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YUCCA MOUNTAIN PROJECT

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Engineered Barrier System Field Tests-Prototype Tests

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1.0 Purpose and Objectives

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

Heater elements will be installed in boreholes and heated to measure moisture movement during heat-up and subsequent cool-down of the rock mass. Throughout the heating and cooling cycle, instruments installed in the rock will monitor such parameters as temperature and moisture content. Rock permeability measurements, rock samples and fracture pattern measurements will also be made before and after the test.

The PEBSFT test has three primary objectives. The first is to develop and evaluate the various measurement systems and techniques that will later be employed in similar tests in the ESF. 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 later tests in the ESF 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 work to QA Level I and II requirements.

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 is identified as 1.10 (Waste Package Characteristics-Postclosure) and 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

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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 PEBSFT described herein. In addition, information from the EBSFT and PEBSFT will provide input to other Information Needs shown in Table. I.

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TABLE I

Information need or investigation	Subject
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. Near-field movement of water and steam in pores and fractures is of primary interest, while 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 which 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 PEBSFT and EBSFT primary objective is to provide in situ information on the environmental processes affecting the near field (i.e. within several meters of a waste package) 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, hydriding, 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 proposed repository horizon is at Yucca Mountain in a devitrified, partially saturated, welded tuff. Work to date suggests that the proposed 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 fields on the rock mass. The thermal field will increase the near-field temperatures and create a region of hot, dry rock around the emplacement borehole. Boiling of the water will occur where the temperatures are sufficiently high. A build up of pore gas pressure is expected to develop in unfractured rock blocks. Steam is expected to flow within the fractures and unfractured rock in response to the gas pressure gradients which develop. A region of increased saturation is expected to form adjacent to 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 negative pore pressures 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. Since the power output of the waste packages decreases with time, the hot region of the rock around the emplacement borehole eventually decreases in size and the dry region will slowly regain some of the water lost to the surrounding areas.

The design of the PEBSFT 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 initial thermal phase. Heater tests conducted in G-tunnel at the Nevada Test Site by Sandia National laboratories (Johnstone and Hadley, 1980: and Zimmerman, 1983; et al. 1985) 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 the unloading, or cooling, phase of the thermal cycle.

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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 saturation "halo" 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 Prototype Engineered Barrier System Field Tests has been divided into the following activities for quality assurance level assignment (QALA).

Activity Number	Description
Q-20-1.1	Develop detailed work planning documents (for example: activity plans, technical implementing procedures, criteria letters) for the PEBSFT. This includes preparation of specific scientific control documents for portions of the work performed under activities described below. It also includes revising procedures developed from previous prototype tests.
S-20-1.1	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.
S-20-2.1	Perform scoping calculations in support of development of study plans. This activity includes the verification and validation process necessary to qualify the numerical methods to be used.

S-20-3.1	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.
S-20-4.1	Perform instrument and test component calibration.
S-20-5.1	Installation of test components.
S-20-6.1	Collect rock and water samples. This activity includes sampling activities before, during, and after heating of the rock.
S-20-7.1	Conduct test, record and archive data. This activity includes all measurement activities, and test control activities performed before, during, and after heating of the rock mass occurs.
S-20-8.1	Reduce and analyze test data and report test results.

5.0 Description of Activities

The following sections provide a general description of the PEBSFT. Specific details will be provided in 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.

5.1 Test Arrangement and Layout

Specific layout etc., for test(s) will be discussed in implementing documents. In general, resistance heaters will be installed in a borehole(s) in G tunnel at the Nevada Test Site or similar facilities.

Instrumentation boreholes will be drilled vertically and horizontally into the test region to provide 3-dimensional access for measurements in boreholes and cross-boreholes.

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5.2 Test Sequence

Prior to installation of instrumentation, heater and instrument boreholes will be inspected to map location and orientation of fractures. In addition, rock permeability will be established by pressurizing isolated sections of the heater borehole(s) and measuring the rate of flow into the rock mass. Following installation and checkout of instrumentation, preheat measurements will be made to establish baseline conditions for all parameters to be monitored.

The rock mass will be heated by use of electrical heaters in the heater borehole(s). Details of how the power will be applied will be found in implementing procedures but will likely be a constant power followed by a gradual power reduction depicting cooldown.

During the heating phase moisture content will be monitored to track moisture movement away from the heater holes and into the cooler rock mass. During the cool-down phase moisture movement back into the dried out regions will be monitored.

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 and shield plugs will be examined for evidence of moisture condensation, corrosion or other deleterious effects.

At the conclusion of the test, core samples will be taken and analyzed for changes. Additional 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 <u>tentative selections</u> based on results from scoping calculations available to date and from a previous prototype test in G-tunnel. 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 final listing will be available in implementing procedures.

- Rock mass temperatures are needed to reconstruct the thermomechanical response of the rock and to evaluate the performance of the test equipment during the heating.

- 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 dielectric constant of the rock, 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 which drive the movement of liquid water within the rock mass. Changes in the moisture content 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 define regions which are losing or gaining water as a function of time.

- The air permeability measurements will be used to detect any changes in the rock surrounding the emplacement borehole caused by the heat cycle imposed on the rock. These measurements will be made along the heater borehole 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.

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- Fracture locations and orientations will be measured by borescope and/or borehole TV surveys performed in all the boreholes before the heater is energized and along the emplacement borehole after the test is completed. This information is needed to understand the effects of heating on the stability of the emplacement borehole walls, and to establish the changes in fracture permeability 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.

- The volume of steam invading the heater borehole will be measured to obtain estimates of how much vapor flows towards the heater borehole.

- Measurements of rock displacements will help determine how the mechanical behavior of the rock mass changes fracture apertures.

- 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 the Waste Package Environment Task and are described under a separate SIP. The purpose of these studies will be to detect possible dissolution and precipitation of dissolved materials as water boils and re-condenses in the near-field.

5.4 Limitations

To actually 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. A true repository-scaled test would provide data that is most likely to be representative of the important environmental conditions in the repository such as peak rock temperatures, 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 the waste package curves. This is an intrinsic limitation of the tests which controls the range of environmental conditions which the tests can impose on the near-field rock mass. The other limiting factors are rock properties such as thermal conductivity, which cannot be controlled.

There are a number of scaling trade-offs which 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 is to vary the physical dimensions of items such as emplacement borehole diameter combined with an appropriately adjusted initial power loading.

All of these trade-offs have potentially significant impact on the testing conditions imposed. Scoping calculations will be used to investigate various possible tradeoffs and to select those which impose near-field conditions which provide the most appropriate data sets needed for model validation. The PEBSFT will be designed on the basis of the scoping/sensitivity studies, however, one of the purposes of the prototype tests is to confirm that the physical processes accounted for in the models are both accurate and sufficiently inclusive. Therefore, the PEBSFT 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 which have been considered and their potential impacts on the near-field environment. The discussion applies equally to PEBSFT 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 to a few years, 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 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 and dissolution. A positive consequence of using repository scale power loading for testing is that the thermal and moisture

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gradients that develop are likely to be more representative of repository conditions.

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
- 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 which describes hydrological and thermal evolution of the rock mass system near a heater emplacement borehole.

Data from the various instruments 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 which describes the thermal, hydrologic and chemical evaluation of the geologic environment. This 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 partially saturated rock near the emplacement borehole. 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. (1986) and in the field (Daily and Ramirez, 1989). The water vapor will condense where the temperatures are sufficiently cool. Part of this water might move into the matrix due to capillary tension; 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 fracture water and matrix.

When the dried region is allowed to cool, it is expected to slowly rewet 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 for the rock fracture and porosity parameters of the heat and mass transport model.

Analysis of rock samples will provide information on chemical, mineralogical, porosity and moisture content at various distances from the borehole that have seen a history of temperature and water migration.

The above information, in conjunction with laboratory studies of 1) dissolution/precipitation kinetics and fluid composition and 2) mechanical fracture properties, will provide input to the characterization of factors effecting 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. HFEM, neutron probe and psychrometer systems.

7.0 Quality Assurance

7.1 Compliance with LLNL QA Program

The following elements will be controlled throughout the course of this scientific investigation in accordance with the procedures, methods and requirements identified in the LLNL QA Program:

- Equipment and Materials
- Software
- Calibration

- Recording of Data
- Analysis
- Interfaces
- Procurement
- Training
- QA Records

Test details and details of how the above elements will be implemented and controlled will be described in Technical Implementing Procedures (TIPs) and/or by the methods prescribed in the LLNL QA Procedures (QPs).

Scientific notebooks will be used to record the progress of work and provide traceability of work activities.

7.2 Quality Assurance Level Assignments

Each of the activities identified in Section 4.0 has been assigned a QA Level in accordance with Quality Procedure 2.8 of the LLNL-YMP QA Procedures. The Level Assignment Sheets identify applicable LLNL YMP QA Procedures and are included as an attachment and made part of this document.

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8.0 References

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, June 1989.

Louis, C. (1969). "A Study of Groundwater Flow in Jointed Rock and its Influence on the Stability of Rock Masses." Rock Mechanics Research Report No. 10, Imperial College, London, England.

Maini, Y. N. T., Noorishad, J. and Sharp, J. (1972). "Theoretical and Field Considerations on the Determination of In Situ Hydraulic Parameters in Fractured Rock." Proceeding of the Symposium on Percolation through Fissured Rock, Stuttgart, Germany.

Montazer, P. M. and Hustruiid, W. A. (1983). "An Investigation of Fracture Permeability Around an Underground Opening In Metamorphic Rocks." Technical Report BMI/OCRD-4.5.

Nitao, J. J. (1988). "Numerical Modeling of the Environment of a Nuclear Waste Package Using the Equivalent Continuum Approximation: Horizontal Emplacement." UCID-2144, Lawrence Livermore National Laboratory, Livermore, CA.

Peters, R. R., Klavetter, E. A., Hall, I. J., Blair, S. C., Hellers, P. R., and Gee, G. W (1984). "Fracture and Matrix Hydrologic Characteristics of Tuffaceous Materials from Yucca Mountain, Nye County, Nevada." SAND84-1471, Sandia National Laboratories, Albuquerque, NM.

Preuss, K. (1985). "Tough Users Guide." LBL-20700, Lawrence Berkeley Laboratory, Berkeley, CA.

Preuss, K., Tsang, Y. W. and Wang, S. Y. (1984). "Numerical Studies of Fluid and Heat Flow Near High-Level Nuclear Waste Packages Emplaced in Partially Saturated Fractured Tuff." LBL-18552, Lawrence Berkeley Laboratory, Berkeley, CA.

Ramirez, A. L. (1988). "Nuclear Waste Management Program Nevada Nuclear Waste Storage Investigations Project Test Plan: Prototype Engineered Barrier Design Testing-Horizontal Emplacement." 033-NNWSI-P11.10, in Quality Assurance Program Plan, Nuclear Waste

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Management Project, Lawrence Livermore National Laboratory, Livermore, CA.

Reynolds, W. C., and Perkins, H. C. (1977). "Engineering Thermodynamics." McGraw-Hill, New York, NY. 690p.

Russo, A. D. and Reda, D. C. (1987). "Drying of an Initially Saturated Fractured Welded Volcanic Tuff." SAND87-0293C. Sandia National Laboratories, Albuquerque, NM.

Schraur, T. W. (1984). "Relationship Between the Gas Conductivity and Geometry of a Natural Fracture." MS Thesis, Department of Hydrology and Water Resources, University of Arizona.

Wang, S. Y. and Narasimhan, T. N. (1986). "Hydrologic Mechanisms Governing Partially Saturated Fluid Flow in Fractured Welded Units and Porous Non-Welded Units at Yucca Mountain." SAND85-7114, Sandia National Laboratories, Albuquerque, NM.

Yow, J., Jr. (1985). "Concept for Waste Package Environment Tests in the Yucca Mountain Exploratory Shaft." UCID-20450, Lawrence Livermore National Laboratory, Livermore, CA.

Zeigier, T. W. (1976). "Determination of Rock Mass Permeability." Technical Report S-TAD. Vicksburg, U. S. Army Engineer Waterways Experiment Station.

Zimmerman, R. M. and Blanford, M. B. (1986). "Expected Thermal and Hydrological Environments for Waste Emplacement Holes Based on G-Tunnel Heater Experiments." Proceedings 27th Symposium on Rock Mechanics, Chapter 125, pp. 874-882.

Zimmerman, R. M. and Finley, R. E. (1986). "Summary of Geomechanical Measurements Taken in and Around the G-Tunnel Underground Facility, NTS." SAND86-1015, Sandia National Laboratories, Albuquerque, NM.

Zimmerman, R. M., Nimick, F. B. and Board, M. B. (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.