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Scientific Investigation Plan

For

Initial Engineered Barrier System Field Tests

WBS 1.2.2.2.4
(SCP #8.3.4.2.4.4.1)

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MASTER

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1.0 Purpose and Objectives

The purpose of this Scientific Investigation Plan (SIP) is to describe tests known as Initial Engineered Barrier System Field Tests (IEBSFT) and identified by Work Breakdown Structure as WBS 1.2.2.2.4. The IEBSFT are precursors to the Engineered Barrier System Field Test (EBSFT), WBS 1.2.2.2.4, to be conducted in the Exploratory Study Facility (ESF) at Yucca Mountain. The EBSFT and IEBSFT are designed to provide information on the interaction between waste packages (simulated by heated containers) and the surrounding rock mass, its vadose water, and infiltrated water. The IEBSFT are being conducted primarily to assure the effectiveness of the EBSFT. The EBSFT will be controlled by a Study Plan that will be prepared later.

Heater assemblies will be installed in drifts or boreholes openings and heated to measure moisture movement during heat-up and subsequent cool-down of the rock mass. In some of the tests, infiltration of water into the heated rock mass will be studied. Throughout the heating and cooling cycle, instruments installed in the rock will monitor such parameters as temperature, moisture content, concentration of some chemical species, and stress and strain. Rock permeability measurements, rock and fluid (water and gas) sampling, and fracture pattern measurements will also be made before and after the test.

The IEBSFT have three primary objectives. The first is to develop and evaluate the various measurement systems and techniques that will later be employed in EBSFT. The second is to provide preliminary data for development of models that will predict the interaction of parameters over the approximate 10,000-year lifetime required for radionuclide decay. Data from EBSFT will be used as input to models as necessary to predict actual repository performance. The third objective is to gain experience and personnel training in planning, controlling, and documenting the Quality Assurance (QA) requirements of quality-affecting work.

2.0 Relationship to Programmatic Objectives

2.1 Information Needs

The Site Characterization Plan (SCP) is divided into a series of issues and information needs that address those issues. One issue, identified as 1.10 (Waste Package Characteristics-Postclosure), deals with the service environment of the waste package. Section 8.3.4.2 of the SCP states that "The waste package environment, upon initial emplacement of the package, will depend on the ambient conditions at the repository level and how those conditions are altered by repository construction and operation. The environment following emplacement will depend on the initial emplacement conditions and how those conditions are altered by the waste package. Therefore, there is an interactive process between design and environment characterization. The design is initially based on the ambient conditions and a prediction of how those conditions would alter under the stresses applied by repository construction and waste emplacement. Once a design is available, analysis of that design provides a set of environmental stress factors. Testing is then done to determine the effect of those stresses, such as thermal and radiation fields and mechanical stresses, on the package environment. Based on those tests and subsequent analysis, designs may be modified and the test and analysis cycle repeated."

Information Need (IN) 1.10.4. (Post Emplacement Near-Field Environment) is one of several investigations that will provide input

to Issue 1.10. IN 1.10.4. is itself composed of several investigations, including the EBSFT and IEBSFT described herein. In addition, information from the EBSFT and IEBSFT will provide input to other Information Needs shown in Table 1.

**TABLE 1. Input from EBSFT and IEBSFT to Information Needs
for the Site Characterization Plan**

<u>Information Need or Investigation</u>	<u>Subject</u>
1.4.2	Material properties of the containment barrier (Section 8.3.5.9.2)
1.4.3	Scenarios and models needed to predict the time to loss of containment and the ensuing degradation of the containment barrier (Section 8.3.5.9.3)
1.4.4	Containment barrier degradation (Section 8.3.5.9.4)
1.5.2	Material properties of the waste form (Section 8.3.5.10.2)
1.5.3	Scenarios and models needed to predict the rate of radionuclide release from the waste package and engineered barrier system (Section 8.3.5.10.3)
1.5.4	Release rates of radionuclides from the

engineered barrier system for
anticipated and unanticipated events
(Section 8.3.5.10.4)

1.10.1 Design information needed
(consideration of waste package-
environment interactions (Section
8.3.4.2.1)

1.10.3 Waste package emplacement
configuration (Section 8.3.4.2.3)

1.11 Configuration of the underground
facility (Section 8.3.2.2)

1.12.2 Seal materials (Section 8.3.3.2.2)

Processes affecting the post-emplacement environment will also influence waste package performance. Many of the activities described below will also provide input to waste package performance assessment models.

The EBSFT will provide site-specific data on near-field hydrologic, thermal, and chemical phenomena during a complete, accelerated thermal cycle in the rock mass. Movement of water and steam in pores and fractures in near-field is of primary interest; thermal and mechanical properties are also of interest because of their roles in driving or influencing water movement. Geochemical processes are also of interest because of their potential influence on hydrologic behavior and because of possible effects on components of the engineered barrier system. The objective of the EBSFT regarding geochemical characteristics is to validate, to the extent practical, the results of laboratory studies that characterize geochemical interactions and to consider any synergistic effects present in situ that were not identified during laboratory testing. These laboratory studies are described in the Scientific Investigation Plan for Waste Package Environment WBS 1.2.2.2.1. (UCID-21326).

2.2 Applicable Regulations

The IEBSFT and EBSFT primary objective is to provide in situ information on the environmental processes affecting the near-field (i.e., where the waste package will raise the temperature significantly above the pre-emplacement ambient temperatures) host rock after waste

package emplacement, as dictated by requirements contained in Section 135(a) of the NRC Rule 10CFR60, which states, in part:

Packages of HLW shall be designed so that the in situ chemical, physical, and nuclear properties of the waste package and its interactions with the emplacement environment do not compromise the function of the waste packages or the performance of the underground facility or the geologic setting.

The design shall include, but not be limited to considerations of the following factors: Solubility, oxidation/reduction reactions, corrosion, hybridizing, gas generation, thermal effects, mechanical strength, mechanical stress, radiolysis, radiation damage, radionuclide retardation, leaching, fire and explosion hazards, thermal loads, and synergistic interactions.

3.0 Background

The potential repository horizon for high-level wastes is at Yucca Mountain in a devitrified, partially saturated, welded tuff. Work to date suggests that the potential repository horizon has a mean matrix porosity of 14% and a mean water saturation of 65% (Montazer and Wilson, 1984). Therefore, the rock mass consists of host rock with pore spaces filled with air and water.

Waste package emplacement will impose thermal and radiation loads on the rock mass. The thermal load will increase the near-field temperatures and create a region of hot, dry rock around the emplacement drifts or boreholes. Rapid evaporation or possible boiling of the vadose water will occur where the temperatures are sufficiently high. A build-up of pore gas pressure is expected to develop in unfractured rock mass. Steam is expected to flow within the fractures and unfractured rock in response to the gas pressure gradients that develop. A region of increased saturation is expected to form adjacent to and outside of the dry rock region as steam condenses within the cooler portions of the rock mass. Part of this condensation will occur along fractures. Some of the condensation may move from the fractures into the matrix due to higher suction potential in the matrix. The remaining water in the fracture may remain immobile due to capillary forces or it may flow along the fracture under gravity, depending on the local fracture aperture. Since the power output of the waste packages decreases with time, the hot region of the rock mass around the emplacement drifts or

boreholes eventually decreases in size and the dry region will slowly regain some of the water lost to the surrounding areas.

Construction of underground facilities (including ramps, drifts, alcoves, and boreholes) and emplacing of waste packages will impose mechanical loads on the rock mass. The thermal load from the waste packages will further change the stress field in the rock mass. The stress field change may have impact on the fracture porosity and connectivity of the rock mass. The change in fracture porosity and connectivity may affect the rock-water interaction and the movement of water and steam mentioned in the preceding paragraph.

The design of the IEBSFT and the EBSFT (to be performed later in the ESF) will focus on determining the distribution of moisture in the near-field environment, particularly after the peak temperatures have passed. This is distinct from other heater tests in welded tuff, which have been more concerned with the thermomechanical response of a rock mass and have generally focused on the heating phase. Heater tests conducted in G-tunnel at the Nevada Test Site by Sandia National Laboratories (Zimmerman, 1982; Zimmerman et al., 1984) examined water migration behavior in heated holes in welded tuffs during a heating phase, but monitoring of post-thermal behavior was not included. This test addresses both the loading (or heating), and the unloading (or cool-down), phases of the thermal cycle. In the IEBSFT and EBSFT, we will also monitor the mechanical response of the rock mass to the thermal loading and unloading. We will also monitor geochemical processes during the entire testing period.

QA level III tests conducted in G-Tunnel during 1988-89 in a 12-inch-diameter horizontal borehole confirm that a dry zone develops around the heater borehole, and the degree of drying increases with proximity to the heater's center. A "halo" of increased saturation develops adjacent to the dry region and migrates away from the heater as rock temperatures increase. Some of the fractures intercepting the heater borehole increase the penetration of hot dry conditions into the rock mass. A build-up of pore gas pressure develops in rock regions where vigorous evaporation is occurring. The air permeability of the fracture system exhibits a strong heterogeneity.

4.0 Activities

Work performed in support of the Initial Engineered Barrier System Field Tests has been divided into the following activities for quality assurance grading. Similar activities would be assigned to the EBSFT, but would be distinguished from the IEBSFT by a ".2" designation instead of ".1." These activities will be graded separately from those of the IEBSFT and will be controlled by the Study Plan, rather than this SIP, because they involve site characterization.

<u>Activity Number</u>	<u>Description</u>
EB-01.1	Collect and analyze material (rock, gas, and water) samples. This activity includes sampling activities before, during, and after heating of the rock. The material samples will be analyzed in the laboratory. Hydrologic properties of the rock samples will be determined. Chemical analyses will be done on the gas and water samples.
EB-02.1	<p>The main test activity, which includes planning, evaluation of test components, procurement, calibration and installation of test components, data acquisition, and test controls:</p> <p>Develop detailed work planning documents when applicable (for example, activity plans,</p>

technical implementing procedures, criteria letters) for the IEBSFT. This includes preparation of specific scientific control documents for portions of the work performed under activities described below. It also includes revising procedures developed for the prototype tests.

Evaluate test components. This includes checkout and debugging of techniques and hardware. It also includes comparative evaluations of candidate test components and methods and the procurement of equipment for these evaluations. These evaluations may be performed in the laboratory or during the course of field experiments.

Conduct, test, record and archive data. This includes all measurements and test controls performed before, during, and after heating of the rock mass occurs.

Procure or manufacture test components. This activity includes the development of specifications and requirements for the equipment. This activity includes reassessment of specifications previously derived for prototype test equipment.

Perform calibration and installation of test components.

EB-05.1

Perform scoping calculations in support of design of the test and develop planning documents, such as study plans. This activity includes the verification and validation process necessary to qualify the numerical methods to be used. Reduce and analyze test data and report test results.

5.0 Description of Activities

The following sections provide a general description of the IEBSFT. Specific details will be provided in the implementing procedures that will be prepared and approved prior to performing quality-affecting activities and that meet the requirements of the various LLNL-YMP QA procedures that govern control of scientific investigations. Two tests will be conducted in the IEBSFT: an abbreviated test and a long-term test. Both tests have the same general procedures, such as drift arrangement and layout, calibration and installation of instruments, parameters to be monitored, etc. The main difference between the two tests is the duration of heating and cool-down phases, which will be discussed in activity plans.

5.1 Test Arrangement and Layout

The EBS design and emplacement configuration are not fully determined at this time. The details of any EBSF tests will be dependent on the EBS design because they consider the interactions between the environment and the EBS. Therefore, this SIP will emphasize principles or objectives of the testing and the general types of testing considerations that need to be provided. Figure 1 shows a general configuration of the emplacement drift, instrumentation drifts, and instrumentation boreholes. Specific layout, etc., for test(s) will be discussed in the implementing documents. Where a layout needs to be discussed, the reference design of emplacement in drifts will be referred to but changes to this may be made in subsequent implementing documents. For convenience, during the

remainder of this document emplacement drifts will be referred to without noting that vertical borehole emplacement is an option. In general, resistance heaters will be installed in drifts or boreholes in the devitrified densely welded nonlithophysal Topopah Springs Tuff (TSW2) and Calico Hill Unit (CHn) in Busted Butte, or the North and South Ramps of Explorative Study Facility (ESF).

Instrumentation boreholes will be drilled vertically (from both above and below) and horizontally into the test region to provide 3-dimensional access for measurements in boreholes and cross-boreholes.

The effect of the waste package layout configuration on the thermohydrological and thermomechanical responses of rock mass will be investigated. Thermal interference of three heated drifts will also be studied. The effect of the scale of power loading will be investigated.

5.2 Test Sequence

Specific heater (emplacement) drifts and instrumentation boreholes or test layouts will be determined based on mapping and fracture descriptions and orientations noted in the test area. Prior to installation of heater and instrument, heater (emplacement) drifts and instrumentation boreholes will be inspected to map the location and orientation of fractures. In addition, air permeability will be measured in some of the instrumentation boreholes. Rock and vadose water samples will be collected for laboratory analysis. Following installation and

checkout of instruments, preheat measurements will be made to establish baseline conditions for all parameters to be monitored.

The rock mass will be heated by electrical heaters in the heater drifts. Details of how the power will be applied will be found in the implementing procedures; power will likely be constant and then gradually reduced, depicting controlled cool-down.

During the heating phase moisture content will be monitored to track moisture movement away from the heater drifts and into the cooler rock mass. During the cool-down phase moisture movement back into the dried-out regions will be monitored. During both phases, geomechanical and geochemical monitoring will be done and water and gas samples will be collected for laboratory analysis.

Following the test, instrumentation will be removed for inspection, evaluation, and recalibration. Selected boreholes will be reinspected for changes in fracture pattern and permeability. Heater canisters will be examined for evidence of moisture condensation, corrosion, or other deleterious effects.

At the conclusion of the test, rock and vadose water samples will be taken and analyzed for changes. Additional rock samples may be available from the overcoring operation that is used to remove instruments sealed or grouted in place prior to the test.

5.3 Parameters to be Measured

The following parameters will be measured for each test before, during and after the thermal cycle is completed to characterize the behavior of the rock mass in the near-field of a waste package. The parameters listed below are tentative selections based on results from scoping calculations available to date and from a previous prototype test in G-Tunnel at the Nevada Test Site. This selection of parameters may be modified as results of scoping calculations become available and test planning progresses. More detailed information as well as a listing will be available in the implementing procedures.

- Rock-mass temperatures are needed to reconstruct the thermomechanical and thermohydrological responses of the rock and to evaluate the performance of the test equipment during the heating and cool-down phases.
- Rock-mass gas pressure and atmospheric pressure are needed to reconstruct the flow regime of the air and water vapor in the rock mass.
- The relative electrical resistivity and dielectric constant of the rock as well as thermal neutron and gamma density counts will be used to infer the spatial and temporal changes in the moisture content of the rock mass.
- Air humidity measurements in the rock mass will be used to calculate the pore pressure gradients that drive the

movement of liquid water within the rock mass. Changes in the moisture content (along with the result of thermal neutron and gamma counts and the measurement of relative electrical resistivity and dielectric constant) and pore pressure information are used to reconstruct the flow regime of liquid water in the rock mass. The spatial variations in moisture content will be used to infer the flow paths of the liquid water, and to define regions that are losing or gaining water as a function of time.

- Air permeability measurements will be used to detect any changes in the rock surrounding the emplacement drifts caused by the thermal load imposed on the rock. These measurements will be made along some of the instrumentation boreholes as soon as all the other boreholes have been drilled and sealed. The measurements will again be repeated after the heating sequence is completed and the heater is removed from the borehole.
- Heater wattage will be monitored to document the thermal loading history of the test.
- Time is needed as a reference for all measurements.
- Infiltration of water during the heating and cool-down phases will be conducted to investigate the effect of thermal load on flow of water in fractures and in matrix.

- Fracture locations and orientations will be measured by borescope and/or borehole TV surveys performed in all the boreholes before the installation of instruments and along the emplacement drifts before and after the tests are completed. This information is needed to understand the effects of heating on the stability of the emplacement drift walls, and to establish the changes in fracture connectivity caused by the heating and cooling cycle. It will also aid in the interpretation of the flow regime of vapor and liquid water in the rock mass and the result of air permeability measurements.
- The volume of water condensed from the steam invading the heater drifts will be measured to obtain estimates of how much vapor flows towards the heater borehole, as part of model validation.
- Measurements of rock displacements and stress changes will help determine how the mechanical behavior of the rock mass changes fracture apertures, as well as other geomechanical responses to thermal perturbations.
- Measurements of acoustic emissions/microseismic activities will help to identify any micro-fracturing that develops. This will be important to resolve permeability changes.

- Determination of the concentration of some chemical species and pH will help to understand geochemical processes in the rock mass during the tests.
- Sampling of debris or dust from heater drifts subsequent to heater removal will allow an assessment to be made of the impacts of any microfracturing of rock or dehydration of fracture filling materials on permeability.
- Post-testing phase geochemical core sampling will obtain core samples in strategic locations for geochemical/petrographic analyses to evaluate the effect of heating on geochemical processes.
- Post-testing phase overcoring of representative grouted holes will allow for geochemical/petrographic analyses to evaluate the impact of grouting on the geochemical testing.
- Chemical characterization of water and rock samples and petrologic studies will be performed on rock/water samples obtained before and after the heating cycle is completed. These studies will be performed under Characterize Chemical and Mineralogical Changes in the Post Emplacement Environment Study (SCP 8.3.4.2.4.1) and Hydrologic Properties of Waste Package Environment Study (SCP 8.3.4.2.4.2) and are described under a separate SIP.

The purpose of these studies will be to detect possible dissolution or alteration of minerals in the matrix and fracture of rock mass as well as precipitation of dissolved materials as water evaporates/boils and re-condenses in the near-field.

5.4 Limitations

To accurately simulate all aspects of the near-field environment of the waste package, the Engineered Barrier System Field Tests should be designed to have the same physical dimensions, same power loading (power per unit length of waste package), and same power decay curves (variation in power output for the waste packages) as a function of time. An actual simulation would also include radiation comparable to that of the wastes to be emplaced. A true repository-scaled test would provide data that are most likely to be representative of the important environmental conditions in the repository such as radiation effects, peak rock temperatures, waste package temperatures, rock thermal gradients, and rock moisture gradients. The physical dimensions and the power loading chosen for the tests can easily be designed to match those for the emplacement drifts in the repository. However, the power decay curves for the tests will have to be highly compressed in time relative to that of the waste package. This is an intrinsic limitation of the tests which controls the range of environmental conditions that the tests can impose on the near-field rock mass. The other limiting factor is rock properties, such as thermal conductivity, that cannot be controlled. Because of safety/handling and licensing issues relative to emplacement of

radioactive sources, there are no plans at this time to include emplacement of radioactive sources as part of the initial tests. Under the current plans, the radiation effect on rock properties cannot be studied. If these plans change, this SIP will be revised.

While field testing cannot simulate the actual heating, cooling, and irradiation conditions of a repository, it can be designed so that the most important coupling processes are adequately monitored. For that purpose, the dried-out volume of the rock mass should be enough to include at least 10 major fractures in every radial direction from the heater. Also, the thermal loading rate should be constrained so that the rate at which moisture is driven through the rock mass does not exceed the rate at which geochemical processes take place.

A number of scaling tradeoffs can be considered. One alternative is to design a test with the same dimensions and initial power loads as those for the repository while using the compressed power decay curve. Another option is to use a higher initial power loading for testing in order to heat the rock faster and approach maximum rock temperatures. Still another option for the case of borehole emplacement is to vary the physical dimensions of items such as emplacement borehole diameter in combination with an appropriately adjusted initial power loading.

All of these tradeoffs have potentially significant impact on the testing conditions imposed. Scoping calculations will be used to investigate various possible tradeoffs and to select those that impose near-field conditions that provide the most appropriate data sets needed for model validation. The IEBSFT will be designed on the basis of the scoping/sensitivity studies; however, one of the purposes of the initial

tests is to confirm that the physical processes accounted for in the models are both accurate and sufficiently inclusive. Therefore, the IEBSFT may not be identical to the EBSFT in terms of scale and other test parameters. The discussion that follows presents some of the scaling tradeoffs that have been considered and their potential impacts on the near-field environment. The discussion applies equally to IEBSFT and EBSFT.

The initial power loading (kilowatts of power per meter of heater) may be the same as the power loading planned for the waste packages in the repository. However, power decay curves for the tests will be greatly compressed such that the test heating cycle will last on the order of several months for the abbreviated test to about five to six years for the long-term test, whereas the heating cycle for a waste package in the repository will last on the order of several hundred years. A possible negative consequence of driving the heaters with a power loading equal to that of the waste packages but with a greatly compressed time scale is that the volume of rock dried out around the test borehole will be much smaller than for the rock around the repository emplacement boreholes. Thus, the effects of fractures and other discontinuities on the test results may be substantially different during testing. Also, maximum rock temperatures are likely to be substantially lower in the tests than in the repository environment, thereby affecting temperature-dependent processes such as mineral precipitation/dissolution or alteration (particularly of secondary minerals/zeolites). Because these geochemical processes are functions both of time and temperature, it is impossible to properly scale the field experiments, and laboratory and analytical

modeling will be required to augment the field tests to address the geochemical/petrologic effects. The scale effect of power loading will be investigated in this test.

6.0 Application of Results

Information to be developed during the course of this test includes:

- Data from the various instrument readout systems.
- Analysis of rock samples for rock properties (to be performed under WBS 1.2.2.2.2).
- Evaluation of equipment and instrument performance.
- Physical examination of boreholes.
- Rock/water samples for geochemical analysis (analysis to be performed under WBS 1.2.2.2.1).
- Development of a conceptual model that describes hydrological and thermal evolution of the rock mass system near a heater emplacement borehole (to be performed under WBS 1.2.2.2.2).
- Development of conceptual models for geomechanical responses (model development to be performed under WBS 1.2.2.2.3).
- Rock/water/grout samples for geochemical analyses of impact of man-made materials (to be performed under WBS 1.2.2.2.1).

Data from the various instrument systems will be recorded by the Data Acquisition System (DAS) during the preheat, heating, and cool-down phases. Based on the analysis of the data, a conceptual model will be constructed to describe the thermal, hydrologic, chemical, and mechanical evaluation of the geologic environment. These data will be compiled, reduced, and provided throughout the course of the test to the PIs responsible for developing the heat and mass transport model (Near Field Flow and Transport Model).

The hydrologic environment expected to develop around a heater during thermal loading is as follows: with time, the heat will dry the originally partially saturated rock near the emplacement drifts. The water vapor formed will be driven by vapor pressure gradients through the matrix until it intersects a fracture; it will then move down-gradient along the fracture as noted in laboratory work performed by Daily et al. (1987) and in the field (Daily and Ramirez, 1989). The water vapor will condense where the temperatures are sufficiently low. Part of this water might move into the matrix due to capillary suction; the remainder might stay in the fracture held by capillary forces or it might flow along the fracture down-gradient. The percentage of water that moves into the matrix will depend on the degree of saturation of the matrix, the matrix hydraulic conductivity, and the contact time between the water in the fracture and matrix.

When the dried region is allowed to cool, it is expected to rewet slowly due to the pore pressure and saturation gradients that develop in the rock around the heater.

Physical examination and permeability measurements of boreholes will provide values of the rock fracture and porosity parameters for the heat and mass transport models.

Analysis of rock samples will provide information on chemistry, mineralogy, porosity, and moisture content at various distances from the emplacement drifts that have seen a history of thermal, hydrological, geochemical, and mechanical disturbances.

The above information, in conjunction with laboratory studies of (1) dissolution/precipitation kinetics, rock/water interaction, and fluid composition and (2) mechanical fracture properties will provide input to the characterization of factors affecting the hydrologic properties of tuff at anticipated repository conditions.

Evaluation of equipment and instrument performance for future use in the ESF will consist of two considerations:

- (1) Reliability/operability/maintainability under the test environmental conditions.
- (2) Agreement among those instruments measuring moisture content and migration, e.g., electrical resistivity tomography, high-frequency electromagnetic tomography, neutron probe, and moisture-measuring devices.

Data from the various instrument systems will be recorded by the Data Acquisition System (DAS) during the preheat, heating, and cool-down phases. Based on the analysis of the data, a conceptual model will be constructed to describe the thermal, hydrologic, chemical, and mechanical evaluation of the geologic environment. These data will be compiled, reduced, and provided throughout the course of the test to the PIs responsible for developing the heat and mass transport model (Near Field Flow and Transport Model).

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8. References

Daily, W. D., W. Lin, and T. Buscheck (1987), "Hydrological Properties of Topopah Spring Tuff: Laboratory Measurements," *J. Geophys. Res.*, Vol. 92, No. B8, pp. 7854-7864.

Daily, W. D., and Ramirez, A. L. (1989), "Evaluation of Electromagnetic Tomography to Map In Situ Water in Heated Welded Tuff," *Water Resources Research*, Vol. 25, No. 6, pp. 1083-1096.

Montazer, P. M., and W. E. Wilson (1984) *Conceptual Hydrologic Model of Flow in the Unsaturated Zone, Yucca Mountain, Nevada*, Water Resources Investigative Report, U.S. Geol. Survey, Denver, CO, USGS-84-4345.

Zimmerman, R. M. (1982), "Issues Related to Field Testing in Tuff," *Proceedings of 23rd Symposium on Rock Mechanics*, AIME, New York, NY, pp. 872-880.

Zimmerman, R. M., F. B. Nimick, and M. B. Board (1984), "Geoengineering Characterization of Welded Tuffs from Laboratory and Field Investigations," *Proceedings of 1984 Symposium on Scientific Basis for Nuclear Waste Management VIII*, Materials Research Society, Boston, MA.

(a) Top View

Figure 1: General layout of emplacement drifts, instrumentation drifts, and instrumentation boreholes. (a) Top view, (b) Front view, and (c) Side view.

(b) Front View

(c) Side View

(c) Side View

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