each of the three boreholes.

4. Piezometer and sampler installation at each seal location is expected to take up to three shifts, with additional access required at irregular intervals to remove samples and replace sample containers.

This phase of the program will therefore involve seven 8-hour shifts (2.3 days) at each test location during shaft construction and 24 shifts (8 days) after shaft completion, for a total of 7 days during and 24 days following construction in Shaft No. 1.

4.7 SHAFT CONSTRUCTION SUPPORT STUDY

The exploratory shafts and shaft stations will be excavated by conventional drill-and-blast procedures and supported over the majority of their length by a composite concrete-steel lining. The lower part of the shafts within the candidate repository horizon will be unlined and supported with rockbolts and mesh. The preliminary concrete lining will be constructed a relatively short distance behind the shaft bottom, and vibration levels from the production blasting must be kept within allowable limits. In addition, instrumentation will be installed concurrent with lining installation, as previously described, and vibration levels at the instrumentation stations must be similarly controlled to avoid instrument damage. The methods to be applied to this study include blast vibration monitoring to evaluate vibration levels within the shaft lining and associated instrumentation during shaft construction, and rockbolt testing to evaluate the suitability of the shaft support method for the unlined sections of the exploratory shafts. The application of this study is in confirming the construction/support method adopted for the exploratory shafts and for input to the repository shaft construction/support method design.

4.7.1 Blast Vibration Monitoring

4.7.1.1 Rationale

Each construction blast within the exploratory shafts will be monitored to measure the peak particle velocities induced in the shaft lining and associated instrumentation in order to determine whether design vibration limits are exceeded. The information will be used to control the blast design to conform to the specified vibration tolerances for the shaft structures and instrumentation.

4.7.1.2 Method

Blast vibration monitoring will be performed in conjunction with the Shaft Seismic Velocity Survey previously described (Section 4.5.3). The blast vibration monitoring, per se, will be performed with two low-frequency, three-component seismometers with calibration coils, located a minimum distance of approximately 30 ft and 70 ft (9 and 21 m), respectively, above the shaft bottom. The monitoring will be performed in accordance with the Shaft Blast Vibration Monitoring Procedure (Golder Associates, 1986l).

The individual seismometers will be fastened to the shaft lining by cast-in-place brackets and connected to a surface-based seismograph recording system with a shielded seismic conductor cable. The seismometer string will be moved on about a weekly basis, depending on the rate of shaft advance.

The instrumentation and equipment, together with the required range and accuracy of the individual measurements, are described in detail in the procedure. The Construction Manager will be required to cast the seismometer brackets in the shaft lining and string the shielded seismic conductor cable during construction. Access will be required to each seismometer on about a weekly basis to relocate the instruments.

4.7.2 Rockbolt Pullout Testing

4.7.2.1 Rationale

Rockbolt testing will be required to evaluate the performance of bolt/anchor assemblies, specifically short-term load capacity, and installation procedures selected for use in the unlined shaft sections. Rockbolt pullout testing is required for initial confirmation of the exploratory shaft support performance and for input to the design of the repository shaft support system.

4.7.2.2 Method

Short-term testing of the rockbolt anchor system will be performed using a conventional rockbolt pullout test, in accordance with the Rockbolt Pullout Test Procedure (Golder Associates, TBDg).

Rockbolt pullout testing will be performed at the start of the shaft section which will be permanently supported using rockbolts and mesh, i.e., the LSA4 candidate repository host stratum) and in each shaft station. Following installation of the designed rockbolt support pattern, approximately five additional bolts will be installed at intermediate locations using the same drilling and installation procedures. The surface area around each test bolt will be prepared and a loading frame will be installed over the bolt to be tested. The load frame includes a reaction plate, hydraulic cylinder (used to load the bolt), electric load cell and bolt head displacement measurement assembly. The bolt/anchor assembly will be tested by increasing the load in steps of approximately 1,000 lbf (4 kN) until a total displacement greater than 1.5 in (38 mm) is recorded, or until the bolt fails. Each load increment will be held constant until the response stabilizes, or for 15 minutes, whichever occurs first. When bolt displacement does not stabilize within 15 minutes of completing each increment of loading, an additional series of bolts may be installed in the same vicinity, with each bolt loaded to a different predetermined value if tensioned bolts are used.

Each test is estimated to require about 2 hours to perform, with the total program requiring one to two shifts in the Shaft No. 2, which is expected to be the first of the two exploratory shafts to reach the LSA4. The instrumentation and equipment, together with the required range and accuracy of the individual measurements taken as part of the test, are described in detail in the referenced Procedure.

4.8 TEST SUPPORT REQUIREMENTS

A majority of the work associated with installation and monitoring of instrumentation in the ESF shafts will be performed by the UTC. However, support from other ESF contractors, including the Construction Manager (CM) and the Mining Subcontractor (MSC), will be required. Support required from these organizations is summarized below under the following categories:

- Support required concurrent with shaft construction on a continuous basis. UTC activities which fall within this category include Geologic Mapping (Section 4.3.1), Groundwater Inflow Monitoring (Section 4.6.1), Blast Vibration Monitoring (Section 4.7.1), and Seismic Velocity Surveying (Section 4.5.3). In addition, that support associated with extension of power and instrument cable conduit during preliminary and final lining placement is also considered to be covered under this category.

- Support required concurrent with shaft construction on an intermittent basis. UTC activities which fall within this category include Mechanical and Thermal Response Monitoring (Section 4.4), Absolute Stress Measurement (Section 4.5.1), Deformation Moduli Measurement (Section 4.5.2), Large-Diameter Core Sampling (Section 4.5.4), Thermal Conductivity Testing (Section 4.5.5), and Rock Bolt Pullout Testing (Section 4.7.2). In addition, those intermittent ADAS hardware installation activities not associated with instrument array installations and drilling hydrologic test boreholes at Operational and Decommissioning Seal sites also fall within this category.

  Geomechanical and thermomechanical property tests should be conducted prior to final lining to avoid penetrating the watertight barrier. Two schedule options have been identified:

  1. Tests to be completed from the shaft bottom (i.e., concurrent with excavation), either through the preliminary lining or prior to preliminary lining placement.

  2. Tests to be conducted from a temporary platform, installed at the test location prior to final lining.

Only support requirements associated with option 1 have been addressed in this section as this option will have a lesser impact on the shaft construction schedule.

- Support required after the completion of shaft construction. Testing which falls within this category includes Shaft Operational Seal Testing (Section 4.6.2) and Construction-Affected Zone Testing (Section 4.6.3). Drilling of test boreholes for these two testing programs may be carried out during shaft sinking, as previously noted.

  This last category of support may be provided exclusively by the CM if a decision is made to postpone post-shaft construction tests until after completion of the At-Depth Facility (ADF).

Integration of the shaft construction and testing/monitoring activities is described, in detail, in the individual study programs (Sections 4.3 through 4.7) and summarized below.

4.8.1 Support Required from Construction Manager (CM)

The CM will be responsible for ensuring that all support requirements are met, either by CM staff or by CM-controlled subcontractor organizations. Those support requirements which are not obviously associated with currently defined CM subcontractors are therefore identified in this section.

4.8.1.1 Support Required Concurrent with Shaft Construction on a Continuous Basis

- For Geologic Mapping:
  - Painting survey reference marks (bearing and horizontal datum) on the shaft wall prior to the commencement of geologic mapping. Horizontal datum to ± 0.1 ft (± 0.03 m) and bearing to ± 0.5 accuracy.
  - Monitoring safety during operations
- For Groundwater Inflow Monitoring:
  - Monitoring safety during operations
- For Blast Vibration Monitoring and Seismic Velocity Surveying:
  - Provision of securable space in the shaft hoist house for recording equipment
  - Provision of a 110V/40A clean, stable power supply to the equipment

- Survey locations of installed seismometers to ± 0.1 ft (± 0.03 m)

- Monitoring safety during test operations

- For ADAS Conduit Extension:

  - Check alignment and position of conduit during installation prior to concrete placement

  - Monitoring safety during operations

4.8.1.2 Support Required Concurrent with Shaft Construction on an Intermittent Basis

- For Mechanical and Thermal Response Monitoring:

  - Marking reference horizontal datum and bearing lines on the rock and/or liner surface previously cleaned by the MSC. Accuracy requirements will be ± 0.1 ft (0.03 m) for the horizontal datum and ± 0.5 for the reference bearing

  - Surveying actual location of installed instrument to an accuracy of ± 0.1 ft (0.03 m)

  - Monitoring safety during operations

- For Absolute Stress Measurement, Deformation Moduli Measurement, and Thermal Conductivity Testing:

  - Marking reference horizontal datum and bearing lines on the rock and/or preliminary lining surface and survey of actual borehole collar to ± 0.1 ft (± 0.03 m) and of the borehole bearing and inclination to ± 0.5

  - Supervision of decommissioning (e.g., grouting) of completed test boreholes, if necessary

  - Monitoring safety during test operations

- For Large-Diameter Core Drilling:

  - Survey control of the borehole collar to ± 0.1 ft (0.03 m)

  - Monitoring safety during operations

- For Rock Bolt Pullout Testing:

  - Survey location of test bolts to ± 0.1 ft (± 0.03m)

  - Monitoring safety during test operations.

4.8.1.3 Support Required After the Completion of Shaft Construction

- For Shaft Operational Seal Testing:

  - Safety inspection of all installed equipment prior to the commencement of testing

  - Survey position of previously installed final lining penetration to be used for seal testing

  - Monitoring safety during test operations

- For Construction-Affected Zone Testing:

  - Safety inspection of all installed equipment prior to the commencement of testing

  - Survey position of previously installed final lining penetrations

  - Monitoring safety during test operations, especially during initial penetration of the final lining and subsequent sealing of test borehole penetration.

4.8.2 Support Required from Mining Subcontractor (MSC)

It is assumed that the same contractor will construct both the shaft and the At-Depth Facility. The support requirements, presented below, therefore include requirements associated with shaft testing which must be satisfied during At-Depth Facility construction.

4.8.2.1 Support Required Concurrent with Shaft Construction on a Continuous Basis

- For Geologic Mapping:

  - Cleaning of the shaft bottom and exposed shaft walls using compressed air or water

  - Installation of a full spectrum lighting system and a 10-ft (3-m) ladder to be deployed from the shaft bottom

  - Cleaning frost from the shaft walls in the upper frozen zone using heaters or other suitable equipment which does not affect shaft wall stability

  - Provision for a telephone link between the mapping section and the surface

  - Provision for a clean, stable 110V/20A electric supply at the mapping section

- For Groundwater Inflow Monitoring:

  - Access to the shaft floor to estimate groundwater inflow rate when large inflow has occurred

  - Installation of additional lighting if required

  - Access to monitoring locations at various levels in the shaft

- For Blast Vibration Monitoring and Seismic Velocity Surveying:

  - Installation of seismometer brackets in the shaft lining and routing of shielded seismometer cables to the surface-based recording equipment; the cable will be extended in increments of approximately 400 ft (122 m)

  - Access to each seismometer on a weekly basis to check and relocate the instruments

  - Timely access to detailed records of blasting pattern, weight of explosives used per delay, and delay pattern

  - Special assistance during single-shot test blasts conducted in the floor of the shaft

- For ADAS Conduit Extension:

  - Installation of brackets on shaft wall and/or shaft liner for suspending conduit

  - Installation of conduit from preinstalled brackets

  - Provision for extending conduit through the kerb ring during concrete placement and protection of conduit ends during subsequent shaft excavation

  - Penetrations in shaft liner components for conduit routing.

4.8.2.2 Support Required Concurrent with Shaft Construction on an Intermittent Basis

- For Mechanical Response Monitoring:

  - Preparation of the shaft bottom and walls, including cleaning and removal of construction equipment as required by the individual test activity

  - Installation of all hardware required for instrumentation installation as indicated on the Appendix B: target station Preparation drawings (see also Section 4.4.3)

- Pulling cables through installed conduit

- Provision for sufficient working space and storage on the galloway for instrumentation array installation activities and equipment

- Provision for utilities and lighting on the galloway

- Provision for special construction items including block-outs, liner penetrations, etc.

- Transport of men and materials from the surface to the galloway on a regular, scheduled basis during shaft construction and instrument array installation or testing

- Mobilization of drilling equipment from the shaft collar to the shaft bottom for drilling extensometer boreholes

- Provision for special lighting, below the galloway, for those activities to be conducted from the shaft bottom (e.g., extensometer installation)

- Provision for utilities at the shaft bottom during drilling, including electricity, compressed air, water, and brine

- Installation of any special hardware required at the shaft bottom for anchoring the drilling equipment

- Transportation of instrumentation from the galloway to the shaft bottom

- Handling and transporting core from the shaft bottom to the surface

- Provision of a grout plant and grout materials, and assistance with grouting the extensometers

- Block-outs or welding for MPBX heads

- Cooperation during erection of concrete forms and placement of concrete around instrumentation. Concrete placement may require the use of non-standard form lengths and careful placement procedures to ensure proper encasement and performance of embedded instrumentation

- Transport of steel liner segments containing welded VWSGs from the surface to the point of installation, including any special precautions to safeguard the instruments during transportation. At some instrument array locations, non-standard sizes of inner liner plate will be required

- For Absolute Stress Measurement, Deformation Moduli Measurement, and Thermal Conductivity Testing:

  - Clean-up of the shaft bottom, at the specified test location, ready for drill rig installation

  - Transport of drill rig, test equipment and instrumentation, and test personnel from the surface to the shaft bottom

  - Installation of a temporary lighting system and provision for utilities at the shaft bottom, including electricity, compressed air, and water or brine

  - Separate instrument-quality compressed air and 110V clean, stable power supply at the shaft bottom for hole cleaning and data logger operation

  - Provision for a telephone link from the shaft bottom to the surface

  - Transportation of recovered core and test samples from the shaft bottom to the surface

  - Decommissioning of completed test boreholes under supervision of CM

  - Provision for moving a 20-gallon capacity brine tank to the galloway

  - Demobilization of the drilling rig after completion of testing at one elevation

- For Large-Diameter Core Drilling

  - Clean-up and leveling of shaft bottom ready for installation of drill rig and support equipment

  - Installation of any hardware required at the shaft bottom for anchoring the drill rig

  - Transportation of the drill rig and support equipment from the surface to the shaft bottom

  - Installation of the drill rig at the shaft bottom

  - Provision for lighting and utilities at the shaft bottom

  - Provision for a telephone link from the shaft bottom to the surface during test operation

  - Assistance with retrieval of large-diameter core and careful transportation of packaged core from the shaft bottom to the surface

- Demobilization of the drill rig and filling of the excavated hole with muck, if required for safety reasons

- For Rock Bolt Pullout Testing:

  - Clean-up of shaft bottom ready for installation of test equipment. Note: The MSC rock bolt installation equipment will remain at the shaft bottom during testing, as testing will be intermittent with rock bolt installation

  - Transportation of test equipment and personnel from the surface to the shaft bottom

  - Provision for lighting and utilities required during test operations (e.g., stable power supply for data logger, and compressed air line extended from the galloway)

  - Installation of test bolts under supervision of UTC personnel

  - Backfilling of holes produced by pullout tests, if required by ESF A/E and/or CM

- For Operational and Decommissioning Seal Tests

  - Clean up of shaft bottom ready for installation of drill rig and support equipment or room on the galloway to locate drill rig

  - Mobilization of the drill rig, support equipment, and personnel

  - Installation of the drill rig at the shaft bottom or on the galloway

  - Provision for lighting and utilities at the drill rig site

  - Provision for a telephone link between the drill rig site and the surface

  - Transportation of recovered core to the surface

  - Demobilization of drilling equipment after test borehole completion

4.8.2.3 Support Required After the Completion of Shaft Construction

- For Shaft Operational Seal Testing:

  - Installation of a double-deck, temporary work platform at the seal location

  - Transportation of test equipment, instrumentation, and personnel between the surface and the work platform as required

  - Provision for lighting and utilities at the work platform

  - Provision for a telephone link from the work platform to the surface

  - Provision for a water tank on the work platform for storage of test fluids

  - Assistance with grouting completed boreholes during piezometer installation, including provision for a grout plant, grout materials, and required operator and labor support

  - Constructing sealed penetrations during cable routing from the borehole collar to the nearest DCU

  - Assistance with extending instrument cables to DCUs

  - Demobilization of work platform and equipment following test completion

- For Construction-Affected Zone Testing:

  - Installation of a work platform at the required test location

  - Transport of drilling equipment, instrumentation, test equipment, and personnel between the surface and the work platform as required

  - Provision for lighting and utilities at the work platform

  - Provision for a telephone link from the work platform to the surface

  - Provision for a water/brine tank on the work platform for storage of test fluids

  - Assistance with grouting completed boreholes during piezometer installation, including provision for a grout plant, grout materials, and required operator and labor support

- Constructing sealed penetrations during cable routing from borehole collars to the nearest DCU.

- Assistance with extending instrument cables to DCUs

- Demobilization of work platform, test equipment, and accessories from completed test station, to either a new test location or the surface

4.9 INSTRUMENT DESIGN BASIS

The site characterization and design confirmation data needs, derived in Chapter 3.0, will be satisfied by the study programs described in Sections 4.3 through 4.7. Site characterization data needs have currently been qualitatively derived from the regulatory issues. As the Salt Repository Program develops, these site characterization data needs will be quantitatively defined through a process of performance allocation and performance assessment. This process will determine the relative sensitivity of site performance models to individual parameters and will therefore assist in defining accuracy requirements associated with parameter measurement. Design confirmation data needs have been derived based on preliminary ESF and conceptual repository designs and the SRP Synthetic Data Base (ONWI, 1986a). As detailed designs are prepared, and site specific information is retrieved from surface-based test boreholes drilled at the Deaf Smith site, the design confirmation data needs will be more accurately defined. Detailed analysis of ESF and repository designs will provide the range of design parameter values. This information will be used to refine the shaft instrumentation selection described below.

In the interim, shaft testing and monitoring instrumentation has been provisionally selected using information contained in Draft Position on Geotechnical Instrumentation in a Salt Repository Environment: Requirements, Performance, Recommendations, and Development Needs (Golder Associates, 1986i), preliminary simplified analyses, and previous experience under similar conditions. Table 4-13 provides a summary of the selected shaft testing and monitoring instrumentation and the estimated range of parameters to be measured by the selected instruments. The range estimates in Table 4-13 were in some cases calculated using:

- An elastic analysis of the response of the lined shafts to the imposed loads (Appendix A.1)

- Evaluation of relevant WIPP mechanical response monitoring data (Appendix A.2).

Other parameter range estimates were made on the basis of limited calculations using assumed material properties, data retrieved from the synthetic data base, and expert opinion.

Table 4-13 Instrument Measurement System and Schedule Requirements[†]

Measurement	Type of Instrument	Instrument Operating Principle	Quantity	Number ADAS Chan/ Instrument	Estimated Physical Measurement Range	Estimated Physical Measurement Accuracy (±)	Estimated Measurement System Range	Estimated Measurement System Accuracy[d] (±)
SHAFT MECHANICAL RESPONSE STUDY[a]								
Shaft 1								
Concrete Liner Strain[u]	Embedment Strain Gage	Vibrating Wire	192	1	-500 to +2,000 με	5 με	500 to 1,000 Hz	0.2 Hz
Steel Liner Strain[u]	Weldable Strain Gage	Vibrating Wire	128	1	-500 to +2,000 με	5 με	900 to 2,500 Hz	0.5 Hz
Concrete Liner Stress[u]	Embedment Stress Cell	Vibrating Wire	212	2	4,000 psi (28 MPa)	10% of reading [min. 20 psi (0.14 MPa)]	1,200 to 2,000 Hz	0.8 Hz
Bitumen Pressure[r]	Pressure Cell	Vibrating Wire	6	2	500 psi (3.5 MPa)	5 psi (35 kPa)	1,200 to 2,000 Hz	1.6 Hz
Seal Pressure[r]	Pressure Transducer	Vibrating Wire	8	2	1,000 psi (7 MPa)	5 psi (35 kPa)	1,200 to 2,000 Hz	0.8 Hz
Movement Between Linings[r]	Jointmeter	Linear Potentiometer	71	2	± 2 in (50 mm)	0.01 in (0.25 mm)	5 VDC	2.5 mV
Hydrostatic Pressure[u]	Piezometer	Vibrating Wire	58	1	1,000 psi (7 MPa)	0.5% of reading [min. 1 psi (7 kPa)]	1,200 to 2,000 Hz	0.1 Hz
Salt Creep[p]	Multiple Position Borehole Extensometer	Rotary Resolving Transformer	28	6	4 in[f] (100 mm)	0.004 in (0.1 mm)	12-bit BCD	---
Rock/Lining Temperature[u]	Temperature Sensor	Vibrating Wire	168	1	-22 to 122°F (-30 to +50°C)	2°F (1°C)	900 to 2,500 Hz	3.5 Hz
Instrument Temperature[v] Compensation	Temperature Sensor	Vibrating Wire	354	1	-22 to 300°F (-30 to +150°C)	2°F (1°C)	900 to 2,500 Hz	1.5 Hz
Shaft Convergence[e,r]	Tape Extensometer	Mechanical Dial Gage	NA	NA	0.25 in (6 mm)	0.005 in (0.1 mm)	NA	NA
Shaft 2								
Concrete Liner Strain[u]	Embedment Strain Gage	Vibrating Wire	88	1	-500 to +2,000 με	5 με	500 to 1,000 Hz	0.2 Hz
Steel Liner Strain[u]	Weldable Strain Gage	Vibrating Wire	92	1	-500 to +2,000 με	5 με	900 to 2,500 Hz	0.5 Hz

Table 4-13 Instrument Measurement System and Schedule Requirements[†] (Continued)

Measurement	Type of Instrument	Instrument Operating Principle	Quantity	Number ADAS Chan/ Instrument	Estimated Physical Measurement Range	Estimated Physical Measurement Accuracy (±)	Estimated Measurement System Range	Estimated Measurement System Accuracy[d] (±)
Concrete Liner Stress[u]	Embedment Stress Cell	Vibrating Wire	132	2	4,000 psi (28 MPa)	10% of reading [min. 20 psi (0.14 MPa)]	1,200 to 2,000 Hz	0.8 Hz
Bitumen Pressure[r]	Pressure Cell	Vibrating Wire	2	2	500 psi (3.5 MPa)	5 psi (35 kPa)	1,200 to 2,000 Hz	1.6 Hz
Seal Pressure[r]	Pressure Transducer	Vibrating Wire	8	2	1,000 psi (7 MPa)	5 psi (35 kPa)	1,200 to 2,000 Hz	0.8 Hz
Movement Between Linings[r]	Jointmeter	Linear Potentiometer	41	6	±2 in (50 mm)	0.01 in (0.25 mm)	5 VDC	2.5 mV
Hydrostatic Pressure[u]	Piezometer	Vibrating Wire	34	1	1,000 psi (7 MPa)	0.5% of reading [min. 1 psi (7 kPa)]	1,200 to 2,000 Hz	0.1 Hz
Salt Creep[p]	Multiple Position Borehole Extensometer	Rotary Resolving Transformer	20	6	4 in[f] (100 mm)	0.004 in (0.1 mm)	12-bit BCD	---
Rock/Lining Temperature[u]	Temperature Sensor	Vibrating Wire	56	1	-22 to 122°F (-30 to +50°C)	2°F (1°C)	900 to 2,500 Hz	3.5 Hz
Instrument Temperature Compensation[v]	Temperature Sensor	Vibrating Wire	234	1	-22 to +300°F (-30 to 150°C)	2°F (1°C)	900 to 2,500 Hz	1.5 Hz
Shaft Convergence[e,r]	Tape Extensometer	Mechanical Dial Gage	NA	NA	0.25 in (6 mm)	0.005 in (0.1 mm)	NA	NA
				MECHANICAL/THERMAL PROPERTIES STUDY				
Absolute Stress Measurement[b,o]								
Borehole Deformation	Borehole Deformation Gage	Strain Gage Bridge	3	8	2×10^{-3} in (50 μm)	0.003×10^{-3} in (0.008 μm)	30 mVDC	3μV
Bit Penetration	Acoustic Distance Measuring Distance	Reflected Signal Timing	1	[TBD]	2 to 8 ft (0.6 to 2.5 m)	0.01 ft (3 mm)	[TBD]	[TBD]
Drill Fluid and Gage Temperature	Resistance Temperature Detector (RTD)	Thermal Coefficient of Resistance	3	1	40 to 90°F (5 to 50°C)	0.2°F (0.1°C)	100 to 120 ohms	0.007 ohm
Biaxial Cell Pressure	Pressure Transducer	Strain Gage Bridge	1	2	5,000 psi (35 MPa)	1 psi (7 kPa)	100 mVDC	4μV

Table 4-13 Instrument Measurement System and Schedule Requirements[†]
(Continued)

Measurement	Type of Instrument	Instrument Operating Principle	Quantity	Number ADAS Chan/ Instrument	Estimated Physical Measurement Range	Estimated Physical Measurement Accuracy (±)	Estimated Measurement System Range	Estimated Measurement System Accuracy[d] (±)
NX - Borehole Jack Testing[b,s]								
Jacking Pressure	Pressure Transducer	Strain Gage Bridge	1	2	10,000 psi (70 MPa)	5 psi (35 kPa)	100 mVDC	10 µV
Borehole Deformation	LVDT	Differential Transformer	2	2	±0.25 in (6 mm)	0.001 in (0.025 mm)	Satisfied by Readout Indicator	
Shaft Seismic Velocity[c] Survey	[TBD]	[TBD]	NA	NA	[TBD]	[TBD]	NA	NA
Thermal Conductivity Testing[b,n]								
Probe Temperature	RTD	Thermal Coefficient of Resistance	10	1	60 to 212°F (15 to 100°C)	0.2°F (0.1°C)	100 to 150 ohms	0.007 ohm
Power Supply Voltage	Voltmeter	Potential Transformer	1	[TBD]	0 to 200 VDC	0.25 VDC	0 to 200 VDC	0.05 V
Power Supply Current	Ammeter	Current Transformer	1	[TBD]	0 to 20 A	0.4 A	0 to 2 VDC	8 mV
				SHAFT SEAL STUDY				
Shaft Operational Seal Testing[b,s] and Construction-Affected Zone Testing[b,s]								
Fluid Pressure	Pressure Transducer	Quartz Oscillator	5	[2]	1,500 psi (10 MPa)	0.05 psi (0.3 kPa)	33 to 39 kHz	0.04 Hz
Fluid Flow	Turbine Flowmeter	Current Pulse Frequency	3	[TBD]	50 gpm (3.8 l/s)	0.2 gpm (15 ml/s)	5 VDC	4 mV
	or							
	Linear Potentiometer	Voltage Divider	3	[TBD]	2 in (51 mm)	0.001 in (0.025 mm)	5 VDC	0.5 mV
Fluid Temperature	RTD	Thermal Coefficient of Resistance	5	1	70 to 140°F (20 to 60°C)	2°F (1°C)	100 to 125 ohms	0.08 ohm

Table 4-13 Instrument Measurement System and Schedule Requirements[†]
(Continued)

Measurement	Type of Instrument	Instrument Operating Principle	Quantity	Number ADAS Chan/ Instrument	Estimated Physical Measurement Range	Estimated Physical Measurement Accuracy (+)	Estimated Measurement System Range	Estimated Measurement System Accuracy[d] (+)
Tracer Concentration	[TBD]	[TBD]	[TBD]	[TBD]	[TBD]	[TBD]	[TBD]	[TBD]
Piezometer Monitoring[a,q]								
Formation Fluid Pressure	Piezometer	Vibrating Wire	90	2	1,000 psi (7 MPa)	0.5% of reading [min. 1 psi (7 kPa)]	1,200 to 2,000 Hz	0.1 Hz
Instrument Temperature Compensation	Temperature Sensor	Vibrating Wire	90	1	60 to 120°F (15 to 50°C)	2°F (1°C)	900 to 2,500 Hz	3.5 Hz
			SHAFT CONSTRUCTION SUPPORT STUDY					
Blast Vibration Monitoring	[TBD]	[TBD]	N/A	N/A	[TBD]	[TBD]	N/A	N/A
Rock Bolt Testing								
A. Pull Testing[b,m]								
Rock Bolt Load	Load Cell	Strain Gage Bridge	1	2	50,000 lbs (0.2 MN)	250 lbs (4 kN)	20 mVDC	20 µV
Bolt Head Displacement	Linear Potentiometer	Voltage Divider	1	2	4 in (100 mm)	0.001 in (0.025 mm)	5 VDC	0.25 mV
B. Long-Term Load Monitoring[a,p]								
Rock Bolt Load	Strain Gaged Rock Bolt	Vibrating Wire	22	1	50,000 lbs (0.2 MN)	1,000 lbs (4 kN)	1,300 to 2,850 Hz	6.2 Hz
	Strain Gaged Rock Bolt	Strain Gage Bridge	22 x 5	1	1,200 µε	5 µε	20 mVDC	17 µV
Temperature	Thermistor	Resistance	22	1	50 to 120°F (10 to 50°C)	2°F (1°C)	10,000 to 1,800 ohms	10 ohms

Notes

[a] Test data to be recorded by Automatic Data Acquisition System.
[b] Test data to be recorded by portable datalogger.

Notes: (Continued)

[c] Test to use autonomous readout indicator.
[d] System accuracies do not include errors associated with algorithms for converting from electrical quantities to engineering units.
[e] Test data to be recorded manually.
[f] Without resetting.
[g] Each MPBX has six anchors.

Data Sampling Schedules

[m] minimum monitoring interval 10 seconds.
[n] minimum monitoring interval 12 seconds.
[o] minimum monitoring interval 15 seconds.
[p] every 1 hour for 24 hours, every 6 hours for the next 7 days, every 24 hours for the next 2 months, every 7 days thereafter.
[q] Data recorded every 2 hours for 12 hours, every 4 hours for the next 12 hours, every 8 hours for the next 24 hours, every 12 hours for the next 5 days, and every day thereafter.
[r] Measurements/surveys to be made every 24 hours for the first 30 days, subject to review.
[s] Minimum monitoring interval TBD.
[t] All data sampling schedules subject to review on the basis of field conditions and monitoring results.
[u] Every 2 hours for the first 5 days, every 6 hours for the next 9 days, every 24 hours for the next 30 days, every 7 days thereafter.
[v] Data sampling schedule same as instrument to which temperature sensor is coupled.

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Many of the ranges presented in Table 4-13 can be considered only tentative at this time. In future revisions of this Study Plan these values will be reviewed and modified based on site specific data and the results of additional site-specific preanalyses (described in Appendix A).

Table 4-13 also presents the required accuracy of physical measurement. In the absence of any specific requirements from the repository or ESF designers, and without quantitative determination of the information required to resolve licensing issues, these accuracy values have been selected based on an assessment of the tests themselves, the current perception of how the data will be used, an assessment of anticipated modeling requirements and design data needs, and estimates of instrument and data recording equipment capabilities.

4.9.1 Preliminary Simplified Analysis of the Mechanical Response of the Shaft Linings to External Site Loads

Appendix A1 presents a simplified analysis of the elastic response of the liner to a limited number of different static loading conditions. This analysis considered the shaft lining system as a series of concentric cylinders constrained by certain displacement and stress compatibility conditions. The mechanical behavior of each of the cylinders is assumed to be consistent with that of a uniform homogeneous isotropic linear-elastic material. The loading conditions used in the analysis were developed from a basic understanding of the shaft construction sequence. The magnitudes of the loads were taken from Table 2-3. The results of this analysis provide one source of information that may be used for evaluating the expected behavioral response of the liner system. However this analysis cannot be used in isolation, because instruments installed in the liner concrete will also respond to effects such as concrete creep, shrinkage during concrete curing, and inelastic behavior caused by the presence of microcracks in the concrete. Therefore, in addition to the simplified theoretical pre-analysis, an estimation of the liner response should be assessed from either measurements made under similar conditions at other sites, or the shaft designer's calculations and analyses.

4.9.2 Preliminary Evaluation of Relevant WIPP Data

Appendix A.2 presents an evaluation of previously published creep data obtained from extensometers installed in shaft walls at the WIPP site. In this Appendix, the published data have been reviewed to assist in evaluating:

- An operating range for individual MPBX sensors
- Anchor depths for obtaining evenly distributed data of radial salt creep around the shafts (discussed previously in Section 4.4)
- A data sampling schedule for the initial months of data collection (discussed in the next section).

The WIPP data was of limited usefulness due to the large time span between shaft excavation and MPBX installation at the WIPP site. Analyses using site specific information and more accurate constitutive models than currently available will therefore be required to predict salt strata displacements during these phases. In the interim, required MPBX sensor ranges have been approximated using combinations of published data as described in Appendix A.2.

4.9.3 Physical Design Constraints and Other Design Bases

A small percentage of the shaft testing and monitoring instrumentation must be designed to operate under severe environmental conditions. Most of the instrumentation will operate under ambient conditions, temperatures being controlled by ventilation air in the shafts. The exceptions are those instruments installed in the freeze zone where temperatures will be controlled initially by the surrounding rock temperature. Instrumentation installed in salt strata will be subject to accelerated corrosion and must be designed/selected to operate under these adverse conditions. Instruments installed in the bitumen will experience high temperature during bitumen placement and corrosion due to hydrocarbon. Piezometer installations will be made in corrosive, aqueous environments.

All instrumentation and data acquisition systems may be required to operate under gassy mine conditions. A detailed analysis of these concerns is contained in the Automatic Data Acquisition System Plan (Golder Associates, 1987b).

4.10 DATA COLLECTION AND ADAS MONITORING REQUIREMENTS

4.10.1 Signal Type, Range, and Accuracy

The shaft instrumentation and testing program will generate data from approximately 1,900 instruments. The ADAS is designed to automate the collection, storage, reduction, and presentation of data to the maximum practical extent. In order to provide an interface with the Automatic Data Acquisition Plan, Table 4-13 presents information about the operating principle of each of the instruments used in the test/monitoring activities, and presents the equivalent signal range and signal accuracy for the physical measurements given.

The signal range values given are representative of the performance of instruments typically used for these measurements. The values for signal accuracy are generally the scaled conversion from the physical measurement accuracy values, which are subsequently divided by 5 to allow for error due to the transducer, the transmission system, and the data reduction algorithm. These values do not necessarily represent the ultimate resolution of the instrument, and may change as test design and instrument qualification testing proceeds.

Signal range and accuracy are given only for those testing/monitoring activities which fall under the Automatic Data Acquisition Plan. Signal range and accuracy for those tests or activities (e.g., Blast Vibration Monitoring) that employ autonomous readout and preprocessing systems which automatically record data on cassette tape or other recording media, for later down-loading to the site computers, are not included.

4.10.2 Data Sampling Schedules

Table 4-13 also presents proposed data sampling schedules for those testing/monitoring activities which fall under the Automatic Data Acquisition Plan. The purpose of establishing data sampling schedules is to ensure that data are collected on a sufficiently regular basis to provide adequate coverage of parameter changes without accumulating an unnecessarily large quantity of repetitive data. Data sampling schedules are formulated on the basis of the expected range of parameter value, the expected rate of change of parameter values, and the measurement accuracy. Data sampling schedules are necessary at this stage of planning to estimate the demands likely to be placed on automatic or manual data collection systems. However, these schedules are not intended to be final and will be reviewed, and modified if appropriate.

For those instruments that will be monitored by the Shaft ADAS Subsystem, data collection will begin as soon as possible after the installation of individual instruments or arrays of instruments has been completed. The data sampling schedule for instruments embedded in the concrete linings will depend upon the rate at which external loads are mobilized and the time-phased effects of concrete curing. It is anticipated that the majority of the external loads will develop over relatively long periods of time, with the possible exception of hydraulic and soil pressures which will develop after freezewall thawing. The initial sampling schedule is therefore primarily associated with monitoring the response of the linings during concrete curing. No theoretical analyses have been performed to date with regard to concrete curing. Nevertheless, it is assumed that maximum effects will be observed during the first seven days when concrete temperatures are likely to peak and strength gain rates decline.

For MPBXs used to monitor salt creep, one hour has been estimated for the initial data sampling rate, based on a combination of limited published data and expert judgement. As the creep rate decreases, the time between sampling sequential data sets will increase. This schedule is applicable to the transient creep phase, and when the steady-state creep phase starts, a new data sampling schedule will be established.

The sampling rates for piezometric monitoring have been developed from expert judgment of the transient ground-water pressure recovery following placement and sealing of each installation. For sand-packed piezometers installed at the interface between the preliminary concrete liner and the rockface in the unfrozen section of the shaft, pressure recovery will be delayed by (1) the need to resaturate the rock mass surrounding the installation, and (2) the overall scale of depressurization caused by shaft sinking. In lieu of detailed preanalysis for such repressurization scenarios in the shafts (see Appendix A.5), initial two-hour readings are considered sufficient to define the pressure recovery trend, with a pseudo-logarithmic transition to progressively longer time intervals consistent with most analytical methods for modeling pressure recovery in water-bearing strata.

Similar considerations apply to sand-packed piezometers in the frozen zone, except that short-term effects during setting of the concrete (e.g., heat of hydration causing ice to melt temporarily in a narrow zone adjacent to the lining) will merit frequent monitoring during the first five days. The data sampling schedule for other geomechanical and thermomechanical monitoring at the upper shaft arrays will therefore be used for these instruments.

Piezometer installations in boreholes drilled from the shafts will be monitored on a schedule similar to the one for sand-packed piezometers in the unfrozen shaft. Resaturation of the monitored interval will not be a problem as synthetic brine will be used to fill each interval if insufficient fluid is available from natural inflow. The low permeabilities anticipated around completion intervals are expected to result in slow equilibration to ambient groundwater pressures.

The data sampling schedules do not include routine maintenance and system self-test activities undertaken as part of the ADAS system operations. The ADAS will check that each component of the measurement systems is still working correctly by reading reference standards and by carrying out frequent sampling of the channels in order to search for data readings that exceed preset limits. These samplings will be integrated with the data sampling schedules.

All data sampling schedules for instruments monitored by the ADAS take effect from the moment installation of an isolated instrument or array of several instruments is completed, and the installation is designated as being "on-line." In this way all instruments for a given array are monitored simultaneously which facilitates comparison of data between individual instruments in the array. During the period between initial instrument connection to the ADAS and the time when the complete array installation is considered to have "come on-line," data will be displayed and viewed on visual display units continuously in order to assess signal stability during the installation period, and to assist in diagnosing faults.

For those instruments that are to be monitored by data loggers (i.e., instruments used in the Mechanical and Thermal Properties Studies, and in the Shaft Seal Study) the data sampling schedules are taken from the relevant test procedures. These schedules take into account the estimated duration of each test and the rate of change of measured parameter values during the test. During the test activity, data will be recorded on cassette tapes or other recording media. After completion of the testing activity data will be down-loaded to the ADAS computer in the Surface ADAS Center for storage in the ESF data base.

For those instruments that are to be monitored either by manual measurement or by autonomous readout and preprocessing systems, the data sampling schedules presented represent the times when measurements or surveys are to be carried out, and do not reflect the rate of data collection during the measurement or survey activity. After each series of measurements or survey is complete, the collected data will be transferred to the Surface ADAS Center for storage in the ESF database to facilitate data retrieval and analysis.

Data will be collected manually on data record sheets for Geologic Mapping, Core Sampling and Logging, and Ground Water Inflow Monitoring. These data will also be transferred to the Surface ADAS Center at regular intervals to facilitate data retrieval and analysis.

5.0 DATA MANAGEMENT

5.1 DATA MANAGEMENT STRATEGY

Details of the strategy for managing data and the methods of reporting data are currently in their initial stages of development by ONWI, pending development of overall program strategies. All original data and supporting documents generated by test activities will be transferred to the Data Management Group (DMG) for processing into Records Turnover Packages (RTPs). Table 5-1 provides a summary of the data documentation that will be generated and identifies the information that will be produced by each test described in Chapter 4.0. The schedule for transfer to the DMG will vary according to the test. Turnover will be scheduled by the DMG Task Leader, consistent with any program limitations on the maximum permissible period between data generation and turnover. As site activities proceed, the Task or Activity Leader for each test will provide the Data Management Group with data transfer schedules by completing a transfer notification and data description sheet. ADAS data will be handled in the same fashion as other tests and transferred to the DMG according to the schedule defined in the ADAS Plan.

Data will be inventoried at the time of transfer to the DMG and then inspected by the DMG to ensure that data are legible and complete. Unique identification labels will be applied to each test data document before the documents are duplicated. Following duplication, the original and duplicate documents will be stored by the DMG in separate approved storage areas to which access will be controlled. The procedures which will be used to control access to original and authenticated duplicate data are described in procedure DMP-2 "Storage and Control of Original and Authenticated Duplicate Data", (Golder Associates, 1986o). In general, it is anticipated that test personnel will make any copies of data necessary for internal use prior to transfer to the DMG; in addition, data recorded on magnetic media will be accessible through the ADAS data base, so that access to originals or authenticated duplicates will be required only in special circumstances. Requests for access to, or copies of, original or authenticated duplicate data maintained by the DMG will be made in writing with Project Manager approval to enable access to computing or duplication facilities to be scheduled. Items will be logged-out of the file and either duplicated or made available for inspection in the data management area under DMG personnel supervision. Upon completion of inspection or duplication, data management personnel will verify the unaltered nature of the materials and return them to the appropriate file.

The DMG will accept data in a variety of formats including magnetic tape or disk, photographs, standard format drawings and test record sheets, coding sheets, and graphic analogs. Standard format sheets are currently being developed as part of test procedure preparation. Other formats may be defined at a later date, and will be selected to meet program requirements. ADAS output will include both raw and processed data tapes, data reduction and conversion programs, and ADAS maintenance logs. Hard copy outputs of processed data and programs may also be produced if required.

Table 5-1. Data Documents Generated by Test or Activity

Test/Activity	Data Documents Generated by Test/Activity[1,2]	Supporting Data for Test/Activity	Information Produced by Test/Activity
SHAFT GEOLOGY STUDY			
1. Geologic Mapping	• Coding forms filled out with: the location and a description of the geologic features and sample localities, a note of the sample numbers, the location of special purpose photography, and a description of the excavation at the time of mapping. • Corrected hardcopy plots of the coded and processed information including rock mass classifications and contoured stereoplots. • Photographs of the mapped surfaces, including special purpose photographs of selected geologic features or materials. • A record of the visual inspection results for all samples collected in support of the geologic mapping program.	• The laboratory test results on selected samples. • Survey data giving locations of reference stations	• A comprehensive description, classification, illustration and characterization of the geology in both of the shafts. • Information for projecting the stratigraphy and structure of the rock beyond the limits of the excavation.
2. Core Logging and Sampling	• A written description of the borehole site and drill set-up. • Coded forms filled out with: the location and description of geologic features, quantitative data, the location of sampled intervals, and sample numbers. • Corrected hardcopy core log plots. • Photographs of the core.	• Laboratory test results on selected samples. • Survey data giving borehole collar locations.	• The geology at specific testing sites remote from the shaft. • Information for projecting the stratigraphy and structure of the host rock beyond the limits of the excavation.
SHAFT MECHANICAL AND THERMAL RESPONSE STUDY			
1. Shaft Convergence	• Completed installation record sheets. • A set of Data Record Sheets on to which entries will be made manually. These entries will be measurements of convergence between pairs of convergence reference points. These data will also be typed manually into the computer and stored as an ADAS file. • Graphical presentation of the variation of measured data with time.	• A copy of the project calibration and inspection sheets for each instruments.	• The location of each convergence reference point. • The convergence of the shaft with time.

Table 5-1. Data Documents Generated by Test or Activity

Test/Activity	Data Documents Generated by Test/Activity[1,2]	Supporting Data for Test/Activity	Information Produced by Test/Activity
2. Multiple Position Borehole Extensometers	For each instrument installed in the rock: • A completed installation of record sheet. • An ADAS file of the measured raw data. • Graphic presentation of the variation of measured data with time.	• A copy of the project calibration and inspection sheets for each instrument installed. • A copy of the borehole core log.	• The location of each anchor point within the rock mass. • The movement towards the shaft opening of various points within the strata with time relative to the borehole collar. • Temperature at the measurement location.
3. Steel Liner and Rebar Strain Measurement	• A completed installation record sheet. • An ADAS file of the raw data. • Graphic representation of the variation of measured data with time.	• A copy of the project calibration and inspection sheets for each instrument installed. • Laboratory test results of steel modulus determination.	• Instrument location. • Strain in the lining or reinforcement with time. • Temperature at the measurement location.
4. Concrete Liner Strain Measurement	• A completed installation record sheet. • An ADAS file of the raw data. • Graphic representation of the variation of measured date with time.	• A copy of the project calibration and inspection sheets for each instrument installed. • Laboratory test results of concrete modulus, density, and	• Instrument location. • Strain in the concrete liner with time. • Temperature at the measurement location.
5. Bitumen Pressure Measurement	• A completed installation record sheet. • An ADAS file of the raw data.	• A copy of the project calibration and inspection sheets for each instrument installed. • Laboratory bitumen density determinations.	• Instrument location. • Pressure in the bitumen layer with time. • Temperature at the measurement location.
6. Concrete Liner Stress and Support Ring Contact Stress Measurement	• A complete installation record sheet. • An ADAS file of the raw data. • Graphic representation of the variation of measured data with time.	• A copy of the project calibration and inspection sheets for each instrument installed. • Laboratory concrete modulus and density determinations.	• Instrument location. • Stress in the concrete lining or at support ring contact with time.
7. Piezometric Monitoring	• Completed installation record sheets. • Piezometer completion logs. • An ADAS file containing the raw measurement data. • Graphical presentation of the test data in the form of piezometer hydrographs.	• Completed installation logs. • Instrument calibration and inspection sheets.	• The location of the measurements within the rock mass. • The temperature at the test location. • Variations of the piezometric fluid pressures with time at the test location.

Table 5-1. Data Documents Generated by Test or Activity

Test/Activity	Data Documents Generated by Test/Activity[1,2]	Supporting Data for Test/Activity	Information Produced by Test/Activity
8. Temperature Monitoring	• A completed installation record sheet. • Completed instrument reading verification record sheets. • Graphical presentation of the measured data versus time. • An ADAS file containing the measured raw data.	• A project calibration and inspection certificate. • Copies of borehole logs. • Copies of laboratory and in situ thermal property data.	• The variation of temperature within the shaft linings and the surrounding rock mass.
9. Rock Bolt Mechanical Response	• A completed rockbolt installation record. • An ADAS file of the raw data. • Graphic representation of the variation	• A copy of the project calibration and inspection sheets for each instrument installed.	• The exact location of each test. • The variation of stress and strain in the instrumented rockbolt with time.
SHAFT MECHANICAL AND THERMAL PROPERTIES STUDY			
1. Absolute Stress Measurement (Overcoring)	• Completed test record sheets. • An ADAS file containing the raw data. • Graphical presentation of the raw test data.	• Copies of the pertinent borehole core logs. • The project calibration and inspection sheets for the instruments. • The laboratory test results for the elastic properties of the rock.	• The location of each overcore test within the rock mass. • The diametral deformation of an EX-borehole in three equispaced directions caused by stress relief in the surrounding rock during overcoring. • The orientation of the three measurement directions. • The temperature of the measuring instruments at the test location. • The secondary principal stresses at the measurement location.
2. Deformation Modulus Measurement	• Completed test record sheets. • Graphical presentation of the test data.	• A copy of the borehole corelogs. • The project calibration and inspection sheets for the instruments.	• The location of each deformation modulus measurement within the rock mass. • The diametral pressure-deformation curve for each test. • The orientation of loading. • The modulus of deformation for each test.

Table 5-1. Data Documents Generated by Test or Activity

Test/Activity	Data Documents Generated by Test/Activity[1,2]	Supporting Data for Test/Activity	Information Produced by Test/Activity
3. Seismic Velocity Survey	• Seismic noise records at all seismometer stations. • Seismometer response checks for pre-operational testing. • Test records. • Seismometer response checks for post-operational testing. • The seismic test log.	• Geological profile of test zones. • Project calibration and inspection sheets for the instruments.	• The vertical seismic velocity profile of the rock mass overlying the repository horizon around the shafts.
4. Thermal Conductivity Testing	• Completed test record sheets. • An ADAS file containing of the raw data.	• Copies of borehole survey logs. • Copies of borehole caliper logs. • Copies of borehole core logs. • Copies of the calibration and inspection sheets for the instruments and equipment. • The laboratory test results for specific heat and density of recovered core.	• The exact position of the test within the rock mass. • The rate of temperature increase per unit power at the test location. • The in situ thermal conductivity of the rock in the vicinity of the test.
SHAFT SEAL STUDY			
1. Groundwater Inflow Monitoring	• A completed installation record sheet. • A completed activity record sheet. • Graphical presentation of the raw test data.	• A copy of the Geological Mapping results at the test location.	• The location, rate and variation of monitored inflow of groundwater to the shaft as excavation proceeds.
2. Permeability Testing	• A completed installation record sheet. • An ADAS file containing the raw test data. • A completed test record sheet. • Graphical presentation of the raw test data.	• A copy of the borehole drilling records. • A copy of the borehole core logs. • A copy of the borehole geophysical test logs. • Instrument calibration sheets and equipment performance records.	• The location of the test within the rock mass. • The temperature of the instruments at the test location. • The continuous variation of fluid flow and pressure in the test interval and guard zones at that location. • The in situ permeability of the rock in the vicinity of the test.

Table 5-1. Data Documents Generated by Test or Activity

Test/Activity	Data Documents Generated by Test/Activity[1,2]	Supporting Data for Test/Activity	Information Produced by Test/Activity
3. Piezometric Monitoring	• Completed installation record sheets. • Piezometer completion logs. • An ADAS file containing the raw measurement data. • Graphical presentation of the test data in the form of Piezometer hydrographs.	• Completed borehole core logs. • Results of single-hole permeability tests carried out in the same borehole. • Instrument calibration and inspection sheets.	• The location of the measurements within the rock mass. • The temperature of the instruments at the test location. • Variation of the piezometric fluid pressures with time at that location.
4. Formation Fluid Sampling	• A written description of the sampling site and the equipment arrangement. • A completed installation record sheet (where appropriate). • A completed sampling record sheet.	• Equipment calibration sheets. • Laboratory test results of chemical analyses.	• None directly.
SHAFT CONSTRUCTION SUPPORT STUDY			
1. Blast Vibration Monitoring	• Seismometer response checks for pre-operational test. • Vibration records. • Seismometer response checks for post-operational test. • A vibration monitoring log.	• A record of the shaft vibration noise prior to the test. • Record of blasting including location, pattern details, charge weights, delay types and intervals.	• The particle velocities in three orthogonal directions generated by construction blasts.
2. Rock Bolt Pull-out Testing	• A completed rockbolt installation record. • A completed test record sheet. • An ADAS file containing the measured raw test data.	• Instrument calibration and inspection sheets.	• The exact location of the test. • The short-term load capacity of the rock-bolt.

Notes:

[1] An "ADAS file" refers to any computer-compatible storage medium on which data are stored in one or more blocks and can be retrieved by some other automated hardware system. For example, an ADAS file may be one or more computer-generated data files that are stored on magnetic tape. Another example is a microprocessor generated data file stored on cassette tape by a data logger. Neither electronic notebooks nor battery backed or programmable memory chips used in some kinds of compact data recorders, are considered primary data records.

[2] Instrument and ADAS maintenance/calibration logs may be paper records or ADAS files that document periodic inspections and calibrations of installed equipment. Portable electronic readout units are not considered primary data records since data from these units will either be recorded as paper records at the test site, or will be transferred to ADAS files by automatic downloading or by entering displayed data through a computer keyboard.

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5.2 DATA REPORTING

In addition to the routine compilation and submittal of Records Turnover Packages, the DMG will coordinate the production of Shaft Study Data Reports. These reports will contain summaries of all shaft study data collected up to the time of report production.

Following an Introduction and a Summary of Construction and Testing during the period covered by the report, summaries of the data for each instrument monitored will be presented. These summaries will generally be in graphical form, with the data expressed in engineering units on a time base. Each graph will be accompanied by an index of data sources used in compiling the plot, identified by Data Document Label. The summaries will be presented in the following five categories:

- Shaft Geology Data Summary
- Shaft Mechanical and Thermal Response Data Summary
- Shaft Mechanical and Thermal Properties Data Summary
- Shaft Seal Data Summary
- Shaft Construction Data Summary.

Within each category, the data will be presented by instrument or test type.

The schedule of report production will depend on program requirements with respect to project milestones, and to some extent on the data generation rate and overall project activities. A tentative schedule would be to produce reports monthly during shaft sinking and lining, when instrument installation activities would be at their height, and quarterly thereafter. Additional information regarding scheduling of data reports is presented in the following Chapter 6.0, Schedules and Milestones.

6.0 SCHEDULE AND MILESTONES

The shaft study program, described in Section 4.0, will be performed in the shafts constructed at the Deaf Smith County, Texas site. The shaft excavation schedule, prepared by the Construction Manager, has previously been presented in Section 2.4 and forms the basis of the integrated testing schedule described below.

6.1 STUDY SCHEDULE

The study schedule has been estimated using sinking and lining rates extracted from Figure 2-17 and test installation and monitoring times presented in Sections 4.3 through 4.7. Sinking and lining rates have been adjusted for time required for geologic mapping and are shown in Table 6-1. Summary schedules have been estimated for each of the ESF shafts in Sections 6.1.1 and 6.1.2. These estimates incorporate the following assumptions:

1. The shaft collar will be excavated and permanently lined to a depth of 90 ft (27 m). No instrumentation is currently shown in the shaft collar area; this aspect of the work is being discussed with the ESF A/E and will be included as appropriate, in future SSP updates.

2. Instruments and test boreholes will be installed at the locations shown on the Appendix B drawings, requiring intermittent test equipment installation and shaft excavation/lining. No allowance has been made at this time for intermittent activities. A detailed schedule will be prepared as part of network development discussed in Chapter 7.0, and will be incorporated in future updates to this SSP.

3. The shaft will be excavated approximately 10 ft (3 m) below the base for each Foundation/Support Ring to provide room for the support ring DCU.

4. Operational and Decommissioning Seal Testing will be carried out after completion of the ESF shafts. All other monitoring and testing activities will be carried out during shaft construction.

5. All Mechanical and Thermal Properties testing will be conducted in Shaft No. 1. This decision is based on the understanding that the connecting drift will be mined from Shaft No. 2, and that this activity can be performed prior to completion of Shaft No. 1.

Due to the preliminary status of the shaft designs and the absence of a detailed construction schedule, only a limited effort has been applied to integrating the testing and construction schedule. Detailed networks will be developed for each shaft once the designs are finalized and a detailed construction sequence has been prepared.

Table 6-1. Shaft Excavation and Lining Rates

Length of Shaft[a] Excavated or Lined (from Figure 2-17) ft	(m)	Activity	Total Time Allocated[b] days	Average Production ft/day	(m/day)	Time For Geologic Mapping[a] days	Total Prorated Production Rate ft/day	(m/day)
937	(286)	Sink/Preliminary Line Frozen Zone	141	6.64	(2.02)	20[c]	5.83	(1.78)
22	(7)	Foundation Key	7	3.14	(0.96)	1[d]	2.78	(0.85)
947	(289)	Final Line Upper Shaft	65	14.57	(4.44)	--	14.57	(4.44)
1409	(430)	Sink/Preliminary Line Lower Shaft	228	6.18	(1.88)	29[c]	5.47	(1.67)
22	(7)	Foundation Key	7	3.14	(0.96)	1[d]	2.78	(0.85)
1424	(434)	Final Line Lower Shaft	143	9.96	(3.04)	--	9.96	(3.04)
109	(33)	Bald Excavation	24	4.54	(1.38)	2[c]	4.15	(1.27)
140	(43)	Station Excavation	14	10.00	(3.05)	3[c]	8.27	(2.52)

[a] Depths based on Title I drawings and PR estimate.

[b] Time allocated from Table 2-17 assuming 7 work days per week.

[c] Assumes mapping rate of 48 ft/day (14.6 m/day) with no unproductive time.

[d] Assumes mapping rate of 24 ft/day (7.3 m/day) with no unproductive time.

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6.1.1 Summary Schedule - Shaft No. 1

The estimated schedule for excavation/lining/instrumentation and testing in Shaft No. 1 is shown in Table 6-2, and summarized below:

- Start Shaft Sinking from Collar — Day 0
- Complete Excavation and Preliminary Lining in the Upper Shaft — Day 182
- Complete Upper Foundation Construction — Day 194
- Complete Final Lining in the Upper Shaft — Day 274
- Complete Excavation and Preliminary Lining in the Lower Shaft — Day 605
- Complete Lower Foundation Construction — Day 617
- Complete Final Lining in the Lower Shaft — Day 783
- Complete Excavation to the Shaft Station Elevation — Day 815
- Complete Shaft Station Excavation — Day 823
- Complete Shaft No. 1 Construction — Day 846

6.1.2 Summary Schedule - Shaft No. 2

The estimated schedule for excavation/lining/instrumentation and testing in Shaft No. 2 is shown in Table 6-3, and summarized below.

- Start Shaft Sinking from Collar — Day 0
- Complete Excavation and Preliminary Lining in the Upper Shaft — Day 177
- Complete Upper Foundation Construction — Day 189
- Complete Final Lining in the Upper Shaft — Day 262
- Complete Excavation and Preliminary Lining in the Lower Shaft — Day 512
- Complete Lower Foundation Construction — Day 524
- Complete Final Lining in the Lower Shaft — Day 673
- Complete Excavation to the Shaft Station Elevation — Day 705

Table 6-2. Shaft No. 1 Excavation and Instrumentation/ Monitoring Schedule

From Depth (ft)	To Depth (ft)	Activity	Duration (Days)	Cumulative Elapsed Time (Days)
90	335	Excavate and Preliminary Line	42.0	42.0
	335	Install Type IIa Array	3.2	45.2
335	345	Excavate and Preliminary Line	1.7	46.9
	345	Install Type IId Array	0.9	47.8
345	745	Excavate and Preliminary Line	68.6	116.4
	745	Install Type IIa Array	3.2	119.6
745	960	Excavate and Preliminary Line	36.9	156.5
	960	Install Type IIa Array	3.7	160.2
960	1030	Excavate and Preliminary Line	12.0	172.2
1030	1055	Large-Diameter Coring	1.5	173.7
1030	1050	Excavate	3.4	177.2
1050	1065	Large-Diameter Coring	1.2	178.4
1050	1070	Excavate	3.4	181.8
	1050	Install Type Ia Array	5.5	187.3
1057	1045	Construct Foundation/Support Ring	7.0	194.3
1045	960	Construct Final Lining	5.8	200.1
	960	Install Type IIa Array	4.5	204.6
960	745	Construct Final Lining	14.8	219.4
	745	Install Type IIa Array	4.5	223.9
745	500	Construct Final Lining	16.8	240.7
	500	Install Pull-Box	0.8	241.5
500	335	Construct Final Lining	11.3	252.8
	335	Install Type IIa Array	4.5	257.3
335	90	Construct Final Lining	16.8	274.1
90	1070	Complete ADAS	2.0	276.1
	1070	Install Ib Array	0.4	276.5
	1070	Install Oper. Seal Monitoring Boreholes	4.0	280.5
1070	1118	Excavate and Line Lower Shaft	8.8	289.3
	1110	Absolute Stress Measurement	10.7	300
	1110	Deformation Moduli Measurement	3.0	303
	1110	Install Decomm. Seal Monitoring Boreholes	2.3	305.3
	1118	Install Type IIb Array	2.6	307.9
1118	1210	Excavate and Preliminary Line	16.8	324.7
	1210	Install Type IIb Array	4.8	329.5
1210	1390	Excavate and Preliminary Line	32.9	362.4
	1390	Install Type IIb Array	2.6	365
1390	1600	Excavate and Preliminary Line	38.4	403.4
	1600	Absolute Stress Measurement	10.7	414.1
	1600	Deformation Moduli Measurement	3.0	417.1
	1600	Install Decomm. Seal Monitoring Boreholes	2.3	419.4
1600	1670	Excavate and Preliminary Line	12.8	432.7

Table 6-2. Shaft No. 1 Excavation and Instrumentation/ Monitoring Schedule

From Depth (ft)	To Depth (ft)	Activity	Duration (Days)	Cumulative Elapsed Time (Days)
	1670	Install Type IId Array	0.7	432.9
1670	1800	Excavate and Preliminary Line	23.8	456.7
	1800	Install Type IIb Array	4.8	461.5
1800	1950	Excavate and Preliminary Line	27.4	488.9
	1950	Install Type IIb Array	2.6	491.5
1950	2150	Excavate and Preliminary Line	36.6	528.1
	2150	Absolute Stress Measurement	10.7	538.8
	2150	Deformation Moduli Measurement	3.0	541.8
	2150	Install Decomm. Seal Monitoring Boreholes	2.3	544.1
2150	2200	Excavate and Preliminary Line	9.1	553.2
	2200	Install Type IIb Array	5.2	558.4
2200	2272	Excavate and Preliminary Line	13.2	571.6
	2272	Thermal Conductivity Test	4.0	575.6
2272	2285	Excavate and Preliminary Line	2.4	578
	2285	Thermal Conductivity Test	4.0	582
2285	2342	Excavate and Preliminary Line	10.4	592.4
	2342	Thermal Conductivity Test	4.0	596.4
2342	2367	Large-Diameter Core Sampling	1.5	597.9
2342	2380	Excavate	6.9	604.8
	2360	Install Type Ia Array	4.8	609.6
2370	2357	Construct Foundation/Support Ring	7.0	616.6
	2350	Install Type Ib Array	3.9	620.5
	2350	Install Oper. Seal Monitoring Boreholes	4.0	624.5
2357	2200	Final Lining Lower Shaft	15.8	640.3
	2200	Install Type IIb Array	5.3	645.6
2200	1950	Final Lining Lower Shaft	25.1	670.7
	1950	Install Type IIb Array	3.5	674.2
1950	1800	Final Lining Lower Shaft	15.1	689.3
	1800	Install Type IIb Array	4.0	693.3
1800	1500	Final Lining Lower Shaft	30.1	723.4
	1500	Install Pullbox	0.8	724.2
1500	1390	Final Lining Lower Shaft	11.0	735.2
	1390	Install Type IIb Array	2.7	737.9
1390	1210	Final Lining Lower Shaft	18.1	756
	1210	Install Type IIb Array	3.2	759.2
1210	1118	Final Lining Lower Shaft	9.2	768.4
	1118	Install Type IIb Array	2.7	771.1
1118	1060	Final Lining Lower Shaft	5.8	777
	1060	Install Type Ib Array	3.8	780.8
1060	2370	ADAS Completion	2.0	782.8
2380	2390	Excavate Lower Shaft	2.4	785.2
	2390	Install Type IIc Array	2.8	788
2390	2445	Excavate Lower Shaft	13.3	801.2

Table 6-2. Shaft No. 1 Excavation and Instrumentation/ Monitoring Schedule

From Depth (ft)	To Depth (ft)	Activity	Duration (Days)	Cumulative Elapsed Time (Days)
	2445	Install Type IIc Array	3.7	804.9
2445	2470	Large Diameter Coring	1.5	806.4
2445	2465	Excavate Lower Shaft	4.8	811.2
2465	2495	Large Diameter Coring	1.5	817.7
2465	2475	Excavate Lower Shaft	2.4	815.1
	2475	Excavate Shaft Station	4.0	819.1
	2475	Install Type A Array	3.4	822.5
2475	2495	Large Diameter Coring	1.3	815.1
2475	2495	Excavate Lower Shaft	4.8	827.4
	2495	Install Type IIc Array	2.8	830.2
2495	2555	Excavate Lower Shaft	14.5	844.6
	2555	Install Type Id Array	1.7	846.3
		Complete Shaft Connection		
		Complete Shaft Oper. Seal Tests	28.0	
		Complete Decommissioning Seal Tests	24.0	

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Table 6-3. Shaft No. 2 Excavation and Instrumentation/ Monitoring Schedule

From Depth (ft)	To Depth (ft)	Activity	Duration (Days)	Cumulative Elapsed Time (Days)
90	335	Excavate and Preliminary Line	42.0	42.0
	335	Install Type IId Array	1.4	43.4
335	345	Excavate and Preliminary Line	1.7	45.1
	345	Install Type IId Array	0.9	46.0
345	960	Excavate and Preliminary Line	105.5	151.5
	960	Install Type IIa Array	3.7	155.2
960	1030	Excavate and Preliminary Line	12.0	167.2
1030	1055	Large Diameter Coring	1.5	168.1
1030	1050	Excavate	3.4	172.2
1050	1065	Large Diameter Coring	1.2	173.4
1050	1070	Excavate	3.4	176.8
	1050	Install Type Ia Array	5.5	182.3
1057	1045	Construct Foundation/Support Ring	7.0	189.3
1045	960	Construct Final Lining	5.8	195.1
	960	Install Type IIa Array	4.5	199.6
960	500	Construct Final Lining	31.6	231.2
	500	Install Pull Box	0.8	232
500	90	Construct Final Lining	28.1	260.1
90	1070	Complete ADAS	2.0	262.1
	1060	Install Ib Array	0.4	262.5
1070	1500	Excavate and Line Lower Shaft	78.6	341.2
	1500	Install Pull Box	0.7	341.9
1500	1950	Excavate and Line Lower Shaft	82.3	424.1
	1950	Install Type IIb Array	2.6	426.7
1950	2200	Excavate and Line Lower Shaft	45.7	472.4
	2200	Install Type IIb Array	4.9	477.3
2200	2340	Excavate and Line Lower Shaft	25.6	502.9
2340	2370	Large Diameter Coring	1.5	504.4
2340	2380	Excavate	7.3	511.7
	2360	Install Type Ia Array	4.8	516.5
2370	2357	Construct Foundation/Support Ring	7.0	523.5
	2350	Install Type Ib Array	3.5	527
2357	2200	Final Lining Lower Shaft	15.8	542.8
	2200	Install Type IIb Array	5.5	548.3
2200	1950	Final Lining Lower Shaft	25.1	573.4
	1950	Install Type IIb Array	3.5	576.9
1950	1500	Final Lining Lower Shaft	45.2	622.1
	1500	Install Pull Box	0.7	622.8
1500	1060	Final Lining Lower Shaft	44.2	667.0
	1060	Install Type Ib Array	3.8	670.8
1060	2370	ADAS Completion	2.0	672.8

Table 6-3. Shaft No. 2 Excavation and Instrumentation/ Monitoring Schedule

From Depth (ft)	To Depth (ft)	Activity	Duration (Days)	Cumulative Elapsed Time (Days)
2380	2390	Excavate Lower Shaft	2.4	675.2
	2390	Install Type IIc Array	2.8	678
2390	2445	Excavate Lower Shaft	13.3	691.2
	2445	Install Type IIc Array	3.7	694.9
2445	2470	Large Diameter Coring	1.5	696.4
2445	2465	Excavate Lower Shaft	4.8	701.2
2465	2495	Large Diameter Coring	1.5	702.7
2465	2475	Excavate Lower Shaft	2.4	705.1
	2475	Excavate Shaft Station	4.0	709.1
	2475	Install Type A Array	3.4	712.5
2475	2495	Excavate Lower Shaft	4.8	717.4
	2495	Install Type IIc Array	2.8	720.2
2495	2555	Excavate Lower Shaft	14.5	734.6
	2555	Install Type Id Array	1.7	736.3

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- Complete Shaft Station Excavation — Day 713
- Complete Shaft No. 2 Construction — Day 736

6.2 MILESTONES

A key study milestone schedule will be established in conjunction with network development and ongoing study plan and test procedure preparation. Key Shaft Study Plan milestones fall into nine major categories:

1. Shaft Study Plan (WBS Element 6.9.4): A Shaft Study Plan (Revision 0) is planned for completion during late FY87. Subsequent revisions will be required to incorporate site-specific geotechnical data and final repository and ESF designs. It is anticipated that these revisions will be submitted annually.

2. Test Procedures (WBS Element 6.9.3): A detailed list of test procedure deliverables associated with the Shaft Study Plan is contained in Table 6-4. This list will be updated annually as test planning continues.

3. Test Personnel Training and Certification: This category of deliverables will contain documentation of required indoctrination and training of test personnel with regard to use of the test procedures and documentation of any required safety training in preparation for the underground work.

4. Test Equipment Purchasing: A detailed test equipment purchasing schedule will be developed in conjunction with network development for all capital equipment required for testing and monitoring in the exploratory shafts. A separate schedule will be developed for ADAS equipment in the Automatic Data Acquisition Plan (Golder Associates, 1987b).

5. Instrument and Equipment Calibration Schedule: Detailed calibration procedures will be developed as part of the Instrument Qualification Program (WBS Element 6.9.1.4). A detailed schedule for shaft instrumentation calibration, to be carried out at the Deaf Smith County UTC facilities, will be prepared in conjunction with network development.

6. Sample Deliverables: Samples will be retrieved from test boreholes (E- and N-size core), Large-Diameter Vertical Coring (12-in-diameter core), Geologic Mapping (grab samples), Ground-Water Inflow Monitoring (disturbed formation fluids), Seal Testing (relatively undisturbed formation fluids), and Construction/Operations Monitoring (construction materials).

   A sample deliverable schedule will be developed in conjunction with network development. In the interim, a tentative schedule, based on the information presented in Tables 6-2 and 6-3, is shown in Table 6-5.

Table 6-4. Shaft Instrumentation and Monitoring Test Procedures

Shaft Test Procedure Name	WBS Number	Scheduled[b] Completion Date
GEOLOGIC TEST PROCEDURES	6.9.3.1	
Geologic Mapping	6.9.3.1.1	July 1986
Drilling Supervision		September 1986
Core Sampling and Logging	6.9.3.1.2	September 1986
GEOMECHANICAL TEST PROCEDURES	6.9.3.2	
Absolute Stress Measurement	6.9.3.2.1	December 1986
NX Borehole Jack	6.9.3.2.2	August 1986
Rock Bolt Pullout Test	6.9.3.2.4	FY88
Stress Change Monitoring	6.9.3.2.5	
- Bitumen Pressure Cell		May 1987
- Embedment Stress Cell		July 1987
Convergence Monitoring	6.9.3.2.6	August 1986
MPBX Installation and Monitoring	6.9.3.2.7	August 1986
Strain Monitoring	6.9.3.2.9	
- Steel Liner Welded VWSG		June 1987
- Re-bar VWSG		FY88
- Embedded Concrete VWSG		June 1987
Jointmeter Monitoring	6.9.3.2.10	FY88
Surveying	6.9.3.2.11	FY88
Rock Bolt Mechanical Response Monitoring	6.9.3.2.12	FY88
THERMOMECHANICAL TEST PROCEDURES	6.9.3.3	
Thermal Conductivity Testing	6.9.3.3.1	August 1986
Shaft Temperature Monitoring	6.9.3.3.2	October 1986
GEOHYDROLOGICAL TEST PROCEDURES	6.9.3.4	
Single Borehole Hydraulic Conductivity	6.9.3.4.1	August 1986
Cross-Hole Hydraulic Conductivity	6.9.3.4.2	September 1987
Cross-Hole Tracer Testing	6.9.3.4.3	FY88
Piezometric Monitoring	6.9.3.4.6	July 1987
Ground-Water Inflow Monitoring	6.9.3.4.7	FY88
Formation Fluid Sampling	6.9.3.4.8	August 1987

Table 6-4. Shaft Instrumentation and Monitoring Test Procedures

Shaft Test Procedure Name	WBS Number	Scheduled[b] Completion Date
OTHER TEST PROCEDURES	6.9.3.5	
Construction/Operations Monitoring	6.9.3.5.1[a]	FY88

a Activity may be carried out by Construction Manager.

b Schedule is for Final Draft Test Procedures. Completion of Test Procedures is dependent upon test development schedule and overall FY funding.

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Table 6-5. Test Start and Completion Schedule[a]

Test or Activity	Shaft No. 1 First Completion	Shaft No. 1 Last[b] Completion	Shaft No. 2 First Completion	Shaft No. 2 Last[b] Completion	Approximate Timing of First Data Report	Approximate Timing of First Topical Report	Approximate Timing for First Samples
SHAFT GEOLOGY STUDY							
Geologic Mapping	2	845	2	735	30	NA	2
Core Logging and Sampling (N-size, frozen)	45	160	155	NA	75	NA	45
(N-size, salt)	330	830	477	720	360	NA	330
(N-size, non-salt)	281	625	427	NA	310	NA	281
(L-size, non-salt)	576	596	NA	NA	610	NA	576
SHAFT MECHANICAL AND THERMAL RESPONSE STUDY							
Shaft Convergence	2	830	2	720	30	NA	NA
MPBX Measurements	330	830	477	720	390	NA	NA
Steel Lining and Re-bar Strain Measurements	187	781	189	671	250	NA	NA
Concrete Lining Strain Measurements	45	781	155	671	105	NA	NA
Bitumen Pressure Measurements	205	257	200	NA	265	NA	NA
Concrete Lining Stress Measurements	45	781	155	671	105	NA	NA
Support Ring Contact Stress Measurements	194	617	189	523	250	NA	NA
Piezometric Measurements	45	846	43	477	105	NA	NA
Shaft Bottom Plug Stress/Strain Measurements	846		736		800	NA	NA
Lining and Rock Mass Temperatures	45	771	155	577	75	NA	NA
Rock Bolt Performance Measurements	785	823	695	713	730	NA	NA
SHAFT MECHANICAL AND THERMAL PROPERTIES STUDY							
Absolute Stress Measurement	300	539	(Note d)	(Note d)	330	600	NA
Deformation Moduli Measurement	303	542	(Note d)	(Note d)	335	600	NA
Seismic Velocity Measurement	2	845	2	735	30	800	NA
Thermal Conductivity Measurement	576	596	(Note d)	(Note d)	610	660	NA
Large-Diameter Coring	174	818	169	703	200	NA	169
SHAFT SEAL STUDY							
Ground-Water Inflow Measurements	300	NA	280	NA	310	NA	280
Permeability Measurements (Operational Seals)	(Note c)	(Note c)	(Note d)	(Note d)	(Note c)	(Note c)	NA
Permeability Measurements (Decommissioning Seals)	(Note c)	(Note c)	(Note d)	(Note d)	(Note c)	(Note c)	NA
Piezometric Measurements (Operational Seals)	281	(Note c)	(Note d)	(Note d)	310	(Note c)	NA
Piezometric Measurements (Decommissioning Seals)	305	(Note c)	(Note d)	(Note d)	340	(Note c)	NA
Formation Fluid Sampling	(Note c)	(Note c)	(Note d)	(Note d)	(Note c)	(Note c)	(Note c)
SHAFT CONSTRUCTION SUPPORT STUDY							
Blast Vibration Measurements	2	(Note e)	2	(Note e)	30	890	NA
Rock Bolt Pullout Tests	784	815	675	705	685	837	NA

(a) Schedule in days from start of shaft construction below shaft collar.
(b) Timing reflects last installation or sample recovery. Monitoring will continue until program requirements are satisfied.
(c) Testing to be started after shaft construction completion.
(d) Testing to be performed in Shaft No. 1 only.

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7. Raw Data Deliverables: Raw data deliverables (see Table 5-1) will be scheduled on a regular, periodic basis following initiation of the shaft testing and monitoring program. The precise schedule will be determined by program requirements (e.g., schedule for preparation of DEIS, FEIS, and LA) and is currently unknown.

8. Data Report Deliverables: Data reports (see Section 5.2) will be produced monthly during shaft construction and quarterly thereafter. Other topical reports (e.g., Absolute Stress Measurement, Deformation Moduli Measurement) will be produced on a schedule determined by the test completion dates discussed in 5. above.

9. Records Turnover Packages: Records turnover packages will be scheduled annually.

6.3 CONCURRENT STUDIES

The major part of the shaft study program will be executed concurrently with shaft sinking; therefore, no opportunities for concurrent testing exist. However, based on the current distribution of testing and monitoring activities in the two shafts, Shaft No. 2 will be completed approximately 110 days before Shaft No. 1. This may permit initiation of construction of the connecting airway and limited At-Depth testing prior to completion of Shaft No. 1.

7.0 ORGANIZATION/MANAGEMENT

A project organization has been developed to manage and execute the overall Underground Testing Program currently described in the Underground Test Plan (Golder Associates, 1986a). This Chapter provides a summary of the key elements of the UTC organization and describes the process of managing the Shaft testing and monitoring program. UTC manpower estimates are presented based on the testing program described in Section 4.4. It is anticipated that estimates of support manpower required from the Construction Manager (CM) and Mining Subcontractor (MSC) will be prepared by the CM based on the requirements presented in Section 4.8.

7.1 ORGANIZATION AND MANPOWER REQUIREMENTS

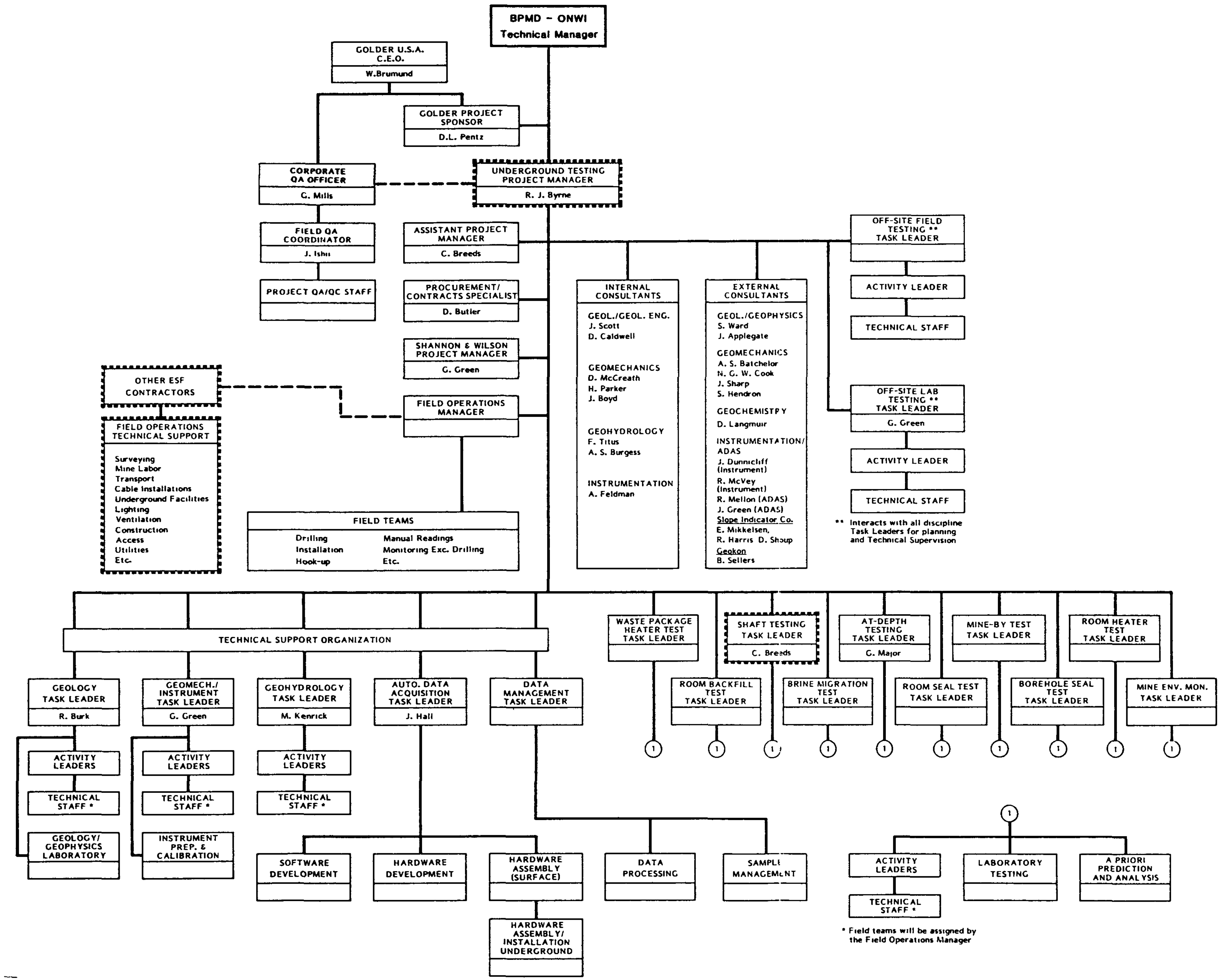
7.1.1 Underground Testing Contractor (UTC) Organization

A Project Management Plan which describes the systems, procedures and overall plans to be used in performing in situ testing in the ESF has been prepared by Golder Associates (1986n). The field project organization for the Underground Testing Contractor (UTC), including those personnel already assigned to the project, is shown in Figure 7-1. The responsibilities of the key personnel in this organization are as follows:

- Underground Testing Project Manager: Responsible for overall direction of project, including both the technical and management requirements of the testing. He will be the principal Underground Testing Contractor interface with the ONWI Technical Manager. Qualifications for this position will include a strong technical background in all aspects of in situ testing and broad project management experience.

- Field Quality Assurance Coordinator: Will manage the receiving inspection, surveillance inspection, document control, quality auditing, and related QA/QC staff and will be directly answerable to the Corporate Quality Assurance Officer. This position requires specialized qualification in Quality Assurance, and familiarity and experience with Golder Associates' Quality Assurance Program.

- Field Operations Manager: Responsible for management of all field activities, control of field support teams, and scheduling of testing within the ESF. Will interface with other ESF contractors, particularly the Construction Manager, to coordinate support activities by these groups. He will be experienced in the organization and management of engineering field programs.



Project Organization

Figure 7-1

- Task Leader: The Shaft Testing Task Leader will manage the monitoring and testing program defined in this Study Plan. The Task Leader's responsibilities will include:

  - Technical direction of the program, its scheduling, and approving any changes to test layouts and procedures.

  - Test documentation and report preparation.

  - Reporting to the UTC Project Manager any significant variations in test procedures or unexpected test results.

  The qualifications of the Shaft Testing Task Leader will include a strong technical background and experience with in situ testing and detailed knowledge of the overall Underground and Shaft Study Programs.

- Activity Leaders: Will be responsible for supervising the individual work packages identified in the Study Plan. They will be members of the Technical Support Organization delegated by the Field Operations Manager to supervise and, in some cases, perform specific technical support services for the Task Leader. The Activity Leader will report directly to the Task Leader and will direct the activities of the other personnel participating in the activity. His areas of responsibility include verifying the qualifications of other personnel assigned to the activity and, if necessary, conducting personnel training sessions; verifying that all equipment is functional and has been calibrated in conformance with QA requirements; determining exact test or instrument locations based on criteria established in the Study Plan; determining the appropriate course of action for any contingencies that may arise during the activity; arranging for, and supervision of, drilling required for the activity; arranging for the test equipment and its transportation to the test site; ensuring that the appropriate Test Procedures and Quality Assurance Procedures are followed during the activity; sample management; maintaining test records, reporting test progress, and performing data reduction and analysis as specified in the Test Procedure; notifying the Task Leader of any significant difficulties or unexpected test results; and supervising the removal of equipment at the completion of the test. The Activity Leader will have technical qualifications in the field of the activity.

- Technical Support Organization: Will provide the qualified professional personnel for the installation, performance, and monitoring of the tests. Professionals on the team will include:

  - Geologists and geophysicists
  - Geomechanical instrumentation specialists
  - Geohydrologists
  - Data acquisition and data management specialists

Each technical discipline will be headed by a Task Leader, who will be responsible for the technical activities of the professionals within that discipline.

- Field Operations Technical Support: Will be supplied by other ESF contractors to provide the services required in support of the testing program (see Section 4.8). This will include:

  - Surveying for layout, general location, and some borehole orientations
  - Excavation and construction
  - Utility installation
  - Lighting
  - Transportation
  - Labor
  - Facility maintenance and repair.

7.1.2 Manpower Requirements

During shaft construction, a variety of technical and support personnel will be required to perform instrument installation and other testing activities. These manpower requirements are discussed in detail below and are summarized in Table 7-1. For these estimates, it has been assumed that (1) both shafts are constructed concurrently, (2) construction will be performed around the clock, seven days per week, and (3) shaft sinking/preliminary lining/testing schedule is as described in Chapter 6.0. The following types of personnel will be required during shaft construction and for subsequent testing/monitoring activities in the shaft:

- Geologic Mapping: During shaft sinking, an eight-person team will be required to perform shaft wall mapping. This team consists of one geologic activity leader, one geologic lab technician, and three two-person mapping crews.

- Blast Vibration Monitoring/Seismic Surveying: A two-person team will be needed during shaft sinking to install monitoring seismometers at designated locations in the shafts and to operate the monitoring equipment.

- Instrumentation/Testing: During both shaft sinking and final lining, the installation of mechanical response monitoring stations will require a four-person installation crew in the shaft at one time. Since this activity is relatively infrequent, it is assumed that two four-person crews will be able to accomplish the installation by working alternating 12-hour shifts. An activity leader will also be required, bringing the total team size to nine. Between periods of installation activity in the shafts, this group will perform (1) instrument acceptance and calibration testing, (2) instrument preparation for installation, (3) manual instrument readings as necessary, and (4) any in-line testing activities, such as stress measurement or thermal conductivity testing, required during shaft sinking.

Table 7-1. Summary of Manpower Requirements for Shaft Instrumentation and Testing

Function	Required Number of Persons
Geologic Mapping	8
Blast Vibration Monitoring/Seismic Surveying	2
Instrumentation/Testing	9
ADAS	5
Data Management	2
Data Reporting	2
Documentation	2
Site Management Personnel	5
Warehousing/Workshop	2
General Support	3
Total	40

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- ADAS: In conjunction with geotechnical instruments at each measurement level, automatic data acquisition equipment such as junction boxes and DCUs will also be installed. In addition, connections between the instruments and the ADAS will be made and tested. These activities will require a two-person crew in the shaft at one time. As for instrument installation, two crews will work alternating 12-hour shifts during these critical periods, with an activity leader bringing the team size to five. Between periods of installation activity in the shafts, this team will prepare and assemble ADAS equipment for future installations.

- Data Management: A two-person team is needed to perform data management activities related to shaft testing and monitoring; their responsibilities will include ensuring that the shaft data is correctly entered into the overall ESF data management system.

- Data Reporting: A two-person crew will be required to prepare periodic reports on data from instruments and testing activities in the shafts. These personnel will be assisted by test personnel and activity leaders under the direction of the Shaft Testing Task Leader.

- Documentation: A two-person crew will be necessary to provide a documentation function (e.g., as-installed drawings) during shaft construction.

- Site Management Personnel: Ultimate technical control of the field activities will be performed by a small group of senior personnel. During shaft construction, this group will consist of the Field Operations Manager and Task Leaders in the areas of Shaft Monitoring and Testing, ADAS, Geology/Hydrology, and Geomechanics, for a total of five persons.

- Warehousing and Workshop: Two persons will be needed to control the storage of equipment and instrumentation at the site, and to provide support in the areas of machining, welding, etc.

- General Support: A group of three persons will be required to provide general services, including secretarial, clerical, drafting, etc., to support the technical teams.

7.2 SAMPLE MANAGEMENT

7.2.1 Sample Control

Test Procedures identify the appropriate method of collection, processing, and testing of samples. At the completion of testing (if required), or when the sample material is no longer needed by the test personnel, all remaining sample material will be transported to a single site for storage and/or disposal. Approved procedures will be utilized for sample control. Any special requirements will be referenced in individual Test Procedures and/or procedures prepared by the laboratory testing contractor or other appropriate end-user.

7.2.2 Responsibilities

The Activity Leader will be responsible for proper identification, inspection, labeling, boxing, and interim storage of all samples collected as part of the test for which he is responsible. At a minimum, this will include adequate information to identify the individual collecting the sample, the test procedure requiring the sample, date and method of collection, a unique sample number or labeling system, sample description, special handling requirements, and the signature of the responsible Activity Leader. In addition, the Activity Leader will prepare and sign a sample transfer record when the sample is turned over for storage or for outside testing. For testing conducted on site, the laboratory Activity Leader assumes responsibility for the sample, including turnover for storage.

7.3 HEALTH AND SAFETY

7.3.1 General Requirements

The Department of Energy has directed that the ESF will be considered a mine and will be subject to the Mine Safety and Health Administration (MSHA) metal and nonmetal safety regulations, as detailed in 30 CFR Part 57, Safety and Health Standards - Underground Metal and Nonmetal Mines. In accordance with applicable federal regulations, a Project Safety Plan that is consistent with prudent engineering design will be prepared.

The MSHA Safety and Health Standards contain 17 subparts which address separate areas related to health and safety in underground mines. All areas that are expected to affect the ESF testing program will be identified and described in the Mine Safety Compliance Plan (in preparation), which will supplement the Project Safety Plan. The 12 areas which are specifically applicable to the Shaft Study Plan are addressed in this safety section which has been prepared to specifically address the safety compliance requirements for the Shaft testing activities.

7.3.2 Compliance Plan

The Compliance Plan defines the means by which compliance with MSHA regulations will be accomplished during the Shaft instrumentation and testing program. Compliance with the regulations will be accomplished through the following activities:

- Personnel Training
- Site and Equipment Inspection
- Use of Permissible and Instrinsically Safe Equipment

- Environmental Monitoring
- Ventilation
- Site and Equipment Safety Testing and Evaluation.

The CFR subparts that are addressed under each activity are identified in Table 7-2. Each activity will involve the use of the seven components of a good safety program as described in the Mine Safety Compliance Plan.

7.3.2.1 Personnel Safety Training

All personnel employed by the Underground Testing Contractor and its subcontractors will be trained in the safety practices applicable to underground operations, support equipment operation, and test equipment operation prior to commencing any underground or testing activity. Training will be conducted by individuals with documented qualifications and approved experience and instruction. All training sessions will be documented and training records maintained in project personnel safety training files. Training will be based on CFR guidelines, and will be provided in the following areas:

Training programs will cover all of the aspects of fire prevention and control listed in subpart C of 30 CFR part 57. Since nearly all of the Shaft testing program involves the use of electrical systems, special emphasis will be placed on methods for prevention and control of electrical fires. Additional emphasis will be placed on the early suppression of fires and procedures for obtaining firefighting assistance.

Although UTC personnel will not be required to work directly with explosives, they will be trained in hazards identification relative to blasting operations.

Personnel required to operate drilling equipment will be trained in the inspection, maintenance, operation, routine and emergency shutdown, and transportation of the equipment.

Most UTC personnel will have loading, hauling, storage, and materials handling activities as part of their regular duties. Training will include proper methods of loading the shaft hoist, determining pickup and center of gravity points on loads, protective packaging methods and requirements, and methods to be followed for galloway storage.

Training in machinery use will be provided for all required types of machinery used underground. Training programs will cover routine inspection, maintenance, and safe use. Typical machinery may include hoists, pumps, and small motors. Training in the safe use of test equipment will be provided as part of the qualification program for test operators, as discussed in Section 8.2.

Training programs will include detailed instructions in the requirements for and use of personal protective gear, such as hard hats, steel-toed boots, and eye and ear protection. Additional instruction will be provided for special safety equipment such as self-rescue devices and communications gear.

Table 7-2. MSHA Safety and Health Standards Pertaining to Shaft Monitoring and Testing

Activity	30 CFR 57 Subparts
Personnel Training	• Fire prevention and control • Explosives safety • Drilling • Loading and hauling • Materials handling and storage • Machinery • Personnel protection • Emergency procedures
Site and Equipment Inspection	• Drilling • Ground control • Electrical • Compressed air (gas) • Machinery • Personnel protection
Permissible and Instrinsically Safety Equipment	• Gassy mine • Ventilation • Electrical
Environmental Monitoring	• Gassy mine • Fire control • Ventilation
Ventilation	• Gassy mine • Fire control • Ventilation
Site and Equipment Safety Testing and Evaluation	• Drilling • Ground control • Loading and hauling • Electrical • Compressed air (gas) • Machinery • Materials handling and storage • Emergency procedures

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Specific detailed training in emergency procedures and use of escape facilities and equipment will be conducted for all personnel prior to authorization to work in the shafts.

7.3.2.2 Site and Equipment Inspection

The site and equipment will be inspected at the beginning of each shift. Personnel coming off shift will transfer breakdown, maintenance, and repair reports to incoming testing staff. The incoming staff will inspect the equipment in question and take appropriate action.

Ground conditions will be inspected by shift supervisors during each shift. Any necessary action, such as scaling, will be undertaken immediately while the testing staff is removed from the area. All new testing areas will be inspected by the shift supervisor and made safe prior to the mobilization of the testing staff and equipment into the area.

Compressed air lines, water lines, and hydraulic systems will be inspected each shift to ensure that all connections are intact, that compressed air hoses are chained securely, and all guards are in place. Compressed gas bottles will be stored with caps secured over the valve ends and when in use will be chained securely in an upright position in a protected area.

All electrical and mechanical equipment, including drilling rigs, pumps, compressors, and hoist, will be inspected by the equipment operator prior to each shift. Since the mine is designated as gassy, all permissible equipment will be inspected for alteration which would require the shutdown of that equipment.

Personnel protection, such as self-rescuers, will be inspected in accordance with MSHA requirements to ensure effective operation and proper storage of supplies.

7.3.2.3 Permissible and Intrinsically Safe Equipment

The ESF has been designated as a gassy mine. This designation requires that all electrical equipment used underground will be either:

- Approved intrinsically safe
- Operated under a permissible label
- Operated under an experimental permit
- Operated in fresh air flow under nonpermissible guidelines.

All electrical equipment will conform to 30 CFR Part 18 and all testing personnel will be familiar with the regulations and how the equipment used by them is rated.

7.3.2.4 Environmental Monitoring

Environmental monitoring will be performed at appropriate time intervals by means of automated sensors located throughout the ESF and connected to the Automatic Data Acquisition System (ADAS). The sensors will monitor the levels of flammable gas in the atmosphere; the ventilation air flow velocity, humidity, temperature, suspended particulate matter, and smoke; and a variety of gases, such as carbon dioxide, oxygen, methane, and carbon monoxide. The data recorded by these sensors will be used to monitor for fire control and ventilation considerations as well as to supplement the manual measurement of flammable gas concentrations required for gassy mine conditions. Details of environmental monitoring will be provided in an Environmental Monitoring Plan [in preparation].

7.3.2.5 Ventilation

The ventilation system will be used to satisfy the gassy mine requirements. Fresh air will be directed onto and through nonpermissible equipment or into areas where there are open flames or welding is taking place. The Construction Manager's staff will be responsible for providing and maintaining adequate ventilation and ensuring that the ventilation system performs as designed. The shaft and underground ventilation systems will be subject to the fire prevention and control considerations to ensure that air flow is regulated to prevent the spread of potential fires.

7.3.2.6 Site and Equipment Safety Testing and Evaluation

Site and equipment safety testing includes the testing of electrical circuits to determine if loading imposed by the testing equipment might increase heat buildup.

All equipment will be tested on a periodic schedule determined by the manufacturer's recommended maintenance program under ESF conditions to ensure the equipment's safe operation. Drilling, handling, electrical, and compressed air equipment will be tested and their performance evaluated to verify that they are maintained in a safe operating condition.

The performance of ground support installed in the shaft will be monitored as part of the Study Plan activities.

All safety testing will be documented and filed with the equipment maintenance information as well as with the Project Safety Office. Equipment and site test locations that have undergone scheduled or unscheduled maintenance servicing or repairs will be tested by the equipment operators prior to being brought into general service.

7.3.3 Safety Support

The Project Management Plan will define the division of responsibility between the Operations, Construction, and Testing groups. The Project Manager will provide the leadership in the safety program by directing the preparation of a comprehensive Program Safety Plan. That plan will assign the responsibility for various activities to each of the operating groups.

The responsibility for the safe performance of all testing and operation of equipment within the Shafts and completed ADF will be assigned through the Project Safety Plan. The separate areas identified by MSHA regulations that will be considered in the preparation of test plans and procedures are described in Table 7-2. The Shaft testing group will require the day-to-day support of the Mining Subcontractor and Construction Manager in complying with the Project Safety Plan. This support is required in the form of technical expertise for construction, excavation, drilling, fabrication and assembly of equipment, transportation, and inspection. All of the support staffing for each test will be coordinated by the respective Task Leaders and scheduled for each test by the Activity Leader.

7.3.4 Management of the Safety Plan

The Project Management Plan will define the methods for instituting the Project Safety Plan and the delegation of authority. [Section to be completed upon the completion of the Project Management Plan.]

8.0 QUALITY ASSURANCE

The shaft testing program will be conducted under the provisions of the Golder Associates Quality Assurance Program Plan (QAPP) (Golder Associates, 1987l) approved for the Site Characterization and Testing in an Exploratory Shaft in Salt project. The QAPP describes the specific project application of Golder Associates' QA program as contained in its QA Manual and implementing QA and Technical Procedures. The QAPP and QA program are designed to fully comply with the provisions of ANSI/ASME NQA-1 and 10 CFR 50, Appendix B as directed by Department of Energy (DOE) Order DOE 5700.6A, and provide the procedural framework that will assure development of valid and traceable data from individual test procedures. Applicable portions of the regulatory requirements described above will be imposed on subtier suppliers, subcontractors, and consultants providing materials, equipment, and services in support of the shaft testing program.

8.1 QUALITY ASSURANCE ORGANIZATION

Overall responsibility for the implementation of Golder Associates' QA program lies with the Corporate QA Officer, who reports directly to the President of Golder Associates' U.S. operations. The Corporate QA Officer supervises the Field QA Coordinator, who has primary onsite responsibility for QA activities relative to the shaft testing program. The Field QA Coordinator will be supported by inspectors and other staff as required to effectively manage the receiving inspection, surveillance inspection, document control, auditing, and related QA activities described in this section. The relationship of the onsite QA organization to the test operations organization is entirely independent, as shown in Figure 7-1.

8.2 QUALIFICATION AND TRAINING OF PERSONNEL

All personnel will be trained in the application of the QA and testing procedures referenced in this section as required by procedure P-2.0-1. QA procedures training is the responsibility of the Corporate QA Officer or a qualified designee. Training and qualification of test personnel is the responsibility of the Task leader or his designee. Test operators and associated project personnel will be trained and qualified in the application of the unique testing procedures approved for this activity by one or more of the following means:

- Participation in developmental testing programs for the affected procedures

- Supervised and documented on-the-job training

- Documented experience with related procedures on other projects
- Classroom study and examination
- Other appropriate documented means at the direction of the Test Operations Manager.

Resumes, examination records, and records of all training sessions will become part of the project QA records.

8.3 TEST CONTROL

Client authorization to proceed with test activities will be requested by submittal of individual Test Activity Plans (TAPs) for approval. Test Activity Plans will be developed for such groups of tests that may be appropriately conducted at various phases or milestones in shaft construction. The plans will address applicable schedules, milestones, technical elements of this document, revisions of test procedures, and QA procedures. The Test Activity Plan will also identify those Specific Work Instructions (SWIs) to be issued to field, laboratory, and office personnel for accomplishment of the test activity, and shall identify and describe interrelationships between client, contractor, and subcontractor QA organizations.

Individual tasks within a test activity will be initiated by means of Specific Work Instructions as described in procedure P-3.0-2. Individual project procedures will be developed to client guidelines, subjected to Independent Technical Review per procedure P-10.0-1, and submitted to the client for approval prior to use. Test procedures will consider the following:

- Description of test scope and purpose
- Location of test activity within the ESF
- Physical layout of test activity
- Detailed instructions on test completion
- Instrumentation requirements (type, range, precision, and accuracy)
- Cautionary information on possible sources of error
- Installation and support requirements
- Detailed instructions on performing the test

- Acceptance or completion criteria

- Inspection hold points, when required

- Data recording and control requirements, including routing or review instructions for completed data sheets or test results

- Data reduction, when required

- Personnel responsibilities, management structure, and project organization

- Schedule

- Safety considerations

- Requirements relative to surveillance inspection, quality audits, and incident reporting.

Distribution of the Shaft Study Plan, the Test Activity Plans, individual Test Procedures, and individual SWIs will be controlled in accordance with procedure P-5.0-1. Test performance will be monitored in process by means of surveillance inspection per procedure P-10.0-3, as described in Section 8.8 below. Materials and equipment received on site will undergo receiving inspection per procedure P-10.0-4; all equipment will be calibrated and controlled as required by procedure P-12.0-1 as described in Section 8.7. Equipment that is in use as part of a test will be placarded as described in P-12.0-1 to indicate operational status of equipment. Compliance with quality program requirements will be evaluated by means of quality audits conducted in accordance with procedure P-18.0-1, as described in Section 8.11.

8.4 SAMPLE IDENTIFICATION, HANDLING, STORAGE, AND TRANSPORTATION

When testing involves the taking of physical samples, individual test procedures will define identification, handling, storage, and transportation requirements in order to ensure sample integrity and traceability. Methods of identification, protection, and handling will be selected that satisfy the unique requirements of each sample type. Packaging methods will ensure that in situ characteristics are preserved for subsequent evaluation or additional testing.

8.5 CONTROL OF PROCUREMENTS

Procurements of materials, equipment, subcontractor services, or consulting services will be controlled by procedure P-4.0-1; implementation of the procedure assures that suppliers undergo a documented process of evaluation prior to order placement. Procurement documents will be evaluated and approved by QA; QA requirements appropriate to the procurement will be formally added to procurement documents prior to approval and issue. Verification of item or equipment compliance with procurement document requirements will be accomplished by receiving inspection in accordance with P-10.0-4; verification of compliance in other procurement situations will be as described in section 3.8 of the QAPP.

8.6 DOCUMENTATION CONTROL

QA procedures are considered controlled documents; onsite distribution and control will be managed by the Field QA Coordinator in the manner indicated in procedure P-5.0-1. Test Activity Plans and individual client-approved test procedures will also be considered controlled documents; distribution onsite will be handled by the Field QA Coordinator in the same manner as QA procedures.

8.7 CONTROL OF MEASURING AND TEST EQUIPMENT

Individual test procedures contain specific requirements for measuring and test equipment necessary for conducting test activities. Calibration, maintenance, issue, and recall of all Golder-owned or leased measuring and test equipment will be controlled by procedure P-12.0-1. Equipment will be issued to test operators from the onsite calibration laboratory; equipment will be in a properly maintained and calibrated condition when issued. All equipment calibrations will be traceable to National Bureau of Standards (NBS) or other nationally recognized standards. The calibration system described in P-12.0-1 provides for a computerized locator/recall system that periodically defines calibration and maintenance due dates and provides the means for retrieving equipment from test operations when recalibration and/or maintenance is required.

8.8 INSPECTION AND TECHNICAL REVIEW

All facets of the test program will be subject to verification by means of inspection or technical review procedures. Materials and equipment associated with testing will be subjected to receiving inspection per procedure P-10.0-4 for verification of compliance with individual purchase orders prior to release to the calibration laboratory or project stores. Computer programs purchased or developed for any of the shaft tests will be independently verified and validated prior to use, as required by procedure TP-2.1-1. In-process inspection per test procedure requirements will be performed at any required hold point. Surveillance inspection per procedure P-10.0-3 will be performed on a representative sample of tests in progress under each Test Activity Plan. Preparation or revision of individual test procedures will be subject to independent technical review per procedure P-10.0-1, as will all reports or documents developed as a result of testing.

8.9 CONTROL OF NONCONFORMANCES AND INCIDENT REPORTING

Deficiencies and nonconformances may be detected as a result of receiving inspection, surveillance inspection, or technical review. Documentation, resolution, and corrective action relative to nonconformances shall be as described in procedure P-15.0-1. Minor deficiencies, as defined in the procedure, may be immediately corrected to the satisfaction of the individual inspector or reviewer. Nonconformances, however, require full documentation, investigation, corrective action, and reporting to the full extent required by the procedure.

Incidents are interpreted to be unexpected events which may have significant impact on cost, schedule, validity of data or analysis, safety, or environment, and may be reported in the same manner as nonconformances. Incidents are considered to be major events clearly not in the category of uncertainties characteristic of geoscientific investigations; client notification is an immediate requirement.

8.10 TEST RECORDS MANAGEMENT

The records control provisions contained within individual test procedures, procedure P-17.0-1, and the Data Management Plan will ensure positive traceability of all test results and documentation from the test planning phase through actual testing, data collection, evaluation, and report preparation to final records turnover package shipment. Records shall be legible, reproducible, identifiable, and retrievable throughout their history. Records associated with shaft testing will include the following:

- Test or operating logs
- Test record or data sheets
- Photographs used as part of test records
- Output tapes from data loggers
- Personnel qualification records
- Surveillance and receiving inspection records, with any associated nonconformance and corrective action reports
- Equipment calibration and maintenance records
- Test Activity Plans
- Specific Work Instructions
- Test-related telecons or correspondence
- Records of Technical Review.

8.11 QUALITY AUDITS

Audits of completed test activities and supporting organizations will be conducted at the direction of the Corporate QA Officer. Audits will be led by a certified Lead Auditor; audit teams will have had no direct responsibilities in the areas being audited and will be qualified in accordance with P-18.0-2. Audits will be conducted according to written checklists and procedure P-18.0-1. Any audit findings and observations will be resolved by the management of the areas audited in ways that reduce or preclude recurrence of deficiencies. Audited areas may be re-audited if necessary to verify implementation or corrective action.

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APPENDIX A1

COMPUTATION OF STRESSES AND STRAINS IN SHAFT LININGS

A1.1 INTRODUCTION

This appendix describes the theoretical analysis used to compute stresses and strains in multiple layer shaft linings under linear-elastic conditions. The results provide an indication of the ranges of values that might be measured by embedded instruments. Estimations of ranges of measurement are necessary to complete instrument design specifications. However, it should be noted that elastic stresses and strains form only one component of a complex behavioral pattern. Other effects, such as concrete creep, shrinkage during concrete curing, and inelastic behavior due to the existence of micro-cracks in the concrete, all contribute to the overall behavior of the lining system. The results of the elastic analysis will probably over-estimate the stresses that will be measured, and under-estimate the displacements and strains.

The stress and strain values used in any range evaluation are also sensitive to the prevailing loading systems. The magnitudes of the boundary loads used here are taken from Table 2-3. These values are taken from the PB-PB/KBB's Final Preliminary Design Report, 1986a. The shaft designers will have designed the shaft lining to withstand loads which are higher by a factor of safety.

Other sources of information for input to instrument design specification include:

- The designer's calculations and expectations for the performance of the shaft lining system
- Measurements made in other similarly sized, sited, and constructed structures
- Information developed from failure strain criteria, etc.

A computer program "SHAFT" is presented which is written in BASICA to run on an IBM-PC. It is a user-interactive program which performs the necessary calculations generated by the theoretical analysis.

A1.2 OBJECTIVE

The objective of this analysis is to provide estimations of the range of stresses and strains induced in the shaft lining system by the loads specified in Table 2-3 under linear-elastic conditions.

A1.3 BACKGROUND

A1.3.1 Shaft Lining Design and Construction

The exploratory shaft design and construction methods have been described in Section 2.0. When completed, the shaft liner will consist of a series of concentric cylinders of different sizes and made from different materials. One of these cylinders, the preliminary lining, will be constructed as excavation proceeds. The remaining cylinders, the final lining, will be constructed upwards from the lining foundation. Instruments will be installed in the linings in conjunction with the construction process. The instruments will therefore respond to the various stages of construction and to the applied boundary loads. Therefore, in addition to predicting the stresses and strains in the lining materials due to the applied loads, the analysis will also be used to investigate the variation of the stresses and strains induced by the construction process. This will provide a prediction of the range of measurements that the instruments will be required to make.

A1.3.2 Loading Systems

The following stages of construction have been considered in applying the analysis to predict the distributions of stress and strain in the liner.

During construction of the final lining in the upper section of the shaft, the bitumen layer, placed between the preliminary and final linings, will impose a hydrostatic radial load on the outside of the final lining and on the inside of the preliminary lining. The final lining will also support its own weight, unlike the preliminary lining that will have been constructed against the frozen wall of the excavation and will be supported by skin friction. The hydrostatic stress on the inwall of the preliminary lining may induce tensile stresses in the concrete since at the time the bitumen is poured only small compressive loads will have been induced previously by ice wall creep; although small and assumed negligible, these compressive loads are sufficient to develop the necessary skin friction. However, estimating the magnitude of the ground reaction to the outward movement of the preliminary liner is a difficult and complex problem and has not been analyzed here.

Ground reaction develops in response to lining movement, as a function of lining stiffness relative to the ground. The nature of the ground reaction will lie between two limits: a rigid boundary (infinitely stiff), and a fully flexible boundary (infinitely soft). The following two conditions have been analyzed for the preliminary lining in the upper shaft:

- Flexible boundary, in which case the maximum stresses will be governed by the tensile strength of the concrete.
- Rigid boundary, in which case the loads on the outer wall of the preliminary liner will be sufficiently large to prevent radial displacements of this boundary.

In the lower section of the shaft, the void between the preliminary and final liners will be filled with grout as construction proceeds. Therefore, it has been assumed that the self-weight of the complete liner will be supported by skin-friction with the rock-wall, and that the two liners will behave as one in responding to the buildup of the long-term ground pressures on the outside of the liners and buildup of groundwater pressure initially on the preliminary liner and, as it becomes saturated, on the outer steel liner.

In terms of the analysis, therefore, free-standing conditions are appropriate for the final liner in the upper shaft, and the preliminary liner in the upper shaft during a period when the skin friction is absent. For all other loading conditions it is appropriate to assume plane strain loading conditions.

A1.3.3 Method of Liner Analysis

The following method of analysis treats each layer of the liner as an individual cylinder. The stress and strain distributions in the cylinder are analyzed in terms of the axial and radial boundary loads. The magnitudes of the radial boundary loads are calculated in terms of the liner boundary loads by considering the compatibility of normal stress and displacement across the interface between neighboring cylinders. At this stage, thermal effects are not considered. Shear stresses on the liner/rock wall boundary are also considered to be negligible (e.g., the magnitude of the shear stress required to support the self-weight of the liner is estimated to be approximately 3 psi [22 kPa]).

The distributions of stress and strain within individual cylinders are determined by considering a small section of the cylinder remote from the ends. The length of this section is sufficiently small that any variation of applied load along its length is negligible compared with the magnitude of the mean applied load. For the case where the liner is free-standing and is supporting its self-weight (i.e., in the upper final liner) the principal of superposition is invoked to combine the plane stress solution for the radial loading on the cylinder with the solution for uniaxial loading (e.g., the self-weight component). The magnitude of the axial stress in each section of liner is calculated from total weight of the lining overlying the section, considering compatibility of axial strains. For the case where the self-weight of the liner is supported by skin-friction with the rock wall, a plane strain solution for the radial loading on the cylinder is more appropriate.

A1.3.4 Assumptions

1. The mechanical behavior of the liner materials are consistent with that of a homogeneous, isotropic, linear-elastic material.

2. For a small section of the thick-walled cylinder, the length is sufficiently small that the variation of the applied loads along the length is negligible compared to the magnitudes of the applied loads. For the purposes of this analysis, therefore, the hydrostatic radial load at some depth is considered constant over the boundary of the isolated section.

3. The stress and strain distributions are continuous functions within the lining materials.

4. Compatibility of radial stress and displacement exists at the interface between neighboring cylinders. (No interface effects).

5. In free-standing conditions, compatibility of axial strain exists in coupled cylinders of different materials.

6. All stresses are effective stresses. A treatment of saturation and pore pressure effects is discussed in Section A1.4.6.

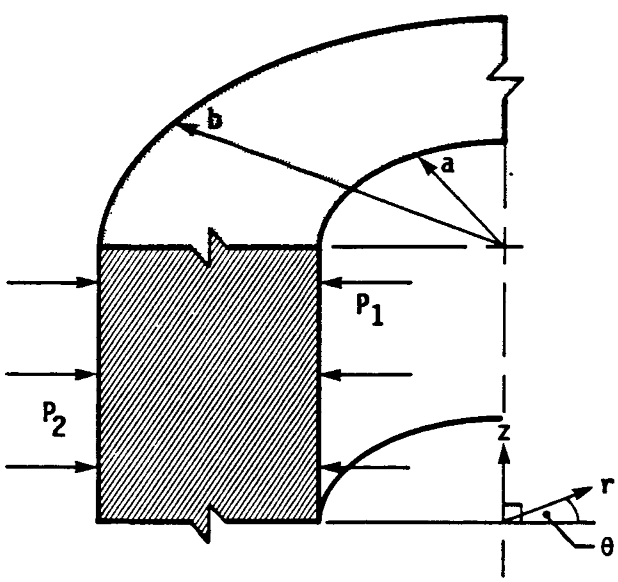
A1.3.5 Sign Convention

Compressive stresses and strains within, and acting on, the cylinders are assigned positive sense, as are displacements towards the axis of the cylinder.

A1.4 THEORETICAL ANALYSIS

A1.4.1 Thick-walled Cylinders Loaded Under Plane Stress Conditions

Consider the following section through a thick-walled cylinder:



Where,

a = Internal radius of the cylinder

b = External radius of the cylinder

r = Radial distance measured from the cylinder axis

θ = Rotation of r around the cylinder axis relative to some arbitrary datum

P_1 = Pressure bearing on the cylinder inwall (at r = a)

P_2 = Pressure bearing on the outside wall of the cylinder (at r = b)

For plane stress conditions, the stress acting parallel to the cylinder axis is set to zero by definition. The shear stress on the cylinder boundaries are also zero.

From the differential equation of equilibrium, the principal stresses at a point in a thick-walled cylinder are given by (Jaeger & Cook, 1976).

(Radial Stress) $$\sigma_r = \frac{P_2 b^2 - P_1 a^2}{b^2 - a^2} - \frac{(P_2 - P_1) a^2 b^2}{b^2 - a^2} \cdot \frac{1}{r^2} \qquad \text{A-1}$$

(Tangential Stress) $$\sigma_\theta = \frac{P_2 b^2 - P_1 a^2}{b^2 - a^2} + \frac{(P_2 - P_1) a^2 b^2}{b^2 - a^2} \cdot \frac{1}{r^2} \qquad \text{A-2}$$

(Axial Stress) $\sigma_z = 0$ by definition A-3

From Hooke's Law the stress-strain relations are:

$$E\xi_r = \sigma_r - \nu\sigma_\theta \qquad \text{A-4}$$

$$E\xi_\theta = \sigma_\theta - \nu\sigma_r \qquad \text{A-5}$$

$$E\xi_z = -\nu(\sigma_r + \sigma_\theta) \qquad \text{A-6}$$

where

E = Young's Modulus
ν = Poisson's Ratio
ξ_r = radial strain
ξ_θ = tangential strain
ξ_z = axial strain

The equations of displacement are (Jaeger & Cook, 1976):

$$\xi_\theta = \frac{u}{r} \qquad \text{A-7}$$

$$\xi_r = \frac{du}{dr} \qquad \text{A-8}$$

The displacement function in the radial direction, u, is determined by combining equations A-1, A-2 and A-7 in equation A-5:

$$E\frac{u}{r} = \frac{P_2b^2 - P_1a^2}{b^2 - a^2} \cdot (1 - \nu) + \frac{(P_2 - P_1)a^2b^2}{b^2 - a^2} \cdot \frac{(1 + \nu)}{r^2}$$

$$u = \frac{P_2b^2 - P_1a^2}{b^2 - a^2} \cdot \frac{(1 - \nu)}{E} \cdot r + \frac{(P_2 - P_1)a^2b^2}{b^2 - a^2} \cdot \frac{(1 + \nu)}{E} \cdot \frac{1}{r} \qquad \text{A-9}$$

Therefore, using equation A-9, and substituting into equations A-7 and A-8 gives:

$$\xi_\theta = \frac{P_2b^2 - P_1a^2}{b^2 - a^2} \cdot \frac{(1 - \nu)}{E} + \frac{(P_2 - P_1)a^2b^2}{b^2 - a^2} \cdot \frac{(1 + \nu)}{E} \cdot \frac{1}{r^2} \qquad \text{A-10}$$

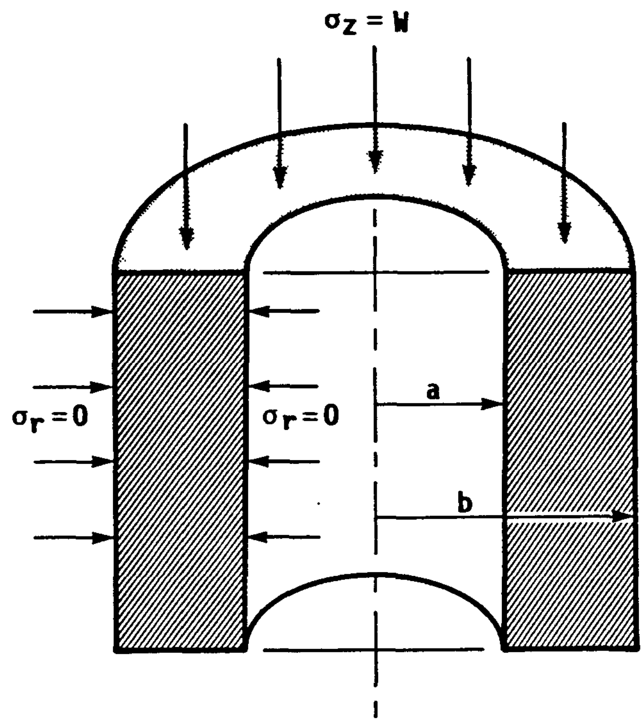
$$\xi_r = \frac{P_2b^2 - P_1a^2}{b^2 - a^2} \cdot \frac{(1 - \nu)}{E} - \frac{(P_2 - P_1)a^2b^2}{b^2 - a^2} \cdot \frac{(1 + \nu)}{E} \cdot \frac{1}{r^2} \qquad \text{A-11}$$

Substituting equations A-1 and A-2 in equation A-6 gives:

$$\xi_z = \frac{-2\nu}{E} \cdot \frac{P_2b^2 - P_1a^2}{b^2 - a^2} \qquad \text{A-12}$$

A1.4.2 Thick-Walled Cylinders Under Uniaxial Loading

Consider:



where a, b are defined as before and P_z is the uniform stress acting parallel to the cylinder axis on the parallel ends.

The principal stresses at a point in the cylinder are given by:

(Radial Stress) $\sigma_r = 0$
(Tangential Stress) $\sigma_\theta = 0$
(Axial Stress) $\sigma_z = W$

From Hooke's Law the stress strain relations are:

$$\xi_r = \xi_\theta = \frac{-\nu}{E} \cdot W \qquad \text{A-13}$$

$$\xi_z = \frac{W}{E} \qquad \text{A-14}$$

The displacement relations are:

$$\xi_\theta = \frac{u}{r} \qquad \text{A-15}$$

$$\xi_r = \frac{du}{dr} \qquad \text{A-16}$$

$$\xi_z = \frac{dw}{dz} \qquad \text{A-17}$$

where w is the displacement function parallel to the axis of the cylinder and u is the radial displacement function normal to the axis of the cylinder.

The radial displacement function, u, is determined by combining equations A-13 and A-15:

$$u = \frac{-\nu W}{E} \cdot r \qquad \text{A-18}$$

A1.4.3 Combined Radial and Axial Loading for Free-Standing Cylinders

Using the Principle of Superposition, the combined solution for both axial and radial loading equals the plane stress problem superposed on the uniaxial stress problem. Therefore:

ξ_r = equation A-11 + equation A-13

ξ_θ = equation A-10 + equation A-13

ξ_z = equation A-12 + equation A-14

u(r) = equation A-9 + equation A-18

This summation gives:

$$u(r) = \frac{P_2b^2 - P_1a^2}{b^2 - a^2} \cdot \frac{(1-\nu)}{E} \cdot r + \frac{(P_2 - P_1)a^2b^2}{b^2 - a^2} \cdot \frac{(1+\nu)}{E} \cdot \frac{1}{r} - \frac{\nu W}{E} \cdot r \qquad \text{A-19}$$

$$\xi_r = \frac{P_2b^2 - P_1a^2}{b^2 - a^2} \cdot \frac{(1-\nu)}{E} - \frac{(P_2 - P_1)a^2b^2}{b^2 - a^2} \cdot \frac{(1+\nu)}{E} \cdot \frac{1}{r^2} - \frac{\nu W}{E} \qquad \text{A-20}$$

$$\xi_\theta = \frac{P_2b^2 - P_1a^2}{b^2 - a^2} \cdot \frac{(1-\nu)}{E} + \frac{(P_2 - P_1)a^2b^2}{b^2 - a^2} \cdot \frac{(1+\nu)}{E} \cdot \frac{1}{r^2} - \frac{\nu W}{E} \qquad \text{A-21}$$

$$\xi_z = \frac{-(P_2b^2 - P_1a^2)}{b^2 - a^2} \cdot \frac{2\nu}{E} + \frac{W}{E} \qquad \text{A-22}$$

For the combined loads, the stress-strain relations are (Hooke's Law):

$$\left.\begin{aligned} E\xi_r &= \sigma_r - \nu(\sigma_\theta + \sigma_z) \\ E\xi_\theta &= \sigma_\theta - \nu(\sigma_r + \sigma_z) \\ E\xi_z &= \sigma_z - \nu(\sigma_r + \sigma_\theta) \end{aligned}\right\} \qquad \text{A-23}$$

Rearranging equation A-23 gives:

$$\sigma_r = \frac{\nu E}{(1+\nu)(1-2\nu)}(\xi_r + \xi_\theta + \xi_z) + \frac{E}{1+\nu} \cdot \xi_r \qquad \text{A-24}$$

$$\sigma_\theta = \frac{\nu E}{(1+\nu)(1-2\nu)}(\xi_r + \xi_\theta + \xi_z) + \frac{E}{1+\nu} \cdot \xi_\theta \qquad \text{A-25}$$

$$\sigma_z = \frac{\nu E}{(1+\nu)(1-2\nu)}(\xi_r + \xi_\theta + \xi_z) + \frac{E}{1+\nu} \cdot \xi_z \qquad \text{A-26}$$

Equations A-19 through A-22, and A-24 through A-26, are appropriate when the cylinder is free-standing, and hence displacements in three dimensions are unrestrained.

A1.4.4 Thick-Walled Cylinders Loaded Under Plane Strain Conditions

Plane strain conditions provide a method of analysis appropriate when the self-weight of the lining is fully supported by skin-friction with the excavation wall. The skin-friction required to restrain deformation along the axis of the cylinder amounts to approximately 3 psi (22 kPa) which is of negligible proportions, and justifies the assumption made.

Consider the same section through a thick-walled cylinder as described in Section A.4.1. For plane strain conditions, the strain in the direction parallel to the cylinder axis is set to zero by definition. The shear stresses on the cylinder boundaries are also zero.

To convert plane stress solutions for a homogeneous, isotropic, linear-elastic material into those for plane strain, the following substitutions are made:

$$\text{for } E, \quad \text{read } \frac{E}{1-\nu^2} \qquad \text{A-27}$$

$$\text{for } \nu, \quad \text{read } \frac{\nu}{1-\nu} \qquad \text{A-28}$$

Therefore, substituting equations A-27 and A-28 into equations A-9 through A-11 gives:

$$u(r) = \frac{P_2b^2 - P_1a^2}{b^2 - a^2} \cdot \frac{(1-2\nu)(1+\nu)}{E} \cdot r + \frac{(P_2-P_1)a^2 b^2}{b^2 - a^2} \cdot \frac{(1+\nu)}{E} \cdot \frac{1}{r} \qquad \text{A-29}$$

$$\xi_r = \frac{P_2b^2 - P_1a^2}{b^2 - a^2} \cdot \frac{(1-2\nu)(1+\nu)}{E} - \frac{(P_2-P_1)a^2 b^2}{b^2 - a^2} \cdot \frac{(1+\nu)}{E} \cdot \frac{1}{r^2} \qquad \text{A-30}$$

$$\xi_\theta = \frac{P_2b^2 - P_1a^2}{b^2 - a^2} \cdot \frac{(1-2\nu)(1+\nu)}{E} + \frac{(P_2-P_1)a^2 b^2}{b^2 - a^2} \cdot \frac{(1+\nu)}{E} \cdot \frac{1}{r^2} \qquad \text{A-31}$$

and by definition $\xi_z = 0$ A-32

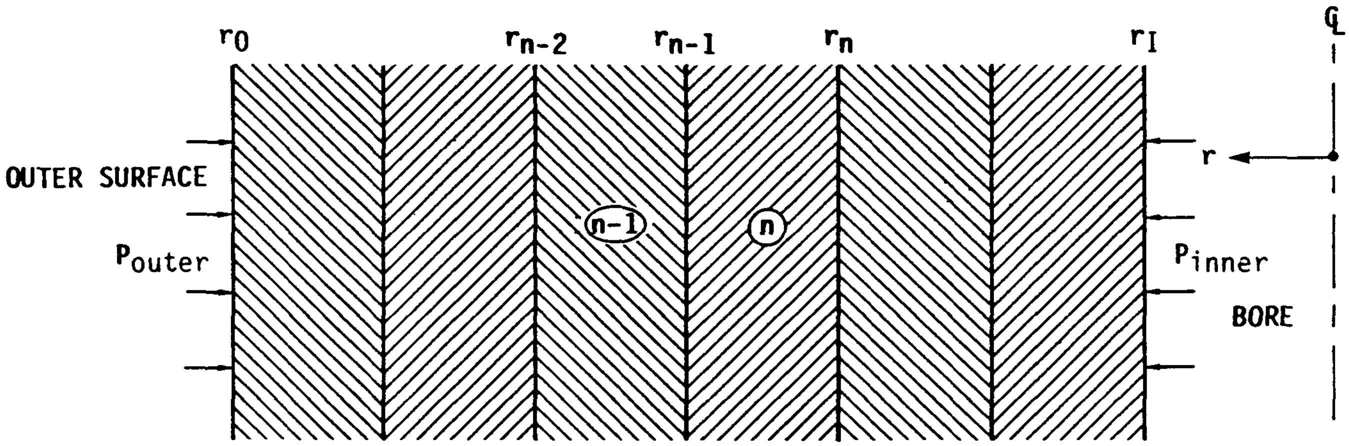
The equations for radial and tangential stresses, σ_r and σ_θ, remain the same as equations A-1 and A-2. The axial stress σ_z is found by substituting equations A-30 through A-32 into equation A-26:

$$\sigma_z = 2\nu \cdot \frac{P_2b^2 - P_1a^2}{b^2 - a^2} \qquad \text{A-33}$$

A1.4.5 Introducing Radial Stress and Displacement Compatibility Between Neighboring Cylinders

A1.4.5.1 Plane Strain Conditions

Consider a series of closely fitting, concentric thick-walled cylinders.



Consider now two adjacent thick-walled cylinders, n and n-1, having different material properties E_n, E_{n-1}, ν_n, ν_{n-1}. The inner and outer radial stresses acting on the cylinder n are given by $(P_{inner})_n$ and $(P_{outer})_n$. Similarly the inner and outer stresses acting on the cylinder n-1 are given by $(P_{inner})_{n-1}$ and $(P_{outer})_{n-1}$. On the boundary, $r = r_{n-1}$:

$$(P_{inner})_{n-1} = (P_{outer})_n \qquad \text{A-34}$$

and

$$[(U(r_{n-1})]_{n-1} = [U(r_{n-1})]_n \qquad \text{A-35}$$

Equations A-34 and A-35 represent the conditions for compatibility for the radial stresses and displacement at the interface between two neighboring cylinders. From equation A-34 for any interface between two adjacent thick-walled cylinders at $r = r_{n-1}$ let the radial stress across the interface be $P = P_{n-1}$.

For the thick-walled cylinder n-1, under plane strain conditions, the radial displacement at $r = r_{n-1}$ is given by (equation A-29):

$$U(r_{n-1}) = \frac{P_{n-2}\, r_{n-2}^2 - P_{n-1}\, r_{n-1}^2}{r_{n-2}^2 - r_{n-1}^2} \cdot \frac{(1-2\nu_{n-1})(1+\nu_{n-1})}{E_{n-1}} \cdot r_{n-1} + \frac{(P_{n-2} - P_{n-1})\, r_{n-1}^2\, r_{n-2}^2}{r_{n-2}^2 - r_{n-1}^2} \cdot \frac{1+\nu_{n-1}}{E_{n-1}} \cdot \frac{1}{r_{n-1}} \qquad \text{A-36}$$

For the thick-walled cylinder (n), under plane strain conditions, the radial displacement at $r = r_{n-1}$ is given by (equation A-29):

$$U(r_{n-1}) = \frac{P_{n-1}\, r_{n-1}^2 - P_n\, r_n^2}{r_{n-1}^2 - r_n^2} \cdot \frac{(1-2\nu_n)(1+\nu_n)}{E_n} \cdot r_{n-1} +$$

$$\frac{(P_{n-1} - P_n)\, r_n^2\, r_{n-1}^2}{r_{n-1}^2 - r_n^2} \cdot \frac{(1+\nu_n)}{E_n} \cdot \frac{1}{r_{n-1}} \qquad \text{A-37}$$

From equation A-35 it follows that equation A-36 = equation A-37. Equating A-36 and A-37 and rearranging to separate the P's gives:

$$K_1 P_{n-2} + K_2 P_{n-1} + K_3 P_n = K_4 \qquad \text{A-38}$$

where

$$K_1 = \frac{2\, r_{n-1}\, r^2_{n-2}}{r^2_{n-2} - r^2_{n-1}} \cdot \frac{(1 - \nu^2_{n-1})}{E_{n-1}} \qquad \text{A-39}$$

$$K_2 = \frac{-r^3_{n-1}}{r^2_{n-2} - r^2_{n-1}} \cdot \frac{(1 - 2\nu_{n-1})(1 + \nu_{n-1})}{E_{n-1}} - \frac{r_{n-1}\, r^2_{n-2}}{r^2_{n-2} - r^2_{n-1}} \cdot \frac{1 + \nu_{n-1}}{E_{n-1}}$$

$$- \frac{r_{n-1}\, r^2_n}{r^2_{n-1} - r^2_n} \cdot \frac{1 + \nu_n}{E_n} - \frac{r^3_{n-1}}{r^2_{n-1} - r^2_n} \cdot \frac{(1 - 2\nu_n)(1 + \nu_n)}{E_n} \qquad \text{A-40}$$

$$K_3 = \frac{2\, r_{n-1}\, r^2_n}{(r^2_{n-1} - r^2_n)} \cdot \frac{(1 - \nu^2_n)}{E_n} \qquad \text{A-41}$$

$$K_4 = 0 \qquad \text{A-42}$$

If the number of layers comprising the whole lining equals 2, then $P_{n-2} = P_{outer}$ and $P_n = P_{inner}$, and there is one equation with one unknown variable P_{n-1}.

If the number of layers comprising the whole lining is greater than or equal to 3, equation A-38 can be written for each of the neighboring pairs of cylinders working from outside to in. The first and last equations will have two unknown variables, the rest will have three unknown variables. As a whole, there will be as many equations as there will be unknown variables. Such a series of equations can be solved simultaneously using a Gaussian Tridiagonal Elimination. The radial stress acting across the interface between each layer of the lining can therefore be determined.

A1.4.5.2 Free-Standing Conditions

Similar expressions to A-38 thru A-42 can be derived for free-standing conditions using equations A-19 and A-35:

$$K_1 = \frac{2 r_{n-1} \, r_{n-2}^2}{(r_{n-2}^2 - r_{n-1}^2) \, E_{n-1}} \qquad \text{A-43}$$

$$K_2 = \frac{-r_{n-1}^3}{r_{n-2}^2 - r_{n-1}^2} \cdot \frac{1-\nu_{n-1}}{E_{n-1}} - \frac{r_{n-1} \, r_{n-2}^2}{r_{n-2}^2 - r_{n-1}^2} \cdot \frac{1+\nu_{n-1}}{E_{n-1}} -$$

$$\frac{r_{n-1} \, r_n^2}{r_{n-1}^2 - r_n^2} \cdot \frac{1+\nu_n}{E_n} - \frac{r_{n-1}^3}{r_{n-1}^2 - r_n^2} \cdot \frac{(1-\nu_n)}{E_n} \qquad \text{A-44}$$

$$K_3 = \frac{2 r_{n-1} \, r_n^2}{(r_{n-1}^2 - r_n^2) \, E_n} \qquad \text{A-45}$$

$$K_4 = \left(W_{n-1} \frac{\nu_{n-1}}{E_{n-1}} - W_n \frac{\nu_n}{E_n} \right) \cdot r_{n-1} \qquad \text{A-46}$$

However, the expression for K_4 contains two unknown variables, W_{n-1} and W_n, which need to be evaluated before equation A-38 can be solved. To do this two additional compatibility conditions must be met. These are:

- The resultant axial force exerted by the axial stresses in all the cylinders must equal the force exerted by the average vertical boundary stress, P_z

$$P_z \, A_T = \sum_{i=1}^{i=N} W_i \, A_i \qquad \text{A-47}$$

where

A_T is the total cross-section area of all the cylinders
A_i is the cross-section area of the ith cylinder
W_i is the axial stress in the ith cylinder
N is the total number of cylinders combined together.

- The axial strain, ξ_z, in each cylinder must be equal in order that there is no decoupling or shear stress at the interface between neighboring cylinders.

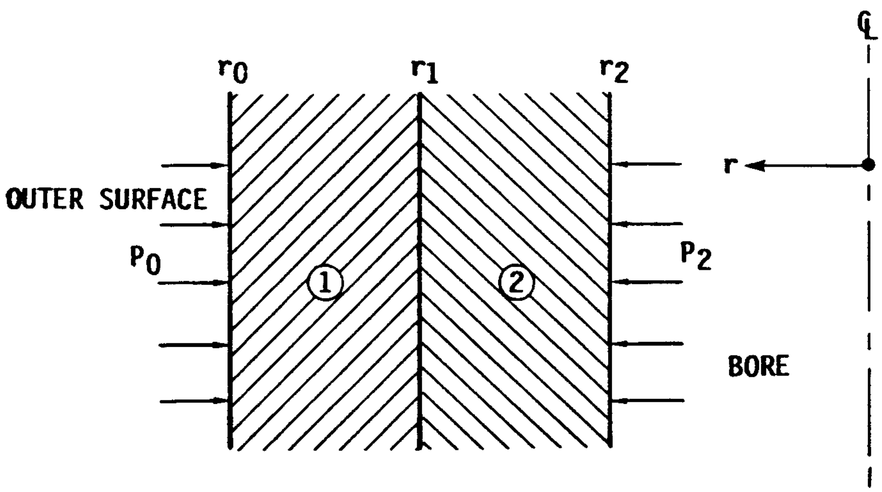
$$\xi_z = \text{constant} \qquad \text{A-48}$$

Equation A-22 derived an expression for a single free-standing cylinder subjected to combined radial and axial loading. For the ith cylinder this gives:

$$\xi_z = \frac{W_i}{E_i} - \frac{P_{i-1}r_{i-1}^2 - P_i r_i^2}{r_{i-1}^2 - r_i^2} \cdot \frac{2\nu_i}{E_i}$$

$$= \frac{W_i}{E_i} - \left\{\frac{2\nu_i}{E_i} \cdot \frac{r_{i-1}^2}{r_{i-1}^2 - r_i^2}\right\} P_{i-1} + \left\{\frac{2\nu_i}{E_i} \cdot \frac{r_i^2}{r_{i-1}^2 - r_i^2}\right\} P_i \qquad \text{A-49}$$

To simplify the following analysis consider a liner comprising only two coupled cylinders. This is appropriate to the present application because in Section A1.6 the largest number of coupled cylinders analyzed under free-standing cylinders is two.



Equation A-48 can be written for each of the cylinders 1 and 2 . Combining these with the compatibility condition in equation A-47 gives:

$$\frac{W_2}{E_2} - \left\{\frac{2\nu_2}{E_2} \cdot \frac{r_1^2}{r_1^2 - r_2^2}\right\} \cdot P_1 + \left\{\frac{2\nu_2}{E_2} \cdot \frac{r_2^2}{r_1^2 - r_2^2}\right\} \cdot P_2 = \frac{W_1}{E_1} - \left\{\frac{2\nu_1}{E_1} \cdot \frac{r_0^2}{r_0^2 - r_1^2}\right\} \cdot P_0 + \left\{\frac{2\nu_1}{E_1} \cdot \frac{r_1^2}{r_0^2 - r_1^2}\right\} \cdot P_1 \qquad \text{A-50}$$

Rearranging terms gives a relationship between W_1 and W_2.

$$W_2 = C_0P_0 + C_1P_1 + C_2P_2 + C_3W_1 \qquad \text{A-51}$$

where

$$C_0 = \frac{-2\nu_1}{E_1} \cdot \frac{E_2r_0^2}{r_0^2 - r_1^2} \qquad \text{A-52}$$

$$C_1 = \frac{2\nu_1}{E_1} \cdot \frac{E_2\ r_1^2}{r_0^2 - r_1^2} + \frac{2\nu_2\ r_1^2}{r_1^2 - r_2^2} \qquad \text{A-53}$$

$$C_2 = \frac{-2\nu_2r_2^2}{r_1^2 - r_2^2} \qquad \text{A-54}$$

$$C_3 = \frac{E_2}{E_1} \qquad \text{A-55}$$

Substituting equation A-51 into equation A-47 for N = 2 gives:

$$P_zA_T = W_1A_1 + (C_0P_0 + C_1P_1 + C_2P_2 + C_3W_1) \cdot A_2 \qquad \text{A-56}$$

Rearranging A-56 gives an expression for W1 in terms of P_0, P_1, P_2 and P_z.

$$W_1 = \left[P_zA_T - (C_0P_0 + C_1P_1 + C_2P_2)\ A_2\right] \cdot \frac{1}{A_1 + C_3A_2} \qquad \text{A-57}$$

Substituting equation A-57 back into equation A-51 gives:

$$W_2 = \frac{C_3 A_T}{A_1 + C_3 A_2} \cdot P_Z + \frac{A_1}{A_1 + C_3 A_2} \left\{ C_0 P_0 + C_1 P_1 + C_2 P_2 \right\} \qquad \text{A-58}$$

Returning now to equation A-38 for the special case of only two coupled cylinders under free-standing conditions.

$$K_1 P_0 + K_2 P_1 + K_3 P_2 = K_4 \qquad \text{A-59}$$

where

$$K_4 = \left\{ W_1 \frac{\nu_1}{E_1} - W_2 \frac{\nu_2}{E_2} \right\} \cdot r_1 \qquad \text{A-60}$$

Substituting equations A-52 to A-55 into equations A-57 and A-58, equations A-57 and A-58 into A-60 and then equations A-43 to A-45 (for the case where n=2) and A-60 into equation A-59, and rearranging terms gives:

$$K_1' P_0 + K_2' P_1 + K_3' P_2 = K_4' P_z \qquad \text{A-61}$$

where

$$K_1' = \frac{2 r_1 r_0^2}{r_0^2 - r_1^2} \left[\frac{1}{E_1} - \frac{\nu_1}{E_1} \cdot \frac{E_1 A_1 \nu_2 + E_2 A_2 \nu_1}{E_1 A_1 + E_2 A_2} \right] \qquad \text{A-62}$$

$$K_2' = \frac{-r_1^3}{r_0^2 - r_1^2} \left[\frac{1-\nu_1}{E_1} - \frac{2\nu_1}{E_1} \cdot \frac{E_1 A_1 \nu_2 + E_2 A_2 \nu_1}{E_1 A_1 + E_2 A_2} \right] - \frac{r_1 r_0^2}{r_0^2 - r_1^2} \cdot \frac{1+\nu_1}{E_1}$$
$$- \frac{r_1 r_2^2}{r_1^2 - r_2^2} \cdot \frac{1+\nu_2}{E_2} - \frac{r_1^3}{r_1^2 - r_2^2} \left[\frac{1-\nu_2}{E_2} - \frac{2\nu_2}{E_2} \cdot \frac{E_1 A_1 \nu_2 + E_2 A_2 \nu_1}{E_1 A_1 + E_2 A_2} \right] \qquad \text{A-63}$$

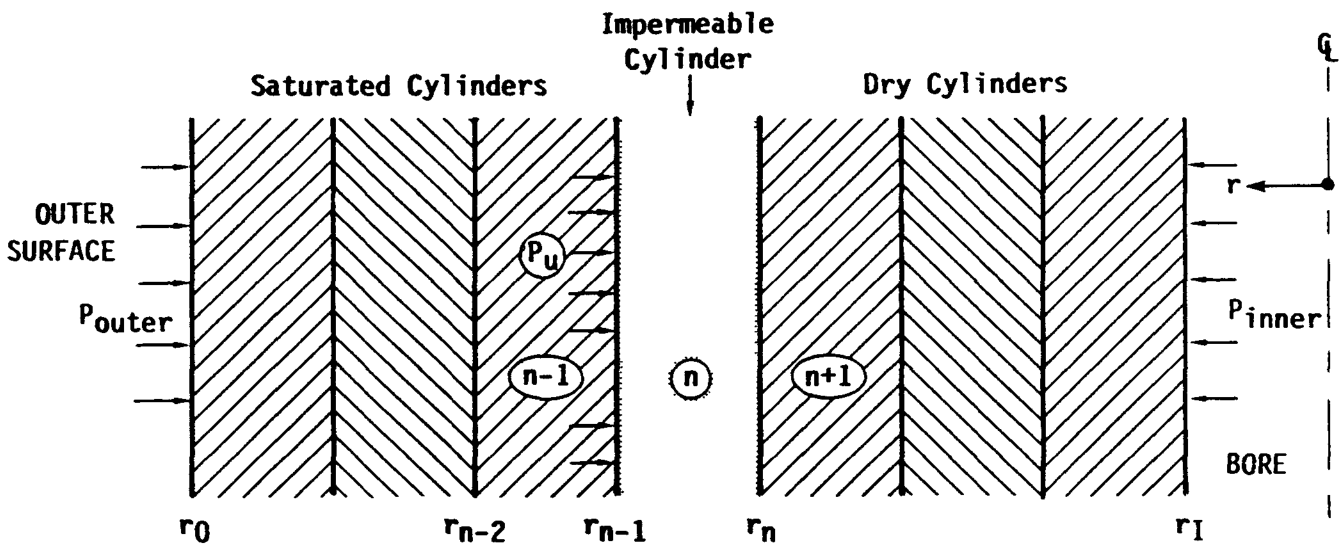
$$K_3' = \frac{2 r_1 r_2^2}{r_1^2 - r_2^2} \left[\frac{1}{E_2} - \frac{\nu_2}{E_2} \cdot \frac{E_1 A_1 \nu_2 + E_2 A_2 \nu_1}{E_1 A_1 + E_2 A_2} \right] \qquad \text{A-64}$$

$$K_4' = A_T r_1 \frac{\nu_1 - \nu_2}{E_1 A_1 + E_2 A_2} \qquad \text{A-65}$$

For two coupled cylinders P_2, P_0 and P_z are the specified outer boundary stresses. If the cylinder dimensions and elastic properties are known, equation A-61 can be solved for P_1, the radial stress across the boundary of the two cylinders. W_1 and W_2, the axial stresses in each cylinder can then be determined using equation A-57 and A-58.

A1.4.6 Treatment of Liner Saturation and Pore Pressure

So far in the discussion the cylinders have been assumed to be dry, pore pressures have been assumed to be negligible, and total stresses have been assumed to be synonymous with effective stresses. Consider now the situation where one of the cylinders is made of an impermeable material, and that all the cylinders on the outside of this impermeable cylinder are saturated with fluid at a pore pressure, P_u.



The complete liner system can still be analyzed in terms of effective stresses using equations developed in preceding sections. However the boundary condition at $r=r_{n-1}$ given by equation A-34 is incorrect. Instead the boundary condition on this boundary is:

$$(P_{outer})_n = (P_{inner})_{n-1} + P_u \qquad \text{A-66}$$

This boundary condition applies only when analyzing the pairs of neighboring cylinders (n-1) and (n), and (n) and (n+1). Consider first the pair of cylinders (n-1) and (n) under plain strain conditions. For the effective stresses in cylinder (n-1) equation A-36 applies. For the effective stresses in cylinder (n) the variable P_{n-1} in equation A-37 must be substituted by $(P_{n-1} + P_u)$ in order to incorporate the additional boundary load, P_u on the impermeable liner. This substitution affects equation A-38 by adding an extra term to the righthand side of the equality, e.g.:

$$K_1 P_{n-2} + K_2 P_{n-1} + K_3 P_n = K_4 + K_5 \qquad \text{A-67}$$

where for plane strain conditions

$$K_5 = \frac{r_{n-1}^3 (1-2\nu_n) + r_n^2 r_{n-1}}{r_{n-1}^2 - r_n^2} \cdot \frac{(1+\nu_n)}{E_n} \cdot P_u \qquad \text{A-68}$$

For the pair of cylinders (n) and (n+1) equation A-37 applies for the effective stresses in cylinder (n+1), but for the effective stresses in cylinder (n), the variable P_{n-2} in equation A-36 must be substituted by $(P_{n-2} + P_u)$. In this case:

$$K_5 = -\left[\frac{r_{n-2}^2 \, r_{n-1}}{r_{n-2}^2 - r_{n-1}^2} \cdot \frac{2\,(1-\nu_{n-1}^2)}{E_{n-1}}\right] \cdot P_u \qquad \text{A-69}$$

again for plane strain conditions.

A similar treatment can be applied for the cylinders under free-standing conditions. However there is no application for such a treatment in Section A1.6 and so the discussion is not pursued further here.

The situation of the liner being saturated on the inside of the permeable layer can also be treated in a similar manner, but the discussion is not pursued further for the same reason that no application has been identified in Section A1.6.

A1.5 CALCULATION

A1.5.1 Calculation Sequence

In the previous section the various equations necessary for solving the distributions of stresses and strains within the shaft linings were derived. This section presents the sequence in which these equations are used, first to determine the normal stresses acting on the boundaries of each individual cylinder of the multiple layer liner, and then to determine the stress and strain distributions within each cylinder.

1. For each layer of the lining in turn, working outside to in through the shaft lining, determine the material type, the inner and outer radi of the cylinder, the elastic properties (Young's Modulus and Poisson's Ratio) and the density of the material.

2. Determine the total number of segments (equals num. segs) by counting the number of entries made in Step 1.

3. Specify the radial stress acting on the inner and outer shaft boundaries, and decide whether the shaft lining is to support its own weight or not (i.e., whether to use free standing or plane strain solutions).

4. If the lining is to be free-standing, specify the depth of interest, and go to Step 11.

5. For plane strain conditions specify if any part of the liner is to be saturated, and if so, specify the pore pressure and the radius of the impermeable boundary.

6. If the number of segments equals 1, then go to Step 10.

7. Consider each pair of adjacent segments in turn, working outside to in. Calculate K_1, K_2, K_3, K_4 for each pair using equations A-39 through A-42. Where appropriate calculate K_5 using equation A-68 or A-69.

8. If the number of segments equals 2, solve the only equation A-38 (or A-67 if appropriate) for P_1, then go to Step 10.

9. If the number of segments is greater than or equal to three, there will be more than one equation A-38 (or equation A-67 if appropriate). Compute the unknown variables, P_1, P_2, $P_3, \ldots P_{num.seg-1}$, using a Gaussian Tridiagonal Elimination.

10. For a selected value of radius r, determine which layer of the lining this falls in and compute:

Radial Strain	ξ_r	using equation A-30
Tangential Strain	ξ_θ	using equation A-31
Axial Strain	ξ_z	using equation A-32
Radial Stress	σ_r	using equation A-1
Tangential Stress	σ_θ	using equation A-2
Axial Stress	σ_z	using equation A-33
Radial Displacement	$u(r)$	using equation A-29

Note: The pore pressure must be added to the calculated radial stress acting inward on the impermeable boundary in order to give the actual radial stress on that boundary.

STOP .

11. For free-standing conditions, if the number of segments equals 1, then go to Step 14.

12. If the number of segments is greater than 2 then the program will default.

13. If the number of segments equals 2, calculate K'_1, K'_2, K'_3, K'_4, using equations A-62 through A-65. Calculate P_z (= height of liner above depth of interest x density of materials x acceleration due to gravity). Calculate P_1 using equation A-61. Calculate W_1 and W_2 using equations A-57 and A-58.

14. For a selected value of radius r, determine which layer of the lining this falls in and compute.

Radial Strain	ξ_r	using equation A-20
Tangential Strain	ξ_θ	using equation A-21
Axial Strain	ξ_z	using equation A-22
Radial Stress	σ_r	using equation A-24
Tangential Stress	σ_θ	using equation A-25
Axial Stress	σ_z	using equation A-26
Radial Displacement	$u(r)$	using equation A-19

STOP

A1.5.2 "SHAFT" - A Program for the IBM-PC

The program "SHAFT" was written to perform the sequence of calculations presented in Section A1.5.1. It was written as a user-interactive program in order to give the user flexibility to change the values of the input variables without the need to spend a lot of time setting up data files. The program was written in BASICA Ver. 2.11, and is run on the IBM-PC.

The calculations are carried out for several values of the radius, r, which are preselected, for the purpose of the application, to be equal to the radi of the various layers comprising the lining.

The user may select:

- The number of layers in the lining (up to a maximum of 7)
- The cylinder radii
- The material type, and the elastic (E, ν) and physical (density) properties
- The radial pressure on the inwall and outerwall of the whole lining
- The groundwater pressure acting on any impermeable membrane within the liner system (plane strain conditions only)
- Whether a free-standing or plane strain analysis is to be used, and if the former, to specify the height of liner overlying the section of interest.

The program has been written to perform the calculations using metric units. The following conversions to Imperial units are applicable.

1 m = 3.28 ft	or	1 ft = 0.3048 m
1 GPa = 64.75 ton/in^2	or	1 ton/in^2 = 0.0154 GPa
1 MPa = 145 psi	or	1 psi = 0.00689 MPa
1 kg/m^3 = 0.0624 lb/ft^3	or	1 lb/ft^3 = 16.02 kg/m^3
1 mm = 0.039 in	or	1 in = 25.4 mm

The program listing is as follows:

```
10 REM *********************************************************************
20 REM PROGRAM TO COMPUTE STRESSES AND STRAINS IN MULTIPLE SHAFT LININGS
30 REM *********************************************************************
40 REM
50 PIE = 3.1416
60 REM SET SIZE OF LINING DATA ARRAYS:
70 DIM SEGMENT$(8), A(7), B(7), E(7), NUE(7), GAMMA(7), P2(7), P1(7), W(7)
80 REM SET SIZE OF OUTPUT DATA ARRAY:
90 DIM D(7,14)
100 REM SET SIZE OF COMPUTATION ARRAYS:
110 DIM KN(7), KN1(7), KN2(7), CN(7)
120 REM -------------------------------------------------------------------
130 REM     CLEAR VDU SCREEN AND PRINT HEADER INFORMATION
140 REM -------------------------------------------------------------------
150 CLS
160 PRINT "------------------------------------------------------------------
----------"
170 PRINT
180 PRINT "                    P R O G R A M   ' S H A F T ' "
190 PRINT
200 PRINT "------------------------------------------------------------------
----------"
210 PRINT
220 PRINT "THIS PROGRAM COMPUTES THE PRINCIPAL STRESSES AND STRAINS IN MULTIPLE"

230 PRINT "SHAFT LININGS UNDER LINEAR ELASTIC CONDITIONS"
240 PRINT
250 REM -------------------------------------------------------------------
260 REM   THE FIRST SECTION OF CODE IS USED TO INPUT DATA FROM THE KEYBOARD
270 REM -------------------------------------------------------------------
280 INPUT "HORIZON DEPTH (m) = "; H
290 PRINT
300 PRINT "WHEN INPUTING SEGMENT DATA, WORK FROM THE OUTER MOST SEGMENT TO"
310 PRINT "THE INNER MOST SEGMENT.  WHEN DATA INPUT IS COMPLETE, TYPE 'END' AS"
320 PRINT "THE LAST SEGMENT MATERIAL.  NO MORE THAN 7 SEGMENTS ARE PERMITTED."
330 PRINT
340 I%=1
350 INPUT "SEGMENT MATERIAL = "; SEGMENT$(I%)
360 IF SEGMENT$(I%)="END" THEN LET NUM.SEGS = I% - 1 : GOTO 430
370 PRINT "INPUT INNER RADIUS (m); OUTER RADIUS (m); YOUNG'S MODULUS (GPa);
380 PRINT "POISSON'S RATIO; AND DENSITY (kg/cu.m)"
390 INPUT A(I%), B(I%), E(I%), NUE(I%), GAMMA(I%)
```

Program Listing "SHAFT" (Continued)

```
400 PRINT
410 I% = I% + 1
420 GOTO 350
430 PRINT
440 PRINT "HAVE ALL SEGMENT DATA BEEN INPUT CORRECTLY (Y/N) ? ";
450 QUIZ$ = INPUT$(1)
460 IF QUIZ$ <> "Y" THEN GOTO 150
470 REM
480 CLS
490 PRINT "IS THE SHAFT LINER (A) FREE STANDING, OR (B) IS A PLANE STRAIN"
500 PRINT "ANALYSIS REQUIRED ? ";
510 ANALYSI$ = INPUT$(1)
520 PRINT ANALYSI$
530 PRINT
540 IF ANALYSI$ = "A" OR ANALYSI$ = "B" THEN GOTO 550 ELSE GOTO 490
550 IF ANALYSI$ = "B" THEN GOTO 580
560 IF ANALYSI$ = "A" AND NUM.SEGS > 2 THEN PRINT "NO MORE THAN TWO SEGMENTS CAN
 BE ANALYZED UNDER FREE STANDING CONDITIONS."
570 IF ANALYSI$ = "A" AND NUM.SEGS > 2 THEN PRINT "PROGRAM WILL ABORT." : END
580 PRINT "------------------------------------------------------------------
----------"
590 PRINT
600 PRINT "INPUT BOUNDARY LOADS HERE."
610 PRINT
620 INPUT "PRESSURE ON OUTSIDE WALL OF LINER (MPa) = "; PO
630 INPUT "PRESSURE ON INWALL OF LINER (MPa) = "; PI
640 IF ANALYSI$ = "A" THEN INPUT "HEIGHT OF LINER ABOVE HORIZON DEPTH (m) = "; P
Z
650 IF ANALYSI$ = "A" THEN GOTO 720
660 PRINT "WILL ANY PART OF THE LINER BE SATURATED AND IS ONE OF THE SEGMENTS"
670 PRINT "IMPERMEABLE (Y/N) ? ";
680 SAT$ = INPUT$(1) : PRINT SAT$
690 IF SAT$ <> "Y" THEN GOTO 720
700 PRINT "INPUT PORE PRESSURE (MPa) AND RADIUS TO IMPERMEABLE BOUNDARY (m)"
710 INPUT PU, RPU
720 PRINT
730 PRINT "HAVE BOUNDARY LOADS BEEN INPUT CORRECTLY (Y/N) ? ";
740 QUIZ$ = INPUT$(1)
750 IF QUIZ$ <> "Y" THEN GOTO 480
760 IF ANALYSI$ = "B" THEN GOTO 880
770 REM --------------------------------
780 REM  CALCULATE AVERAGE VERTICAL STRESS
790 REM  DUE TO OVERBURDEN WEIGHT
800 REM --------------------------------
810 WEIGHT = 0
820 FOR I% = 1 TO NUM.SEGS
830 WEIGHT = WEIGHT + GAMMA(I%)*PZ*PIE*(B(I%)*B(I%) - A(I%)*A(I%))
840 NEXT
850 TOTAL.AREA = PIE * (B(1)*B(1) - A(NUM.SEGS)*A(NUM.SEGS))
860 PZ = WEIGHT * 9.810001 / TOTAL.AREA / 1000000!
870 W(1) = PZ
```

Program Listing "SHAFT" (Continued)

```
880 REM -----------------------------------------------------------------
890 REM   THE NEXT SECTION OF CODE COMPUTES THE INNER AND OUTER RADIAL LOADS
900 REM   ACTING ON EACH CYLINDER COMPRISING THE WHOLE LINER
910 REM -----------------------------------------------------------------
920 CLS
930 IF NUM.SEGS = 1 THEN GOTO 1840
940 FOR I% = 2 TO NUM.SEGS
950 REM --------------------
960 REM READ DATA FROM ARRAYS
970 REM --------------------
980 RN = A(I%)
990 RN1 = A(I%-1)
1000 RN2 = B(I%-1)
1010 EN = E(I%)*1000
1020 EN1 = E(I%-1)*1000
1030 NU = NUE(I%)
1040 NU1 = NUE(I%-1)
1050 AN1 = PIE * (RN2*RN2 - RN1*RN1)
1060 AN = PIE * (RN1*RN1 - RN*RN)
1070 REM ---------------------
1080 REM ASSIGN CONSTANT VALUES
1090 REM ---------------------
1100 C1 = RN1*RN2*RN2
1110 C2 = (RN2*RN2 - RN1*RN1) * EN1
1120 C3 = RN1*RN*RN
1130 C4 = (RN1*RN1 - RN*RN) * EN
1140 C5 = RN1*RN1*RN1/C2*(1-NU1)
1150 C6 = C1/C2*(1+NU1)
1160 C7 = C3/C4*(1+NU)
1170 C8 = RN1*RN1*RN1/C4*(1-NU)
1180 C9 = 1 - NU1*NU1
1190 C10 = 1 - 2*NU1
1200 C11 = 1 - 2*NU
1210 C12 = 1 - NU*NU
1220 C13 = EN1*AN1 + EN*AN
1230 C14 = (EN1*AN1*NU + EN*AN*NU1) / C13
1240 C15 = C5 / (1-NU1) * (1 - NU1 - 2*NU1*C14)
1250 C16 = C8 / (1-NU) * (1 - NU - 2*NU*C14)
1260 IF ANALYSI$ = "B" THEN GOTO 1380
1270 REM ---------------------------------------
1280 REM COMPUTE K-VALUES FOR FREE STANDING LINERS
1290 REM ---------------------------------------
1300 K3(I%-1) = 2*C3/C4*(1-NU*C14)
1310 K2(I%-1) = -C15-C7-C6-C16
1320 K1(I%-1) = 2*C1/C2*(1-NU1*C14)
1330 K4(I%-1) = PZ * TOTAL.AREA * RN1 * (NU1-NU) / C13
1340 GOTO 1450
1350 REM ----------------------------------------
1360 REM COMPUTE K-VALUES FOR PLANE STRAIN ANALYSIS
1370 REM ----------------------------------------
1380 K3(I%-1) = 2*C3/C4*C12
```

```
1390 K2(I%-1) = -(C8/(1-NU)*(1+NU)*C11) - C7 - C6 - (C5/(1-NU1)*(1+NU1)*C10)
1400 K1(I%-1) = 2*C1/C2*C9
1410 K4(I%-1) = 0
1420 IF SAT$ <> "Y" THEN GOTO 1450
1430 IF RN1 = RPU THEN LET K4(I%-1) = (C8*C11/(1-NU)*(1+NU) + C7) * PU
1440 IF RN2 = RPU THEN LET K4(I%-1) = -(C1/C2*2*C9)*PU
1450 NEXT
1460 REM ---------------------------------------------
1470 REM  PERFORM THE GAUSSIAN TRIDIAGONAL ELIMINATION
1480 REM  TO DETERMINE P1, P2, ...... , P.NUM.SEGS
1490 REM ---------------------------------------------
1500 K4(1) = K4(1) - K1(1)*PO
1510 IF NUM.SEGS = 2 THEN GOTO 1680
1520 REM
1530 FOR I% = 2 TO NUM.SEGS-1
1540 XMULT = K1(I%)/K2(I%-1)
1550 K2(I%) = K2(I%) - (XMULT * K3(I%-1))
1560 K4(I%) = K4(I%) - XMULT * K4(I%-1)
1570 NEXT
1580 REM
1590 LET K4(I%-1) = K4(I%-1) - (K3(I%-1)*PI)
1600 LET P2(NUM.SEGS) = K4(I%-1) / K2(I%-1)
1610 LET P1(NUM.SEGS-1) = P2(NUM.SEGS)
1620 FOR I% = (NUM.SEGS-1) TO 2 STEP -1
1630 P2(I%) = (K4(I%-1) - K3(I%-1) * P1(I%)) / K2(I%-1)
1640 P1(I%-1) = P2(I%)
1650 NEXT
1660 GOTO 1710
1670 REM
1680 LET K4(1) = K4(1) - (K3(1)*PI)
1690 P2(2) = K4(1)/K2(1)
1700 P1(1) = P2(2)
1710 REM -------------------------------
1720 REM INSERT PORE PRESSURE ON
1730 REM IMPERMEABLE LINER IF APPROPRIATE
1740 REM -------------------------------
1750 IF ANALYSIS$ = "A" THEN GOTO 1840
1760 IF SAT$ = "N" THEN GOTO 1840
1770 FOR I% = 1 TO NUM.SEGS
1780 IF B(I%) = RPU THEN LET P2(I%) = P2(I%) + PU
1790 NEXT
1800 REM ---------------------------
1810 REM  END OF GAUSSIAN TRIDIAGONAL
1820 REM  ELIMINATION
1830 REM ---------------------------
1840 P2(1) = PO  :  P1(NUM.SEGS) = PI
1850 IF ANALYSIS$ = "A" THEN PRINT "COMPUTATION OF SEGMENT RADIAL STRESSES FOR FR
EE STANDING LINERS"
1860 IF ANALYSIS$ = "B" THEN PRINT "COMPUTATION OF SEGMENT RADIAL STRESSES FOR PL
ANE STRAIN ANALYSIS"
1870 PRINT "HAS BEEN COMPLETED."
```

```
1880 PRINT
1890 IF ANALYSIS$ = "B" THEN GOTO 2120
1900 REM ---------------------------------------
1910 REM  FOR FREE-STANDING CYLINDERS CALCULATE
1920 REM  VERTICAL STRESSES IN EACH LINER SEGMENT
1930 REM ---------------------------------------
1940 IF NUM.SEGS = 1 THEN GOTO 2120
1950 E1 = E(1)*1000
1960 E2 = E(2)*1000
1970 NU1 = NUE(1)
1980 NU2 = NUE(2)
1990 A1 = PIE * (B(1)*B(1) - A(1)*A(1))
2000 A2 = PIE * (B(2)*B(2) - A(2)*A(2))
2010 R0 = B(1)
2020 R1 = A(1)
2030 R2 = A(2)
2040 C0 = -2*NU1/E1*E2*R0*R0/(R0*R0-R1*R1)
2050 C2 = -2*NU2*R2*R2/(R1*R1-R2*R2)
2060 C1 = -C0/R0/R0*R1*R1 + -C2/R2/R2*R1*R1
2070 C3 = E2/E1
2080 C4 = A1 + C3*A2
2090 C5 = C0*P2(1) + C1*P2(2) + C2*P1(2)
2100 W(1) = (PZ*TOTAL.AREA - C5*A2)/C4
2110 W(2) = PZ*TOTAL.AREA*C3/C4 + A1*C5/C4
2120 REM -----------------------------------------------------------------------------
2130 REM   THE NEXT SECTION OF TEXT CALCULATES THE STRESSES AND STRAINS AT THE
2140 REM   INWALL AND OUTER WALL OF EACH CYLINDER COMPRISING THE LINER
2150 REM -----------------------------------------------------------------------------
2160 TITLE.1$ = "SEGMENT  BOUNDARY  TANGNT   RADIAL   AXIAL    TANGNT   RADIAL
 AXIAL    RADIAL"
2170 TITLE.2$ = "MATERIAL           STRAIN   STRAIN   STRAIN   STRESS   STRESS
 STRESS   CLOSURE"
2180 TITLE.3$ = "                   (E-6)    (E-6)    (E-6)    (MPa)    (MPa)
 (MPa)     (mm)"
2190 PRINT TITLE.1$
2200 PRINT TITLE.2$
2210 PRINT TITLE.3$
2220 PRINT
2230 FOR I% = 1 TO NUM.SEGS
2240 REM ----------------------------------
2250 REM  CALCULATION LOOP STARTS BY SETTING
2260 REM  THE CONSTANTS FOR THE CYLINDER
2270 REM ----------------------------------
2280 BB = B(I%) * B(I%)
2290 AA = A(I%) * A(I%)
2300 P2BB = P2(I%) * BB
2310 P1AA = P1(I%) * AA
2320 AABB = AA * BB
2330 DP = P2(I%) - P1(I%)
2340 DR = BB - AA
```

Program Listing "SHAFT" (Continued)

```
2350 C1 = (1 - NUE(I%))/E(I%)/1000
2360 C2 = (1 + NUE(I%))/E(I%)/1000
2370 C3 = ((-2) * NUE(I%))/E(I%)/1000
2380 C5 = (P2BB - P1AA)/DR
2390 C6 = W(I%)/E(I%)/1000
2400 C7 = C6 * NUE(I%)
2410 C8 = NUE(I%)/(1-2*NUE(I%))/C2
2420 C9 = 1 - 2*NUE(I%)
2430 C10 = DP*AA*BB/DR
2440 C11 = C5*C2*C9*1000000!
2450 K1 = (C5 * C1 - C7)*1000000!
2460 K2 = (DP * AA * BB * C2 / DR)*1000000!
2470 K3 = (C5 * C3 + C6)*1000000!
2480 J% = 2*I% - 1
2490 IF ANALYSI$ = "B" THEN GOTO 2800
2500 REM ---------------------------------
2510 REM  CALCULATE THE STRESSES AND STRAINS
2520 REM  FOR FREE STANDING CYLINDERS
2530 REM ---------------------------------
2540 K4 = K2 / BB
2550 D(1,J%) = K1 + K4       : REM (MICROSTRAIN)
2560 D(2,J%) = K1 - K4       : REM (MICROSTRAIN)
2570 D(3,J%) = K3            : REM (MICROSTRAIN)
2580 D(7,J%) = (K1*B(I%) + K2/B(I%))/1000 : REM (mm)
2590 SUM.E.O = K1 + K1 + K3 : REM (MICROSTRAIN)
2600 K4 = K2 / AA
2610 D(1,J%+1) = K1 + K4     : REM (MICROSTRAIN)
2620 D(2,J%+1) = K1 - K4     : REM (MICROSTRAIN)
2630 D(3,J%+1) = K3          : REM (MICROSTRAIN)
2640 D(7,J%+1) = (K1*A(I%) + K2/A(I%))/1000 : REM (mm)
2650 SUM.E.I = K1 + K1 + K3 : REM (MICROSTRAIN)
2660 REM
2670 C9 = C8 * SUM.E.O
2680 D(4,J%) = (C9 + D(1,J%)/C2)/1000000!  : REM (MPa)
2690 D(5,J%) = (C9 + D(2,J%)/C2)/1000000!  : REM (MPa)
2700 D(6,J%) = (C9 + D(3,J%)/C2)/1000000!  : REM (MPa)
2710 C9 = C8 * SUM.E.I
2720 D(4,J%+1) = (C9 + D(1,J%+1)/C2)/1000000! : REM (MPa)
2730 D(5,J%+1) = (C9 + D(2,J%+1)/C2)/1000000! : REM (MPa)
2740 D(6,J%+1) = (C9 + D(3,J%+1)/C2)/1000000! : REM (MPa)
2750 GOTO 3020
2760 REM ---------------------------------
2770 REM  CALCULATE THE STRESSES AND STRAINS
2780 REM  FOR PLANE STRAIN CONDITIONS
2790 REM ---------------------------------
2800 K4 = K2 / BB
2810 D(1,J%) = C11 + K4         : REM (MICROSTRAIN)
2820 D(2,J%) = C11 - K4         : REM (MICROSTRAIN)
2830 D(3,J%) = 0                : REM (MICROSTRAIN)
2840 K4 = K2 / AA
2850 D(1,J%+1) = C11 + K4       : REM (MICROSTRAIN)
```

```
2860 D(2,J%+1) = C11 - K4          : REM (MICROSTRAIN)
2870 D(3,J%+1) = 0                 : REM (MICROSTRAIN)
2880 REM
2890 D(4,J%) = C5 + C10/BB         : REM (MPa)
2900 D(5,J%) = C5 - C10/BB         : REM (MPa)
2910 D(6,J%) = 2*NUE(I%)*C5        : REM (MPa)
2920 REM
2930 D(4,J%+1) = C5 + C10/AA       : REM (MPa)
2940 D(5,J%+1) = C5 - C10/AA       : REM (MPa)
2950 D(6,J%+1) = 2*NUE(I%)*C5      : REM (MPa)
2960 REM
2970 D(7,J%) = (C11*B(I%) + K2/B(I%))/1000   : REM (mm)
2980 D(7,J%+1) = (C11*A(I%) + K2/A(I%))/1000 : REM (mm)
2990 REM -------------------------------
3000 REM  PRINT OUTPUT DATA TO THE SCREEN
3010 REM -------------------------------
3020 OUTPUT.O$ = "\      \   OUTER  +####.#  +####.#  +####.#  +###.##  +###.##
 +###.##  +##.###"
3030 OUTPUT.I$ = "\      \   INNER  +####.#  +####.#  +####.#  +###.##  +###.##
 +###.##  +##.###"
3040 PRINT USING OUTPUT.O$; SEGMENT$(I%), D(1,J%), D(2,J%), D(3,J%), D(4,J%), D(
5,J%), D(6,J%), D(7,J%)
3050 PRINT USING OUTPUT.I$; SEGMENT$(I%), D(1,J%+1), D(2,J%+1), D(3,J%+1), D(4,J
%+1), D(5,J%+1), D(6,J%+1), D(7,J%+1)
3060 REM
3070 NEXT I%
3080 REM --------------------------------------------------------------------
3090 REM    THE LAST SECTION OF CODE PROVIDES THE USER WITH AN OPTION TO
3100 REM    LIST THE INPUT AND OUTPUT DATA ON A PRINTER
3110 REM --------------------------------------------------------------------
3120 PRINT
3130 PRINT "DO YOU WISH THIS OUTPUT TO BE DIRECTED TO A PRINTER (Y/N) ? ";
3140 QUIZ$ = INPUT$(1)
3150 IF QUIZ$<>"Y" THEN GOTO 3590
3160 LPRINT
3170 LPRINT
3180 LPRINT
3190 LPRINT
3200 LPRINT
3210 LPRINT
3220 LPRINT USING "HORIZON DEPTH = ####.# m"; H
3230 LPRINT
3240 LPRINT
3250 LPRINT
3260 LPRINT "INPUT DATA :"
3270 LPRINT
3280 LPRINT "SEGMENT MATERIAL INNER  OUTER  YOUNG'S POISSON'S DENSITY"
3290 LPRINT "                 RADIUS RADIUS MODULUS   RATIO"
3300 LPRINT "                   (m)    (m)   (GPa)            (kg/cu.m)"
3310 OUTPUT.4$ = "   #    \       \ ##.### ##.###  ###.#    #.##     ####"
3320 FOR I% = 1 TO NUM.SEGS
```

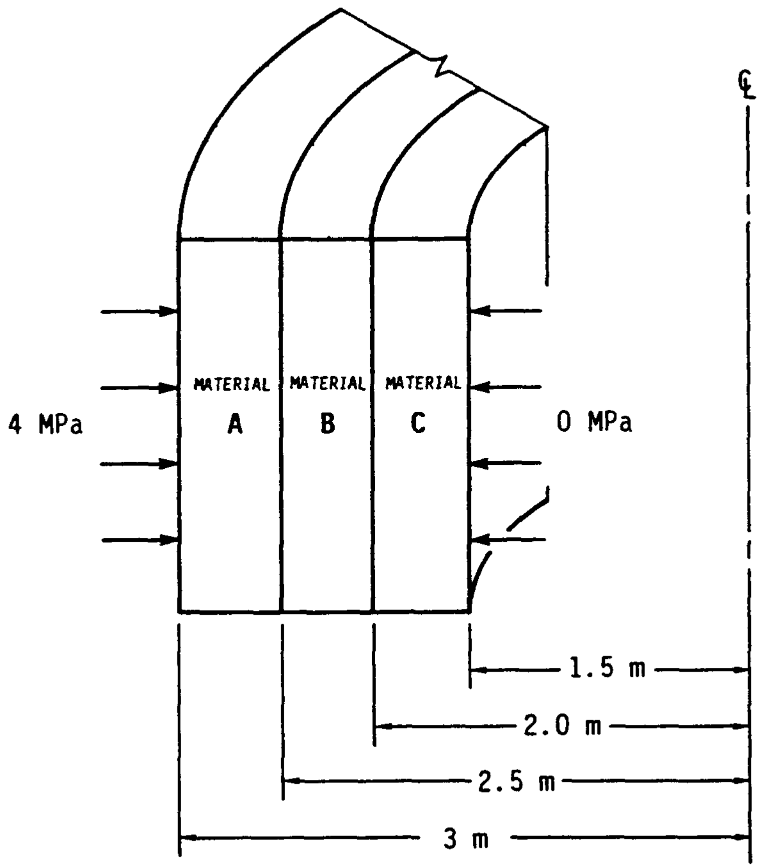
```
3330 LPRINT USING OUTPUT.4$; I%, SEGMENT$(I%), A(I%), B(I%), E(I%), NUE(I%), GAM
MA(I%)
3340 NEXT I%
3350 LPRINT
3360 LPRINT
3370 LPRINT
3380 IF ANALYSIS$ = "A" THEN LPRINT "BOUNDARY CONDITIONS :  FREE STANDING CYLINDE
R"
3390 IF ANALYSIS$ = "B" THEN LPRINT "BOUNDARY CONDITIONS :  PLANE STRAIN CONDITIO
NS"
3400 LPRINT
3410 LPRINT USING "EXTERNAL PRESSURE = ##.## MPa"; PO
3420 LPRINT USING "INTERNAL PRESSURE = ##.## MPa"; PI
3430 IF ANALYSIS$ = "A" THEN LPRINT USING "TOTAL VERTICAL WEIGHT = ###.## MN"; PZ
*TOTAL.AREA
3440 IF ANALYSIS$ = "B" AND SAT$ = "Y" THEN LPRINT USING "PORE PRESSURE OF ##.##
MPa BEARING ON LINER AT RADIUS #.###"; PU, RPU
3450 LPRINT
3460 LPRINT
3470 LPRINT
3480 LPRINT "OUTPUT DATA :
3490 LPRINT
3500 LPRINT TITLE.1$
3510 LPRINT TITLE.2$
3520 LPRINT TITLE.3$
3530 FOR I% = 1 TO NUM.SEGS
3540 J% = 2*I% - 1
3550 LPRINT
3560 LPRINT USING OUTPUT.0$; SEGMENT$(I%), D(1,J%), D(2,J%), D(3,J%), D(4,J%), D
(5,J%), D(6,J%), D(7,J%)
3570 LPRINT USING OUTPUT.1$; SEGMENT$(I%), D(1,J%+1), D(2,J%+1), D(3,J%+1), D(4,
J%+1), D(5,J%+1), D(6,J%+1), D(7,J%+1)
3580 NEXT I%
3590 REM ------------------------------------------------------------------
3600 REM                               EXIT OPTIONS
3610 REM ------------------------------------------------------------------
3620 PRINT
3630 PRINT
3640 PRINT "DO YOU WISH TO RUN THE PROGRAM AGAIN (Y/N) ? "
3650 QUIZ$ = INPUT$(1)
3660 IF QUIZ$ = "Y" THEN CLEAR : GOTO 10
3670 CLS : SYSTEM
3680 END
```

A flow chart for the program operation is presented in Figure A-1.

A1.5.3 Test Problems

The following problems were used to check the accuracy of the output from the program. These problems do not provide verification of all sections of the code.

A1.5.3.1 Plane Strain Conditions



At a depth of 700 m, an infinitely long shaft liner is made up of three impermeable concentric cylinders, A, B, C, whose properties and dimensions are given below. Determine the magnitudes of the radial, tangential, and axial, stresses and strains, and the magnitude of the radial displacement, at the boundaries of the liner, and at the boundaries of the constituent cylinders under plane strain conditions.

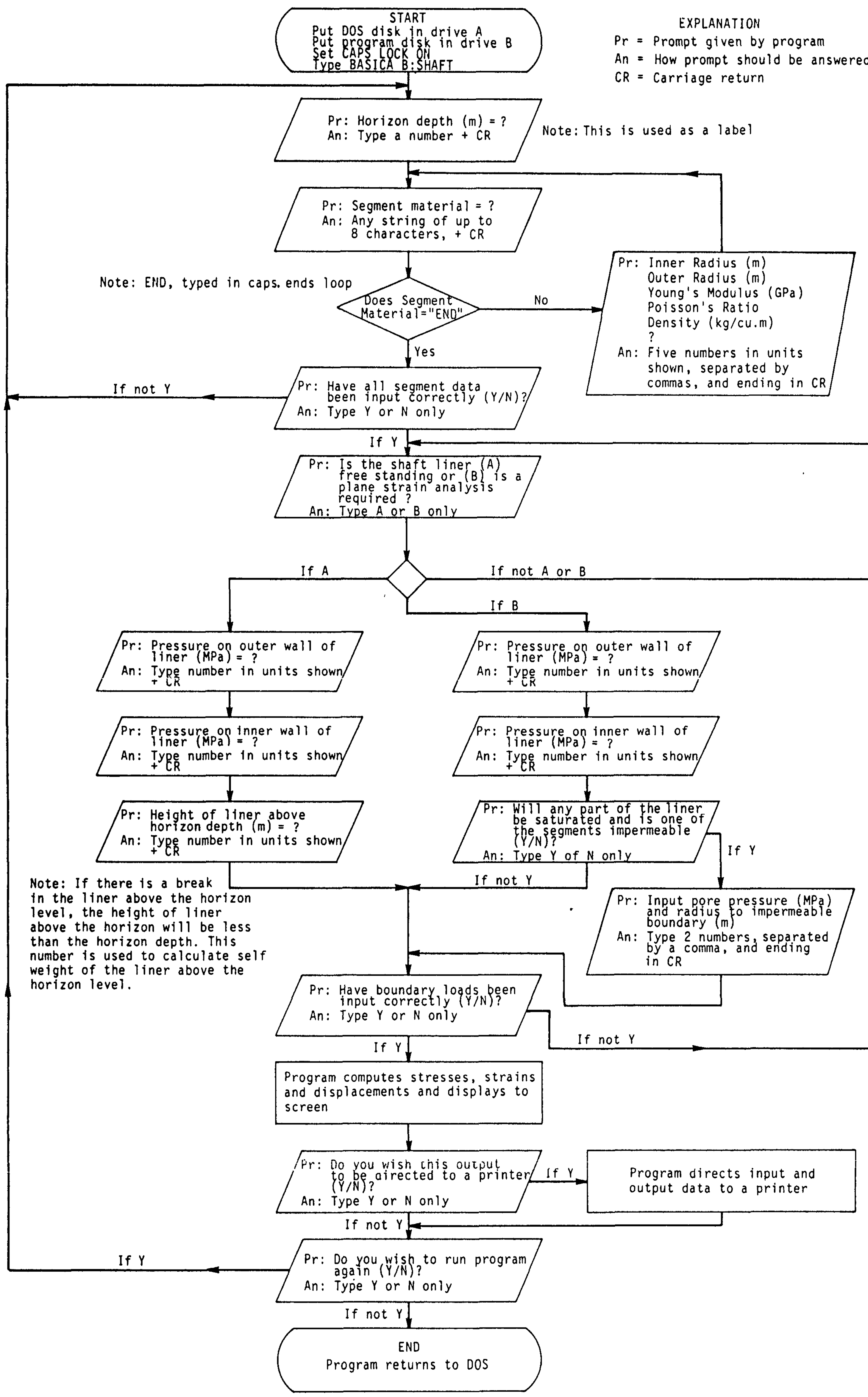
Material Properties

Liner Material	Young's Modulus (MPa)	Poisson's Ratio	Density (kg/m^3)
A	40×10^3	0.2	2,500
B	40×10^3	0.2	2,500
C	40×10^3	0.2	2,500

Program operation is summarized in Figure A-1. The appropriate replies to the input prompts are as follows:

PROMPT	REPLY
Horizon Depth (m) = ?	700 ↵
Segment Material = ?	A ↵
Inner Radius (m), Outer Radius (m), Young's Modulus (GPa), Poisson's Ratio, Density (kg/cu.m) = ?	2.5,3.0,40,0.2,2500 ↵
Segment Material = ?	B ↵
Inner Radius (m), Outer Radius (m), Young's Modulus (GPa), Poisson's Ratio Density (kg/cu/m) = ?	2.0,2.5,40,0.2,2500 ↵
Segment Material = ?	C ↵
Inner Radius (m), Outer Radius (m), Young's Modulus (GPa), Poisson's Ratio, Density (kg/cu.m) = ?	1.5,2.0,40,0.2,2500 ↵
Segment Material = ?	END ↵
Is the Shaft Liner (A) Free Standing, or (B) is a Plane Strain analysis required?	B
Pressure on outside wall of liner (MPa) = ?	4 ↵
Pressure on inwall of liner (MPa) = ?	0 ↵
Will any part of the liner be saturated and is one of the segments impermeable (Y/N)?	N

2



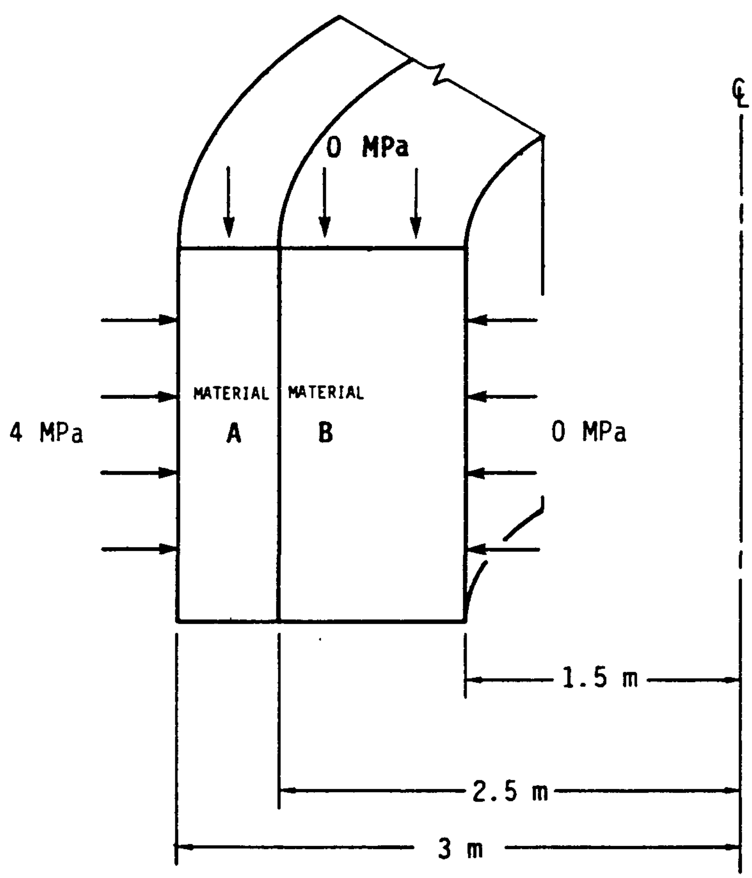
Flow Chart for Program Operation of SHAFT

Figure A-1

If the program has run successfully, the following program output will be displayed on the screen:

Segment Material	Boundary	Tangent Strain (E-6)	Radial Strain (E-6)	Axial Strain (E-6)	Tangent Stress (MPa)	Radial Stress (MPa)	Axial Stress (MPa)	Radial Closure (mm)
A	Outer	+136.0	+56.0	0	+6.67	+4.00	+2.13	+0.408
A	Inner	+153.6	+38.4	0	+7.25	+3.41	+2.13	+0.384
B	Outer	+153.6	+38.4	0	+7.25	+3.41	+2.13	+0.384
B	Inner	+186.0	+6.00	0	+8.33	+2.33	+2.13	+0.372
C	Outer	+186.0	+6.00	0	+8.33	+2.33	+2.13	+0.372
C	Inner	+256.0	-64.0	0	+10.67	0	+2.13	+0.384

A1.5.3.2 Free-Standing Conditions



At a depth of 700 m, an infinitely long shaft liner is made up of two impermeable concentric cyliners, A and B, whose properties and dimensions are given below. Determine the magnitues of the radial, tangential, and axial, stresses and strains, and the magnitude of the radial displacement, at the boundaries of the liner, and at the boundaries of the constituent cylinders under free-standing conditions.

Material Properties

Liner Material	Young's Modulus (MPa)	Poisson's Ratio	Density (kg/m3)
A	40×10^3	0.2	2,500
B	40×10^3	0.2	2,500

Program operation is summarized in Figure A-1. The appropriate replies to the input prompts are as follows:

PROMPT	REPLY
Horizon Depth (m) = ?	700 ↵
Segment Material = ?	A ↵
Inner Radius (m), Outer Radius (m), Young's Modulus (GPa), Poisson's Ratio, Density (kg/cu.m) = ?	2.5,3.0,40,0.2,2500 ↵
Segment Material = ?	B ↵
Inner Radius (m), Outer Radius (m), Young's Modulus (GPa), Poisson's Ratio Density (kg/cu/m) = ?	1.5,2.5,40,0.2,2500 ↵
Segment Material = ?	END ↵
Is the Shaft Line (A) Free Standing or (B) is a Plane Strain analysis required?	A
Pressure on outside wall of liner (MPa) = ?	4 ↵
Pressure on inwall of liner (MPa) = ?	0 ↵
Height of liner above horizon depth (m) = ?	0 ↵

If the program has run successfully, the following program output will be displayed on the screen:

Segment Material	Boundary	Tangent Strain (E-6)	Radial Strain (E-6)	Axial Strain (E-6)	Tangent Stress (MPa)	Radial Stress (MPa)	Axial Stress (MPa)	Radial Closure (mm)
A	Outer	+146.7	+66.7	-53.3	+6.67	+4.00	0	+0.440
A	Inner	+164.3	+49.1	-53.3	+7.25	+3.41	0	+0.411
B	Outer	+164.3	+49.1	-53.3	+7.25	+3.41	0	+0.411
B	Inner	+266.7	-53.3	-53.3	+10.67	0	0	+0.400

A1.6 APPLICATION

This section uses the program, SHAFT, to investigate the elastic response of the ESF shaft lining system to the loading systems described in Section A1.3.2.

A1.6.1 Input Data

A1.6.1.1 Liner Dimensions

The dimensions of the various components of the shaft liner are given in Figures 2-8, 2-9 and Table 2-4.

A1.6.1.2 Material Properties

The types of materials specified in the design of the shaft lining are given in Figures 2-8 and 2-9. The mechanical and physical properties assigned for these materials are as follows:

Material	Type	Young's Modulus (GPa)	Poisson's Ratio	Density (kg/m^3)
Concrete	4,000 psi	25[1]	0.25[1]	2300[2]
	6,000 psi	30[1]	0.25[1]	2300[2]
	8,000 psi	35[1]	0.25[1]	2300[2]
Steel	mild	207[1]	0.3[1]	7750[2]
Grout	cement	16.5[3]	0.25	1800[2]
Bitumen	fluid	--	--	1250[3]

----

[1]Merritt, F.S., 1968.

[2]Parsons Brinckerhoff, 1986.

[3]Buck, A.D. and Mather, K., 1982.

A1.6.1.3 Applied Loads

The applied loads used in each calculation are given with each separate problem in Section A1.6.2. The static rock/earth pressures, and the groundwater pressures used in the shaft liner design are presented in Table 2-3.

A1.6.2 Solutions to Site-Specific Applications

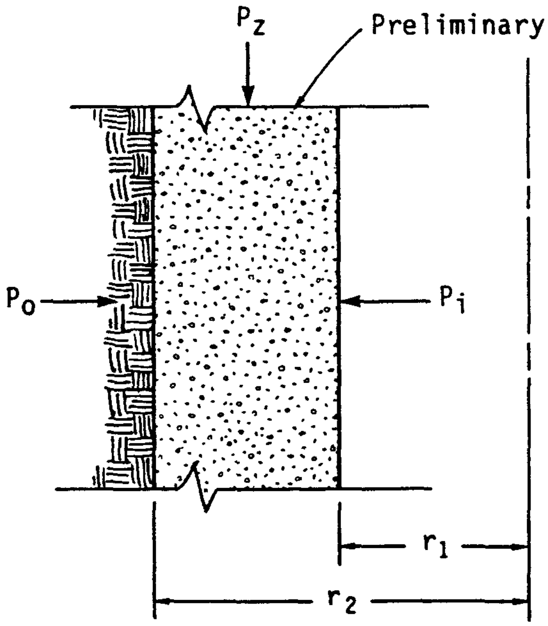
A1.6.2.1 Problem 1

The first problem considers the preliminary liner in the uppermost section of shaft only. Construction has reached a stage where the preliminary liner has been constructed against the freeze wall, and the final liner is being constructed. The instruments will have been installed in the preliminary liner under zero stress, and it is expected that very little load, due to ice wall creep, will have been imposed on the liner, because the liner will have been constructed after freeze wall creep has stabilized. Therefore the instruments will respond to the addition of hydrostatic bitumen pressure on the inwall and the subsequent ground reaction provided by the freeze wall.

The instruments that will measure the largest response will have been installed at about 293 m (960 ft). At this depth the maximum bitumen pressure will be 3.59 MPa (413 psi).

Estimation of the ground reaction to outward movement of the liner is a complex problem to analyze. At this stage of construction the weight of the liner will be fully supported by skin friction with the freeze wall, therefore a plane strain analysis is appropriate. At one extreme, the instrument response will be bounded by the tensile strength of the concrete. At the other extreme the freeze wall may form a rigid boundary.

For this problem the input data are:



Horizon Depth, z = 293 m

Liner Material	Inner Radius (m)	Outer Radius (m)	Young's Modulus (GPa)	Poisson's Ratio	Density (kg/m^3)
Concrete	2.667	3.023	25	0.25	2300

Plane Strain Conditions
Tensile strength of the concrete P_t = -3.05 MPa*

For the case where the freeze wall forms a rigid boundary

$$Pi = 3.59 \text{ MPa} \qquad U(r_2) = 0$$

Using equation A-29 it can be shown that Po = 3.279 MPa.

For this problem the output data are:

SEGMENT MATERIAL	BOUNDARY	TANGNT STRAIN (E-6)	RADIAL STRAIN (E-6)	AXIAL STRAIN (E-6)	TANGNT STRESS (MPa)	RADIAL STRESS (MPa)	AXIAL STRESS (MPa)	RADIAL CLOSURE (mm)
CONCRETE	OUTER	+0.1	+109.3	+0.0	+1.09	+3.28	+1.09	+0.000
CONCRETE	INNER	-15.5	+124.8	+0.0	+0.78	+3.59	+1.09	-0.041

For the case where the freeze wall forms a flexible boundary and the concrete tensile strength is exceeded

$$\text{let } Po = 0 \qquad \sigma_\theta > P_T = -3.05 \text{ MPa}$$

Using equation A-2 it can be shown that the tensile strength will be reached at the inner boundary r_1, when Pi = 0.374 MPa

* $7\sqrt{f'_c}$ after Merritt, F.S. (ed.) (1968). Standard Handbook for Civil Engineers. McGraw-Hill, New York, p. 8-3.

For this problem the output data are:

SEGMENT MATERIAL	BOUNDARY	TANGNT STRAIN (E-6)	RADIAL STRAIN (E-6)	AXIAL STRAIN (E-6)	TANGNT STRESS (MPa)	RADIAL STRESS (MPa)	AXIAL STRESS (MPa)	RADIAL CLOSURE (mm)
CONCRETE	OUTER	-98.5	+32.8	+0.0	-2.63	+0.00	-0.66	-0.298
CONCRETE	INNER	-117.2	+51.5	+0.0	-3.00	+0.37	-0.66	-0.313

If tensile failure is reached, and parts of the liner become isolated, the instruments would respond to an isotropic loading equal to the hydrostatic pressure of the bitumen. Under these conditions the measured stresses will be equal to the applied loads in all directions = +3.59 MPa, and the strains which will also be equal in all directions are found using any of equations A-23 to be = +71.8 microstrain.

A1.6.2.2 Problem 2

Consider the same section of preliminary liner, as in the previous problem. Construction of the final liner is now complete, and the freeze wall has thawed. At this point the adhesion with the rock wall may be temporarily lost. In this case, therefore, the liner supports its self-weight, and free-standing conditions exist.

Again the instrument response in the liner will be constrained by the tensile strength of the material. In this case the load on the outer wall will be the hydrostatic pressure of the groundwater.

$$Po = 2.268 \text{ MPa} \qquad \sigma_\theta > P_T = -3.05 \text{ MPa}$$

Using equation A-2, it can be shown that the tensile strength will be reached at the boundary r_1 when Pi = 2.93 MPa.

For this problem the output data are:

SEGMENT MATERIAL	BOUNDARY	TANGNT STRAIN (E-6)	RADIAL STRAIN (E-6)	AXIAL STRAIN (E-6)	TANGNT STRESS (MPa)	RADIAL STRESS (MPa)	AXIAL STRESS (MPa)	RADIAL CLOSURE (mm)
CONCRETE	OUTER	-184.0	+48.4	+265.6	-2.38	+2.27	+6.61	-0.556
CONCRETE	INNER	-217.1	+81.5	+265.6	-3.04	+2.93	+6.61	-0.579

If tensile failure is reached, and parts of the liner become isolated, the instruments would respond to an isotropic loading equal to the hydrostatic pressure of the bitumen. Under these conditions the measured stresses will be equal to the applied loads in all directions = +3.59 MPa, and the strains which will also be equal in all directions are found using any of equations A-23 to be = +71.8 microstrain.

A1.6.2.3 Problem 3

Consider the same stage of construction as in Problem 2, but that adhesion with the rock wall is not lost, because active earth movements occur during thawing. Considering the case when the liner is not saturated, the pressure on the outside of the cylinder becomes equal to the groundwater pressure plus the static earth pressure (approximately 4.25 MPa). Plane strain conditions exist and the load system comprises:

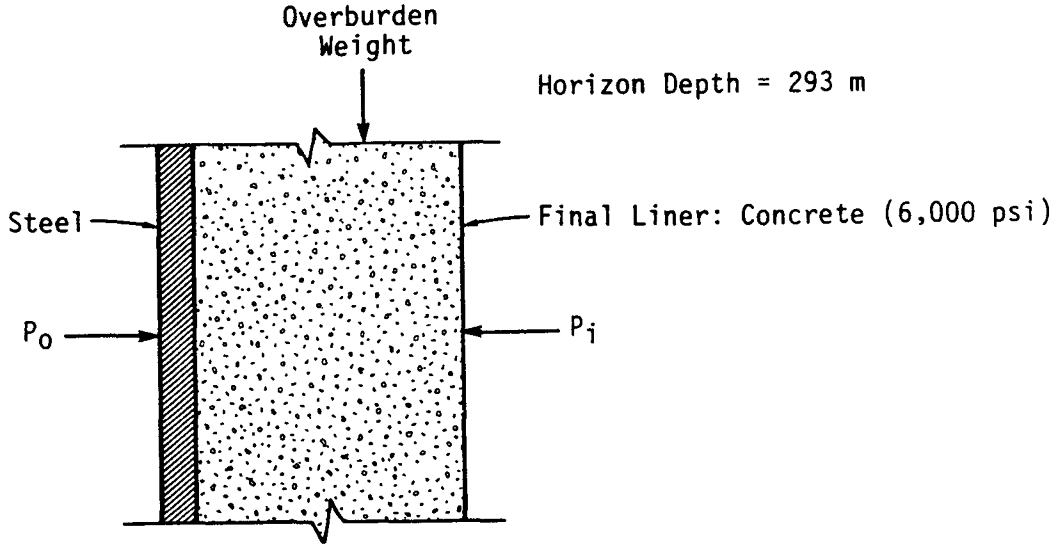
Pressure on the inwall P_i = 3.59 MPa
Pressure on the outerwall P_o = 4.25 MPa

OUTPUT DATA :

SEGMENT MATERIAL	BOUNDARY	TANGNT STRAIN (E-6)	RADIAL STRAIN (E-6)	AXIAL STRAIN (E-6)	TANGNT STRESS (MPa)	RADIAL STRESS (MPa)	AXIAL STRESS (MPa)	RADIAL CLOSURE (mm)
CONCRETE	OUTER	+280.1	+48.3	+0.0	+8.89	+4.25	+3.28	+0.847
CONCRETE	INNER	+313.1	+15.3	+0.0	+9.55	+3.59	+3.28	+0.835

A1.6.2.4 Problem 4

This problem now considers a section of the final liner in the uppermost section of shaft. The liner will be self supporting and so free-standing conditions exist. For a given section of the liner, the boundary loads will be the bitumen pressure acting on the outerwall, and the self weight of the liner components built above that section. Installation of the instruments will be integrated with the construction activity. Instruments will therefore respond to changes of stress and strain as construction proceeds. The instruments that will measure the greatest response will have been installed at about 293 m (960 ft).



INPUT DATA :

SEGMENT	MATERIAL	INNER RADIUS (m)	OUTER RADIUS (m)	YOUNG'S MODULUS (GPa)	POISSON'S RATIO	UNIT WEIGHT (kg/cu.m)
1	STEEL	2.502	2.515	207.0	0.30	7750
2	CONCRETE	1.854	2.502	30.0	0.25	2300

BOUNDARY CONDITIONS : FREE STANDING CYLINDER

EXTERNAL PRESSURE = 3.59 MPa
INTERNAL PRESSURE = 0.00 MPa
TOTAL VERTICAL WEIGHT = 63.19 MN

OUTPUT DATA :

SEGMENT MATERIAL	BOUNDARY	TANGNT STRAIN (E-6)	RADIAL STRAIN (E-6)	AXIAL STRAIN (E-6)	TANGNT STRESS (MPa)	RADIAL STRESS (MPa)	AXIAL STRESS (MPa)	RADIAL CLOSURE (mm)
STEEL	OUTER	+288.9	-148.1	+86.7	+73.18	+3.59	+40.97	+0.727
STEEL	INNER	+291.2	-150.4	+86.7	+73.54	+3.23	+40.97	+0.729
CONCRETE	OUTER	+291.2	-36.3	+86.7	+11.09	+3.23	+6.18	+0.729
CONCRETE	INNER	+425.7	-170.8	+86.7	+14.32	+0.00	+6.18	+0.789

A1.6.2.5 Problem 5

In the lower section of the shaft, the space between the preliminary and final liners will be backfilled with grout as construction proceeds. Therefore the self-weight of the final liner will be transferred to and supported by skin friction with the rock wall. Plane strain conditions are appropriate for analyzing the liner response to the imposed loads. It is assumed that the buildup of groundwater on the outside of the liner is sufficiently slow to saturate the preliminary liner concrete and grout layers before groundwater pressures start to rise. Therefore the ground pressure will act on the outside of the preliminary liner, but groundwater pressures will act on the outer steel liner. The liner will be excavated through competent rock, installation of instruments will be integrated with construction. Therefore, the instruments will respond only to the build up of loads on the outside of the liner and pore pressures in the preliminary liner.

This problem is subdivided into three parts because the dimensions of the liner vary with depth. For each set of liner dimensions, the instruments that will measure the greatest response will be those installed at 509 m (1,670 ft), 594 m (1,950 ft), and 671 m (2,200 ft).

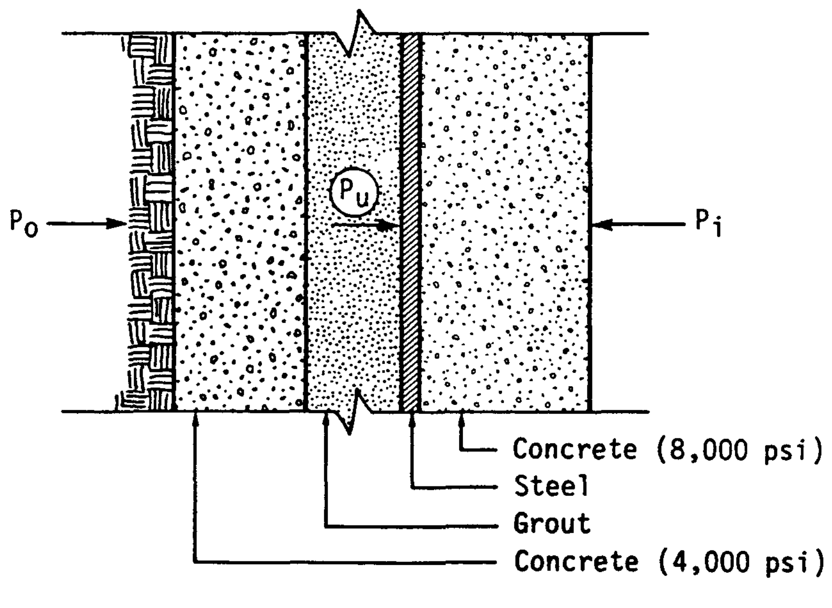
At these heights, the ground loads and pore pressures are (calculated from Table 2-3):

Height	Rock	Hydrostatic
509 m	1.74 MPa	4.82 MPa
596 m	2.01 MPa	5.89 MPa
671 m	2.24 MPa	6.72 MPa

The input data are as follows:

a)

Horizon Depth = 509 m



HORIZON DEPTH = 509.0 m

INPUT DATA :

SEGMENT	MATERIAL	INNER RADIUS (m)	OUTER RADIUS (m)	YOUNG'S MODULUS (GPa)	POISSON'S RATIO	UNIT WEIGHT (kg/cu.m)
1	CONCRETE	2.705	2.870	25.0	0.25	2300
2	GROUT	2.492	2.705	16.5	0.25	1800
3	STEEL	2.477	2.492	207.0	0.30	7750
4	CONCRETE	1.829	2.477	35.0	0.25	2300

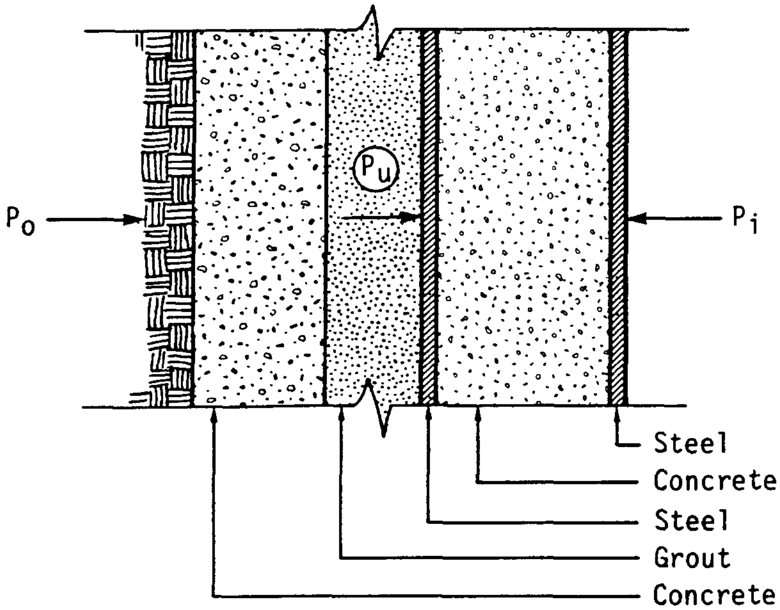
BOUNDARY CONDITIONS : PLANE STRAIN CONDITIONS

EXTERNAL PRESSURE = 1.74 MPa
INTERNAL PRESSURE = 0.00 MPa
PORE PRESSURE OF 4.82 MPa BEARING ON LINER AT RADIUS 2.492

OUTPUT DATA :

SEGMENT MATERIAL	BOUNDARY	TANGNT STRAIN (E-6)	RADIAL STRAIN (E-6)	AXIAL STRAIN (E-6)	TANGNT STRESS (MPa)	RADIAL STRESS (MPa)	AXIAL STRESS (MPa)	RADIAL CLOSURE (mm)
CONCRETE	OUTER	+344.0	-56.7	+0.0	+9.75	+1.74	+2.87	+0.987
CONCRETE	INNER	+369.2	-81.9	+0.0	+10.26	+1.24	+2.87	+0.999
GROUT	OUTER	+369.2	-60.6	+0.0	+6.91	+1.24	+2.04	+0.999
GROUT	INNER	+407.5	-99.0	+0.0	+7.42	+0.73	+2.04	+1.016
STEEL	OUTER	+407.5	-154.7	+0.0	+95.08	+5.55	+30.19	+1.016
STEEL	INNER	+411.0	-158.2	+0.0	+95.63	+5.01	+30.19	+1.018
CONCRETE	OUTER	+411.0	-17.8	+0.0	+17.01	+5.01	+5.50	+1.018
CONCRETE	INNER	+589.8	-196.6	+0.0	+22.02	+0.00	+5.50	+1.079

b) Horizon Depth = 594 m



HORIZON DEPTH = 594.0 m

INPUT DATA :

SEGMENT	MATERIAL	INNER RADIUS (m)	OUTER RADIUS (m)	YOUNG'S MODULUS (GPa)	POISSON'S RATIO	UNIT WEIGHT (kg/cu.m)
1	CONCRETE	2.601	2.870	25.0	0.25	2300
2	GROUT	2.499	2.601	16.5	0.25	1800
3	STEEL	2.483	2.499	207.0	0.30	7750
4	CONCRETE	1.854	2.483	35.0	0.25	2300
5	STEEL	1.829	1.854	207.0	0.30	7750

BOUNDARY CONDITIONS : PLANE STRAIN CONDITIONS

EXTERNAL PRESSURE = 2.01 MPa
INTERNAL PRESSURE = 0.00 MPa
PORE PRESSURE OF 5.82 MPa BEARING ON LINER AT RADIUS 2.499

OUTPUT DATA :

SEGMENT MATERIAL	BOUNDARY	TANGNT STRAIN (E-6)	RADIAL STRAIN (E-6)	AXIAL STRAIN (E-6)	TANGNT STRESS (MPa)	RADIAL STRESS (MPa)	AXIAL STRESS (MPa)	RADIAL CLOSURE (mm)
CONCRETE	OUTER	+342.7	-47.2	+0.0	+9.81	+2.01	+2.95	+0.983
CONCRETE	INNER	+385.1	-89.6	+0.0	+10.66	+1.16	+2.95	+1.002
GROUT	OUTER	+385.1	-69.7	+0.0	+7.16	+1.16	+2.08	+1.002
GROUT	INNER	+404.0	-88.6	+0.0	+7.41	+0.91	+2.08	+1.010
STEEL	OUTER	+404.0	-149.0	+0.0	+94.78	+6.73	+30.45	+1.010
STEEL	INNER	+407.6	-152.6	+0.0	+95.35	+6.16	+30.45	+1.012
CONCRETE	OUTER	+407.6	+10.9	+0.0	+17.27	+6.16	+5.86	+1.012
CONCRETE	INNER	+565.0	-146.5	+0.0	+21.68	+1.75	+5.86	+1.048
STEEL	OUTER	+565.0	-235.8	+0.0	+129.27	+1.75	+39.31	+1.048
STEEL	INNER	+576.0	-246.9	+0.0	+131.03	+0.00	+39.31	+1.054

c) same section as b), but Horizon Depth = 671 m

HORIZON DEPTH = 671.0 m

INPUT DATA :

SEGMENT	MATERIAL	INNER RADIUS (m)	OUTER RADIUS (m)	YOUNG'S MODULUS (GPa)	POISSON'S RATIO	UNIT WEIGHT (kg/cu.m)
1	CONCRETE	2.705	2.870	25.0	0.25	2300
2	GROUT	2.499	2.705	16.5	0.25	1800
3	STEEL	2.483	2.499	207.0	0.30	7750
4	CONCRETE	1.861	2.483	35.0	0.25	2300
5	STEEL	1.829	1.861	207.0	0.30	7750

BOUNDARY CONDITIONS : PLANE STRAIN CONDITIONS

EXTERNAL PRESSURE = 2.24 MPa
INTERNAL PRESSURE = 0.00 MPa
PORE PRESSURE OF 6.72 MPa BEARING ON LINER AT RADIUS 2.499

OUTPUT DATA :

SEGMENT MATERIAL	BOUNDARY	TANGNT STRAIN	RADIAL STRAIN	AXIAL STRAIN	TANGNT STRESS	RADIAL STRESS	AXIAL STRESS	RADIAL CLOSURE
		(E-6)	(E-6)	(E-6)	(MPa)	(MPa)	(MPa)	(mm)
CONCRETE	OUTER	+384.7	-53.6	+0.0	+11.01	+2.24	+3.31	+1.104
CONCRETE	INNER	+412.3	-81.1	+0.0	+11.56	+1.69	+3.31	+1.115
GROUT	OUTER	+412.3	-52.1	+0.0	+7.82	+1.69	+2.38	+1.115
GROUT	INNER	+452.2	-92.0	+0.0	+8.35	+1.16	+2.38	+1.130
STEEL	OUTER	+452.2	-165.5	+0.0	+106.23	+7.88	+34.23	+1.130
STEEL	INNER	+456.2	-169.5	+0.0	+106.87	+7.25	+34.23	+1.133
CONCRETE	OUTER	+456.2	+20.5	+0.0	+19.45	+7.25	+6.67	+1.133
CONCRETE	INNER	+626.1	-149.5	+0.0	+24.20	+2.49	+6.67	+1.165
STEEL	OUTER	+626.1	-259.4	+0.0	+143.49	+2.49	+43.79	+1.165
STEEL	INNER	+641.7	-275.0	+0.0	+145.98	+0.00	+43.79	+1.174

A1.6.3 Summary of Results

Table A-1 summarizes the largest range of the elastic stresses and strains likely to be encountered in the shaft lining system. It should be recognized that when instruments are installed in-line with construction, the initial reading will represent the zero datum. The range values given in the table represent the elastic increments (either tensile or compressive) from this zero datum due to the application of the specified loading system.

Furthermore, it should be noted that these range values do not necessarily predict the range of measurement that might be measured. Such a prediction should also reflect effects such as concrete creep, shrinkage, microcracking and load concentrations (as opposed to "average" conditions), and should be judged against measurements made at other sites under similar conditions. Above all, it should be recognized that the values presented in this summary represent solutions for only the particular loading systems specified. The calculated values therefore constitute estimates of the elastic component of the shaft lining system behavior, and should be evaluated during instrument range specification, in the light of the assumptions used.

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Table A-1. Range Summary[4]

Location	Tangent[1] Strain	Radial[1] Strain	Axial[1] Strain	Tangent[1] Stress	Radial[1] Stress	Axial[1] Stress	Radial Displacement (mm) Towards Shaft Axis
	(microstrain)			(MPa)			
Preliminary Concrete Liner - Upper Shaft:							
In Compression	+313.1	+124.8	0	+9.55	+4.25	+3.28	+0.85
In Tension	-217.1[2]	+81.5	+265.6	-3.04	+2.93	+6.61	-0.58
Preliminary Concrete Liner - Lower Shaft:							
In Compression	+412.3	-89.6[2]	0	+11.56[3]	+2.24[3]	+3.31[3]	+1.12
Bitumen					+3.6 (bitustatic)		
Grout	+452.2	-99.0[2]	0	+8.35[3]	+1.69[3]	2.38[3]	+1.13
Outer Steel Liner:							
Upper shaft	+291.2	-150.4	+86.7	+73.54	+3.59	+40.97	+0.73
Lower Shaft	+456.2	-169.5	0	+106.87	+7.88	+34.23	+1.13
Final Concrete Liner:							
Upper Shaft	+425.7	-170.8[2]	+86.7	+14.32	+3.23	+6.18	+0.79
Lower Shaft	+626.1	-196.6	0	+24.20	+7.25	+6.67	+1.17
Inner Steel Liner:							
Lower Shaft	+641.7	-275.0	0	+145.98	+2.49	+43.79	+1.17

1 Sign Convention: Compressive stresses and contracting strains positive.

2 Assumes continuity of concrete to failure - no cracks.

3 Effective stress only.

4 Each range starts at zero.

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A2 MPBX MONITORING PRE-ANALYSIS REQUIREMENTS

A2.1 Introduction

In this study plan it is proposed to install MPBXs in the salt around the shafts as close to the shaft bottom as possible. The objective is to obtain as complete coverage as possible of all phases of the creep.

Two sources of published salt creep data around shafts were reviewed to assist in evaluating the following:

- An operating range for the MPBXs
- Appropriate distribution of anchor depths around the shafts
- A data sampling schedule.

The two sources of data were:

- WIPP Quarterly Geotechnical Field Data Report, September 1985 (Bechtel, 1985)
- Deformation Around a Mine Shaft in Salt (Barron and Toews, 1963).

No data sources have been identified which include long-term deformations measured using extensometers installed immediately after excavation. The reviewed data is therefore of limited value in determining the MPBX operating range.

A2.2 Instrument Operation Range

Barron and Toews (1963) estimate that the extensometers used in the Yarbo No. 1 shaft at Esterhazy, Saskatchewan, were installed less than 3 days after the excavation passed the proposed instrument location depth. The data for radial salt creep around the 18-ft(5.5-m)-diameter shaft at 3,080-ft (939-m) depth indicate a collar movement of about 0.8 inches (20 mm) during the first 35 days after instrument installation, and a movement of about 0.5 inches (12.5 mm) for the 10-ft (3-m) anchor.

The extensometers used in the WIPP C&SH shaft were installed approximately 290 days after the excavation passed the location depth, and as a result do not report any of the transient creep phase. These data for 1037 ft, 1564 ft, and 2057 ft (316, 477, and 627 m) depths in a 12-ft (3.7-m) finished diameter shaft indicate a maximum mean collar movement of about 0.5 inches (12.5 mm) 3 years after instrument installation, and a maximum movement of about 0.2 inches (5 mm) for the 36-ft(11-m)-deep anchor.

The extensometers used in the WIPP Waste shaft were installed within 3 to 5 months after slashing the original 6-ft(1.8-m)-diameter shaft to 20-ft (6.1 m) diameter. The data for 1071 ft, 1566 ft, and 2059 ft (327, 477, and 628 m) depths indicate a maximum mean collar movement relative to a 37-ft(11.3 m)-deep anchor of about 0.22 inches (5.6 mm) during the first 10 months after instrument installation. No equivalent data are provided for shaft convergence, so no estimate can be made of the movement of the deepest anchor.

The published results do not provide sufficient data to determine the likely operating range for the instruments. Therefore, in the absence of suitable field data, modeling of displacement around the ESF shafts will be required to define instrument operating ranges. These modeling requirements are further discussed in Section A2.5.

A2.3 Anchor Depths

In order to obtain an even spread of data covering the radial creep displacements around the shafts, an evaluation of the radial displacement profile is required. In the November 1984, WIPP Quarterly Geotechnical Field Data Report (Bechtel, 1984), Bechtel used an exponential function to "fit" the existing WIPP shaft data. The objectives of the curve fitting exercise were to establish the distance of a point, relative to the excavated shaft wall, which would move less than 0.01 inch (0.25 mm) during the first 18 months after excavation. For this analysis, the depth was found to be 65 ft (20 m).

Barron and Toews (1963) and Golder Associates (1986p) have used an inverse radius function to "fit" the displacement profiles at specific times after shaft excavation. This function is consistent with the hypothesis that deformations occur under conditions of zero volumetric straining and is supported by published data (Golder Associates, 1986p). The normalized function is written:

$$\frac{U\ (r)}{U\ (a)} = \frac{a}{r}$$

when: a is the radius of the unlined shaft

U (a) is the radial displacement of the shaft wall at a specific time

r is the radial distance, measured from the shaft centerline, to a point in the rock mass

U (r) is the radial displacement of a point located at a distance r from the shaft centerline at the specific time.

At this stage of test planning, the deepest extensometer anchor depths have been selected so that anchor movement will be less than 5 percent of the diametral shaft wall convergence. On this basis, the distance from the shaft centerline to the deepest anchor would be 105 ft and 70 ft (32 and 21 m) for excavated shaft diameters of 21 ft and 14 ft (6.4 and 4.3 m), respectively. In these two instances, the distance to the anchor from the MPBX head (recessed in the shaft wall) would be 95 ft and 63 ft (29 and 19 m), respectively.

In order to obtain an even distribution of data covering the radial creep displacement between the deepest anchor and the shaft wall, the five intermediate anchors of a six-anchor MPBX should be located at distances from the shaft wall that will move 85 percent, 70 percent, 55 percent, 40 percent, and 25 percent of the shaft wall movement. On this basis, using the same relationship, the depths to each anchor from the MPBX head are 2, 4.5, 8.5, 16, 32, and 95 ft (0.6, 1.4, 2.6, 4.9, 9.8, and 29 m) for the 21-ft(6.4-m)-diameter shaft, and 1.2, 3, 6, 11, 21, and 63 ft (0.4, 0.9, 1.8, 3.4, 6.4, and 19 m) for the 14-ft(4.3-m)-diameter shaft.

A2.4 Data Sampling Schedule

The purpose of selecting a data sampling schedule is to ensure that data are collected on a sufficiently regular basis to provide adequate coverage of the material behavior without accumulating an unnecessarily large quantity of repetitive data. The complexity of the data sampling schedule will depend on how the rate of change of measured displacement varies with time. Above all, the data sampling schedule must ultimately be linked to the site conditions, and therefore any data sampling schedule specified during the test planning stage will be reviewed and modified when sufficient data are obtained to evaluate its suitability for subsequent date collection.

In the absence of a site specific preanalysis and suitable range of published data, it is appropriate for planning purposes to adopt the same data sampling schedule as suggested in the At-Depth Study Plan (Golder Associates, 1987a) for monitoring the salt creep in the At-Depth Facility. The data sampling schedule proposed for the At-Depth Facility is as follows:

- Every hour for the first 24 hours
- Every 6 hours for the next 7 days
- Every day for the next 2 months
- Every 7 days thereafter.

A2.5 Test Preanalysis Requirements

In order to provide the necessary information with which to evaluate instrument operating range, anchor depths, and data sampling schedules, the following preanalyses need to be carried out.

- Annulus between the probe and the borehole wall is filled with saturated sodium chloride brine
- Prior to heating cycle, temperature distribution in the probe and the rock mass is uniform at 30°C
- The rock mass is homogeneous and isotropic with respect to thermal conductivity
- Heat transfer is by conduction only.

A3.3 Test Preanalysis Requirements

In order to provide the necessary information with which to evaluate the appropriate power requirement and heating time for the thermal conductivity tests, the following preanalyses need to be carried out.

Case 1:

In order to establish the zone of rock heated by a line heat source over a four-hour period of time, predictions of rock temperature around the heat source will be required. The following information is requested.

- Curves of rock temperature at 10 minutes, 30 minutes, 1 hour, 2 hours, 3 hours, and 4 hours after power to the heater is switched on, versus distance from the line heat source out to a point where the calculated rock temperature increases by less than 1°F (0.5°C). Assume that the rock mass has a thermal conductivity of 20 Btu/ft^2/hr/°F/in (3 W/mK).
- A curve of probe temperature versus time for the 4 hour period.

Case 2:

Same as Case 1 but using a rock thermal conductivity of 35 Btu/ft^2/hr/°F/in (5 W/mK).

Case 3:

Same as Case 1 but using a rock thermal conductivity of 50 Btu/ft^2/hr/°F/in (7 W/mK).

A4 TEMPERATURE MONITORING PREANALYSIS REQUIREMENTS

A4.1 Introduction

Preanalysis is required in connection with rock mass and concrete liner temperature monitoring to finalize sensor locations and borehole lengths. The objectives of this preanalysis are to establish:

1. The probable zone of influence of concrete hydration in the frozen zone in order to confirm that proposed temperature monitoring borehole lengths are adequate.

2. The temperature profiles along the proposed measurement axes in the concrete liners in order to confirm that proposed sensor locations and spacings are appropriate.

A4.2 Model Assumptions

The cases to be analyzed can be treated as two-dimensional axisymmetric. General assumptions to be used in setting up the heat transfer model are as follows:

- The rock mass is homogeneous, and isotropic with respect to thermal conductivity
- Air temperature in the shaft reflects conditioning and seasonal variations
- Air flow rates reflect appropriate anticipated seasonal variations
- Specific heat for the rock and/or concrete is [TBD]
- Density of the rock and/or concrete is [TBD]
- Measurement locations and axes are presented in Section 4.4 of this Study Plan
- Realistic operation schedules for the freeze wall
- Realistic hydration rates for the concrete
- Realistic construction schedules.

A4.3 Testing Preanalysis Requirements

In order to provide the necessary information with which to evaluate appropriate temperature sensor locations in the shaft linings and adjacent rock, the following preanalyses need to be carried out.

Case 1:

Temperature profiles in the frozen zone at 745 ft (227 m) below surface.

- *Curves of temperature versus distance from the inwall of the* shaft liner (preliminary lining initially, final lining later) out to a point 10 ft (3 m) into the rock mass. Assume an initial rock temperature of -13°F (-25°C). Use rock thermal conductivity of 20 Btu/ft^2/hr/°F/in (3 W/mK). Curves to be plotted for times:

  Every 12 hours for the first 5 days after placing the preliminary lining concrete; every 48 hours for the next 10 days; every 10 days until placement of the final liner concrete; every 12 hours for the next 5 days; every 48 hours for the next 10 days; every 10 days for the next 2 months; every six months for the next 5 years.

- Same as first problem for Case 1 but using a rock thermal conductivity of 35 Btu/ft^2/hr/°F/in (5 W/mK).

- Same as first problem for Case 1 but using a rock thermal conductivity of 50 Btu/ft^2/hr/°F/in (7 W/mK).

Case 2:

Temperature profiles below the frozen zone at 1,950 (594 m) ft below surface.

- Curves of temperature versus distance from the inwall of the shaft liner (preliminary lining initially, final lining later) out to a point 10 ft (3 m) into the rock mass. Assume an initial rock temperature of 86°F (30°C). Use a rock thermal conductivity of 20 Btu/ft^2/hr/°F/in (3 W/mK). Curves to be plotted for the same time intervals used in Case 1.

- Same as first problem for Case 2 but using a rock thermal conductivity of 35 Btu/ft^2/hr/°F/in (5 W/mK).

- Same as first problem for Case 2 but using a rock thermal conductivity of 50 Btu/ft^2/hr/°F/in (7 W/mK).

A5 PIEZOMETER MONITORING PREANALYSIS REQUIREMENTS

A5.1 Introduction

The selection of appropriate piezometric monitoring schedules is a function of the expected rates for transient changes in ground-water pressure within the zones monitored by the proposed piezometer installations in the ESF shafts. Preanalysis of hydraulic head distributions and temporal variations in the hydrologic regime surrounding the shafts is required to determine probable ground-water repressurization rates in strata following placement of the preliminary liner as shaft excavation progresses. Preanalysis can best be achieved by simulating changes in the hydrologic regime using transient radial-flow modeling, with each shaft considered as a variable hydraulic sink. The approach to preanalysis should focus on sensitivity analysis to examine the importance of certain phenomena, followed by a more deterministic analysis resulting in definitive hydraulic response curves at specific piezometer locations.

A5.2 Model Assumptions

Modeling of the hydrologic regime around each of the ESF shafts will consist of the following steps:

1. Selection of an appropriate finite-element numerical ground-water flow model permitting:

   - Simulation of axisymmetric radial flow in response to pressure gradients in the vertical plane
   - Inclusion of variable-density formation fluids
   - Coupling of changes in the temperature, density, viscosity, and compressibility of the formation fluids
   - Variation of permeability as a function of stress

2. Assumptions inherent to the selected model are likely to include:

   - All lithologies are continuous porous media
   - Ground-water flow obeys Darcy's Law
   - Transient ground-water flow includes the release of water from storage, as embodied in the Diffusion Equation
   - The stratigraphic sequence can be idealized as a series of layers, each of which can be discretized into a number of elemental volumes with uniform hydrogeologic properties.

- Ground water in the stratigraphic sequence occurs as a continuous, fully saturated regime.

3. Development of the discretized finite-element mesh to represent the stratigraphy and boundary conditions specific to the Deaf Smith County Site, initially including:

   - Discretization of individual formations from the Dewey Lake through to the LSA 4 basal carbonate, as per SRP Information Sheet Hydrol of the Synthetic Geotechnical Design Reference Data for the Deaf Smith Site (ONWI, 1986a)

   - Definition of a horizontal boundary below the LSA 4 basal carbonate which is either 1) a no-flow boundary, or 2) an outflow boundary in response to the overall downward hydraulic gradient observed across the Permian sequence (sensitivity analysis and model calibration will be required to determine the most appropriate choice)

   - Definition of a fixed-head lateral boundary at 3300 ft (1000 m) radial distance from the shaft centerline, with midpoint formation pressures as specified on SRP Information Sheet Hydro8 of the Synthetic Geotechnical Design Reference Data for the Deaf Smith Site (ONWI, 1986a)

   - Definition of a fixed-head horizontal boundary above the Dewey Lake, with a hydraulic potential equal to the potentiometric surface in the Dockum, as specified on SRP Information Sheet Hydro7 of the Synthetic Geotechnical Design Reference Data for the Deaf Smith Site (ONWI, 1986a)

   - Variable boundary conditions along the shaft wall consistent with current shaft excavation diameters and lining designs and simulated in a realistic time-frame to correspond with anticipated shaft excavation rates and lining schedules as specified in [TBD].

4. Assignment of hydrogeologic formation and fluid property parameter values to individual strata as per the following SRP Information Sheets in the Synthetic Geotechnical Design Reference Data for the Deaf Smith Site (ONWI, 1986a):

   - Horizontal intrinsic permeability from Hydro4

   - Vertical intrinsic permeability calculated using the information contained in Hydro14

   - Specific storage (if used) from Hydro15. (Use of specific storage as a lumped parameter encapsulating fluid density, fluid compressibility, rock porosity, rock grain compressibility, and rock matrix compressibility may need to verified through sensitivity analysis.)

- Fluid density from Hydro10D but modified to reflect a more realistic increase in salinity with depth (see Section 2.1.2)

- Formation midpoint fluid temperatures from Hydro9

5. Assignment of additional parameter values inadequately covered or not available in the Synthetic Geotechnical Design Reference Data for the Deaf Smith Site (ONWI, 1986a), from standard references, including:

   - Densities of saline solutions

   - Compressibilities of pure water and NaCl solutions

   - Viscosities of pure water and NaCl solutions.

6. Assumptions about stress levels and their effect on rock permeability. The permeability of the shaft-wall rock may exhibit some dependence on levels of stress within the rock; compressive circumferential stresses associated with arching are likely to reduce the aperture of any fractures in the rockface, and thus reduce intrinsic permeability. In the absence of site-specific data, assumptions as to the form of the dependence function will be required:

   - In situ stress levels from SRP Information Sheet Rock22 in the Synthetic Geotechnical Design Reference Data for the Deaf Smith Site (ONWI, 1986a), and from other appropriate sources [TBD]

   - Information on the redistribution of stress around the shaft during and after excavation and lining [source: TBD]

   - Information on the effect of changes in stress on the permeability of shaft-wall rock [source: TBD].

7. Assumptions about the hydrologic integrity of the preliminary shaft lining. The preliminary shaft lining will be poured against the shaft wall in successive lifts, sealing off the ingress of ground water to varying degrees. The rate and amount of repressurization occurring in the formation fluid behind the shaft wall will depend on the degree of cement bonding established between the liner and the rockface, and on the amount of seepage occurring through liner construction joints. These construction variables will be difficult to predict in advance, and sensitivity analysis will be required to assess the need for their incorporation into analysis models.

A5.3 Analytical Requirements

Model simulations are required for the following:

1. Calibration runs of the model to ensure adequate simulate the observed quasi-hydrostatic pressure distribution with depth prior to excavation of any shafts. Output should consist of contoured fluid pressure distributions over the full model cross-section.

2. Sensitivity analysis runs to examine the appropriateness of the assumed boundary conditions. Output should consist of contoured fluid pressure distributions over the full model cross-section.

3. Excavation simulation runs. In the lower shaft section, below the frozen zone, the successive excavation of each shaft round will produce a depressurization of formation fluids in the surrounding strata. In some cases, this will be accompanied by the inflow of ground water. The degree and radial extent of depressurization occurring within each strata will be required as base information prior to the runs described below. One set of output will be required for each of the following times:

   o Completion of the excavation of each shaft round

   o Completion of each concrete pour for the preliminary liner.

   Hydraulic response curves (pressure vs time) will be required at all proposed piezometer locations (see Section 4.6) on a time scale consistent with the time-marching constraints inherent to the numerical model used. Output should also include values for the inflow of ground-water from each length of exposed rock wall, and any flow coming through the preliminary lining.

4. Sensitivity analysis runs to examine the importance and effect of the following variables, unknowns and assumptions:

   - The values used for horizontal and vertical formation permeability

   - The permeability of the preliminary shaft lining

   - The effect of stress on the permeability of rock around the shaft opening

   - The use of constant specific storage values as opposed to varying the individual fundamental parameters comprising specific storage

5. Additional runs may be required to establish the degree of hydrologic interference occurring between the two ESF shafts. This becomes a true three-dimensional problem and may be estimated initially using quasi-analytical techniques based on output from the modeling task described above. Such hydrologic effects should be quoted as time-dependent additional pressure drawdowns in each formation at one shaft due to excavation of the other shaft.

APPENDIX B

ADAS AND INSTRUMENT ARRAY INSTALLATION DETAILS

A representative sample of detailed layout and location drawings for shaft mechanical response monitoring arrays is attached. A complete hierarchy of detailed drawings that will be prepared for both Shaft 1 and Shaft 2 when the shaft layouts are finalized is included in drawings 01-0000A and 02-0000A respectively.

Component drawings and specifications are not presented in this Appendix. Specifications (catalogue sheets) for procured items, such as conduit, will be included in the drawings when these details are finalized. Drawings and specifications for items that are to be designed by the A/E and supplied by the CM, such as the ADAS tub mounting brackets or instrument hanging posts, will be included in future revisions of the Testing Interface Specification (Golder Associates, 1987k). Drawings and specifications for components that are part of the Shaft ADAS Subsystem, such as DCU boxes, and ADAS tubs, are presented in the Automatic Data Acquisition Plan (Golder Associates, 1987b). Details of protective covers to be installed over ADAS equipment and recessed instruments located in the shaft walls are presented in the relevant instrument installation procedures.

The drawings contained in this Appendix are as follows:

01-0000A	Shaft Study Plan, Shaft 1 Drawings Hierarchy
02-0000A	Shaft Study Plan, Shaft 2 Drawings Hierarchy
01-0100A	Schematic Layout of ADAS Components in Shaft 1
02-0100A	Schematic Layout of ADAS Components in Shaft 2
01-0702A	Preparation Details, Shaft 1, Preliminary Lining, 960 ft Target Station
01-0703A	Instrument Array Assembly Details, Shaft 1, Preliminary Lining, 960 ft Target Station
01-0704A	Instrument Cable Routing Details, Shaft 1, Preliminary Lining, 960 ft Target Station
01-0705A	Preparation Details, Shaft 1, Final Lining, 960 ft Target Station
01-0706A	Instrument Array Assembly Details, Shaft 1, Final Lining, 960 ft Target Station
01-1802A	Preparation Details, Shaft 1, Preliminary Lining, 2200 ft Target Station
01-1803A	Instrument Array Assembly Details, Shaft 1, Preliminary Lining, 2200 ft Target Station
01-1804A	Instrument Cable Routing Details, Shaft 1, Preliminary Lining, 2200 ft Target Station
01-1805A	Preparation Details, Shaft 1, Final Lining, 2200 ft Target Station
01-1806A	Instrument Array Assembly Details, Shaft 1, Final Lining, 2200 ft Target Station
01-1807A	Instrument Cable Routing Details, Shaft 1, Final Lining, 2200 ft Target Station

APPENDIX C

LABORATORY TESTING REQUIREMENTS

The test program required to address adequately the information needs of the site characterization process and performance assessment consists of a combination of surface-based testing, surface borehole testing, laboratory testing, and underground testing. The draft Underground Test Plan (Golder Associates, 1986a) identifies the types of tests that can be used to address the information needs. A laboratory testing program will be developed separately to comprehensively address laboratory testing requirements of the site characterization program. However, a number of specific laboratory tests will be required in direct support of the shaft monitoring and testing program to enable data reduction and analysis. It may be possible to reduce the total amount of laboratory testing by using some testing to satisfy both the site characterization laboratory testing requirements and the support requirements for the shaft testing.

A tentative list of laboratory testing requirements in support of the shaft testing program has been prepared to indicate the character and extent of these testing requirements (Table C-1). The numbers of tests specified have been estimated based on the currently proposed shaft testing program; any increase in the shaft testing may increase the laboratory testing support requirements. Using laboratory tests to support more than one test could reduce the number of tests required. In general, it will be necessary to test samples taken from the immediate vicinity of the site of the test that the laboratory testing is supporting. The number of tests specified is a preliminary estimate only; it will be modified as the details of the shaft program are developed.

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TABLE C-1. Laboratory Testing Requirements in Support of Shaft Monitoring and Testing Program

Shaft Test	Supporting Laboratory Tests	Number of Supporting Tests
	Shaft Geology Study	
Geologic Mapping[a]	Petrographic analysis using thin sections	200
	Sediment analysis using binocular microscope	200
	Mineral staining	200
Core Logging and Sampling[a]	Point-load tests	200
	Schmidt hammer tests	200
	Shaft Mechanical Response Study	
Concrete Stress and Strain Monitoring	Creep tests	TBD
	Sample volume change monitoring	TBD
	Young's modulus	TBD
	Poisson's ratio	TBD
Bitumen Pressure Monitoring	Density	TBD
Piezometer Monitoring	Hydrochemical analyses	TBD
	Fluid density	TBD
	Fluid viscosities	TBD
	Fluid compressibility	TBD

TABLE C-1. Laboratory Testing Requirements in Support of Shaft Monitoring and Testing Program (Page 2 of 3)

Shaft Test	Supporting Laboratory Tests	Number of Supporting Tests
	Mechanical/Thermal Properties Study	
Absolute Stress Measurement	Young's Modulus[b]	TBD
	Poisson's Ratio	TBD
NX Borehole Jack Testing	Poisson's Ratio	TBD
Shaft Seismic Velocity Survey	Bulk density	TBD
Thermal Conductivity Testing	Specific heat	TBD
	Density	TBD
	Shaft Seal Study	
Groundwater Inflow Monitoring	Hydrochemical analyses	TBD
	Fluid density	TBD
	Fluid viscosities	TBD
	Fluid compressibility	TBD

TABLE C-1. Laboratory Testing Requirements in Support of Shaft Monitoring and Testing Program
(Page 3 of 3)

Shaft Test	Supporting Laboratory Tests	Number of Supporting Tests
Shaft Operational Seal Testing and Construction-Affected Zone Testing	Hydrochemical analyses	TBD
	Fluid density	TBD
	Fluid viscosities	TBD
	Fluid compressibility	TBD
	Moisture content	TBD
	Triaxial permeability	TBD
	Porosity	TBD
	Bulk compressibility	TBD
	Shaft Construction Support Study	
Blast Vibration Monitoring	Sonic compression and shear wave velocity	TBD
	Bulk density	TBD

Note: [a] All laboratory testing for these tasks, with the possible exception of preparing thin sections, will be undertaken by the UTC.

[b] Laboratory testing will only be required if the rock is so weak that large enough biaxial samples cannot be obtained.