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YUCCA MOUNTAIN SITE CHARACTERIZATION PROJECT
Study Plan for In Situ Testing of Seal Components: SCP Study 8.3.3.2.2.3

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Revision 0
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ABSTRACT

Section 8.3.3.2.2.3 of the Site Characterization Plan (U.S. Department of Energy [DOE], 1988) discusses the need to evaluate, through in situ tests, the behavior and characteristics of seals and backfill components for the proposed high-level radioactive waste repository at Yucca Mountain, Nevada. This study plan summarizes the in situ experiments intended to demonstrate that the proposed sealing and backfilling strategies are adequate to seal boreholes, ramps, shafts, and the underground openings for the Yucca Mountain repository. These experiments will provide input for repository design and for performance assessments of the repository system.

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LIST OF ABBREVIATIONS/ACRONYMS

ACD	Advanced Conceptual Design
AE	Acoustic Emission
ASTM	American Society for Testing and Materials
CFR	Code of Federal Regulations
DOE	U.S. Department of Energy
ESF	Exploratory Studies Facility
LA	License Application
LAD	License Application Design
LANL	Los Alamos National Laboratory
LHD	Load Haul Dump
MPZ	Modified Permeability Zone
NRC	U.S. Nuclear Regulatory Commission
PC	Performance Confirmation
QC	Quality Control
SNL/NM	Sandia National Laboratories/New Mexico
SCP	Site Characterization Plan
SP	Study Plan
TCO	Test Coordination Office
YMP	Yucca Mountain Project
WIPP	Waste Isolation Pilot Plant

1.0 PURPOSE AND OBJECTIVES

The U.S. Department of Energy (DOE) is conducting studies at Yucca Mountain, Nevada, that has potential to serve as the location for a high-level radioactive waste repository. Geologic, hydrologic, and geotechnical information about the site and certain engineered features are required for design studies and for activities directed toward assessing the waste-isolation capabilities of the overall repository system. Acquisition of site characterization and design-related information is the focus of a multidisciplinary site characterization effort described in the Site Characterization Plan (SCP) (USDOE, 1988). Figure 1-1 shows the general location of Yucca Mountain, along with the proposed outline of the repository based on preliminary design concepts.

The Yucca Mountain site consists of a gently eastward-dipping sequence of volcanic tuffs, comprised primarily of welded ash flows interlayered with nonwelded and reworked units. Various alterations, including devitrification, zeolitization, and the formation of clays, are also found at the site. The units are variably fractured, and faulting has offset the units. Figure 1-2 shows the stratigraphy at Yucca Mountain, along with the potential repository horizon in the densely welded Topopah Spring Member. The most immediate design interest focuses on this unit and the overlying units through which the repository ramps and shafts will be excavated. The Yucca Mountain Project (YMP) sealing program is responsible for demonstrating the performance and constructability of various sealing and backfilling components for the proposed repository as outlined in 10 Code of Federal Regulations (CFR) 60 (U.S. Nuclear Regulatory Commission [NRC], 1986). Seals are required in the shafts, ramps, and boreholes so that they do not act as preferential pathways for flow into or out of the proposed repository. Also, additional sealing components may be necessary at the repository horizon to direct any available water away from emplacement areas by encouraging infiltration into the underlying formation, and by sealing water producing zones.

The YMP repository sealing program concentrates on cemetitious and earthen materials (Fernandez et al., 1987; Hinkebein and Fernandez, 1989). Cementitious materials are the primary components for fracture grouting and borehole, shaft, and ramp seal emplacements. The use of clays is also being considered. Preliminary laboratory testing and geochemical evaluations of cementitious materials have been conducted (Licastro et al., 1990; Hinkebein and Gardiner, 1991). Fernandez et al., 1993 and 1994, have presented preliminary seal testing concepts and a strategy for sealing exploratory boreholes. In situ testing of seal components and techniques have not been attempted for the YMP, however, SNL/NM has demonstrated in situ seal component testing ability from other waste isolation projects, most notably the Waste Isolation Pilot Plant (WIPP). The small scale test described in this study plan have been modeled after similar experiments at WIPP (Stormont, 1986). Finley and Tillerson, 1992, provide a summary of small-scale seal tests at the WIPP using concretes, clays, crushed salt, and mixtures of clay and crushed salt. It is the intent of the YMP sealing program to draw on these experiences and to use standard off-the-shelf instrumentation and equipment as much as possible.

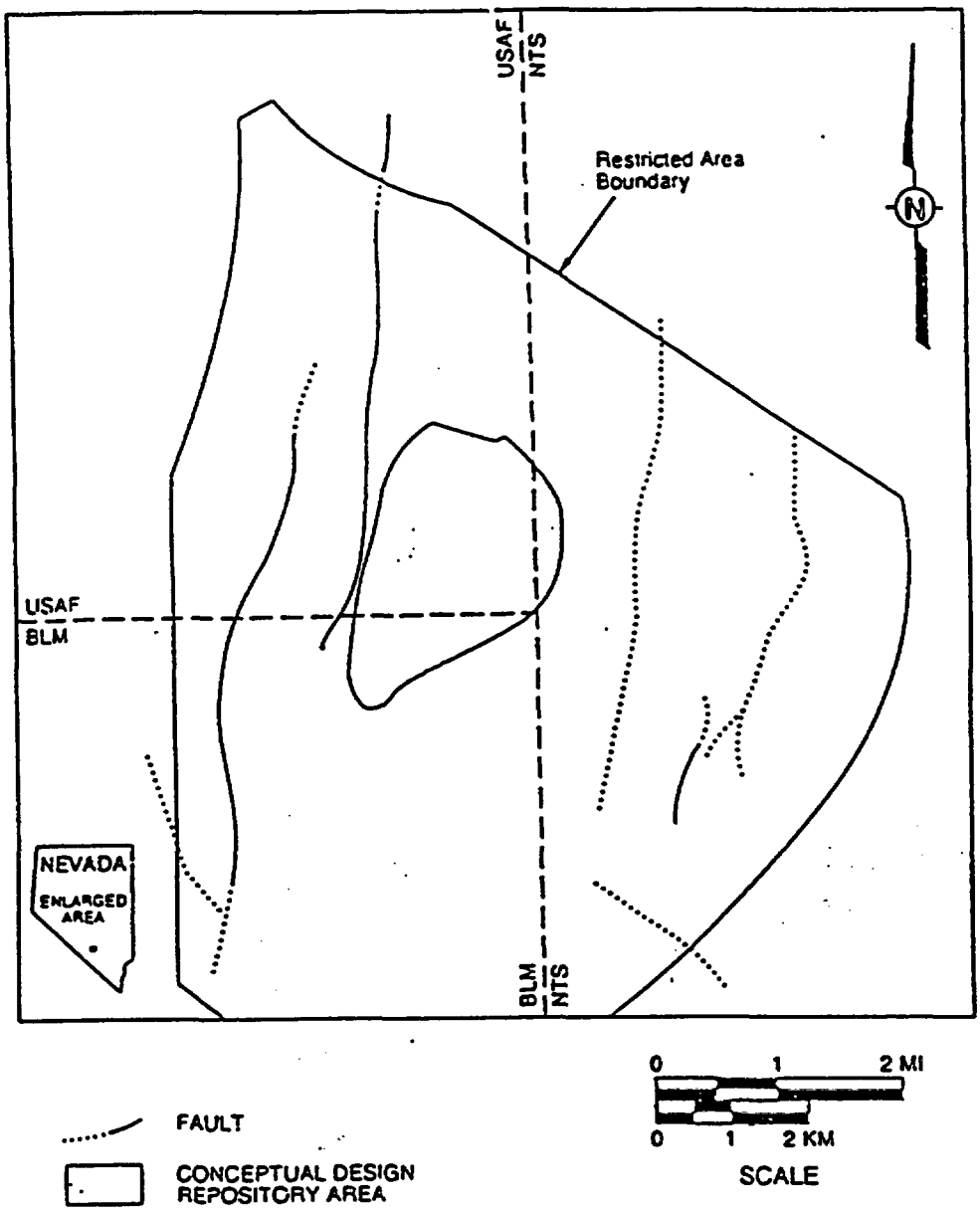
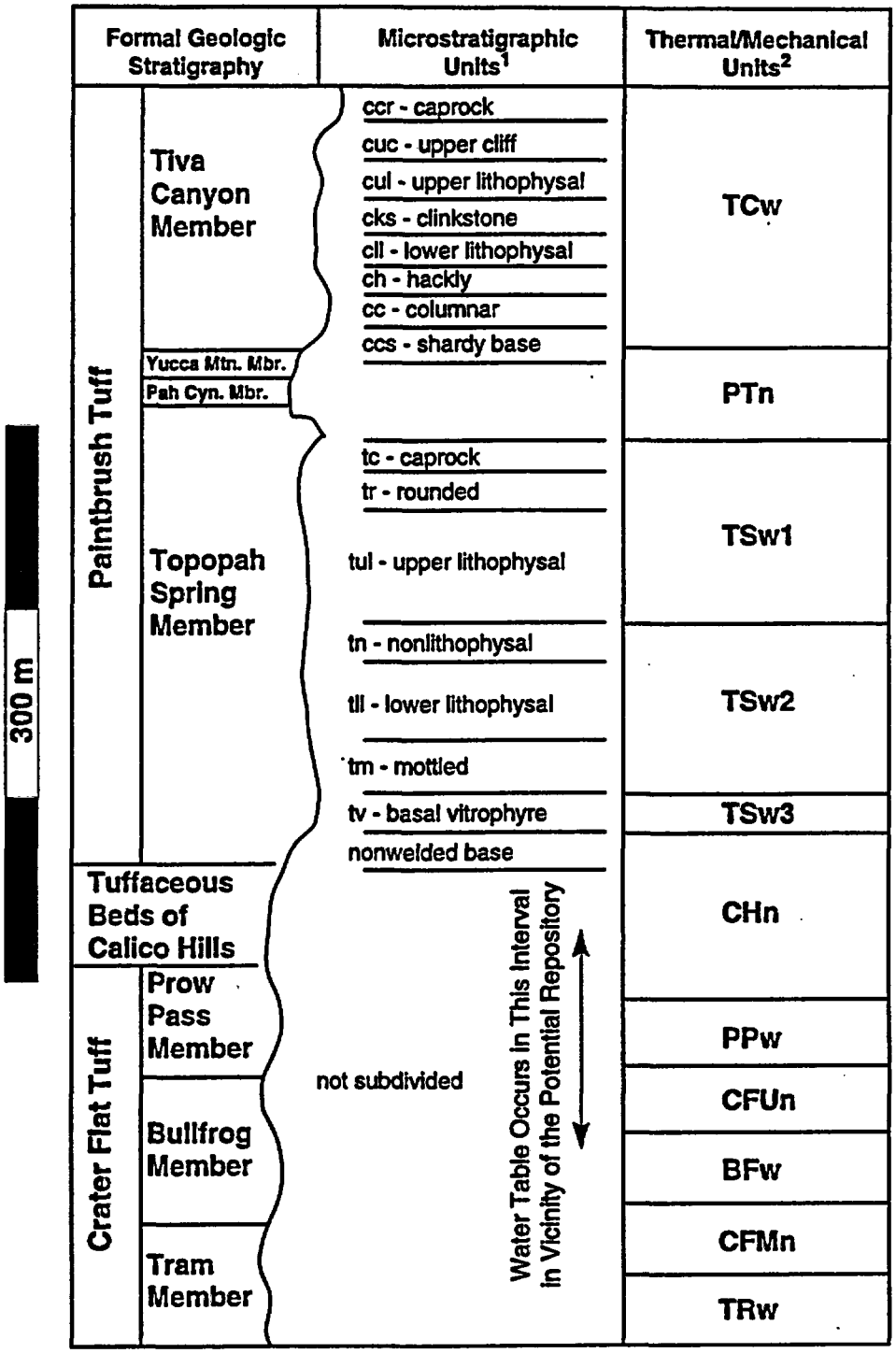


Figure 1-1. Index Map Showing the Location of the Potential Yucca Mountain Repository Site in Southern Nevada



Notes: 1 *Modified after Scott and Bonk (1984) for the immediate repository vicinity.*
2 *From Ortiz et. al, 1985.*
Thicknesses and "Weathering Profile" are highly schematic, and character varies with location.

Figure 1-2. Comparative Stratigraphic Terminology in Common Usage at Yucca Mountain (Rautman and Flint, 1992)

An issue of extreme importance for the YMP sealing program is the longevity and durability of the sealing components. This includes both the mechanical and geochemical stability of the seal materials and components as they relate to long-term performance. The mechanical stability of seal components is primarily related to the seismic and thermal behavior of emplaced seals as well as hydraulic or seismic driven migration of fines leading to fracture filling. Although seal components are primarily planned to be emplaced in low temperature regions, some emplacements may experience limited elevated temperatures. Therefore, it is necessary to evaluate seal material and seal system behavior under a range of moderately elevated temperatures. These elevated temperatures could cause differential thermal expansion, thermal stresses, and hydrothermal fluid movement which could adversely affect seal system performance. Also, dynamic loading of seal systems is expected over long time periods. The response of seal systems to such dynamic loadings should be evaluated, particularly the shear strength of seals emplaced in shafts and boreholes.

This study (8.3.3.2.2.3, "In Situ Testing of Seal Components") is primarily aimed at evaluating seal system performance within the rock units of interest at the proposed repository at reasonable scales. A limited amount of thermally and dynamically perturbed testing of these seal systems is presented. This in situ testing is complemented with a detailed laboratory testing program described in SCP study 8.3.3.2.2.1 "Seal Material Properties Development." The laboratory testing focuses on characterization, hydrologic and structural testing of candidate seal materials under a range of controlled conditions including ambient, and thermally and dynamically perturbed conditions. It is expected that the laboratory testing will provide greater control so that detailed evaluations of longevity and durability can be performed under expected, accelerated, and extreme conditions. Naturally, the laboratory testing will closely interface with the in situ testing of seal components described in this study plan.

1.1 Objectives of the Study

The purpose of the work described in this study plan is to evaluate the performance of and to provide input for design of sealing and backfilling components, to evaluate seal and backfill-construction techniques and equipment, and to evaluate the performance assessment aspects of seal designs and components for the Yucca Mountain repository. This will be accomplished through in situ experiments (described in this study plan), including small-scale tests that primarily will provide information on seal components for preliminary design of the seals and backfill for the proposed repository, tests aimed at demonstrating technology for sealing exploratory boreholes associated with the Yucca Mountain Site Characterization Project, and large-scale tests that primarily will provide data for performance confirmation (PC) aimed at developing final designs for the repository seals and backfill. Backfill surrounding the waste packages, as part of the Engineered Barrier System (EBS), is not part of this study plan.

Fernandez et al., (1987) identified sealing components for the Yucca Mountain repository to include shaft, ramp, and borehole seals and associated fill; emplacement-room fill and seals; and the Topopah Spring Member itself. Sealing components include anchor-to-bedrock plugs in the

shafts and ramps, dams (graded rockfill with fine core), borehole seals, general shaft fill, drift backfill, bulkheads (if necessary), backfilled sumps, and channels in backfilled rooms (see Figure 1-3). The generic goals of the sealing and backfilling program are to minimize the amount of water that can contact the waste packages by diverting water away from the waste emplacement areas; by minimizing the amount of water flowing into the repository horizon from all sources, both natural and manmade; and by using the natural infiltration of the Topopah Spring member welded tuff to remove any water from the repository horizon. Seals and backfill are also intended to limit the potential for gaseous releases of radionuclides as discussed in detail in Fernandez et al., 1993. The need for and suggested performance of these components depend on the geomechanical and geohydrologic conditions encountered at the site, including fault systems and potential perched water; the design of the repository, including shafts and ramps; and the constraints imposed by other engineered systems. Materials that have been identified for use as sealing components include shrinkage-compensating cements, grouts, and concretes; clays; and crushed and graded tuff.

Figure 1-4 shows potential locations for various sealing components for a repository design concept. These sealing locations are generic in the sense that specific designs can only be made as conditions are encountered in the underground. The locations of the various sealing components, although generic in Figure 1-4, include unfractured portions of the Paintbrush and Topopah Spring Member welded tuffs and the nonwelded Calico Hills unit below the repository. For instance, full plugs are required in all penetrations that access the surface or the groundwater table (in the vicinity of the repository). Also, it is necessary for these plugs to be located in regions that exhibit minimal fracturing. Fernandez et al. (1987, 1994) identified sealing locations for these penetrations within minimally fractured regions of the overlying nonwelded Paintbrush Tuffs, the Tiva Canyon welded tuff, and the upper portions of the Topopah Spring welded tuff. Further, plugs will be required in the upper portions of the Calico Hills nonwelded tuff for boreholes penetrating below the repository horizon. And bulkheads and backfilling may be required for excavations into the Calico Hills unit. Fracture-grouting may be required for localized areas around other seal components that require remedial treatment of fractures. Dams may be constructed wherever and whenever necessary, based on geologic and hydrologic information obtained during site characterization. Backfilling may be required to maintain the structural integrity of the rock surrounding other seal components or to minimize the potential for failure around repository openings. Generic design concepts for shaft, ramp, and borehole plugs, along with infiltration-enhancing dams, are given in Figure 1-5. The figure does illustrate general concepts including the restriction of water flow down shafts, ramps, and boreholes (plugs); the diversion of water away from the waste emplacement areas; and the enhancement of groundwater infiltration into the Topopah Spring Unit (dams, grouting, etc.). These figures are conceptual in nature and are intended to illustrate how the sealing program can address design requirements described above.

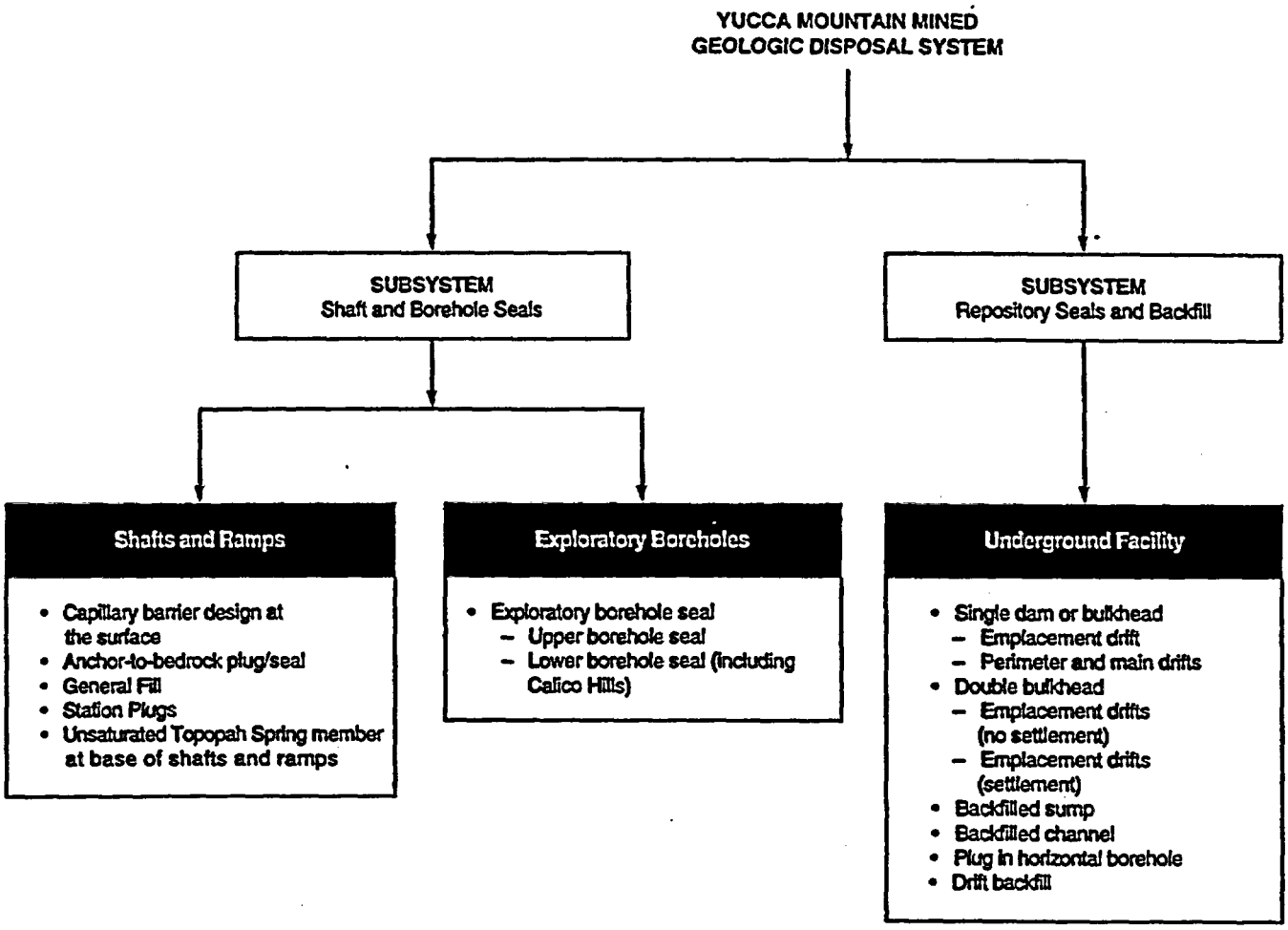


Figure 1-3. Sealing Subsystem, Seal Locations, and Seal Components, Modified from the Site Characterization Plan (DOE, 1988)

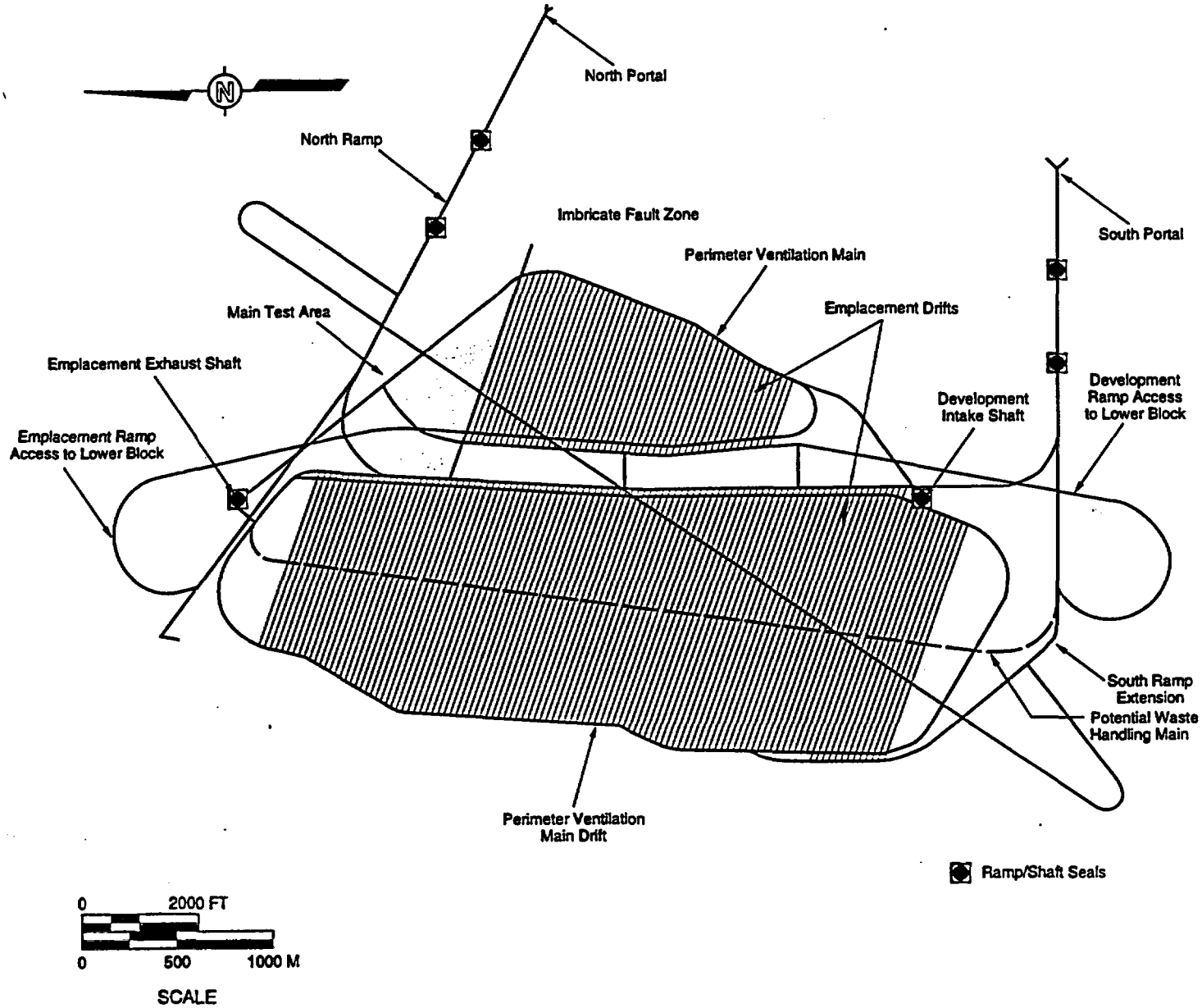
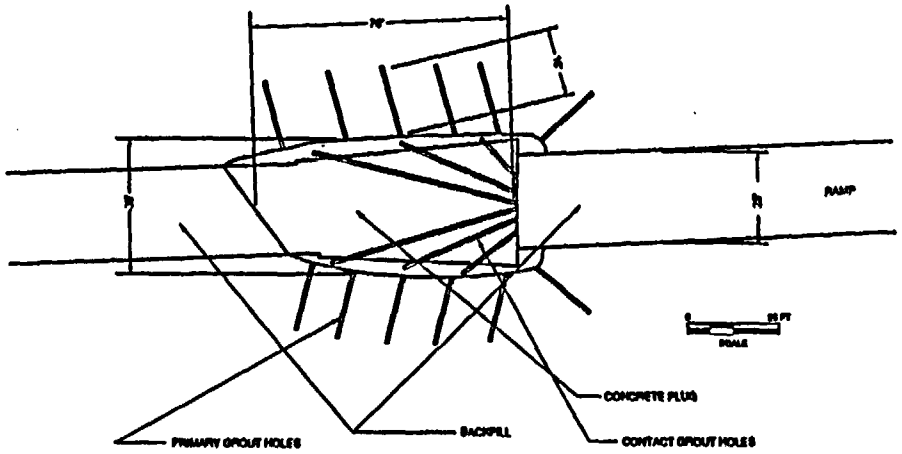


Figure 1-4. Locations of Proposed Shaft/Ramp Seals



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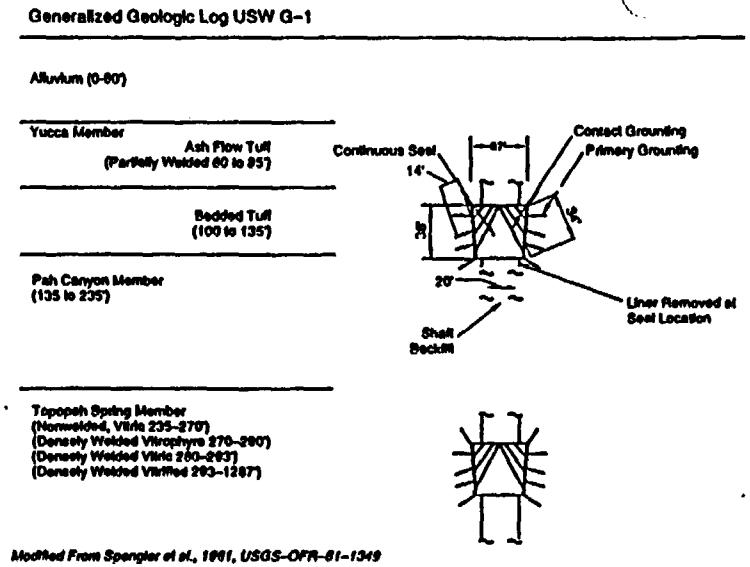

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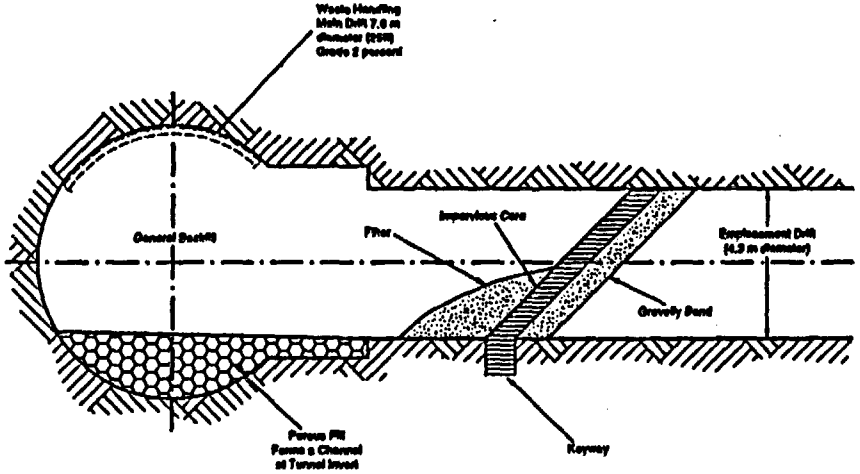

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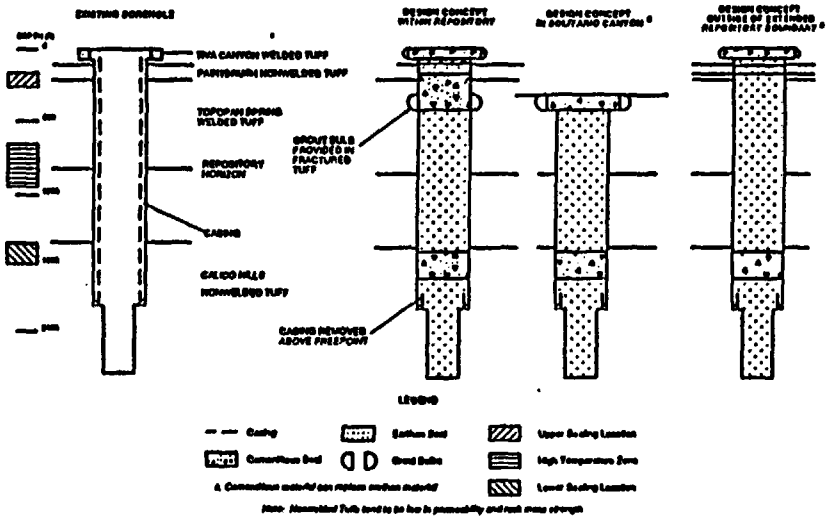


(d)

Figure 1-5. Generic Design Concepts for: (a) Cementitious Ramp Seal, (b) Shaft Seal, (c) Dams, and (d) Boreholes

1.2 Technical Issues Adressed

The borehole and design testing described in this study plan must be initiated to help resolve issues related to the abandonment of boreholes used for site characterization and to resolve uncertainty in seal-component response for repository design. The sealing program should establish the following:

- The effectiveness of emplacement equipment and methods
- The effectiveness of testing instrumentation
- The effectiveness of the seal subsystems
- The reliability of the seal subsystems under anticipated and extreme conditions
- The basis for the final design of seal components.

The regulatory requirements contained in 10 CFR 60 (NRC, 1986) provide the primary basis for the testing of sealing components. The requirements of interest for the sealing program fall into three areas: design testing guidance for the seals (Section 60.142), performance criteria for the overall repository system (Sections 60.112 and 60.140), and general criteria for the seals (Section 60.134).

Table 1-1 presents technical issues identified in the Site Characterization Plan (SCP) (USDOE, 1988) that are addressed by the sealing testing described in this Study Plan (SP).

Table 1-1 SCP Issues to be Resolved

Issue 1.12	Have the characteristics and configurations of the shaft and borehole seals been adequately established to (a) show compliance with the post-closure design criteria of 10 CFR 60.134, and (b) provide information for the resolution of the performance issues?
Issue 1.1	Will the mined geologic disposal system meet the system performance objectives for limiting radionuclide releases to the accessible environment as required by 10 CFR 60.112 and 40 CFR 191.13?
Issue 4.4	Are the technologies of repository construction, operation, closure, and decommissioning adequately established to support resolution of the performance issues?

This list of issues contain numerous uncertainties regarding technologies to be used for sealing and backfilling a potential repository at Yucca Mountain. These uncertainties are presented in Table 1-2.

Table 1-2 Correlation Between Seal Performance and Emplacement Uncertainties With Proposed Tests

Uncertainty	Approach Used Including Proposed Test
ANCHOR-TO-BEDROCK PLUG	
1. Can a plug be placed with specific properties to form an effective hydrologic barrier (tentative upper bound goal of 10^{-5} to 10^{-4} cm/s saturated hydraulic conductivity)?	Assess the geohydrologic properties of the site prior to conducting the plug test. Use a progressive approach to test a cementitious seal by understanding the thermomechanical response of a cementitious seal in situ and the hydrological performance of the seal through the following: • Small-scale borehole tests • Borehole seal test between drifts • Large-scale plug test. For the large-scale test, the most effective manner to test the modified permeability zone (MPZ) and the interface zone may be to core into those zones. Also, perform hydrological test of plug core after testing and supporting laboratory tests of concrete before placement.
2. Can a plug having specified structural design requirements be constructed?	Following proper setting of the plug, core into the plug to test the strength of the samples. Samples should be of various sizes to assess the effect of sample size. Consider the testing of the concrete nondestructively or by hydrofracturing over a portion of the plug.
3. Can the liner be removed before plug placement without propagating the MPZ outward?	First, characterize the MPZ for the shaft nondestructively. In testing plugs in shafts, the liners will be removed, and a keyway will be constructed. Removal will require a drill-and-blast (D&B) technique and/or a hydraulic splitter technique.
4. Can a keyway be excavated before plug construction?	Resolution of this uncertainty is obtained in conjunction with removal of the liner.
5. Can grout be placed effectively by the selection of a suitable grout pattern, the use of grout pipes, and the selection of grout injection pressures?	In various fracture settings, grout holes having various grout patterns should be drilled. The rock is characterized hydrologically. The grout is placed and subsequently drilled out. The hole is then re-characterized. The conditions encountered while constructing the ramps will determine where the testing should be performed.
6. Can grout workability be assured during placement in the in situ moisture and temperature environment?	Testing of the viscosity at the point of grout placement and laboratory testing of the same property of grout is required. This testing is intended to be a quality-control test.

Table 1-2 Continued

Uncertainty	Approach Used Including Proposed Test
7. Can shrinkage and temperature effects due to hydration significantly alter the interface zone?	A basic understanding of shrinkage and emplacement techniques will be required. This understanding will be achieved by laboratory and bench-scale testing. The influence of the heat of hydration and the placement technique should be understood before going into the field. Field tests are intended to be confirmatory. • Small-scale in situ seal tests, and • Possible large-scale shaft seal test.
8. Can concrete workability be assured during placement to eliminate either premature settling or particle segregation?	To address this uncertainty, field and laboratory testing of the workability of the concrete would be required. The important concern is maintenance of the properties of the concrete while it is being transported to the point of emplacement. Transport of concrete through a conduit in the underground facility can be performed to simulate the distance of transport at the surface.
GENERAL SHAFT BACKFILL	
9. Can the shaft fill be emplaced by either mechanical, pneumatic, or other methods to form an effective hydrologic barrier (tentative goal upper bound of 10^{-2} cm/s saturated hydraulic conductivity)?	There are two basic performance requirements that the shaft fill should achieve. These include the water-flow and airflow tests. The following tests are proposed: • Laboratory testing to demonstrate the basic physics of flow. (The starting point will be definition of the relationship of gradation to hydraulic conductivity. Understanding the relationship between conductivity and consolidation is necessary.) • Field testing to illustrate the ability to emplace backfill at some predetermined state. The testing would first be run using air and then water. Several different gradations will be used to achieve the desired properties. Furthermore, mixtures of clay and crushed tuff may be tested.
10. Can an earthen material be placed by mechanical, pneumatic, or other methods to achieve specified properties?	Evaluation of the consolidation of crushed tuff can be performed in multiple ways. The field testing will simulate the compaction of crushed tuff using actual emplacement techniques. This material will then be extracted, and laboratory tests will be performed. All work is preceded by laboratory testing.
11. What is the effect of emplacement techniques on the creation of fines?	To simulate the response of the backfill to the operations, it will be necessary to place the backfill under conditions closely simulating the actual emplacement conditions. A facility at the surface that uses realistic techniques is proposed to understand the actual compaction state. An understanding of the kind of fines created is important when determining the actual gradation for the shaft fill.

Table 1-2 Continued

Uncertainty	Approach Used Including Proposed Test
SINGLE EMBANKMENT AND DRIFT FILL	
12. Can grout be placed effectively by the selection of a suitable grout pattern, the use of grout pipes, and the selection of grout injection pressures?	The proposed tests are similar to those described for the anchor-to-bedrock plug.
13. Can grout workability be assured during the emplacement in the in situ moisture and temperature environment?	Same as the issue described for the anchor-to-bedrock plug.
14. Can a continuous grout structure be achieved by redrilling holes many times and grouting without affecting the sump drainage capacity?	The proposed tests are similar to those described for the anchor-to-bedrock plug. There is an additional concern that the orientation of the fractures should be varied to simulate the conditions of fractures parallel to the drifts and perpendicular to the drifts. Testing of the spread of the grout curtain associated with the dam is necessary as well as the hydraulic testing of the grout curtain after grout emplacement. The holes that are used for verification of the grout extent can be used for the hydraulic conductivity testing. Viscosity and the yield strength are two of the most critical parameters for grout emplacement. Following detailed characterization of the fracture in the area of grouting, ties between their properties, the orientation of the fracture network, and the rate and depth of the penetration will be evaluated.
15. Can drift backfill be placed by mechanical, pneumatic, or other methods to form an effective hydrologic barrier and to achieve specific properties?	The objective here is to demonstrate that backfill can be emplaced according to some predetermined criteria. Therefore, a large-scale test emplacing the drift fill would be necessary to verify that the criteria is met. Repetitive tests may be required to understand how the placement techniques affect the properties of the drift fill.
16. Can cracks due to shrinkage, thermal effects or dynamic effects create significant water paths?	There are several issues associated with this uncertainty: the effect of heat on the separation of the backfill from the rock, the effect of saturation and desaturation on the consolidation properties of the backfill, and the cracking of the fill due to the same effects. Testing will be performed on a single embankment determined through analyses evaluating the potential for piping. Full-scale test may be performed to address these issues, supported by laboratory compaction tests.
17. Can a single embankment retard the lateral migration of flow.	This test is an evaluation of the composite system. The flow through the rock, backfill, and the embankment will all be instrumented. Progressive testing is proposed in a surface test facility, in the Tiva Canyon unit, and finally in the Topopah Spring unit. Small-scale tests are initially.

Table 1-2 Continued

Uncertainty	Approach Used Including Proposed Test
18. Can the migration of fines behind the single embankment clog the fractures?	An understanding of fines migration is necessary to resolve this issue. Laboratory testing will initially be performed, followed by in situ tests
19. Can fines be removed from the floor or controlled from entering the fracture system to reduce the silting potential?	See above.
BACKFILLED SUMP	
20. Can fines be removed from the floor to reduce silting potential?	This is not a testing issue but rather an operational concern. The entire issue of fines clogging the fracture system and reducing the hydraulic conductivity of the rock is dependent on the fracture system itself. Prevalent fractures having large apertures should be protected so that even sand-sized particles or larger will not enter the fracture. This concept argues in favor of a filter near the fracture itself. All fines migration problems also require the characterization of fines in flows entering the underground facility.
CHANNEL IN BACKFILLED ROOM	
21. Can backfill be placed in a channel subjected to quality-control testing of specified gradations to reduce the silting potential and achieve the performance objective?	Similar to the emplacement of a filter around a large fracture, the placement of drift fill should be done around the channel fill so that the channel does not become clogged. Laboratory testing using bench-scale testing should be used to satisfy this uncertainty.
EXPLORATORY BOREHOLES	
22. Can the casing be removed and a plug emplaced in an exploratory borehole at the Calico Hills level and in the Paintbrush tuff horizon?	This uncertainty is strictly a feasibility question. The answer will be resolved by demonstrating the removal of casing and the installation of a plug.
23. Can a plug be installed in the Tiva Canyon, Paintbrush nonwelded, and Calico Hills units with specific conductivities?	The installation of a cementitious seal can be demonstrated by testing easily accessible seals as in the small-scale in situ tests. Finally, a surface-scale operation must be performed to illustrate that an acceptable seal can be emplaced from the surface. Part of this effort will include the placement of bentonite pellets in a highly fractured zone in the welded devitrified zone. The migration potential of bentonite must be evaluated. This will necessitate small-scale testing at the repository level to effectively place bentonite pellets.
CALICO HILLS DRIFT SEAL	

Table-1-2 Concluded

Uncertainty	Approach Used Including Proposed Test
24. Can the drifts in the Calico Hills unit be adequately sealed?	The current justification for testing in the Calico Hills unit is to understand the basic properties of the recompacted nonwelded tuff that is extracted from this unit. These properties will include the consolidation properties, the creation of fines, the hydraulic conductivity of the recompacted material, and the strength properties of the fill. If the fracturing is different from the units above, fracture grouting experiments may be necessary. Additionally, a second test, such as a bulkhead test, may be required to seal environments where special problems may occur.

(after Fernandez et al., 1993)

The general approach to the in situ testing of seal components is to identify uncertainties. Once the uncertainties are identified, small-scale in situ tests are conducted under expected and unexpected conditions. These results of these preliminary in situ tests along with the complementary laboratory testing described in SCP study 8.3.3.2.2.1 are then used to guide future larger-scale PC tests. Laboratory testing of seal components and materials described in SCP study 8.3.3.2.2.1 "Seal Material Properties Development," will augment and contribute to the in situ testing, providing information on chemical compatibilities and longevity of materials, as well as hydrologic performance, under controlled laboratory conditions. Numerical modeling of seal component performance will also be used to confirm design assumptions and to allow prediction of future performance under expected and unexpected conditions.

2.0 SCOPE OF WORK

Fernandez et al., (1993) provides a detailed description of sealing and backfilling tests aimed at resolving all technical issues and uncertainties related to sealing and decommissioning the proposed repository at Yucca Mountain. This study plan describes two types of tests: seal component tests (supporting design and site characterization) and performance confirmation (PC) tests. The design-related tests are typically smaller in scale and provide early-time input for resolution of design uncertainties for the surface-based drilling program and for repository design. The design-related tests are described in detail in this study plan, whereas the PC tests are presented in limited detail. It is expected that the design of the larger-scale PC tests will change as information is gathered from the preliminary design tests; consequently, the PC tests will be described in greater detail in revisions to this study plan. Table 2-1 (modified from Fernandez et al., 1993) presents the seal components and PC sealing and backfilling tests. Table 2-1 also provides a "cross-reference" of the key uncertainties identified in Table 1-2 to each of the tests presented in Table 2-1.

The general approach to in situ sealing and backfilling tests is to first conduct small-scale in situ component tests in which specific parameters of interest to sealing and backfilling are evaluated. These smaller-scale tests offer the opportunity to access the seal via post-test coring/excavation. Tests at this scale also offer the opportunity to evaluate test techniques and equipment. The design of larger-scale PC tests will be based on the results of the small-scale tests. A brief description of each of the proposed tests follows. A more detailed description of the design-related tests are presented in subsequent sections of this SP.

2.1 Summary Description of Seal Testing

This section describes briefly each of the seal component tests supporting design and PC tests listed in Table 2-1. The seal component tests supporting design are presented in greater detail in subsequent sections of this study plan. The PC tests will be further defined in revisions to this study plan and will largely be based on the results of the initial in situ seal component testing. The timing of in situ sealing tests will be coordinated to support program needs. Therefore, in situ sealing tests supporting design should be implemented first with other tests such as PC testing postponed to the initial construction phase.

The small scale in situ tests evaluate the thermomechanical response, hydrologic response, and geochemical stability of cementitious seals, of different diameter, in welded and nonwelded tuff. The first test objective is to evaluate the structural performance at the interface zone as it relates to moisture and the thermal environment during cement hydration and possible external thermal loading. The second objective is evaluated by periodic flow testing of the seal system. The third can be assessed through long-term evaluations and "post-mortem" testing of the seals and

Table 2-1 Summary of Sealing Tests and Associated Objectives

Test and Related Uncertainties	Objective
SEAL COMPONENT TESTS SUPPORTING DESIGN	
Small-Scale In Situ Test Uncertainties [2] [6] [7] [17] (see Table 1-2)	To characterize the thermal and stress response of the hydration of the grout or concrete placed in nonwelded and welded tuff environments.
Intermediate-Scale Borehole Seal Test Uncertainty [1] (see Table 1-2)	To characterize the hydrologic performance of borehole seals.
Remote Borehole Sealing Test Uncertainty [1] (see Table 1-2)	To understand the hydrologic performance of remote borehole seals.
Fracture Grouting Test Uncertainties [5] [8] [12] (see Table 1-2)	To understand the hydrologic effectiveness of grout penetration in a number of different fractured environments.
Small-Scale Seepage Control Test Uncertainty [10] (see Table 1-2)	To evaluate the extent of a water plume from a flooded hole and the hydrologic performance of graded fill materials.
Surface Backfill Test Uncertainties [10] [11] (see Table 1-2)	To establish the consolidation behavior and the preliminary hydrologic performance of drift and shaft fill, including nonwelded and welded rockfill, due to emplacement techniques.
Grouted Rock Mass Test Uncertainty [16] (see Table 1-2)	To assess the thermal effects on the permeability of a fractured rock mass, as well as the thermal effects on a fractured rock mass that is grouted.
PERFORMANCE CONFIRMATION (PC) TESTS	
Large-Scale Shaft Seal and Shaft Fill Test Uncertainties [1] [3] [4] [7] [8] [15] [18] [19] [20] [21] (see Table 1-2)	To characterize the hydrologic behavior of rigid shaft seals (including the interface zone, the modified permeability zone, and the seal itself). Also, to characterize the hydrologic performance and the consolidation behavior of rockfill comprised of nonwelded and welded tuff with and without additives.
Seepage Control Test Uncertainty [15] (see Table 1-2)	To understand the hydrologic performance of drift fill and filter designs, together with the drainage through the underlying fractured rock, the potential migration of fines and subsequent clogging of the underlying fractures, the drainage enhancement provided by various drainage designs, the effects of saturation and desaturation on the rockfill properties, and the thermal effects on the rockfill/rock interface and the rockfill itself.
Backfill Test Uncertainty [9] (see Table 1-2)	To characterize the structural and hydrologic performance of various rockfill material.
Bulkhead Test in the Calico Hills Unit Uncertainties [24] [23] [22] (see Table 1-2)	To characterize the conductivity and structural performance of a full-scale bulkhead in the Calico Hills unit.

(after Fernandez et al., 1993)

surrounding rock. These tests will examine the behavior of 0.10-, 0.30-, 0.46- and 0.91-m diameter seals instrumented to measure temperature, and interface stress. Instrumentation also can be placed near the seal center, where the largest confinement occurs, and near the ends of the seal, where the host-rock formation provides less constraint. Dynamic loading (using, for example portable downhole sources) and monitoring instrumentation can be periodically applied to the rock surrounding the seals for evaluations of dynamic stability. For this test options, flow tests would be performed on the seals prior to and after dynamic loading.

The remote borehole sealing tests would determine the hydrologic performance of selected seals placed in exploratory boreholes. This test would implement seal designs for an exploratory borehole with geologic characterization, borehole preparation, seal emplacement, and seal testing performed remotely from the surface. The testing simulates identification of the sealing zone, casing removal (if possible), borehole-surface preparation, and emplacement of the seal by remote methods. Tests will be performed in the Calico Hills unit, the Topopah Spring Member, and in the Paintbrush nonwelded tuff. Knowledge gained from the small-scale in situ seal tests would be used to direct the remote borehole sealing tests.

The fracture-grouting tests are intended to assess the ability of grout to penetrate fractures and to reduce the overall conductivity of the fractured rock. The main objectives of fracture grouting tests are to emplace grout to achieve a reduction in fluid flow through selected geologic media and to strengthen the rock mass. These tests are planned primarily for the fractured, densely welded portion of the Tiva Canyon and Topopah Spring Members. Because the intent of these tests is to assess the effectiveness of the grouting operation in various geologic settings, several grouts and grouting techniques may be necessary. The performance of the grout emplacement could be evaluated by in situ characterization before and after grouting, using fluid flow testing techniques. Also, acoustic emission techniques could be used to evaluate the extent of grout penetration during grouting. Post-test coring will be used to assess changes to mechanical properties. Additionally, single and/or multiple grouted rows could be tested to understand the effectiveness of various grouting designs. Also, elevated temperatures could be applied to the grouted rock to simulate repository conditions and to allow for estimates of the long-term performance of such grouts.

The Small-Scale Seepage Control Test will provide information on the seepage potential of the Topopah Spring Unit on a scale smaller than a full-sized drift. This test could be conducted in a large-diameter borehole or in a drift at the repository horizon. The objective of this test is identical to the large-scale seepage control test conducted under the PC testing program, i.e., to investigate the hydrologic performance of the drift fill with drainage into underlying rock, fines migration, and potential clogging of underlying fractures. The test would require pre- and post-test characterization of the underlying rock, which would possibly require excavation of some of the material to check for fines migration into fractures.

Surface backfill tests are proposed to obtain a preliminary understanding of the performance of the rockfill at the surface prior to placement of rockfill underground using different emplacement methods. The tests would provide an understanding of particle breakage during excavation. A basic understanding of the relationship between the emplacement techniques and the quality of the rockfill can be obtained using full-scale equipment. The benefit of conducting operations at the surface is that these tests could serve as prototype tests prior to fielding complex underground tests. Other issues, such as instrumentation suitability and hydrologic performance of the rockfill, also could be addressed.

The grouted rock mass tests include testing on an isolated block of tuff instrumented with various stress, strain, temperature, and deformation gages to evaluate the thermomechanical and hydrologic properties of a typical planar joint. The tests simulate loadings using four flatjacks. The main test objective is to evaluate the thermomechanical and hydrologic properties of a typical joint in welded tuff. The properties of the joint would be evaluated under grouted and ungrouted conditions at ambient and elevated temperatures. Hydrologic performance of the joint also would be observed during both phases of these tests. The tests are designed to control stress- and temperature-boundary conditions for the rock block.

The large-scale shaft seal and shaft fill test involve the placement of a concrete seal and rockfill in simulated shafts. The test objectives are similar to those of the Calico Hills bulkhead test. The seal would be emplaced using a method similar to that of the final sealing procedure of the shaft. A shaft would be developed between two drifts separated by 15 to 20 meters, and the shaft would be lined. Following an appropriate time for the liner to cure, shaft fill would be placed and hydrologic tests conducted on the shaft fill material. The instrumentation would involve placement of settlement gages, earth pressure cells, tensiometers, and pore pressure cells. The intent of this instrumentation is to assess the coupled settlement and hydrologic properties of the rockfill. Following the testing of the rockfill under simulated conditions, a selected portion of the liner could be removed, a keyway excavated, the cementitious seal placed, contact grouting performed if necessary, and hydrologic testing performed. Because it is anticipated that the hydraulic conductivity of the seal will be low, a transient-pulse technique may be necessary to find the hydraulic conductivity of the shaft fill. While conducting this test, the rockfill placed over the seal would be instrumented with settlement gages, a multiple-position borehole extensometer system, earth-pressure cells, tensiometers, and pore pressure cells. Instrumentation also would be placed at the interface between the rock and the seal to monitor the changes in stress, strain, and temperature as the concrete hydrates.

The seepage control tests are intended to address several objectives. These objectives include understanding the hydrologic performance of drift fill with drainage through underlying rock, fines migration, and the potential clogging of underlying fractures. The tests would be conducted in fractured, densely welded tuff and would evaluate the effectiveness of a filter or single embankment in restricting the lateral migration of flow in a drift. The tests would simulate both anticipated and unanticipated conditions by introducing varying quantities of water into the test

area. This pulse of water into the drift backfill could modify the as-emplaced condition of the rockfill by dislodging the fine-sized particles in the drift fill. The effectiveness of the underlying rock in draining water also would be assessed. The extent of rock saturation beneath the upper drift could be assessed from the lower drift. This assessment of rock drainage requires characterization of the rock mass surrounding the excavation. Therefore, prior to introducing any water into the test area, the rock mass beneath the test section would be hydrologically characterized, using suitable direct or geophysical techniques, such as surface resistivity, borehole induction log, ground-penetrating radar, and cross-borehole seismic tomography.

The backfill tests are intended to determine the thermomechanical and hydrologic performance of various rockfill materials. These tests would be an extension of the surface backfill test and would use the engineered backfill specifications determined in the surface phase. The thermomechanical response of the backfill would be evaluated to determine the coupled response of the rockfill and the rock under simulated thermal loads. Heaters can be emplaced around the drift to simulate both far-field thermal loads and the effect of hydrothermal solutions on long-term performance. The displacement of the rock and the rockfill includes the response of water on the compaction behavior of the rockfill. Also, SCP study 8.3.3.2.2.1 "Seal Material Properties Development," includes controlled laboratory tests aimed at evaluating long-term seal material behavior including potential degradation of the performance due to elevated temperature.

The bulkhead test would be performed on a rigid bulkhead in the Calico Hills unit. The primary test objective is to understand the hydrologic and structural aspects of a full-scale bulkhead test if such seals become necessary. Uncertainties associated with the emplacement of the large-sealed bulkhead in an elevated temperature environment could be addressed. This PC test will evaluate the in situ performance of cementitious material emplaced to obtain low conductivity by controlling thermal effects of hydration. Grouting of the modified permeability zone (MPZ) and the interface zone also would be evaluated. Water pressures could be allowed to develop naturally behind the bulkhead, inducing flow through the bulkhead, the interface zone, and the surrounding MPZ. As in the small-scale in situ tests, the stresses, strains, and temperatures would be monitored within the bulkhead and at the interface zone.

2.2 Detailed Descriptions of Seal Component Tests Supporting Design and Site Characterization.

In the sections that follow, seal component tests that support repository design and site characterization activities are presented in greater detail. These tests are presented in greater detail because they are planned to be the first sealing tests conducted. Other tests such as the PC tests may be delayed to later phases of the licensing process and will be included in more detail in subsequent versions of this study plan.

2.2.1 Small-Scale Plug Tests

These tests consist of two separate tests: small-scale in situ tests and remote borehole sealing tests. This suite of experiments is intended to resolve uncertainties associated with placement and performance of borehole seals and shaft and ramp plugs. These uncertainties include seal material and seal-interface mechanical, thermal, hydrologic, and geochemical performance, as well as uncertainties in emplacement and evaluation technologies. These tests are designed so that specific aspects can be evaluated under controlled conditions in each test series. The small-scale in situ tests primarily evaluate the thermomechanical, hydrologic, and geochemical performance of cementitious seals at several different scales and the remote borehole sealing tests evaluate both constructability and hydrologic performance issues associated with sealing exploratory boreholes from the ground surface.

A primary component in borehole, shaft, and ramp seals and plugs are cementitious materials. Although not the only seal materials that may be used (bentonite may also be used in specific applications), cements will serve as the primary seal materials to provide both structural stability and short-term hydrologic performance and, as such, must be evaluated under expected and extreme repository conditions.

During emplacement of cementitious seals, the heat of hydration of the cements produces increases in temperature and thermal gradients resulting in thermal stresses within both the plug and the surrounding rock. Initially the plug is in a plastic state as thermal stresses increase. Following hydration of the cement, the plug is in a more rigid elastic state, and the thermal stresses reduce because of cooling.

Design-mix development for cementitious seals considers such parameters as water-to-cement ratio, aggregate size, and temperature and moisture conditions at depth. The design mix attains workability partially through control of these parameters. Licastro et al., 1990, and Fernandez et al., 1994, present preliminary mix designs for concretes, sanded grouts, and microfine grouts that are expected to be geochemically compatible with the host environment. These preliminary mixtures are presented in Tables 2-2 through 2-4. These preliminary mixtures may be modified based on continued materials research conducted under SCP study 8.3.3.2.2.1. The geothermal conditions at depth control the temperature of the rock surrounding the plug. The placement temperature of the cement slurry controls the initial temperature of the mix; exothermic reactions of cement hydration then elevate the temperature. The water-to-cement ratio, humidity, and availability of moisture during curing controls the initial mixture proportions.

The plug expands thermally during curing and contracts during subsequent cooling. Residual compressive or tensile stresses develop within the plug and may result in separation at the interface zone. The permanent effect depends partially on the heat of hydration and thermal

diffusion to the surrounding rock mass. It also depends on the thermal expansion coefficients of the plug and the surrounding rock and changes in the thermomechanical properties over time.

Table 2-2 Preliminary Compositions of Sanded Mortar and Concretes for In Situ Sealing Tests

Component	Sanded Mortar (84-12R2)	Concrete (84-12CR1)
	Weight %	Weight %
Class H cement	18.1	12.3
Water	17.9	10.9
Silica fume	4.1	2.8
Silica flour	12.6	8.5
Slag	21.0	14.2
Silica sand (20-40 mesh)	26.0	0.0
Concrete sand	0.0	16.4
Aggregate (3/4 in. MSA)	0.0	34.5
Dispersant D-65 wetting agent	0.3	0.4
Defoamer	0.1	0.02
Total	100.1	100.02

from: Licastro et al, 1986 and Fernandez et al., 1994

Table 2-3 Preliminary Portland Cement Grouts for In Situ Sealing Tests (fractures greater than 1mm)

Component	Grout PG-5	Grout PG-6
	weight %	weight %
Cement, Class A	32.3	23.7
Silica fume	6.4	4.8
Silica flour	13.5	9.8
Gel (bentonite clay)	0.6	1.5
Silica sand (20-40 mesh)	0.0	26.1
Dispersant, D-65 (wetting agent)	0.1	0.1
Plastiment	1.3 fluid ounces	1.6 fluid ounces
Water	47.1	34.0
Total	100.0	100.0

Table 2-4 Preliminary Microfine Cement Grouts for In Situ Sealing Tests (fractures less than 1mm)

Component	Microfine Grout PG-1	Microfine Grout PG-2
Microfine cement MC-500, kg	80	80
NS 200 dispersant, liters	0.7	0.7
Water, liters	160	80

from: Licastro et al, 1986 and Fernandez et al.,

In general, the formation of expansive constituents (e.g., ettringite) in the cement mixtures leads to volumetric expansion of cement (Hoff, 1974) and the development of interface stress. The effectiveness of the plug depends on the temperature, moisture environments, the evolution of thermomechanical properties, and the degree of restraint during setting. Moisture and temperature environments affect the rate of exothermic reaction and, therefore, the rates of expansive-constituent formation and hardening in cements (Beirute and Tragesser, 1973). Clearly, a reduction in water available for cement hydration reduces the rate and amount of expansive constituent formation. Expansivity may be optimized only if moisture is continually available during curing. Table 2-2 shows preliminary concrete and sanded mortar mixtures proposed for this testing. Actual mix designs will be developed under SCP Study 8.3.3.2.2.1 "Seal Material Properties Development."

Analysis of the development of interface stress during curing requires knowledge of expansivity and stiffness as functions of time and restraint. Both volumetric expansion and stiffness properties change with time during curing. The relationship between the plug-material stiffness and the volumetric expansivity can be characterized as early stiffening (i.e., the material stiffens before the main expansive phase) or late stiffening (i.e., the material stiffens after the main expansive phase). A material characterized by early stiffening will develop a higher interface stress, which may reduce the potential for interface flow. A material characterized by late-stiffening will develop a lower interface stress, because expansion precedes hardening or stiffening of the material. Also, the degree of restraint offered by the surrounding rock mass will affect the development of the interface stress. In principle, ettringite (a principal expansive mineral assemblage in expansive cements) grows preferentially toward regions of lower stress. In tests on cement performed by Ish-Shalom and Bentur (1975), a stress value of 0.4 MPa was developed under uniaxial restraint, whereas values exceeding 9.8 MPa were developed under isotropic triaxial restraint.

Initial placement temperatures also affect the development of interface stress. An increased placement temperature will increase the peak temperature in the plug due to the rapid release of the heat of hydration, resulting in heat diffusing away from the plug. In contrast, a reduced placement temperature may result in a smaller initial temperature rise such that the peak temperature never exceeds the ambient rock temperature.

An important objective of these series of tests is to predict temperature with space and time during placement and curing. These predictions are necessary for proper placement of instrumentation to measure thermal gradients and their thermomechanical effects and to identify high curing temperatures that could damage instrumentation or make the interpretation of results difficult.

An issue of prime importance for long-term seal performance is the geochemical stability. The geochemical stability of sealing materials will primarily be evaluated in controlled extreme and accelerated laboratory tests described in SCP Study 8.3.3.2.2.1 "Seal Material Properties Development." This laboratory testing will contribute to the evaluation of long-term and accelerated in situ sealing tests.

2.2.1.1 Small-Scale In Situ Seal Tests

This test series includes cementitious seals in shallow boreholes (2 to 4 m deep) instrumented with stress, strain, and temperature gages in the seals and surrounding rock to evaluate the cement hydration effects as well as temperature changes caused by potential accelerated in situ testing. Hydrologic testing can be accomplished using angled access boreholes to pressurize the region below the seal or alternatively using large diameter packer assemblies or simple falling head setups above the seals. The boreholes will range from 10, 30, 46, and 91-cm in diameter. These sizes are necessary to evaluate the effects of scale on the cement hydration, plus allow comparisons between the mechanical response and hydrologic performance from the remote borehole seal tests described below. Tests will be conducted in both welded and nonwelded tuffs and should include at least two tests of each diameter in each of the tuffs. One set of tests would be instrumented and the other would be without instrumentation for hydrologic testing. It has been demonstrated in similar tests conducted for the WIPP that the cabling associated with embedded instrumentation can act as preferential pathways for flow (Peterson, 1987). Therefore, the seals tested with instrumentation should not be used for flow testing. The tests can be conducted in alcoves constructed from the ramp and Exploratory Studies Facilities (ESF). Evaluations of the dynamic stability of the emplaced seals can be accomplished with downhole seismic sources in boreholes near the seal locations.

The objective of small-scale in situ seal tests is to evaluate emplaced hydrologic performance as well as the structural performance of the interface zone, which depends on moisture and the thermal environment, during the hydration of cementitious material. The degree of restraint offered by the surrounding rock mass also affects interface-stress development and represents a condition not easily evaluated in the laboratory. Previous investigations in basalt (Kelsall et al., 1982) show the relative importance of the interface zone in minimizing seal system permeability and performance. To place seals of low conductivity with a high level of hydrologic performance, it is necessary to evaluate, through realistic in situ testing, the effects of cement

volume change, hydration, and temperature on the interface stress. Current sealing concepts locate the primary sealing components in exploratory boreholes, shafts, and ramps, generally away from the extreme high-temperature regions. Testing of the sealing components at moderately elevated temperatures and with available water may be necessary to simulate seal conditions in situ for some repository thermal-loading scenarios. The small diameter of the seal tests allows several seals to be emplaced inexpensively, so that longer-term chemical compatibility testing can be performed routinely through time. Some seals can be overcored and removed on a routine basis over the next several years and can be chemically evaluated to determine whether degradation of the seal material is occurring. Some seals should be left in place for perhaps decades so that realistic estimates of seal longevity can be made upon closure of the facility.

2.2.1.1.1 General Approach

The layout for the small-scale in situ seal tests consists of conducting separate tests in welded and nonwelded tuff. The tests will consist of evaluating four different-sized seals in welded tuff, two of which are shown in Figures 2-1 and 2-2. Note that these figures illustrate tests for the 0.46-m and 0.91-m diameter seals, respectively. The tests consist of instrumented seals and uninstrumented seals. The instrumented seals are intended to evaluate the thermomechanical response and the uninstrumented seals will evaluate the hydrologic response. Both sets of tests can be used to evaluate the dynamic and geochemical response of the seals to the environment. For the instrumented seals, instrumentation will be placed near the center and near the ends of the seal. Circumferential and radial strains, as well as temperatures can be measured in directions of 0, 60, and 120 degrees around the seal to evaluate the stresses and temperatures developed within the seal as a result of cement curing and externally applied heat. The tests conducted at 0.30 m will be compared to hydrologic performance of similar uninstrumented 0.30-m-diameter seals conducted under the remote borehole tests described in Section 2.2.1.2.

The general sequence for the small-scale seal testing is as follows. A suitable test location will be selected in welded and/or nonwelded tuff, within alcoves at the ESF. A simplified surface-fracture characterization will be performed. Downhole characterization using air permeability testing equipment with multiple straddle-packers and guard zones will be performed to characterize the formation's local air permeability. Fracture-grouting will be performed (if necessary) in the rock surrounding the proposed seal location. A second series of air permeability characterization will be performed in the vicinity of the proposed seal location. The seal will then be emplaced along with instrumentation. A third series of air permeability testing will be performed. Finally, remedial squeeze grouting will be performed on the emplaced seal system, if necessary, to seal any potential leak paths that may occur along the interface between the seal and rock. A final series of air and liquid permeability tests using downhole, multiple straddle-packers with guard zones will be performed to quantify the seal system permeability. Additional permeability tests will be conducted on these seals on regular intervals throughout the site characterization period to evaluate possible degradation effects. Some seals may be removed for laboratory evaluations of geochemistry.

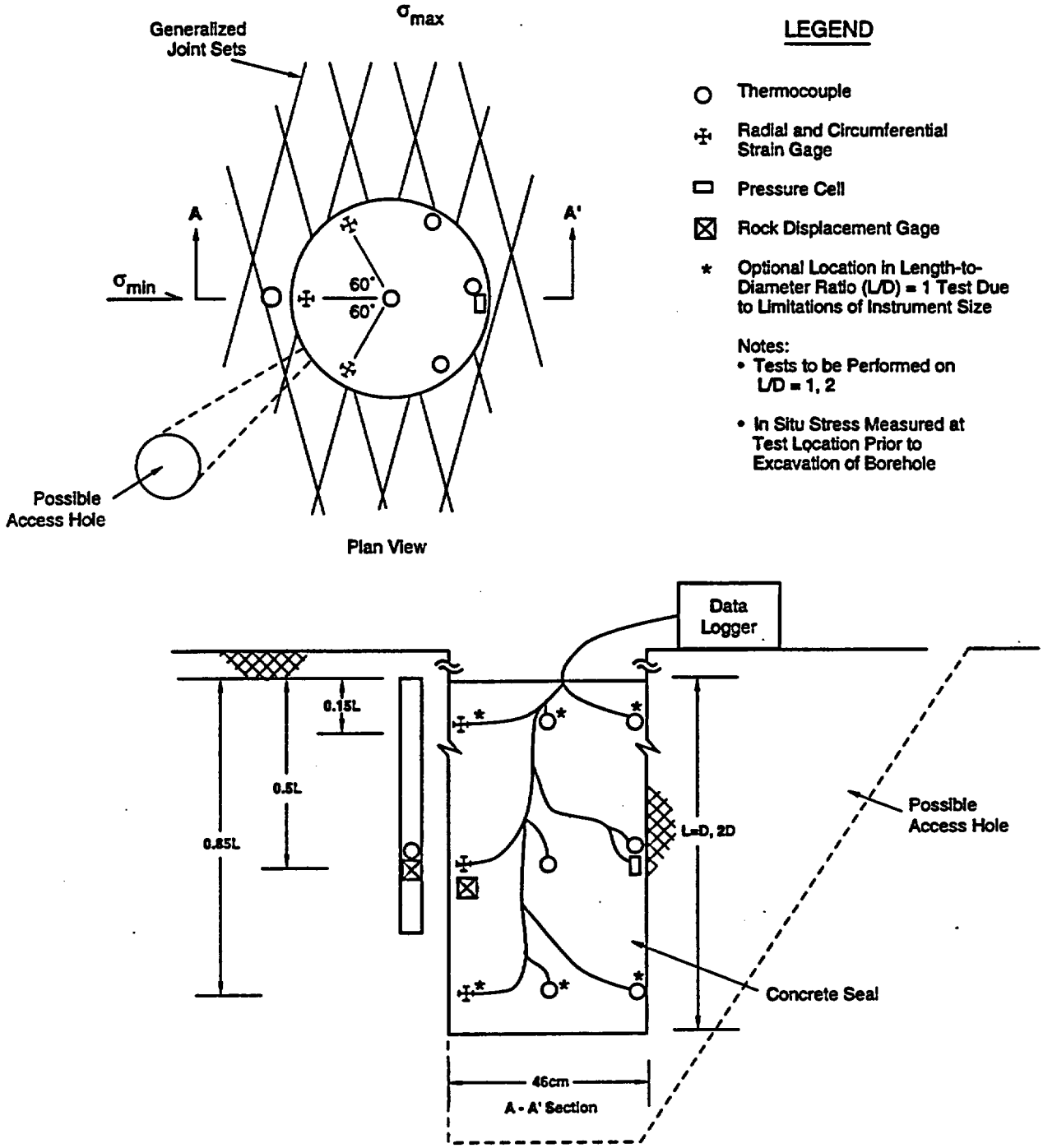


Figure 2-1. Small-Scale In Situ Test (46 cm)—Welded (after Fernandez et al., 1993)

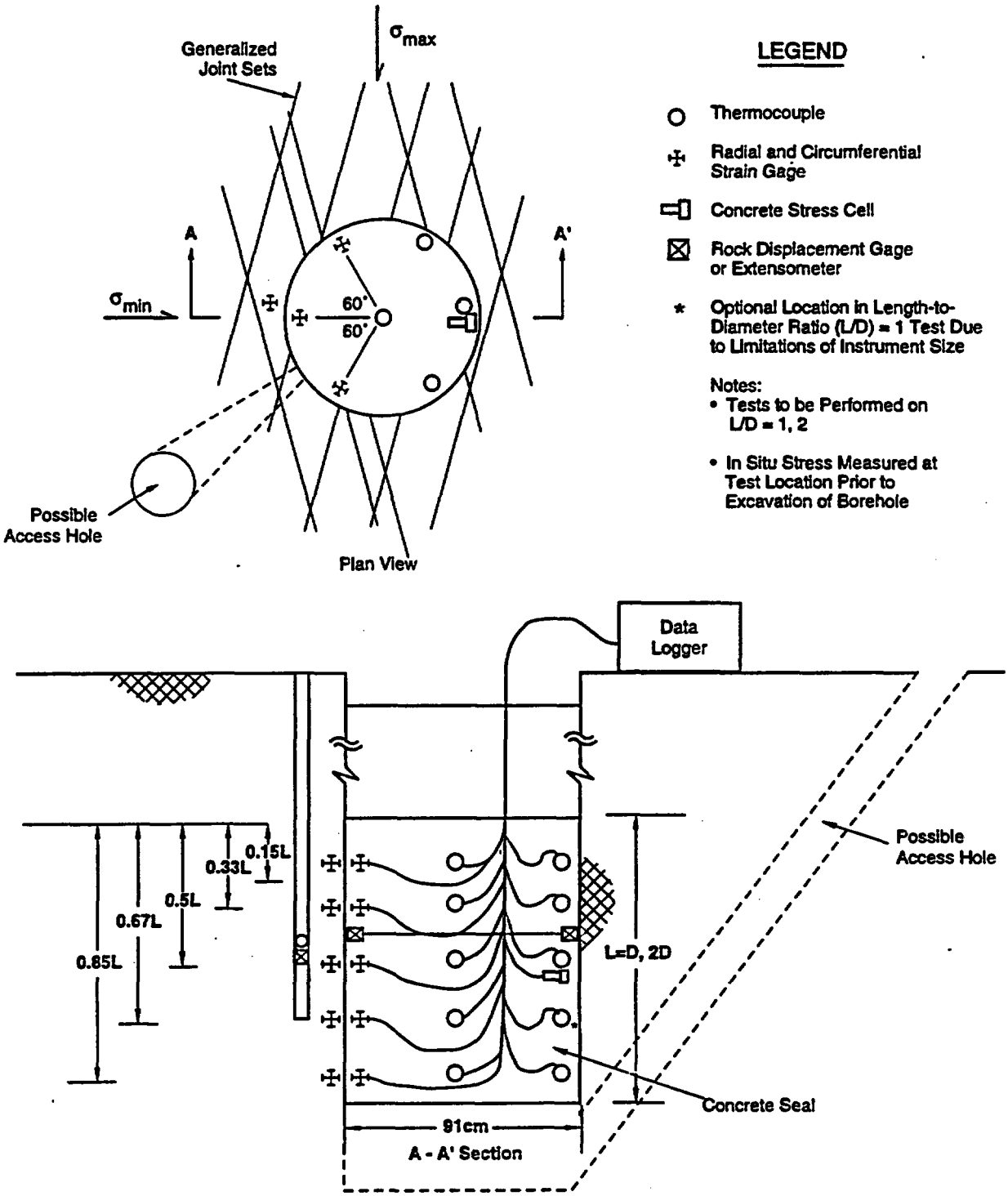


Figure 2-2. Small-Scale In Situ Test (91 cm)—Welded (after Fernandez et al., 1993)

The various sized seals will provide information on the effects of scale on the thermomechanical and hydrologic behavior of the emplaced selas. The larger plugs have a lower surface area to volume ratio; therefore, hydration temperatures are expected to exceed those of the smaller-diameter plug tests. This "scaling" information is necessary for evaluations of the performance of the full-scale shaft-and-ramp plug emplacements.

Seal emplacement may require injection pressure, primarily for treatment of fractures intersecting the boreholes, and possibly for grouting the interface between the emplaced seal and the surrounding rock. A safe injection pressure is a pressure that develops radial interface stress along the periphery of the seal but does not adversely affect the surrounding rock. Therefore, information regarding the in situ stress at the seal test locations is necessary to define safe injection pressures. The plug can then be placed using standard methods.

After the initial testing of the small-scale seals, accelerated thermal testing and/or dynamic testing can be conducted to collect information to support evaluations of the long-term performance of seal systems. The emplaced seals could be periodically tested over time to evaluate changes in performance due to geochemical changes or dynamic mechanical weakening of the seal/rock
interface. Also, some smaller seals could be emplaced purely for periodic removal to evaluate geochemistry changes in the seal/rock interface.

2.2.1.1.2 Key Parameters

The parameters to be measured during the small-scale in situ seal tests include the following:

- Mechanical/Structural Measurements
  - Test-induced stress measurements (changes) in the seal material and the surrounding rock
  - Thermomechanical behavior (stress/strain) of the seal and surrounding rock
- Thermal Measurements
  - Concrete temperatures
- Rock Temperatures.
  - Hydrologic Measurements
- Physical Properties of Seal Materials:
  - Porosity
  - Density in the hardened state
  - Cement particle size
  - In situ air and liquid permeability
  - As-built material properties
  - Setting time
  - Workability
  - Density
  - Viscosity

  - Temperature
- Strength Properties of Seal Materials:
  - Unconfined compressive strength
  - Poisson's ratio
  - Triaxial compressive strength
  - Modulus
- Seal Material Chemical Characteristics:
  - Mineralogy
  - Bulk chemistry of the constituents
  - Resistance to dissolutioning
  - Geochemical changes
- Rock Properties:
  - Air permeability
  - Fracture characteristics
  - Mineralogy/petrology/bulk chemistry
  - Chemical changes
  - Water chemistry

2.2.1.1.3 Methods to be Used

Mechanical measurements will be made for the 0.30-m, 0.46-m, and 0.91-m diameter seals. Mechanical measurements are not planned for the 0.10-m diameter seals because of the small size and potential difficulty of instrumenting and cabling the emplacements. Measurements in the 0.30-m- to 0.46-m-diameter tests are restricted primarily to the cementitious seal materials, because of the limiting size of the borehole. Instruments and cable routing will intentionally be limited so that their effect on the seal-material response is minimized. In the 0.91-m-diameter tests, the number of instrumented seal cross sections can be increased, and the rock mass surrounding the boreholes can also be instrumented.

Anticipated instrument/gage locations for the instrumented seals are shown in Figures 2-1 and 2-2. The 0.30-m- and 0.46-m-diameter tests will have instruments at depths of 15, 50, and 85 percent of the sealed length. The 0.91-m-diameter tests will be instrumented at additional depths of 33 and 67 percent of the sealed length. These intervals identify the locations of thermocouples, pressure cells, strain gages, and displacement gages. The larger-diameter tests will also have instrumentation installed along the interface between the seal and the host rock.

The temperatures expected for these small-scale in situ tests from the hydration of the cements are on the order of 22 (ambient rock temperature) to 50°C. Thermocouple locations are shown on Figures 2-1 and 2-2. Sensors with a range of 0° to 100°C are expected to be sufficient for thermal measurements for both the ambient and thermally perturbed testing.

Stresses will develop in the concrete as a result of the temperature changes associated with the cement hydration and setting of the concrete, as well as thermal expansion of the surrounding rock mass due to external heating. The 0.30-m- and the 0.46-m-diameter small-scale seal tests will be configured with an embedded pressure cell near the seal/rock interface to evaluate the changes in radial stress that are expected to occur during curing (Figure 2-1). The size of the pressure cell will be minimized to limit the effect of the instrumentation on the measured stress changes. The larger-diameter small-scale in situ seal tests will be configured with a stress cell embedded in the seal at midheight and located near the seal/rock interface (Figure 2-2). The stress cell selected will be designed to measure stresses independent of the changes in modulus of the concrete that are expected to occur as the concrete hardens. The stress cell will be placed at the seal/rock interface prior to seal emplacement.

Displacement gages will be installed in the host rock in boreholes that parallel the emplacement hole (see Figures 2-1 and 2-2). These displacement gages will measure host-rock displacement as a result of the emplacement pressures (if any) and the result of seal expansion on the host rock.

Radial and circumferential strains will be measured in the cementitious seals of the 0.30-m- and 0.46-m-diameter emplacements and in both the seal and borehole surface in the 0.91-m-diameter emplacements (Figures 2-1 and 2-2). It is anticipated that these strains will be measured with encapsulated gages embedded in the seal, and the rock surface strains will be measured using bonded surface gages.

Early-time concrete-strain data will be difficult to interpret, because the concrete is changing from a viscous liquid to a solid, and material properties will be changing rapidly during this time period (Stormont, 1987). Detailed laboratory testing of the cementitious materials used in these tests will be required for in situ data interpretation. A brief description of the lab test parameters of interest is presented in Section 2.2.1.2.5.3 of this study plan.

For the hydrologic testing of the uninstrumented 0.10-m, 0.30-m, 0.46-m, and 0.91-m diameter seals, the methods include fluid-flow testing with downhole straddle packer assemblies using air and water as the permeating fluids, and simple constant head or falling head borehole tests. These injections can be performed through the angled access borehole underneath the emplaced seal (primarily for the larger diameter seals) or above the seal using straddle-packer assemblies.

Three types of in situ flow tests may be used to measure the hydrologic behavior of the seal systems: constant-pressure flow tests (steady-state flow), shut-in or pressure decay tests, and tracer tests. These tests can be conducted using either gas or liquid as the permeating fluid. Constant-pressure flow tests measure the flow rate required to maintain a desired pressure in the test interval. Permeability values are then calculated from the measured flow and downhole pressure data. Temperatures are measured so that thermodynamic effects can be identified and considered when required.

Shut-in tests are used when flow rates are expected to be low. The tests consist of a test interval pressurized to a desired shut-in pressure. The subsequent pressure decay is measured with time. As in the constant-pressure tests, the temperature is measured to account for thermodynamic effects. The permeability is calculated from the measured pressure drop.

Tracer tests may be performed as a means of identifying potential leak paths through the seal system (Fernandez et al., 1993). The tracer arrival history can be used to infer the nature of the potential flow paths.

The fractured nature of the welded tuffs and attendant high permeability or hydraulic conductivity (10^{-3} cm/s) suggest that steady-state flow assumptions will be valid during the characterization portions of the tests. After grouting and placement of the seals, pressure decay tests may be necessary to evaluate the flow.

Pressure transducers, tensiometers, and flowmeters can be used to measure pressure changes and flows during the hydrologic and pneumatic testing. Various tracers are available for use in tracer testing, if performed. Dyes can be injected near the end of the testing sequence as an aid in identifying flow paths. These tracers can be injected into the region under the seal through inclined boreholes and are monitored from above to determine whether flow occurs through the formation or through the seal or seal/rock interface.

2.2.1.1.4 Representativeness of Tests

The small-scale in situ seal tests are intended to evaluate the mechanical/structural response of cementitious sealing materials and the surrounding host rock to seal emplacement. The mechanical/structural response is important, because a critical component to seal performance is the interface between the seal and the host rock. Seals constructed in boreholes, shafts, and ramps will be designed to minimize shrinkage of the seal material and to control temperature so that this interface does not become a preferential pathway for fluid flow, thereby bypassing the seal. These tests at reduced scale are necessary first-steps at evaluating the ability to emplace these seals at full-scale. Also, these tests are conducted at a scale appropriate for exploratory boreholes at Yucca Mountain. The 0.30-m-diameter emplacements used to evaluate the mechanical response of the seal and host rock will be duplicated in the intermediate and remote borehole sealing tests in which hydrologic performance will be measured. This comparison is necessary in extrapolating the measured mechanical response to the real measure of seal performance, fluid flow.

2.2.1.1.5 Constraints
2.2.1.1.5.1 Testing Impacts on the Site

The nature of the small-scale in situ seal tests requires that they be conducted in a portion of a dedicated alcove in the welded and nonwelded tuffs penetrated by the ESF off the repository blocks. The volume of cement will be minimized. The recommended seal materials will be evaluated for their potential impact on the site prior to conducting these experiments. General utilities services will be required for testing, as will drilling and mine operations support.

2.2.1.1.5.2 The Need to Simulate Repository Conditions

Repository conditions will be simulated in these tests. The first tests are expected to be conducted at ambient temperature; therefore, the placement of seals will be generally away from regions of elevated temperatures. Additional testing at slightly elevated temperatures may be required after completion of the ambient temperature testing in order to simulate repository conditions after waste emplacement. An array of heaters would be designed and installed to simulate elevated temperature.

2.2.1.1.5.3 Laboratory versus Field-Scale Testing

The in situ testing described in this study plan is intended to evaluate sealing materials, designs, and techniques under realistic in situ conditions prior to full-scale or actual emplacements at Yucca Mountain. These smaller-scale tests realistically simulate the scale of exploratory boreholes at Yucca Mountain, which range in size from 0.076 m to 1.22 m in diameter. Laboratory testing, however necessary, is insufficient to support these goals because the laboratory tests cannot simulate the behavior of fractures and the interface zone on a large enough scale. Laboratory testing of cementitious sealing materials for plugs and grouts is still required to define the thermomechanical, thermohydrologic, and geochemical properties of the sealing materials; consequently, laboratory testing of cementitious materials will continue concurrently with the in situ testing program under SCP study 8.3.3.2.2.1 "Seal Material Properties Development."

The cementitious materials proposed for use in the in situ tests are described in section 2.2.1 and elsewhere (Fernandez et al., 1994). Several different cementitious materials for seals are proposed for different environments. The laboratory properties necessary for successful in situ emplacements include the following:

- Fluid Properties:
  - Setting time
  - Workability
  - Density
  - Viscosity
- Physical Properties:

  - Porosity
  - Density in the hardened state
  - Cement particle size
- Mechanical Properties:
  - Unconfined compressive strength
  - Poisson's ratio
  - Triaxial compressive strength
  - Modulus
- Chemical Characteristics:
  - Mineralogy
  - Bulk chemistry of the constituents
  - Resistance to dissolutioning.
- Geochemical Effects
- Hydrothermal Effects
- Biologic Effects

In addition, the effects of wet and dry curing and curing time on properties will also be evaluated.

2.2.1.1.5.4 Test-to-Test Interference

The in situ sealing tests described in this study plan will be conducted in dedicated alcoves within the ESF facility. It will be necessary to minimize interference from both heater tests and fluid injection tests that may be conducted in the facility; consequently, careful coordination with the Los Alamos National Laboratory (LANL) Test Coordination Office (TCO) will be required to assure that test-to-test interference is kept to a minimum. The locations for these in situ sealing tests will be away from other testing locations. Test interference analyses will be performed prior to initiating the experiments described in this study plan.

2.2.1.1.5.5 Construction-to-Test Interference

The tests described in this study plan are intended to be conducted in alcoves or other dedicated testing locations away from the traffic of construction activities. The tests will not begin until the major construction activities have been completed around the proposed test locations in the facility. Additional construction or operational interference within the alcoves should be minimized during conduct of the tests. The test construction and operations are on a small scale and should not impact other construction activities. Large-diameter drilling equipment (up to 0.91 m in diameter) will be required for drilling seal test emplacement holes. This equipment may require additional overhead room for operation than standard drilling equipment commonly used.

2.2.1.1.5.6 Alternative Methods

There are no known alternatives for evaluating the mechanical response of seals on a reasonable scale. Some supporting work in the laboratory is necessary to assist in describing specific material properties; however, seal-system performance is largely dependent on the material behavior at the interface, which can only be evaluated in situ for the scales of interest.

2.2.1.2 Remote Borehole Seal Tests

Remote borehole seal tests will provide information on the technology for remotely emplacing seals in exploratory boreholes and the techniques for remotely evaluating the performance of emplaced seals. These tests will be conducted in the same locations as the small-scale in situ tests described in Section 2.2.1 above and also in selected boreholes outside the ESF and the potential repository block in the vicinity of Yucca Mountain. Two sizes of boreholes will be tested one 0.10 m and one 0.3 m in diameter. The small diameter was selected because of the ease of fielding that scale along with compatibility with existing field equipment for measuring flow through seals.

Both air and liquid permeability tests will be conducted on the remote borehole sealing tests. The air permeability will generally be used for pre-test characterization of the surrounding formation prior to emplacement of the seals. Liquid permeability tests will be conducted after completion of the seal emplacements. The flow test data from these tests will be correlated with the mechanical/structural and hydrologic results from the small-scale in situ seal tests as a means of quantifying the relative effects of casing removal and borehole wall treatments on emplaced seal permeability. In addition, techniques for measuring seal performance remotely will be evaluated. The results of these practical evaluations will serve to provide information for actual borehole seal emplacement designs.

2.2.1.2.1 General Approach

The remote borehole sealing test will follow the same general sequence as in the small-scale seal tests but will be performed at depth (Figure 2-3). For emplacement of a deep seal, the casing will be removed at the seal location, and the borehole walls will be conditioned. Portions of the casing could be initially removed and the hole would be backfilled. After identifying the selected sealing location in the welded or nonwelded tuff through video logging, a seal would be emplaced using low-pressure injection methods.

The casing could be removed using several methods. At the base of the casing, where the casing is cemented to the formation, rotary shoes could cut the cement or earthen material (Fernandez, et al., 1993). Subsequently, the casing could be removed using outside mechanical cutters, inside hydraulic or mechanical casing cutters, chemical cutters, or jet casing cutters. Evaluation of the

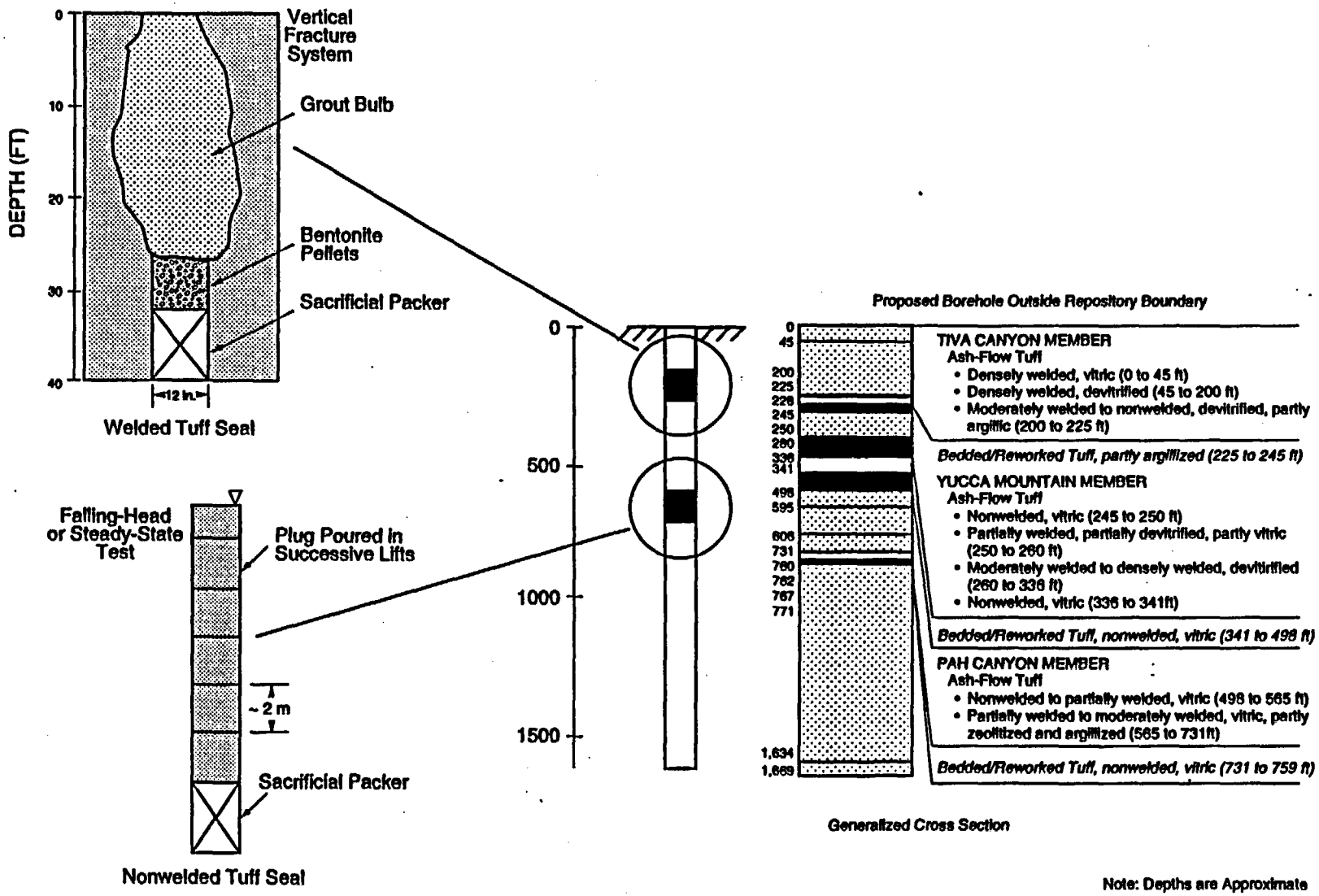


Figure 2-3. Remote Borehole Sealing Test (after Fernandez et al., 1993)

efficacy of casing removal will be performed. Contingency plans for casing removal and borehole wall treatment will be developed based on the results of these tests. For actual borehole seal emplacements, alternative plans for unexpected conditions such as the inability to remove sections of casing may be required.

A test in the seal zone would be performed to find a safe injection pressure that would develop radial interface stress along the periphery of the seal without degrading the surrounding formation. An alternative method of emplacement would be the dump bailer, which would tag the mechanical packer or seal and raise above it. This bailer opens by detonating a charge that shatters a glass dish to release material at the seal location. After completion of the seal in several lifts, the flow would be tested, the measured parameters being the flow rate and the hydraulic potential.

2.2.1.2.2 Key Parameters

The parameters to be measured in the remote borehole seal tests will focus primarily of the seal-system permeability and seal-construction information. Parameters measured/information obtained include:

- Seal properties:
  - In situ air and liquid permeability
  - As-built material properties
  - Setting time
  - Workability
  - Density
  - Viscosity
  - Temperature
- Physical Properties:
  - Porosity
  - Density in the hardened state
  - Cement particle size
- Strength Properties:
  - Unconfined compressive strength
  - Poisson's ratio
  - Triaxial compressive strength
  - Modulus
- Chemical Characteristics:
  - Mineralogy
  - Bulk chemistry of the constituents
  - Resistance to dissolutioning
  - Long-term geochemical changes
- Water chemistry

- Rock Properties:
  - Air permeability
  - Fracture characteristics
  - Mineralogy/petrology/bulk chemistry

2.2.1.2.3 Methods to be Used

Methods to be used in the conduct of the remote borehole sealing tests are restricted to fluid-flow testing with downhole straddle packer assemblies using air and water as the permeating fluids. Also, well completion and modification techniques used for removal of casing and borehole wall treatment can be used for the remote borehole testing. These techniques are described in greater detail in Fernandez and Richardson (1994).

Three types of in situ flow tests may be used to measure the hydrologic behavior of the seal systems in the remote borehole sealing tests: constant-pressure flow tests (steady-state flow), shut-in or pressure decay tests, and tracer tests. These tests can be conducted using either gas or liquid as the permeating fluid. Constant-pressure flow tests measure the flow rate required to maintain a desired pressure in the test interval. Permeability values are then calculated from the measured flow and downhole pressure data. Temperatures are measured.so that thermodynamic effects can be identified and considered when required.

Shut-in tests are used when flow rates are expected to be low. The tests consist of a test interval pressurized to a desired shut-in pressure. The subsequent pressure decay is measured with time. As in the constant-pressure tests, the temperature is measured to account for thermodynamic effects. The permeability is calculated from the measured pressure drop.

Tracer tests may be performed as a means of identifying potential leak paths through the seal system (Fernandez et al., 1993). The tracer arrival history can be used to infer the nature of the potential flow paths.

The fractured nature of the welded tuffs and attendant high permeability or hydraulic conductivity (10^{-3} cm/s) suggest that steady-state flow assumptions may be valid during the characterization portions of the tests. After grouting and placement of the seals, pressure decay tests may be necessary to evaluate the flow.

Pressure transducers, tensiometers, and flowmeters will be used to measure pressure changes and flows during the hydrologic and pneumatic testing. Various tracers are available for use in tracer testing, if performed. Dyes can be injected near the end of the testing sequence as an aid in identifying flow paths. These tracers can be injected into the region under the seal through

inclined boreholes and are monitored from above to determine if flow occurs through the formation or through the seal or seal/rock interface.

2.2.1.2.4 Representativeness of Tests

The hydrologic behavior of emplaced seal systems under realistic in situ conditions is the real measure of seal-system performance. The remote borehole seal tests are intended to evaluate this behavior. Seals constructed in boreholes, shafts, and ramps will be designed to minimize flow of water and, perhaps, air flow into and out of the repository. These tests at reduced scale are necessary first-steps at evaluating the ability to emplace these seals at full-scale. Also, these tests are conducted at a scale appropriate to necessary seals for exploratory boreholes at Yucca Mountain. The 0.30-m-diameter emplacements used to evaluate the hydrologic behavior of the seal system duplicate in size the mechanical/structural tests conducted under the small-scale in situ tests discussed in Section 2.2.1.1. This comparison is necessary in extrapolating the measured mechanical response to fluid flow.

2.2.1.2.5 Constraints
2.2.1.2.5.1 Testing Impacts on the Site

The nature of the remote borehole seal tests requires that the tests be conducted in a portion of a dedicated alcove in the welded and nonwelded tuffs penetrated by the ESF and in dedicated surface boreholes outside the ESF. The volume of cements and clays will be minimized. The recommended seal materials will be evaluated for their potential impact on the site prior to conducting these experiments. General utilities services will be required for testing, as well as for drilling and mine operations support.

2.2.1.2.5.2 The Need to Simulate Repository Conditions

The remote borehole seal tests are configured to simulate repository conditions. The placement of seals in boreholes will be generally away from regions of elevated temperatures. In addition, actual borehole seals will be emplaced, and their performance will be evaluated using remote borehole technologies. Therefore, these first tests are expected to be conducted at ambient temperature in a remote configuration, but near enough to the drift or surface so that post-test evaluations can be reasonably completed. Additional testing at slightly elevated temperatures may be required after completion of the ambient temperature testing in order to simulate repository conditions after waste is emplaced. Heat can be applied through line heaters emplaced in boreholes around the test area. The techniques and equipment developed and evaluated during this testing will ultimately be used to seal deep boreholes at Yucca Mountain. Long-term simulations including accelerated tests and analyses may be required to demonstrate adequate long-term performance.

2.2.1.2.5.3 Laboratory versus Field-Scale Tests

The remote borehole seal tests described in this study plan are intended to evaluate sealing materials, designs, and techniques under realistic in situ conditions prior to actual borehole seal emplacements at Yucca Mountain. The in situ tests realistically simulate the sealing of exploratory boreholes at Yucca Mountain, which range in diameter from 0.076 m to 1.22 m. However, laboratory testing of cementitious sealing materials for plugs and grouts is still needed to define material specifications; consequently, laboratory testing of cementitious materials and perhaps clays will continue concurrently with the in situ testing program. These tests are conducted under SCP study 8.3.3.2.2.1 "Seal Material Properties Development."

The cementitious materials proposed for the in situ tests contain cement, reactive silica, nonreactive silica, superplasticizer, defoamer, and water. Several different cementitious materials for seals are proposed for different geochemical environments. The laboratory properties necessary for successful in situ emplacements include:

- Fluid Properties:
  - Setting time
  - Workability
  - Density
  - Viscosity
- Physical Properties:
  - Porosity
  - Density in the hardened state
  - Cement particle size
- Strength Properties:
  - Unconfined compressive strength
  - Poisson's ratio
  - Triaxial compressive strength
  - Modulus
- Chemical Characteristics:
  - Mineralogy
  - Bulk chemistry of the constituents
  - Resistance to dissolutioning
- Geochemical Effects
- Hydrothermal Effects
- Biologic Effects

In addition, the effects of wet and dry curing and curing time on properties will also be evaluated.

The mechanical stability and migration potential of clay sealing materials along with the effects of wetting and drying cycles must be evaluated in the laboratory. Also, the effects of varying clay emplaced density on swelling potential should be evaluated.

2.2.1.2.5.4 Test-to-Test Interference

The remote borehole sealing tests described in this study plan will be conducted in dedicated alcoves within the ESF facility and in dedicated boreholes outside the ESF. It will be necessary to minimize interference from both heater tests and fluid injection tests that may be conducted in the facility or near the surface boreholes; consequently, careful coordination with the LANL TCO will be required to assure that test-to-test interference is kept to a minimum. The locations for these in situ sealing tests will be away from other testing locations. Test interference analyses will be performed prior to initiating the experiments described in this study plan.

2.2.1.2.5.5 Construction-to-Test Interference

The tests described in this study plan are intended to be conducted in alcoves or other surface testing locations away from the traffic of construction activities. Also, these tests will not begin until the major construction activities have been completed in the facility around the proposed test locations. Additional construction or operational interference within the alcoves or at the surface locations should be minimized during conduct of the tests. The test construction and operations are of a small scale and should not impact other construction activities. Drilling equipment will be required for drilling seal test emplacement holes in both the underground and at the surface locations. Overcoring bits may also be required.

2.2.1.2.5.6 Alternative Methods

There are no known alternatives for evaluating the hydrologic response of seals and evaluate the necessary equipment on a reasonable scale. Some supporting work in the laboratory is necessary to assist in describing specific material properties. However, seal system performance depends on the material behavior at the interface, which can only be evaluated in situ for the scales of interest, and on post-emplacement long-term alteration of the materials within and adjacent to the seal.

2.2.2 Grouting Tests

Fracture-grouting is an integral part of the overall sealing strategy. Grouting may be performed as a remediation technique to seal around dams or plugs, to minimize potential water inflow along faults or fracture systems, and to pretreat and seal around borehole plugs. The performance of selected cement grouts to act as sealing materials must be demonstrated in realistic in situ tests prior to actual application in the repository. Unlike borehole, ramp, or shaft seals, grouting may

be necessary in regions expected to experience significant heat from the decay of radioactive waste. Therefore, some testing at elevated temperature is required to evaluate the thermal performance of grouts.

It is expected that fracture grouting may be a required seal component at various locations throughout the underground facility at Yucca Mountain. It is also expected that the nature of the rock fractures will vary with location throughout the facility. The relative orientations of fractures with respect to the underground openings will also vary, because the underground excavations are designed with different bearings. It is anticipated that several tests with boreholes inclined at several angles to the fractures would be required. The nature of the fractures include:

- Spacing, extent, and orientation of the fractures
- Rock strength
- Rock stress (in situ and disturbed)
- Homogeneity and anisotropy of fracturing
- Aperture
- Roughness
- Flow path tortuosity.

Grouts may be injected into fractures in the rock surrounding the boreholes and the underground openings that must be sealed. The general objectives in fracture-grouting include emplacing the grout to achieve a reduction in fluid flow and/or to achieve a strengthening of the rock mass. To assure that the grout maintains acceptable strength, deformability, and permeability, the grout should be resistant to physical and chemical deterioration. Therefore, cementitious mixtures have been developed that are expected to remain stable in the geochemical environment at Yucca Mountain (Licastro, et al., 1990; Fernandez et al., 1994). Also, certain clays, particularly those of the smectite group (e.g., montmorillonite), are found as alteration products at Yucca Mountain (Bish, 1988) and are expected to be relatively stable geochemically. Completely filling the fracture reduces the potential for dissolution of the grout as water enters between the grout and fracture wall. A high-strength grout will strengthen the rock mass and will result in a greater resistance to deformation, fracture, and failure. A dense mixture may also be effective in resisting chemical deterioration, due to its lower porosity and permeability. Clay grouts could have the opposite effect on rock mass strength and deformability resulting in weaker, more deformable rock.

Two types of grouts are under consideration for sealing fractures for the Yucca Mountain repository: clays and cement grouts. Clays generally have a higher self-healing ability than cement-based grouts and are less likely to be damaged by rock mass movements via dynamic or thermally induced deformations; however, they may be more susceptible to erosion and may have a lower strength than cements. Clays can also exhibit the beneficial characteristic of swelling in the presence of water. Some recent research has been completed on bentonite (montmorillonite)

grouts (Pusch and Borgesson, 1989; Ran and Daemen, 1991). Unlike the smectite clays, the cementitious materials are not native to the volcanic tuffs of Yucca Mountain. The SNL/NM YMP sealing program has developed cementitious materials that are similar in bulk chemistry to the tuffs and contain enough reactive silica to react with the calcium hydroxide to form a more stable calcium-silica-hydrate (C-S-H) (Licastro et al., 1990; Fernandez et al., 1994). Laboratory analyses show that the C-S-H mineral phases (such as tobermorite) are more stable than other expansive phases, such as ettringite at an elevated temperature. Therefore all cementitious grouts are designed to include enough reactive silica to form C-S-H mineral assemblages. Preliminary fracture grouting cement mixtures were presented in section 2.2.1. Tables 2-3 and 2-4 show preliminary cement grout mixtures proposed for this testing. Table 2-3 lists preliminary grout mixtures for larger fractures and Table 2-4 lists preliminary microfine cement grout mixtures for fine fractures.

A final consideration for fracture-grouting is the aperture of the fractures to be grouted. Cementitious and clay grouts are particulate grouts that can block the flow of the grout into the fractures, resulting in poor penetration. For fine fractures with apertures of 10 to 100 μm, a microfine cement is recommended (Fernandez et al., 1989). For fracture apertures from 100 μm to 1 mm, a lower-water-content microfine cement is recommended. For fracture apertures between 1 mm and 1 cm, a neat portland cement grout is recommended. For fractures with apertures larger than 1 cm, the addition of silica sand and bentonite to the grout is recommended. More complete descriptions of the recommended cement grouts are presented in Licastro et al. (1990) and Fernandez et al. (1994).

Two different phases of in situ tests are recommended for evaluation of the effectiveness of fracture-grouting. The first phase will be performed under ambient temperature conditions in single and multiple boreholes in fractured welded tuff (Tiva Canyon and Topopah Springs Members) and possibly in the nonwelded tuff. The second phase will include elevated temperatures along with measurements of stress change. Both phases will include geophysical and hydrologic or pneumatic characterization before, during, and after grout injection along with post-test characterization of the grout penetration. Acoustic emission techniques can be employed to evaluate grout penetration during grout injection. Samples of the grouted fractures will be removed through coring to evaluate the grouting's effectiveness.

2.2.2.1 Fracture-Grouting Test

The first phase of grouting tests will be conducted at ambient temperatures and will help to define the penetrability and continuity of various grouts injected into fractured rock for future sealing applications. These tests will assist the evaluations of the performance of seals emplaced in boreholes for the intermediate and remote borehole sealing tests described in Section 2.2.1.2 of this study plan. These tests will also assist in grout design through proper selection of grout materials and properties for specific fracturing applications and design of grout injection hole patterns and injection parameters.

Ambient fracture-grouting tests will be initially conducted in single and multiple boreholes drilled at various orientations in selected alcoves in the underground facility. Single-hole tests will be conducted first, and the results will be used to refine the design of multiple-hole tests. Various orientations are suggested because such grouting may be required for actual seal emplacements. Heated-grout testing will be conducted after the completion of ambient testing and the development of an understanding of the ambient performance of the various grouts is obtained. Tests can be evaluated over longer time periods or by accelerated thermal/hydrothermal testing.

2.2.2.1.1 General Approach

An understanding of the geology and hydrology of the rock mass is essential to interpret the effectiveness of any grouting operation. Permeability testing will be conducted prior to any grout injections. Standard practice in the civil construction industry is to use water injection tests (Lugeon tests) to characterize the permeability of the formation. However, the Yucca Mountain site is located in the unsaturated zone, and the use of water for testing should be kept to a minimum. Limited volume liquid permeability or air permeability techniques will be used and, if possible, correlation between the two techniques established.

The sequencing of activities for each test shall be similar, as follows:

- Dry-drill grout injection hole(s).
- Conduct geophysical logging, visual inspection, and permeability characterization of each borehole.
- Perform interval grouting in ascending stages, noting injected volumes, injection pressures, grout characteristics. Acoustic Emission (AE) signatures, sample collection for laboratory, and field quality control (QC) tests.
- Swab injection holes and conduct geophysical, visual inspection, and permeability testing.
- Evaluate grout-penetration distances via core drilling.
- Conduct secondary grout injection(s).
- Conduct post-test characterizations using geophysics, permeability testing and sampling.

The first phase of testing will consider a single borehole and a pair of boreholes to simplify the flow paths for grout movement within the fractures. A grout will be selected with specific properties (viscosity, grout setup time, etc.) to penetrate in a specific time over a certain distance for effectiveness. The grout penetration will be modeled for the single boreholes, and the modeling and analysis will be verified through field observation. As discussed previously, several borehole orientations relative to the fracture patterns will be interpreted. A double borehole system will also be modeled, analyzed, and interpreted after the single borehole tests. This information will then be used to select hole patterns for multiple-hole injection discussed subsequently in the second phase of testing if determined necessary. Multiple-hole grout

injection might involve a series of grout holes grouted in a specific sequence. Figure 2-4 shows a typical multiborehole grout-injection test layout. Actual layouts will be defined based on in situ fracture conditions encountered after excavation. Multiple-hole grout injections will be used to evaluate the ability to produce a continuous grouted barrier and will aid in developing injection hole patterns and spacings.

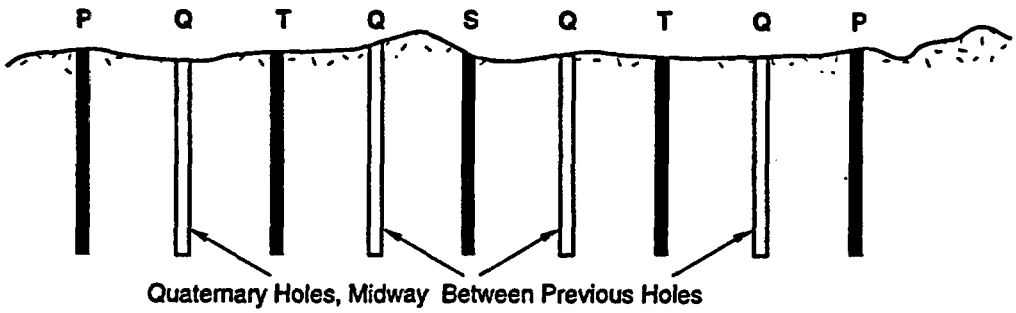
Development of detailed plans for subsequent heated tests will be performed after completion of some of the ambient temperature testing. Generalization for a heated grouting test would include similar test configurations to the ambient testing; however, heaters, temperature measurements, and stress change instrumentation will be required to evaluate the performance of the grouting subjected to a heated environment.

An extremely important aspect of the in situ testing will be supporting laboratory testing of cast grout samples and retrieved grouted fractures. Relatively undisturbed samples of grouted fractures can be obtained using bolting and overcoring techniques. Air permeability testing will be performed on a routine basis. Because of potential chemical interaction effects and the need to retard water, water may be used on selected basis.

2.2.2.1.2 Key Parameters

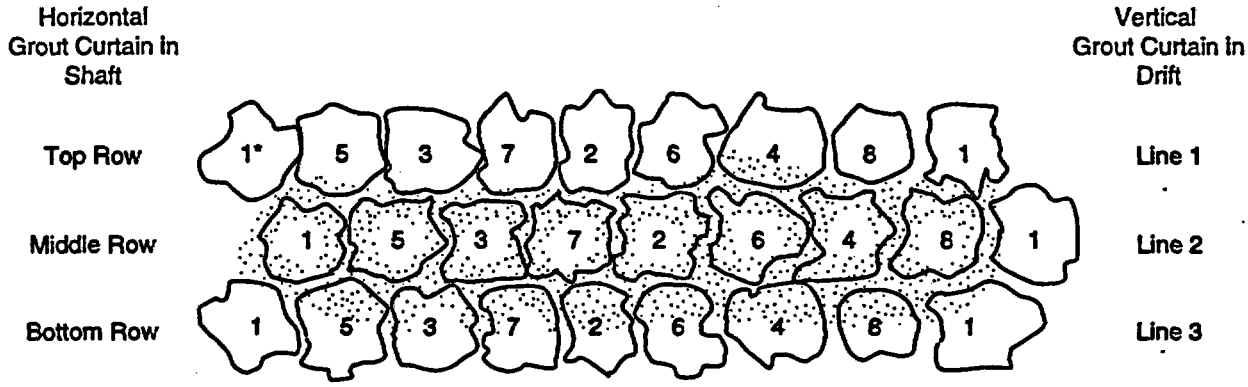
The parameters to be measured and information to be obtained during the fracture grouting tests include:

- Grout Material Properties (laboratory):
- Fluid properties
- Dynamic viscosity
- Cohesion
- Bleed
- Set time
- Density
- Porosity
- Density in hardened state
- Cement particle size
- Mechanical Properties of Grout:
  - Unconfined compressive strength
  - Poisson's ratio
  - Triaxial strength
  - Shear strength of grouted fractures
  - Young's modulus
- Hydrologic Propertie of Grouts:
  - Permeability



	Order in Grouting
P - Primary Holes	1st
S - Secondary Holes	2nd
T - Tertiary Holes	3rd
Q - Quaternary Holes	4th

(a) Single Line, Cross-sectional View



* Numbers indicate sequence within a single line of grouting

(b) Multiple-Line Grout Curtain in Shaft or Drift, Plan View

Figure 2-4. Idealized Grouting Patterns for Multi-borehole Grout Injection Layout (after Fernandez et al., 1993)

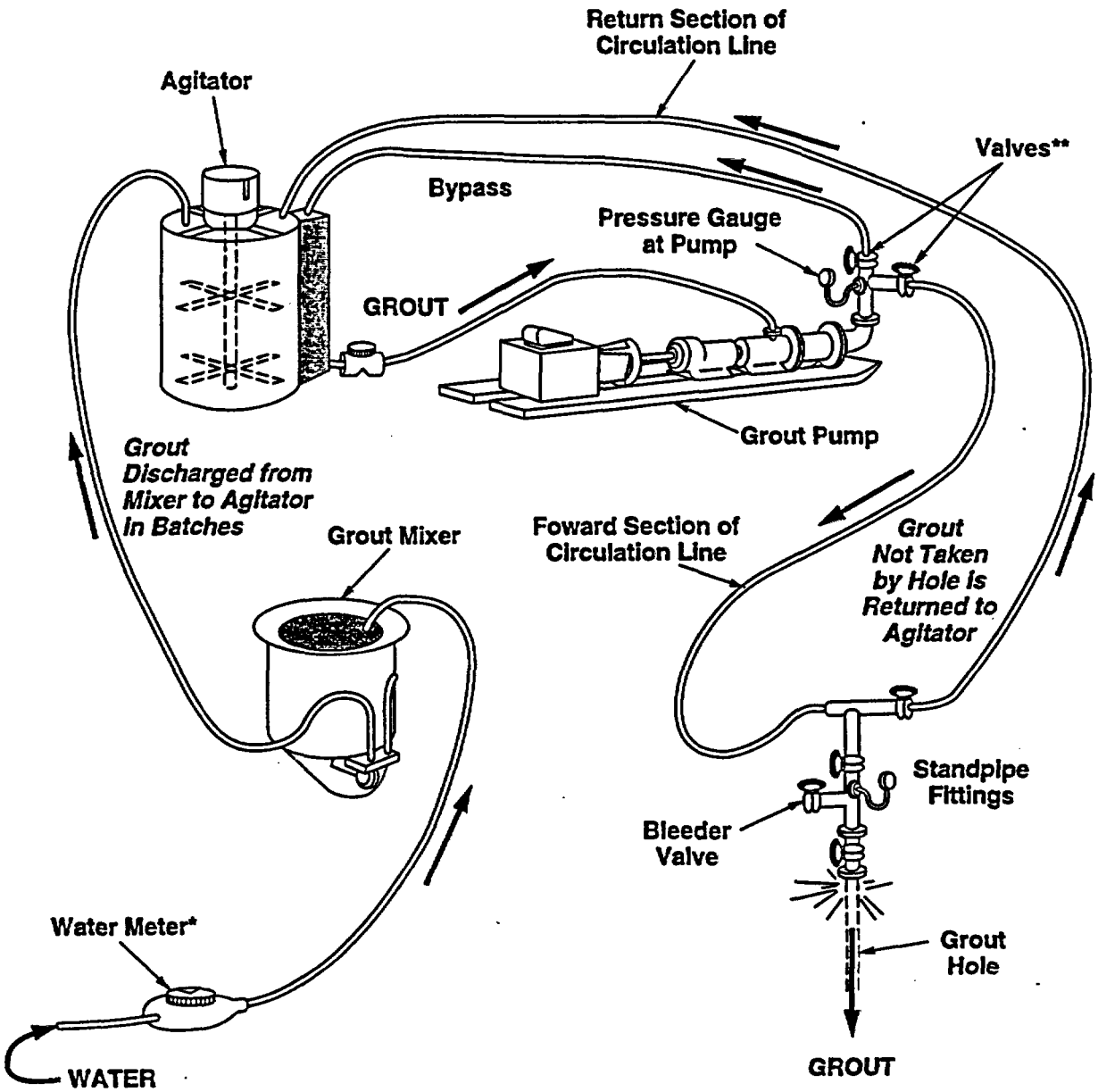
  - Saturation
- Chemical characteristics of Grout:
  - Mineralogy
  - Bulk chemistry
  - Resistance to dissolution
- Grout Injection Information (field):
  - Injection Pressures
  - Grout Penetration rates and distances
  - Grout Injection volumes
  - Grout Continuity
  - In situ rock mass permeability and permeability changes
  - Grouted rock mass durability (heated)
  - Mixing and pumping procedures.

2.2.2.1.3 Methods to be Used

Two schools of thought exist regarding injection pressures for grouting. One maintains pressures below the overburden stress to minimize injection related disturbance. The other allows for fracture opening by injecting at higher pressures. Although it is not known which approach yields better performance, it is felt that minimization of disturbance should be the preferred method to the Yucca Mountain Sealing Program initially. This is due to the potential uncertainties related to further field (away from the injection) disturbance that could accompany high injection pressures. This disturbance would likely be difficult to quantify or predict. Therefore, high injection pressures should not be attempted until lower pressure injection techniques have been evaluated.

Standard techniques for fracture-grouting used in the civil construction and mining engineering industries will be used. A standard setup for grout injection is illustrated in Figure 2-5 (Houlsby, 1990). Grout is usually injected using a static injection pressure that is defined based on the in situ stress and the extent of penetration desired. It is known that grouts will preferentially flow into the wider aperture fractures (Nonveiller, 1989); therefore, some estimates of the pre-grout apertures will be required. It will be necessary to monitor the rock movement during grouting using either downhole extensometers or cross-drift extensometers as shown in Figure 2-6 to assess grout penetration and its effect, if any, on fracture apertures. This monitoring will provide control over any changes that may have occurred to the fracture geometry during injection.

Methods to be used in the conduct of the fracture-grouting tests include fluid-flow testing with downhole straddle packer assemblies using air and water as the permeating fluids. Three types of in situ flow tests are anticipated to be used to measure the hydrologic performance of the grout injections: constant-pressure flow tests (steady-state flow), shut-in or pressure decay tests, and tracer tests. These tests can be conducted using either gas or liquid as the permeating fluid. Constant-pressure flow tests will measure the flow rate required to maintain a desired pressure in the test interval. Permeability values will then be calculated from the measured flow and



* For measuring water to the mixer
** For controlling the quantity of grout fed into the circulation line

Figure 2-5. Typical Equipment Layout for a Grouting Operation (Houlsby, 1990)

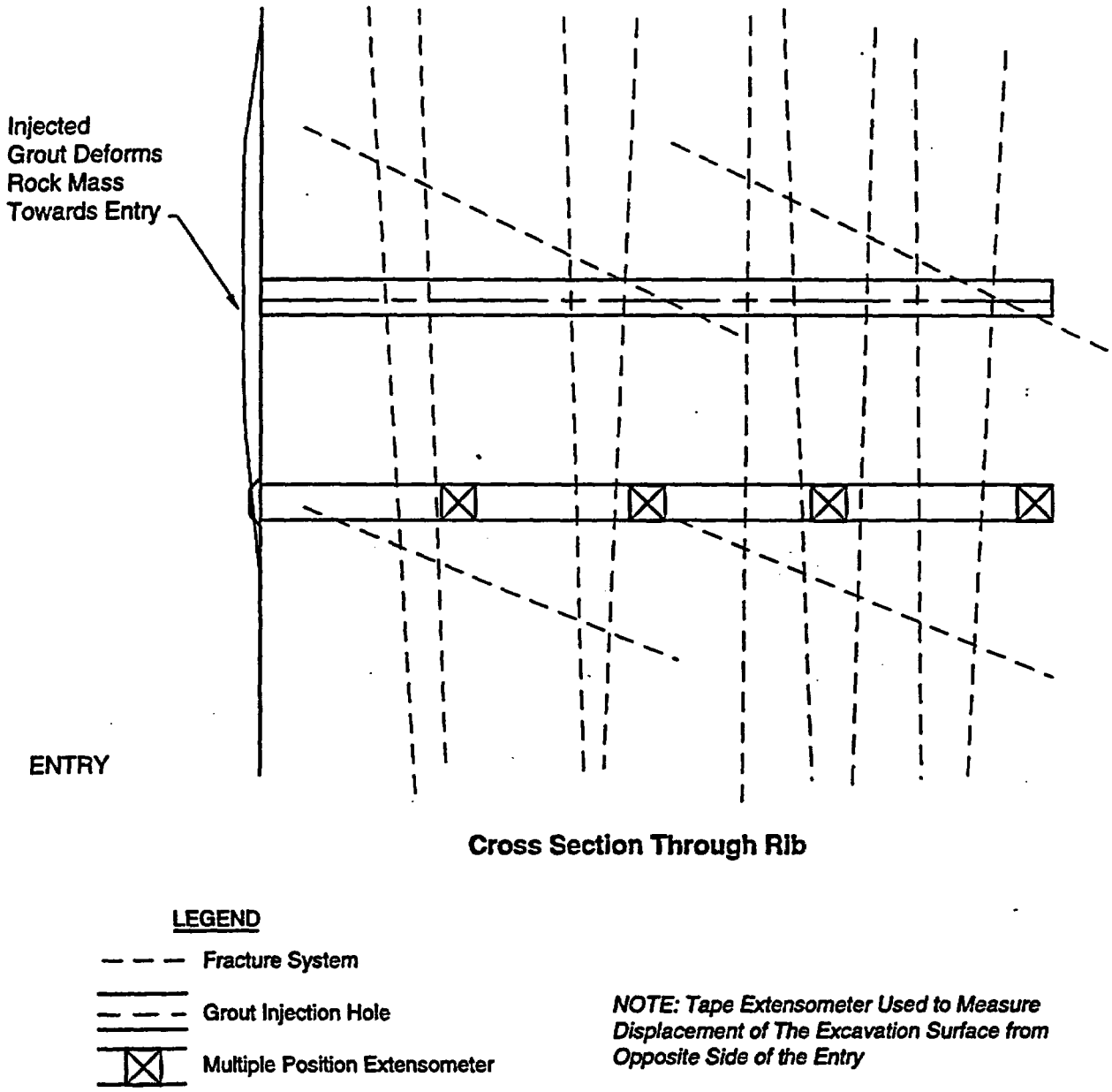


Figure 2-6. Instrumentation Layout for Monitoring Ground Displacement During Grouting

downhole pressure data. Temperatures will be measured, so that thermodynamic effects can be identified and considered when required. Shut-in tests are used when flow rates are expected to be low. The tests pressurized a test interval to a desired pressure, performing shut-in, and measuring the subsequent pressure decay with time. As in the constant pressure tests, the temperature is measured to account for thermodynamic effects. The permeability is calculated from the measured pressure drop.

Tracer tests may be performed as a means of identifying potential flow paths through the grouted rock mass. The tracer arrival history can be used to infer the nature of the potential flow paths.

The fractured nature of the welded tuffs and attendant high permeability or hydraulic conductivity (10^{-3} cm/s) suggest that steady-state flow assumptions will be valid during the pre-grouting characterization portions of the tests. After grout injection, pressure-decay tests may be necessary to evaluate the flow. Pressure transducers and flowmeters will be used to measure pressure changes and flows during the hydrologic and pneumatic testing. Various tracers are available that can be used for the tracer testing if it is performed. These tracers can be injected into the grouted region and monitored in other "receiver" boreholes to determine if and how flow occurs through the grouted formation.

Acoustic emission techniques have been used to monitor the flow of grouts in geologic materials (Huck and Koerner, 1982). This geophysical technique can be used in the fracture grouting tests as a means of identifying the depth of penetration of grouts into the fractured rock mass. Other geophysical techniques may also be used to evaluate the penetration and continuity of grouting.

Instrumentation for the heated fracture grouting tests will be identified following completion of ambient testing; however, temperatures, and stress change will be monitored.

2.2.2.1.4 Representativeness of Tests

Fracture-grouting tests are used to evaluate the hydrologic and mechanical performance of selected grouts under realistic in situ conditions. The hydrologic behavior is the real measure of seal system (including grout) performance. Seals, including grouts, constructed in boreholes, shafts, and ramps will be designed to minimize flow of water and perhaps air flow into and out of the repository. The single- and double-borehole injection tests at the field scale with limited extent are necessary for evaluating the ability to emplace and verify these grouts prior to actual grout curtain emplacements.

2.2.2.1.5 Constraints

2.2.2.1.5.1 Testing Impacts on the Site

The nature of the fracture-grouting tests requires that they be conducted in portions of dedicated alcoves in the welded and nonwelded tuffs penetrated by the ESF outside the repository block, primarily in the Tiva Canyon and Topopah Spring Members. The volume of grouts will be minimized. The materials will be evaluated for their potential impacts on the site prior to conducting the experiments. The use of water will be kept to a minimum during permeability testing. The application of heat will be restricted to small volumes of rock during the second phase of this testing. General utilities services will be required for testing as will drilling and mine operations support.

2.2.2.1.5.2 The Need to Simulate Repository Conditions

Fracture-grouting tests are configured to simulate repository conditions. The placement of grouts from boreholes will be generally away from regions of elevated temperatures; however, some grouting may be required in regions of elevated temperature. In addition, the performance of actual grouting around seal components and in fracture zones will be evaluated using remote borehole or geophysical technologies. The first tests are expected to be conducted at ambient temperature in a remote configuration, but near enough to the drift or surface so that post-test evaluations can be reasonably completed. Additional testing at elevated temperatures may be required after completion of the ambient temperature testing in order to simulate repository conditions after waste is emplaced.

2.2.2.1.5.3 Laboratory versus Field-Scale Tests

Fracture-grouting tests described in this study plan are intended to evaluate grouting materials, designs, and techniques under realistic in situ conditions prior to actual emplacements at Yucca Mountain. These in situ tests realistically simulate the grouting of fractured rock at Yucca Mountain. Laboratory testing, however necessary, is insufficient to support these goals. Laboratory testing of cementitious sealing materials for plugs and grouts is needed to define material specifications; consequently, laboratory testing of cementitious materials and perhaps clays will continue concurrently with the in situ testing program.

The cementitious materials proposed for the in situ tests contain cement, reactive silica, nonreactive silica, superplasticizer, defoamer, and water. Several different cementitious materials for seals are proposed for different geochemical environments. The laboratory properties necessary for successful in situ emplacements include the following:

- Fluid Properties:
  - Setting time
  - Workability

  - Density
  - Viscosity
- Physical Properties:
  - Porosity
  - Density in the hardened state
  - Cement particle size
- Strength Properties:
  - Unconfined compressive strength
  - Poisson's ratio
  - Triaxial compressive strength
  - Modulus
- Chemical Characteristics:
  - Mineralogy
  - Bulk chemistry of the constituents
  - Resistance to dissolutioning
- Geochemical Effects
- Hydrothermal Effects
- Biologic Effects

In addition, the effects of wet and dry curing and curing time on properties will also be evaluated.

2.2.2.1.5.4 Test-to-Test Interference

Fracture-grouting tests described in this study plan will be conducted in dedicated alcoves within the ESF facility in the Tiva Canyon and Topopah Spring Members. It will be necessary to minimize interference from both heater tests and fluid injection tests that may be conducted in the facility; consequently, careful coordination with the LANL TCO will be required to assure that test-to-test interference is kept to a minimum. The locations for these in situ sealing tests will be away from other testing locations. Test interference analyses will be performed prior to initiating the experiments discussed in this study plan.

2.2.2.1.5.5 Construction-to-Test Interference

The tests described in this study plan are intended to be conducted in alcoves away from the traffic of construction activities. The tests will not begin until the major construction activities have been completed in the facility around the proposed test locations. The test construction and operations are of a small scale and should not impact other construction activities. Additional construction or operational interference within the alcoves should be minimized during the tests. Drilling equipment will be required for drilling seal test emplacement holes in both the underground and at the surface locations. Overcoring bits may be required.

2.2.2.1.5.6 Alternative Methods

There are no known alternatives for evaluating the performance of grouted rock masses and evaluating the necessary equipment and techniques on a reasonable scale. Some supporting work in the laboratory is necessary to assist in describing specific material properties for evaluation of the in situ tests. However, grouted rock mass performance is largely dependent on material behavior and interactions, which can only be evaluated in situ for the scales of interest.

2.2.3 Graded Fill Tests

Backfill may be used for a variety of purposes to satisfy the hydrologic, and structural performance requirements for the repository. Backfill may be emplaced in waste disposal rooms or access drifts. The potential uses of backfill related to sealing include:

- Backfill in selected sealing areas used as a preventative measure for unraveling of rock.
- Backfill in the Calico Hill Unit to prevent collapse in this lower strength unit.
- Engineered fill forming the central portion of an earthen seal.

Additionally, the thermal/hydrologic properties of the backfill and the effects of heat on the mechanical performance of the backfill may be important issues to be addressed at a later date with subsequent testing. This testing will support design of sealing related water control and structural support structures within the repository, possibly in regions that experience elevated temperatures.

A critical component of the overall repository sealing strategy is the use of graded fills (dams) and backfill underground to limit the amount of water from all sources contacting the waste packages and to maintain the structural integrity of the host rock, particularly around other sealing locations. These goals will be accomplished by diverting inflow, by maintaining or enhancing infiltration into the fractured formation, and by providing structural support of the underground openings. The current sealing strategy includes the construction of graded embankment structures as illustrated in Figure 2-7 (Fernandez et al., 1993). These "dams" will be constructed to encourage vertical infiltration down into the fractured formation before the water can contact the waste. Although design decisions regarding backfilling the underground have not yet been made, backfilling at selected locations around sealing components may be necessary to minimize potential damage to the surrounding rock depending on site-specific factors. The backfill will provide structural support, thereby reducing the risk of deleterious rock movement around seals. This movement or breakage could create preferential pathways around the seals making them ineffective at restricting water flow.

There are three particular questions of concern in the design of graded fill and backfill structures for the Yucca Mountain repository that must maintain their integrity for long time periods:

(a) Option 1

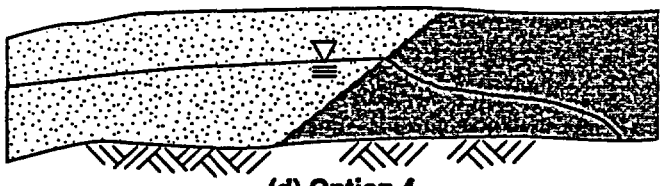
Benefits
- Retain larger amounts of water
- Increase drainage and storage capacity of floor
- Can be emplaced in predefined areas

(b) Option 2

Benefits
- Same as Option 1
- Reduced extent of phreatic surface

(c) Option 3

Benefits
- Same as Option 2
- Filter design more stable
- Ease of construction
- Optional keyway and grout curtain



(d) Option 4

Benefits
- Same as Option 3
- Simple and effective

Coarse Backfill

Intermediate Backfill

Low Permeability Layer

Figure 2-7. Single Embankment Concepts (From Fernandez et al., 1993)

- What is the lateral migration of water and infiltration in drifts due to graded fill structures?
- Will fines migration from fill possibly clog fractures rendering the formation ineffective for water infiltration?
- What are the properties of emplaced backfill including particle breakage and hydrology?

These questions will be addressed in two seal component tests supporting design, in a surface backfill test, and a small-scale seepage-control test.

2.2.3.1 Surface Backfill Test

The surface backfill test is intended to support underground design by evaluating the properties of backfill at a controlled surface site or at a dedicated underground location. The backfill will be emplaced using technology being considered for use in the underground at Yucca Mountain, such as pneumatic stowing. Although the use of backfill in waste emplacement areas has not been decided, the hydrologic and mechanical properties should be evaluated in large-scale tests so that rational design decisions can be made. Also, backfilling may be required to provide structural support to rock surrounding other sealing systems or in channels and sumps used to divert and remove water.

Currently information on the engineered properties of rockfill placed in underground openings is limited. Fernandez and Richardson, (1994) performed a technology review of technologies and experience from the mining industry. Common techniques include mechanical placement, hydraulic stowing, and pneumatic stowing. Occasionally, cements are added to the backfill to add strength. The current in-drift emplacement concepts preclude easy access for backfilling, and the use of hydraulic slurries with or without cements will probably not be allowed, because of the need to minimize both geochemical changes and added water in the waste emplacement areas. Therefore, pneumatic techniques appear to offer the most reasonable method for remote placement of backfill. The initial test will focus on pneumatic techniques, however; additional testing may be conducted to focus on other techniques as well.

As indicated above, two important objectives of this testing are an understanding of the material properties of the as-placed fill along with its hydrologic response. This surface testing will address the movement of water and fines through the backfill. Both water and fines movement depend on the gradation of the material, which depends on other factors such as the material itself and the emplacement technique. During the material-handling process, rock breakage can occur that may adversely affect the properties of the backfill and, particularly, the surrounding rock. The degree of this breakage and fines generation cannot be accurately predicted without performing placement tests. Incorporating actual handling procedures in the test will allow an accurate determination of the fines that will be created. After the nature of the fines is known, a reasonable assessment of their impact on "dam" performance and infiltration can be made.

Additional testing using mechanical compaction may be necessary, if it is determined that the backfill needs to be emplaced at higher densities.

2.2.3.1.1 General Approach

The general approach for this testing will be to use a dedicated surface or underground space in which crushed tuff can be emplaced using techniques identical to those intended for the underground facility using either pneumatic or mechanical placement. For a full-scale test, the facility should have a length of at least 13 m (3 times the emplacement drift diameter) to simulate in situ conditions adequately. Figure 2-8 shows schematically the layout for this experiment. Fielding of the test includes:

- Particle preparation, including sieving and blending the crushed material
- Placing the backfill using pneumatic stowing equipment or mechanical equipment
- Emplacing instrumentation (such as pressure cells), if necessary
- Post-test characterization of as-built particle size, gradation, and stratification (if any).

Careful QC testing (Fernandez et al., 1993) will be maintained regarding emplacement parameters, such as bulk weights of backfill emplaced, emplacement rates, etc. The results of the tests will be used to assist in making design decisions for backfilling the repository.

Samples of the emplaced backfill will be obtained for laboratory evaluation of density, moisture content, and particle-size gradation. These data will then be compared to the pre-emplaced properties to evaluate the effects of the emplacement technique(s) on material properties. Additional laboratory testing can be performed to estimate bulk mechanical properties, so that estimates of available support (to the rock mass) can be made. Additional laboratory tests of the hydraulic conductivity of the backfill will also be conducted.

Fines migration will be evaluated by performing unsaturated flow tests on the emplaced backfill and by evaluating outlet filter caking during and after the tests. This will provide an empirical estimate of the potential for migration of fines and is important for estimating the infiltration potential in and near backfilled openings.

The results of the particle-size, gradation, and stratification evaluations will be used to define additional testing requirements to evaluate the potential for fines migration. This evaluation is important in estimating the potential for "clogging" of the natural fractures.

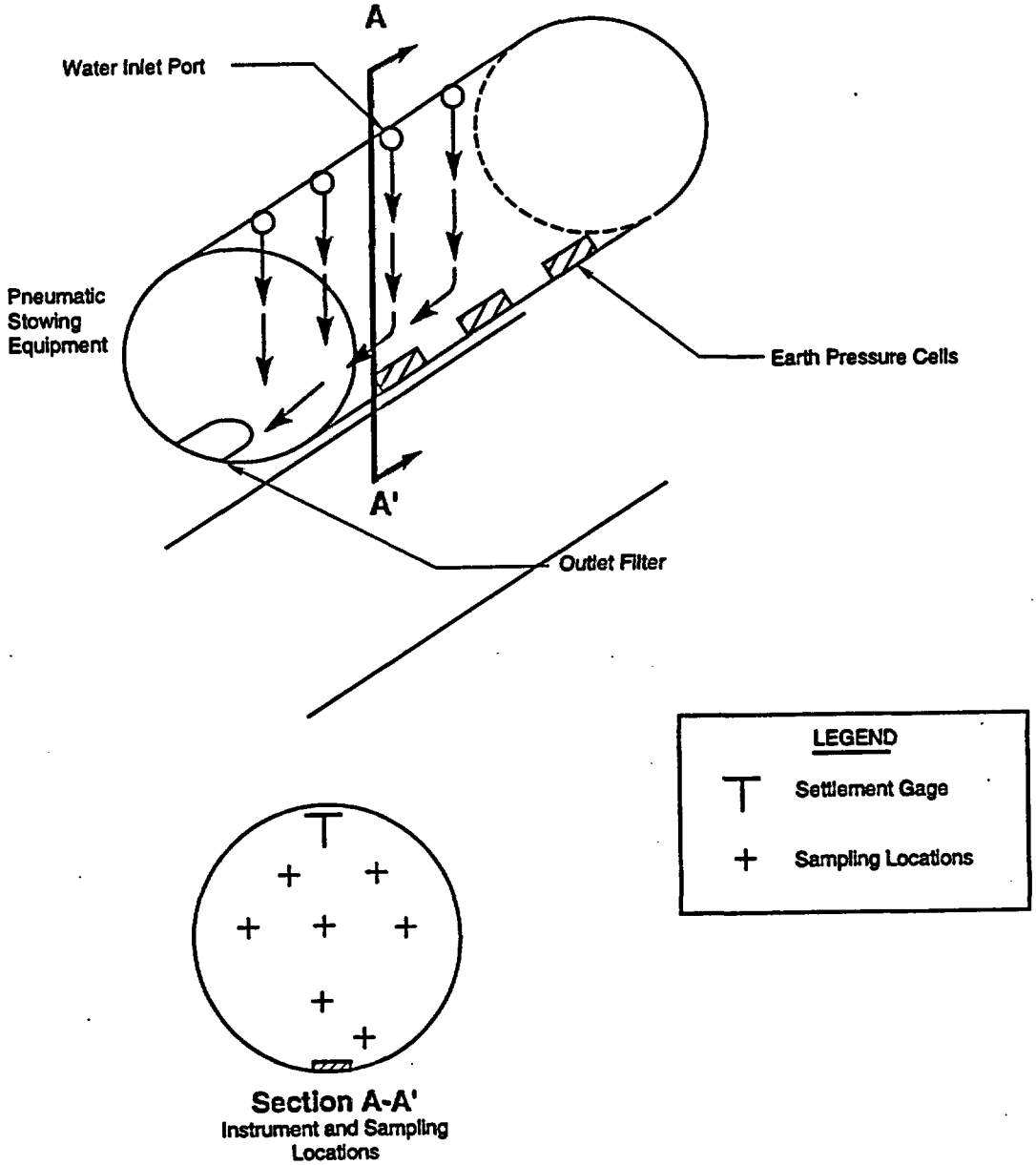


Figure 2-8. Schematic Instrument and Sampling Locations for Surface Backfill Test

2.2.3.1.2 Key Parameters

The parameters to be measured and the information to be obtained during the surface backfill tests include:

- Backfill particle size, gradation, and stratification before and after emplacement
- Backfill moisture content
- Backfill bulk density as a function of compactive effort and emplacement technique
- Backfill hydraulic conductivity
- Backfill fines migration
- Emplacement equipment wear and emplacement rates
- Backfill geochemistry and geochemistry changes

2.2.3.1.3 Methods to be Used

Standard equipment for emplacement of backfill in underground openings such as pneumatic stowing and/or mechanical Load Haul Dump (LHD) type units, will be used to simulate closely (as well as feasible) actual emplacement techniques and materials. Sampling will be performed using standard techniques employed in the civil construction industry. Supporting laboratory testing (i.e., density, hydraulic conductivity, particle size/gradation, moisture content) will use standard American Society for Testing and Materials (ASTM) standard testing methods (Fernandez et al., 1993). Careful record of the emplacements will be maintained so that accurate predictions of backfilling rates, costs, and equipment wear can be made.

Estimates of fines migration will be made by applying water uniformly to the top of the backfill in limited quantities. An outlet filter will be used to withdraw water from the test. The migration of fines can be estimated by systematically evaluating segregation of fines near the filter during the test and during post test evaluations of particle-size segregation with the test itself. The amount of water used will be kept to a minimum but will be representative of possible conditions in the repository.

As stated previously, the surface backfill test could be conducted either above ground or in a dedicated underground drift. Certain advantages exist for conducting this test in either location. A surface location would allow greater control over the water used and consumed in the test. However, the migration of fines into fractures and the attendant effect on infiltration could best be evaluated in the underground.

2.2.3.1.4 Representativeness of Tests

The surface backfill tests are intended to evaluate the emplacement and performance of emplaced backfill under realistic conditions and scale. These tests at field scale with limited extent first-

steps at evaluating the ability to emplace and verify the character of backfill prior to actual emplacements.

2.2.3.1.5 Constraints
2.2.3.1.5.1 Testing Impacts on the Site

The nature of the surface-backfill tests requires that they be conducted in either a surface facility or in portions of dedicated alcoves in the welded tuffs penetrated by the ESF. If the test is conducted at the surface, there will be no impact on the site. If the test is conducted in the underground, the impacts will be kept to a minimum by restricting the amount of water used. Dust generated will be controlled with adequate ventilation. Backfill used will be compatible with the surrounding host rock. General utilities services will be required for testing as will drilling, sampling, and mine operations support.

2.2.3.1.5.2 The Need to Simulate Repository Conditions

The surface-backfill tests are configured to simulate repository conditions. The placement of backfill in either a surface or underground facility using techniques expected to be used in the actual backfilling is necessary to evaluate the performance of backfill and the effects of backfill on other seal components. The first tests are expected to be conducted at ambient temperature. Additional testing at elevated temperatures may be required after completion of the ambient temperature testing in order to simulate repository conditions after waste is emplaced depending on project decisions regarding the need for backfilling in heated areas. Heat can be applied using blanket or rod heaters on the surface of the test structure. Long-term simulations including accelerated tests and analyses may be required to demonstrate adequate long-term performance.

2.2.3.1.5.3 Laboratory versus Field-Scale Tests

The surface-backfill tests described in this SP are intended to evaluate backfill materials, designs, and emplacement techniques under realistic in situ conditions prior to actual emplacements at Yucca Mountain. These in situ tests realistically simulate backfilling to be performed at Yucca Mountain. Laboratory testing, however necessary, is insufficient to support these goals, since laboratory techniques cannot simulate emplacement in the repository. Laboratory testing of backfill materials is necessary to support the large-scale tests. Laboratory testing will provide the following information:

- Backfill particle size, gradation, and stratification before and after emplacement
- Backfill moisture content
- Backfill bulk density as a function of compactive effort and emplacement technique
- Backfill hydraulic conductivity.

2.2.3.1.5.4 Test-to-Test Interference

The surface-backfill tests described in this SP will be conducted in dedicated surface facilities or alcoves within the ESF facility. It will be necessary to minimize interference from both heater tests and fluid-injection tests that may be conducted in the facility; consequently, careful coordination with the LANL TCO will be required to assure that test-to-test interference is kept to a minimum. No interference is expected if this test is conducted at the surface. The locations for these in situ sealing tests will be away from other testing locations. The use of water for this test will be kept to a minimum and will be collected as much as practical. Test interference analyses analyses will be performed prior to initiating the experiments described in this study plan.

2.2.3.1.5.5 Construction-to-Test Interference

The tests described in this SP are intended to be conducted at dedicated surface facilities or in alcoves away from the traffic of construction activities. Also, these tests will not begin until the major construction activities have been completed in the facility around the proposed test locations. Additional construction or operational interference at the surface or within the alcoves should be minimized during conduct of the tests. The test construction and operations are of a small-scale (for these types of operations) and should be configured and scheduled to not impact other construction activities.

2.2.3.1.5.6 Alternative Methods

There are no known alternatives for evaluating the performance of backfill and for evaluating the necessary equipment and techniques on a reasonable scale. Some supporting work could be conducted on backfill in the laboratory at various scales. However, backfill performance is largely dependent on materials handling, which can only be evaluated in situ for the scales of interest.

2.2.3.2 Small-Scale Seepage Control Test

The small-scale seepage control test is intended to develop an understanding of the hydrologic behavior of graded fill sealing components along with the attendant infiltration into the underlying rock. It is also intended to provide information on the potential migration of fines and clogging of the underlying fractures. The test is intended to be conducted from alcoves in the fractured welded tuffs of the Tiva Canyon and Topopah Spring Members.

Sealing concepts for the YMP include graded fill structures (dams) that are intended to divert any available water away from waste-emplacement areas and to promote infiltration into the underlying formation. These structures are planned for the repository horizon and can be emplaced in regions of higher temperature to control and divert flow. The use of graded particle

sizes of mined tuff are planned for these structures. Fernandez et al. (1993) propose single embankment structures, such as those illustrated in Figure 2-9, in which the hydraulic conductivity of the "fine" material is about $1x10^{-4}$ cm/s and the "coarse" general fill is about $1x10^{-1}$ cm/s. These structures utilize permeability changes in the graded fill to restrict flow, alter the phreatic surface, and promote infiltration in the underlying fractured rock. Analyses using hydraulic conductivities typical of soils similar in particle-size gradation to materials expected from the rock excavation process have been performed (Fernandez et al, 1993). These analyses suggest that hydraulic conductivities of about $1x10^{-4}$ cm/s for the low permeability fines and a hydraulic conductivity contrast of about 1.5 to 2.0 with the general backfill will effectively cause a source of 1 gpm inflow to infiltrate into the fractured tuff within 19 to 25 m from the embankment toe.

Water entering the repository would ideally be drained in the floor of the drifts. Assuming locally saturated conditions (under these conditions), the hydraulic conductivity of the highly fractured, welded portion of the Topopah Spring Member is dominated by the fractures. Therefore, under saturated conditions, most drainage will occur through the fractures. Water in sufficient quantities could move through the backfill, which will be comprised of material of various particle sizes. Fine-sized particles could be transported over time into the fractures, thereby reducing the hydraulic conductivity in that region. This would result in a decrease in the infiltration capacity of the rock, thereby reducing the effectiveness of this critical component in the overall sealing strategy. The proposed configurations must be evaluated for the movement of finer and the attendant reduction in infiltration.

2.2.3.2.1 General Approach

The general approach for testing the performance of seepage-control structures at Yucca Mountain will be to conduct a small-scale test in a borehole prior to defining larger-scale testing (if necessary). The proposed testing will include evaluating water flow in the backfill and into the underlying rock and the influence of a seepage-control structure (permeability interface) in controlling the movement of water in the borehole. The test will evaluate the hydrologic performance of materials expected to be representative of the muck from the excavation process at Yucca Mountain. It is also desired that only limited additional handling (e.g., sieving, sorting) of the muck will be required for emplacement of these graded fill structures. Therefore, one aspect of this test will be to identify the particle size(s) and distribution(s) from the available muck, which will be most advantageous for construction of the graded fill structures.

The initial test includes a nominal 1-m-diameter borehole drilled between two drifts at a slight downward angle. Monitoring boreholes under the large diameter borehole will be used for geophysical instrumentation and observation of the wetting front. The test is to be conducted in the densely welded portion of the Tiva Canyon or Topopah Springs welded tuffs. The general test configuration is shown in Figure 2-10. Characterization of the fracturing, including orientation, density and aperture (if possible), will be performed from the various boreholes. The graded fill with a permeability contrast will be emplaced in the large-diameter borehole as shown

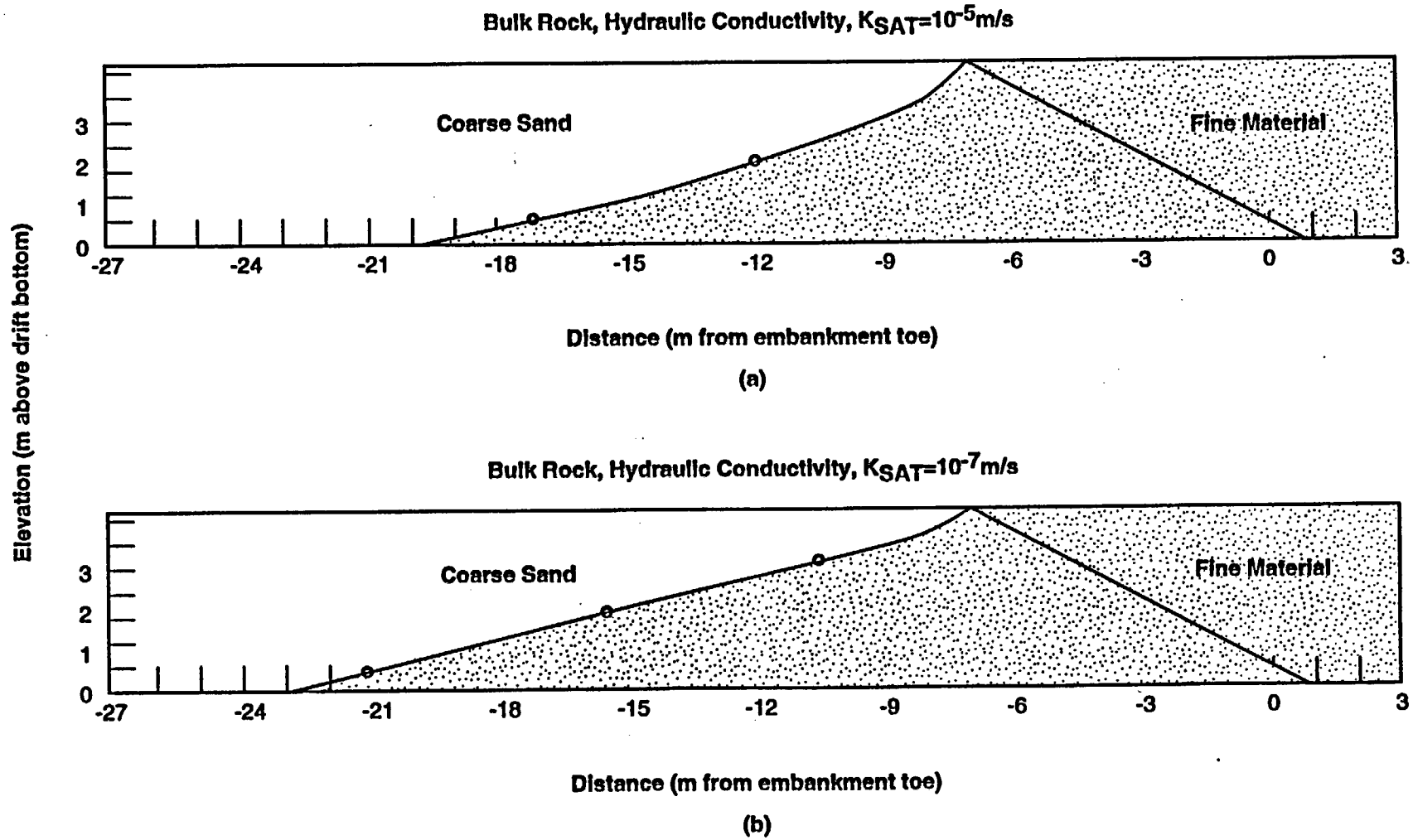


Figure 2-9. Effect of Material Contrast on Extent of Phreatic Surface: (a) Case 1 and (b) Case 2 (After Fernandez et al., 1993)

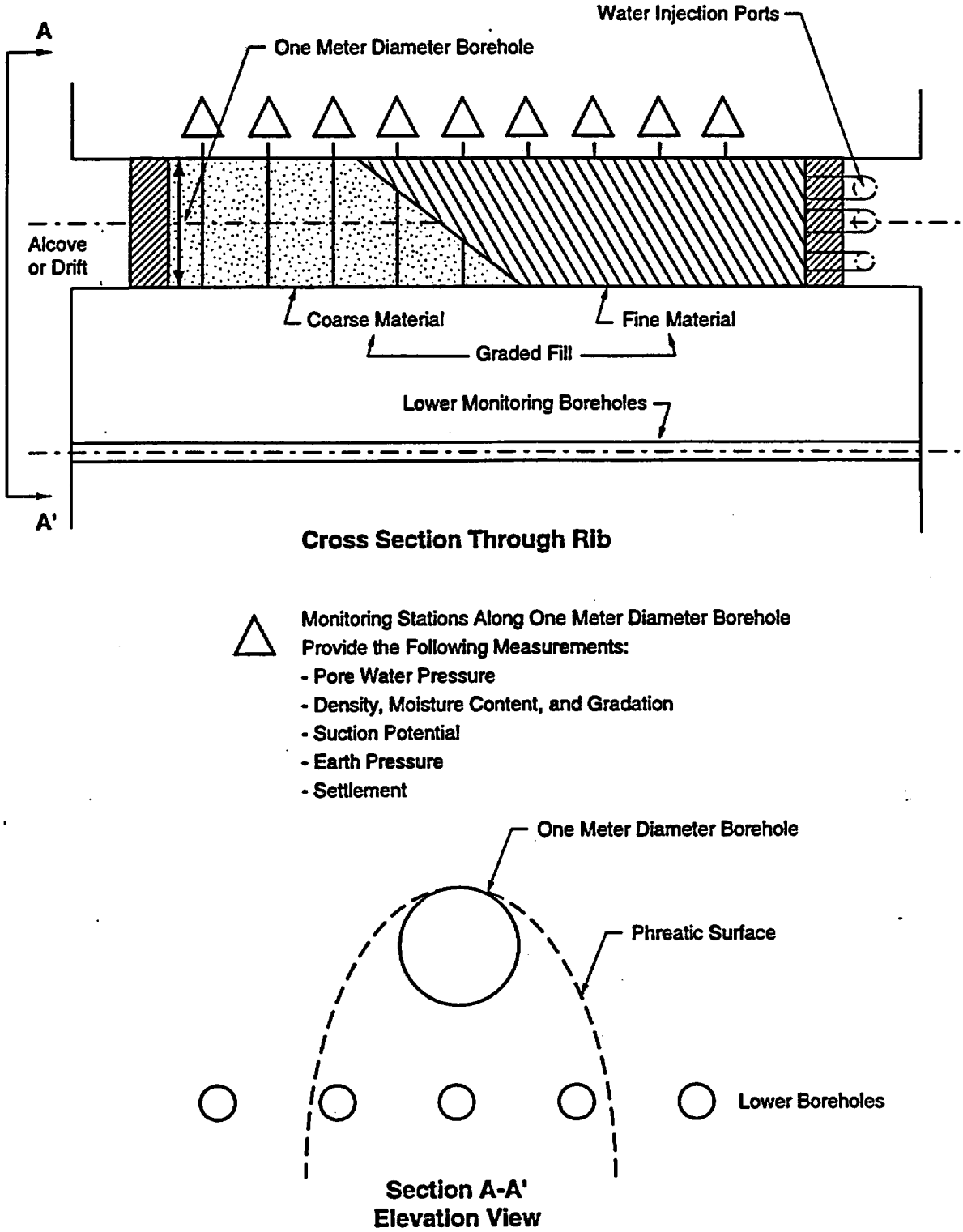


Figure 2-10. Horizontal Borehole Seepage Control Test

in Figure 2-10. Laboratory testing of graded fill will be completed prior to specifying the graded fill for this test. This testing will provide design input for the field tests and will also be used for analysis. Pore pressure within the graded fill will also be monitored during the testing. Moisture content, density, particle size gradation will be measured before and after completion of the test.

2.2.3.2.2 Key Parameters

The parameters to be measured and information to be obtained during the small-scale seepage control tests include:

- Backfill particle size, gradation, and stratification before and after emplacement
- Backfill moisture content
- Backfill bulk density as a function of compactive effort and emplacement technique
- Backfill hydraulic conductivity
- Backfill fines migration
- Backfill pore pressure
- Backfill geochemistry
- Infiltration
- Design input for seepage control structures (hydraulic conductivity contrast requirements, lengths, particle sizes, and distributions).

2.2.3.2.3 Methods to be Used

Standard equipment for emplacement of backfill in underground openings, such as pneumatic stowing and/or mechanical methods, will be used. The intent of this testing is to evaluate the effect of a permeability contrast in a graded fill structure on the infiltration rates in fractured welded tuff. Sampling will be performed using standard techniques employed in the civil construction industry. Supporting laboratory testing (i.e., density, hydraulic conductivity, particle size/gradation, moisture content) will use standard ASTM standard testing methods (Fernandez et al., 1993). Pore pressures will be measured using techniques and instruments common to civil construction practices. Fracture characterization will be performed using core logs and visual inspection. This will be used to define the injection rates for the water on the upstream side of the test. An outlet filter will be used to withdraw water from the test if any passes completely through. The migration of fines can be estimated by systematically evaluating segregation of fines near the filter during the test and during post test evaluations of particle size segregation with the test itself. The amount of water used will be kept to a minimum but will be representative of possible conditions in the repository.

2.2.3.2.4 Representativeness of Tests

The small-scale seepage control tests are intended to evaluate the performance of emplaced graded fill under realistic conditions infiltration conditions. These tests at small scale are

necessary first-steps at evaluating the effectiveness of graded fill structures at enhancing infiltration into the host rock. These tests are quite representative of expected conditions within the repository.

2.2.3.2.5 Constraints

2.2.3.2.5.1 Testing Impacts on the Site

The nature of the small-scale seepage control tests requires that they be conducted in portions of dedicated alcoves in the welded tuffs penetrated by the ESF. The impacts of this test on the site will be kept to a minimum by restricting the amount of water used. Dust generated will be controlled with adequate ventilation. Backfill and graded fill used will be compatible with the surrounding host rock. Water will be collected to the extent possible during testing. General utilities services will be required for testing as well as for drilling, sampling, and mine operations support.

2.2.3.2.5.2 The Need to Simulate Repository

The small-scale seepage control tests are configured to simulate repository conditions. Although these tests are initially conducted on a small scale, the behavior of the graded fill is not expected to differ significantly from what would be expected at full scale. If the results of these initial tests warrant, large-scale tests will be performed. The construction of the graded structures, although at small scale, will be similar to actual full-scale emplacements. The first tests are expected to be conducted at ambient temperature. Additional testing at elevated temperatures may be required after completion of the ambient temperature testing in order to simulate repository conditions after waste is emplaced.

2.2.3.2.5.3 Laboratory versus Field-Scale Tests

The small-seepage control tests described in this SP are intended to evaluate the performance of graded fill structures by using materials with permeability contrasts to restrict water flow and encourage infiltration into the underlying formation. Although not full-scale, these in situ tests realistically simulate structures at Yucca Mountain. Laboratory testing of backfill materials is necessary to support the field tests and will provide the following information:

- Backfill particle size, gradation, and stratification before and after emplacement
- Backfill moisture content
- Backfill bulk density as a function of compactive effort and emplacement technique
- Backfill hydraulic conductivity
- Backfill geochemistry and geochemistry changes

2.2.3.2.5.4 Test-to-Test Interference

The small-scale seepage control tests described in this SP will be conducted in dedicated alcoves within the ESF facility in either the Tiva Canyon or Topopah Springs Member welded tuffs. It will be necessary to minimize interference among tests that may be conducted in the facility in the vicinity of the small-scale seepage control test; consequently, careful coordination with the LANL TCO will be required to assure that test-to-test interference is kept to a minimum. The locations for these in situ sealing tests will be away from other testing locations. Test interference analyses will be performed prior to initiating the experiments described in this study plan. The use of water for this test will be kept to a minimum and will be collected as much as practical.

2.2.3.2.5.5 Construction-to-Test Interference

The tests described in this SP are intended to be conducted in dedicated alcoves away from the traffic of construction activities. The tests will not begin until the major construction activities have been completed in the facility around the proposed test locations. Additional construction or operational interference within the alcoves should be minimized during conduct of the tests. The test construction and operations are on a small scale (for these types of operations) and should be configured and scheduled not to impact other construction activities.

2.2.3.2.5.6 Alternative Methods

There are no known alternatives, other than full-scale testing, for evaluating the performance of graded fill structures and for evaluating the necessary equipment and techniques on a reasonable scale. Supporting work must be conducted on backfill in the laboratory at various scales. However, seepage control structure performance is largely dependent on the interactions between the structure and the host rock, which can only be evaluated in situ for the scales of interest.

3.0 APPLICATION OF THE RESULTS

3.1 Site Characterization Applications

The site characterization applications of the in situ sealing tests described in this SP are largely those related to the abandonment plans required for the surface-based drilling program. The construction plans for these boreholes must include rational plans for abandonment following completion of their site characterization activities. The abandonment plans will follow the broad guidelines outlined in Fernandez et al., (1994). The results of the borehole sealing tests described in this SP will be used to define performance of these abandoned boreholes. Additionally, information regarding the infiltration capability of the host rock will be obtained from these tests.

3.2 Design Applications

Numerous design applications result from the experiments described in this SP. Specifically, the small-scale seal tests results will be used to design sealing components for shafts and ramps. Fracture-grouting tests will provide information regarding the design and performance of grouting for faults and fracture zones and around other sealing components. The graded fill tests will provide information to repository designers regarding the mechanical, hydrological properties of backfill and the ability to emplace it properly. The tests described in this SP will provide early information, so that sealing requirements can be incorporated into repository design.

3.3 Performance Assessment Applications

The sealing tests described in this SP provide information to be used in the performance assessments of the engineered repository at Yucca Mountain. Specifically, the borehole sealing tests will provide part of the needed data on the potential for water inflows from shafts, boreholes, and ramps. Fracture-grouting data can be used to assess potential water inflows from fracture zones and faults. The graded fill tests will provide part of the needed data that will be used to evaluate the amount of water that may contact the waste packages.

4.0 SCHEDULE

4.1 Beginning and Ending Dates

The broad range of tests described in this SP are intended to:

1. Reduce uncertainties associated with the performance and emplacement of sealing components
2. Maintain flexibility in resolving sealing issues.

Flexibility is required to address several site uncertainties, including presence or absence of freely flowing water in the underground facility, the significance of faults and other discontinuities, and the hydrologic properties of the host rock. Uncertainties will be reduced as the facility is constructed, which may impact the design of in situ sealing tests and seal designs. The testing described in this SP will commence upon approval. Certain pre-test planning and preparation activities will precede approval of this SP.

To a large extent, the testing conducted under this SP may continue through license application (LA) and into the PC period. The information obtained under this study will support both LA and PC activities.

4.2 Milestones

Definition of detailed milestones and schedules associated with in situ testing studies must be sufficiently flexible. Consequently, it is difficult to define these milestones with confidence in a high-level document such as this SP. This is particularly true for the "In Situ Testing of Seal Components Study," because no previous prototype testing of this kind has been completed. Therefore, additional effort may be required to define instrumentation and techniques better.

The in situ testing described in this study will be conducted in a progressive manner, with simple tests being conducted first and with the more complex tests following. The more complex tests will be designed based on knowledge and experience gained from the first tests. Specific milestones for deliverables will be developed as part of on-going project-planning activities. These milestones and deliverables will be the result largely of negotiated agreements with customers of this study. Start and end dates will follow from the milestones and other requirements driving the end-user activities.

This study is guided by the major project milestones associated with advanced conceptual design (ACD) and the license application design (LAD). Each of these major milestones will be associated with performance assessment evaluations (including sealing) of site and design data.

The tests described in this study will provide both design and preliminary assessment data to support these major project milestones.

4.3 Relationships to Other Studies/Activities

The "In Situ Testing of Seal Components Study" requires input from a number of other studies and provides information particularly to design and performance assessment activities. The following studies and "Investigations from the SCP" will provide information to support the testing described in this SP:

Table 4-1 Supporting SCP Studies

8.3.1.2.1.1 Study:	Characterization of the Meteorology for Regional Hydrology
8.3.1.2.1.2 Study:	Characterization of Runoff and Streamflow
8.3.1.2.1.3 Study:	Characterization of the Regional Groundwater Flow System
8.3.1.2.2.1 Study:	Characterization of Unsaturated Zone Infiltration
8.3.1.2.2.4 Study:	Characterization of Yucca Mountain Percolation in the Unsaturated Zone¾Exploratory Studies Facility (ESF) Study
8.3.1.2.2.8 Study:	Fluid Flow in Unsaturated, Fractured Rock
8.3.1.2.3.1 Study:	Characterization of the Site Saturated Zone Groundwater Flow System
8.3.1.3.1.1 Study	Ground Water Chemistry Model
8.3.1.3.2.1 Study	Mineralogy, Petrology, and Chemistry of Transport Pathways
8.3.1.3.2.2 Study	History of Mineralogic and Geochemical Alteration at Yucca Mountain
8.3.1.3.3.2 Study	Kinetics and Thermodynamics of Mineral Evolution
8.3.1.3.3.3 Study	Conceptual Model of Mineral Evolution
8.3.1.4.1 Investigation:	Development of an Integrated Drilling Program and Integration of Geophysical Activities
8.3.1.4.2.2 Study:	Characterization of the Structural Features Within the Site Area
8.3.1.5.1.6 Study:	Characterization of the Future Regional Climate and Environments
8.3.1.5.2.2 Study:	Characterization of the future Regional Hydrology due to Climate Changes
8.3.1.6.1.1 Study:	Distribution and Characteristics of present and Past Erosion
8.3.1.15.2.1 Study:	Characterization of the Site Ambient Stress Conditions
8.3.1.16.1.1 Study:	Characterization of the Flood Potential at Yucca Mountain
8.3.1.16.3.1 Study:	Determination of the Preclosure Hydrologic Conditions of the Unsaturated Zone at Yucca Mountain, Nevada
8.3.1.17.3.3 Study:	Ground-Motion from Regional Earthquakes and Underground Nuclear Explosions
8.3.1.17.4.7 Study:	Subsurface Geometry and Concealed Extensions of Quaternary Faults at Yucca Mountain
8.3.4.2.4.2 Study	Hydrologic Properties of Waste Package Environment
8.3.4.2.4.5 Study	Effects of Man Made Materials on the Waste Package Environment

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