10-1-85 51 ①

I-23254

⑫

DR-1318-8

UCID- 20450

Concept for Waste Package Environment Tests
in the Yucca Mountain Exploratory Shaft

Jesse L. Yow, Jr.

May 1985

Lawrence
Livermore
National
Laboratory

This is an informal report intended primarily for internal or limited external distribution. The opinions and conclusions stated are those of the author and may or may not be those of the Laboratory.
Work performed under the auspices of the U.S. Department of Energy by the Lawrence Livermore National Laboratory under Contract W-7405-Eng-48.

Nuclear Waste
Management
Projects

DISTRIBUTION OF THIS DOCUMENT IS UNLIMITED

DISCLAIMER

This report was prepared as an account of work sponsored by an agency of the United States Government. Neither the United States Government nor any agency thereof, nor any of their employees, makes any warranty, express or implied, or assumes any legal liability or responsibility for the accuracy, completeness, or usefulness of any information, apparatus, product, or process disclosed, or represents that its use would not infringe privately or publicly owned rights. Reference herein to any specific commercial product, process, or service by trade name, trademark, manufacturer, or otherwise does not necessarily constitute or imply its endorsement, recommendation, or favoring by the United States Government or any agency thereof. The views and opinions of authors expressed herein do not necessarily state or reflect those of the United States Government or any agency thereof.

CONCEPT FOR WASTE PACKAGE ENVIRONMENT TESTS IN THE YUCCA MOUNTAIN EXPLORATORY SHAFT

UCID--20450

DE86 000052

Jesse L. Yow, Jr.
Lawrence Livermore National Laboratory

May 1985

MASTER

DISTRIBUTION OF THIS DOCUMENT IS UNLIMITED

PREFACE

The Waste Package Environment Tests described in this conceptual plan are part of an extensive program of in situ testing being planned by the Nevada Nuclear Waste Storage Investigations (NNWSI) project for the exploratory shaft at Yucca Mountain. This program of testing is described in the NNWSI Exploratory Shaft Test Plan (ESTP), which is in preparation. The ESTP provides the programmatic setting for the Waste Package Environment Tests.

TABLE OF CONTENTS

1.0	Title.	1
2.0	Contact.	1
3.0	Purpose and Rationale.	1
4.0	General Description of Tests	3
5.0	Detailed Description of Tests.	10
5.1	Conceptual Details of Tests	10
5.1.1	Test Under Ambient Moisture Conditions	12
5.1.2	Test Under Simulated Recharge Conditions	13
5.1.3	Test Including Packing Material.	14
5.2	Instrumentation and Supporting Measurements	15
5.2.1	Borehole Instrumentation	15
5.2.2	Geophysical Measurements	17
5.2.3	Petrologic and Geochemical Studies	18
6.0	Location of Tests.	21
7.0	Data Acquisition and Management.	21
8.0	Data Analysis.	24
9.0	Quality Assurance.	25
10.0	Safety	27
11.0	Environmental Effects.	27
12.0	Reports.	27
13.0	Organization Responsibilities and Interfaces	28
14.0	References	29

ABSTRACT

The Nevada Nuclear Waste Storage Investigations (NNWSI) project is studying a tuffaceous rock unit located at Yucca Mountain on the western boundary of the Nevada Test Site, Nye County, Nevada. The objective is to evaluate the suitability of the volcanic rocks located above the water table at Yucca Mountain as a potential location for a repository for high level radioactive waste. As part of the NNWSI project, Lawrence Livermore National Laboratory (LLNL) is responsible for the design of the waste package and for determining the expected performance of the waste package in the repository environment.

To design an optimal waste package system for the unsaturated emplacement environment, the mechanisms by which liquid water can return to contact the metal canister after peaking of the thermal load must be established. Definition of these flux and flow mechanisms is essential for estimating canister corrosion modes and rates. Therefore, three waste package environment tests are being designed for the in situ phase of exploratory shaft testing. These tests emphasize measurement techniques that offer the possibility of characterizing the movement of water into and through the pores and fractures of the densely welded Topopah Spring Member. Other measurement techniques will be used to examine the interactions between moisture migration and the thermomechanical rock mass behavior.

Three reduced-scale heater tests will use electrical resistive heaters in a horizontal configuration. All three tests are designed to investigate moisture conditions in the rock during heating and cooling phases of a thermal cycle so that the effects of these moisture conditions on the performance of the waste package system may be established. The tests are unique in that they address the cooling portion of the thermal cycle. In addition to a number of types of thermomechanical and hydrologic measurements to be made, geophysical techniques will be used to obtain information on moisture conditions in the rock as a function of time and location.

*Work performed under the auspices of the U.S. Department of Energy by the Lawrence Livermore National Laboratory under contract number W-7405-ENG-48.

1.0 Title: Waste Package Environment Tests

2.0	<u>Contact:</u> Lyn Ballou	Jesse Yow, Jr.
	Lawrence Livermore	Lawrence Livermore
	National Laboratory	National Laboratory
	Livermore, CA 94550	Livermore, CA 94550

3.0 PURPOSE AND RATIONALE

The primary purpose of the Waste Package Environment Tests is to provide information about the near field hydrological, thermal, and mechanical environment of the waste package for use in assessing the expected performance of the waste package subsystem. The need for this information is reflected in NNWSI draft Key Issue 1, and Issues 1.9, 1.13, and 1.14 as of April, 1985. The rationale of the tests is driven by the need for this information, but is constrained by the measurement capabilities that can be applied in situ, and by the ability of analytical and numerical models to use the data obtained with the measurements. A secondary purpose of the tests is to provide the option of testing certain components that may be part of the engineered barrier system, such as packing materials.

The Waste Package System Model (see the NNWSI Site Characterization Plan) is being developed to evaluate the expected performance of the subsystem with respect to containment period and release rate performance objectives specified by 10 CFR 60.113. This subsystem performance assessment, which is conducted by LLNL, is part of the overall repository system performance assessment carried out by Sandia National Laboratories (SNL). The purpose of the entire performance assessment effort is to determine the suitability of the Yucca Mountain site as a repository for high level radioactive wastes.

A complete description of NNWSI performance assessment is beyond the scope of this test description (see the NNWSI Performance Assessment Plan, 1985). Nevertheless, many of the types of information required by the performance assessment calculations can be identified from the types of data

required for heat and mass transport modeling of the near field environment. The containment period provided by an emplaced waste package is largely governed by corrosion of the package materials. Corrosion is in turn controlled by the quantities and properties (including temperature) of the water, air, and steam that circulate in the near field environment. Similarly, the transport of radionuclides after containment breach is dependent on fluid flux around the waste form. Thus, the distribution of fluids around the waste emplacement hole must be defined as a function of time and location during the thermal cycle, and particularly after the peak temperatures have passed and cooling occurs, in order for the performance of the waste package subsystem to be assessed. The numerical models that evaluate package corrosion and radionuclide release will use results of near-field environment modeling which will be based on results of Waste Package Environment Tests described here. These detailed analyses of physical and geochemical processes will, in turn, be used to support performance assessment calculations of the waste package subsystem and the overall Yucca Mountain waste disposal system.

The Waste Package Environment Tests will measure several parameters as a function of location and time in the near field environment. The tests include an accelerated thermal cycle to examine the cooling side of the thermal pulse. The parameters to be measured or derived include temperature, moisture content, pore water pressure (matric potential), rock mass deformation, and rock mass stress changes (Table 1 in Section 5.2). Temperatures and pore pressures will be used directly with the moisture content data to define the spacial distribution of liquid water with time around the emplacement hole. Rock mass deformation and stress changes will be used with conceptual models of discontinuity stiffness (Goodman, 1980; and Yow, 1985) to indirectly evaluate average fracture aperture changes; fracture closure is expected to force fluid migration to occur primarily as flow in the porous matrix. This information will be used in fracture flow models to analyze situations where fracture flow mechanisms are dominant. Rock core samples will be obtained before and after the tests to allow laboratory determination of index properties such as porosity, partial permeability, fracture stiffness, and elastic modulus. Such index properties are needed to facilitate integration of Waste Package Environment Test results with the results of other tests.

The data described above will be used in three ways to meet the needs of performance assessment of the waste package subsystem. First, the data, as a function of location and time, will be used to identify the dominant hydrologic mechanisms that are active in the thermally and mechanically perturbed environment around the emplacement hole. These mechanisms are part of the response of the near field environment to the thermal loading (10 CFR 60.21); of particular significance is the relative importance of matrix versus fracture flow during successive stages of the thermal cycle.

Second, data from the in situ tests will be compared with results from laboratory-scale experiments to see how well laboratory tests replicate in situ phenomena (and help meet 10 CFR 60.101). The samples and data will be examined closely for evidence of fracture healing, for example, such as has occurred (Lin and Daily, 1984) during laboratory tests of fracture permeability in tuff samples under varying saturations. Changes in the hydrologic regime surrounding the waste packages could be induced by fracture healing, with the consequences for waste package performance depending in part on the spacial location and degree of healing. Independent of healing phenomena, transient fracture closure under the thermal load may also induce hydrologic changes; this has been documented in heater tests in granite by Montan and Bradkin (1984).

Third, the results of the in situ tests will provide a data set for verification of near field models, and will also (more importantly) verify our understanding of the phenomenology that must be incorporated in the models. Because tests of the waste package environment cannot be conducted at enough locations to create a statistically significant database, the alternative approach of thoroughly understanding the physics of the near field environment must be taken so that models of the waste package environment (10 CFR 60.21) used in performance assessment are defensible.

4.0 GENERAL DESCRIPTION OF THE TESTS

Three reduced-scale heater tests are planned as shown in Fig. 1. Electrical resistive heaters will be emplaced in a horizontal configuration,

Figure 1. Typical plan view for Waste Package Environment Tests based on horizontal emplacement configuration.

although the current reference design for NNWSI is vertical emplacement. The horizontal configuration is generally simpler to emplace, operate, and model. However, if NNWSI reaches a final decision to emplace canisters vertically, the design of this test might be modified as shown in Fig. 2 to reflect this configuration. The capability of horizontally-oriented tests to evaluate hydrological conditions in a fractured porous medium will be the basis upon which a decision is made to reconfigure the tests.

All three tests are designed to investigate moisture movement and saturation conditions in the host rock during heating and cooling periods of waste storage, and possibly to measure the effects of the moisture conditions on performance of parts of the waste package system. The first test (I) will measure moisture movement during the thermal cycle using ambient moisture as the initial condition. The second test (II) will include a simulated heavy percolation event using a water injection system. The third test (III) will include both possible packing materials and a simulated percolation condition to augment Test II results.

The heaters in each test will be cycled through heating and cooling stages such as shown in Fig. 3 to simulate thermal conditions in the waste package environment. The movement of air, steam, and water in the near field around the heater emplacement hole during the temperature cycles will be measured. Critical measurement periods will occur as the maximum drying occurs and when the rock mass temperature subsequently begins to drop below the boiling point of water with the possibility for liquid water to return to the rock matrix and fractures immediately adjacent to the hole. Test I will be performed under ambient rock mass moisture conditions, whereas tests II and III will examine the effect of a single pulse of percolating water which might correspond to an extended period of surface precipitation.

Instruments will be installed in the rock mass around the heaters to measure temperature, moisture content, pore pressure, stress change, and displacement as a function of time and location. High-frequency electromagnetic (HFEM) measurements and other geophysical probes will be used to measure the moisture content in the rock before, during, and after thermal

Figure 2. Typical plan view for Waste Package Environment Tests based on vertical emplacement configuration.

Figure 3a. Thermal loading history to be used in Waste Package Environment Tests.

Figure 3b. Temperatures around the heater emplacement hole resulting from thermal loading of Figure 3a.

cycling in Test I, and to monitor fluid movement through fractures and pores in Tests II and III in which water is added to the near field environment. Rock cores will be obtained before and after the thermal cycles for mineralogical analyses to investigate solution and precipitation of solid phases by steam and hot water, and to compare these results with mineral dissolution evidence which will be available from analyses of water chemistry. Laboratory measurements of relative air and liquid permeability will be made on similar samples. Particular attention will be given to possible fracture healing phenomena.

The design of the Waste Package Environment Tests is focused on determining the distribution of moisture in the near-field environment, particularly after the peak temperatures have passed. This is distinct from most heater tests in crystalline rocks and salt (e.g., Sambeek et al.; 1980 Gregory and Kim, 1981; and Zimmerman, 1983) 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) examined water migration behavior in heated holes in welded tuffs during a heating phase, but discrimination of fracture moisture conditions from matrix moisture conditions in the surrounding rock mass and monitoring of post-thermal behavior were not included. The G-Tunnel experiments were designed to measure in situ thermal conductivity of the rock mass to assess thermal behavior of the partially saturated tuff during the heating phase. It must be emphasized that the Waste Package Environment Tests are the only Exploratory Shaft (ES) tests to address the unloading, or cooling, phase of the thermal cycle. Other ES tests address the loading phase (heating phase) of the thermal cycle (e.g., the Canister Scale Heater Experiment).

Several tests will be carried out during sinking of the Exploratory Shaft and during in situ testing to measure current ambient infiltration rates and mechanisms. These include the Infiltration Test, the Diffusion and Fracture Transport Tests, and the Bulk Permeability Test. They will provide information on ambient hydrologic conditions in the host rock horizon. Other tests to be conducted during the in situ phase of testing will provide

information on stresses and displacements expected from thermal loads for use in repository design. The effects of temperature and stress on joint permeabilities and thermal expansion of the rock mass, for example, will be determined in the Heated Block Test. The effects of pore dewatering on the heat transfer properties of the Topopah Spring welded tuff will be determined by the Heated Block Test, the Waste Package Environment Tests, and the Canister Scale Heater Experiment.

Results from the Heated Block Test, the Canister Scale Heater Experiment, and the Waste Package Environment Tests will be used to determine the importance of spacial scale in extrapolating from laboratory measurements to in situ conditions in the host rock. They will further be valuable in assessing the validity of computer models used to predict rock mass behavior during the thermal cycle. Because of concern regarding the effects of scale on the representativeness of the measurements (which will be particularly critical in a highly fractured, laterally heterogeneous rock mass) large scale in situ tests such as the Waste Package Environment Tests and the Heated Block Test and Canister-Scale Heater Experiment are essential. Since the number of tests that can be performed is limited, a thorough understanding of the interaction of parameters affecting test results is necessary in order to extrapolate those results.

5.0 DETAILED DESCRIPTION OF TESTS

5.1 CONCEPTUAL DETAILS OF TESTS

Three reduced-scale heater tests will be performed as described in this section. Actual test geometry and instrumentation will be based on the results of scoping calculations and instrument evaluations now in progress, and will be described in the engineering test plan for these tests. Figure 4 shows schematically tentative elevation and section views of one of the three tests, and possible positioning of the instrumentation and the heater unit. All three tests are designed to investigate moisture conditions in the host rock during the thermal cycle produced by high-level waste emplacement.

Figure 4. Typical layout for one Waste Package Environment Test.

Electrical resistance heaters will be used to simulate the heat produced by radioactive decay. Preliminary calculations indicate that with a heat loading of approximately 5 kW, the 100°C isotherm will reach a radial position about 1 m into the surrounding rock in approximately three months (as shown in Fig. 3). This thermal loading is higher than that of the reference PWR spent fuel package (O'Neal et al., 1984). A stepped cooldown period of approximately six to nine months may be used to allow the entire rock volume surrounding the heater to drop below 100°C. More refined calculations and modeling will be completed prior to testing to determine the expected time-temperature fields around the heaters. Actual heater power levels will be varied in order to achieve desired temperature profiles; this manipulation will be based on pretest calculations and the temperatures observed in the rock mass as each test progresses. Field confirmation of temperature profiles will provide confidence that simulations of the near-field environment are based on realistic conditions.

Preliminary plans are to drill heater holes approximately 12.2 m (40 ft) into the rock mass. Only the inner 6.1 m (20 ft) will be heated in order to reduce interference from humidity and temperature changes in the drifts. Detailed scoping calculations will be used to determine the minimum required separation of the instrumented heated zone of each test from the drift and from other tests. Similar studies will also be used to determine the optimal spacing and location of instrumentation boreholes, extensometers, stressmeters, and thermocouples so that the rock mass is most heavily instrumented in the zone which experiences vaporization front transitions, and where dehydration of clays or other mineral alteration is anticipated.

5.1.1 Test Under Ambient Moisture Conditions (Test I)

Test I is the simplest of the three and is designed to determine the effects of waste heating and cooling under ambient moisture conditions. This test consists of an electrically heated, thermally-simulated waste package emplaced in a horizontal borehole. Results will provide baseline information for comparison with the hydrologically perturbed conditions in the second and third tests.

The goal of this test is to determine near field thermomechanical and hydrologic properties of the rock mass, and to obtain hydrothermal characteristics and geochemical data for the proposed host rock at Yucca Mountain. The presence of water in fractures will be estimated by methods which obtain a three-dimensional characterization of the rock mass hydrologic response. Volumetric changes in minerals such as phase changes in cristobalite occur due to heat alone, and may induce permeability changes in the near field host rock. Healing of fractures could also occur (Lin and Daily, 1984), so relative permeability measurements will be made in the laboratory on samples acquired from each test location before and after the heating phase. Detailed geochemical and petrologic studies will be used to document changes in near-field host rock. This test can be used to support the relationship of laboratory test results to in situ near-field conditions, and will be important for improving interpretations of laboratory data and for modifying models that are found to be incorrect or inadequate.

5.1.2 Test Under Simulated Recharge Conditions (Test II)

Test II is similar to Test I in basic design except that it will be outfitted with an overlying water injection system so that addition of water can ensure that water and steam behavior near the heater can be monitored during the thermal cycle. Single and multiple horizontal line water sources are under consideration. Ambient rock saturation conditions are variable but might not exceed 50%. With minimal water available in the near-field environment, liquid water may not return to the heater emplacement hole naturally on the time-scale available for testing. It thus may become necessary to add water to the emplacement environment so that these hydrologic and hydraulic conditions can be observed. Depending on how water is added to the system, Test II could represent the percolation caused by a wet climatic period. While Test I may obtain results that can be used to evaluate models of natural moisture conditions, Tests II and III will bracket a range of moisture conditions to ensure that we get data for near-field modeling for performance assessment use.

5.1.3 Test Including Packing Material (Test III)

Test III may be a test of packing material concepts in the in situ environment. Preliminary studies (Oversby, 1984a) show that for canisters containing spent fuel it may be advantageous to include a packing material of crushed, compressed tuff to meet performance objectives for radionuclide control. The choice of a sorptive packing material would result from an expectation that release rates from certain segregated phases in spent fuel may be high enough to require an additional barrier.

Laboratory tests (Oversby, 1984a) suggest that it is possible to fabricate compressed tuff with thermal conductivities that are 60-80% of undisturbed values. If such a packing material can be shown to be likely to remain stable throughout the expected range of temperature and moisture conditions in a repository, then additional assurance can be gained for meeting performance objectives for isolation of radionuclides. Design and testing of crushed, compressed tuffs may be conducted prior to the In Situ Phase of Exploratory Shaft testing. However, if a decision is made to use such a packing material, additional confirmatory tests will be conducted during testing in the Exploratory Shaft.

It has been suggested that under the conditions of low vertical flux expected in the Topopah Spring horizon, there may be natural capillary barriers established between packing materials and surrounding host rock (Roseboom, 1983). Instrumentation similar to that in the other tests will be used to measure the moisture conditions under infiltration from the injection system. Values for matric potential, the driving force in unsaturated flow, will be derived so that performance of the capillary system can be predicted. For such a system to be utilized as part of the waste package subsystem, it would be necessary to show that the capillary barrier would remain effective over the range of expected conditions in the repository after permanent closure.

In the event that consideration of a packing material is discontinued, Test III will provide an opportunity to test the near-field waste package environment under a third set of moisture conditions. With test

results obtained under ambient moisture conditions (Test I) and under two different moisture percolation rates (Tests II and III), we will be able to bracket credible moisture flux scenarios.

5.2 INSTRUMENTATION AND SUPPORTING MEASUREMENTS

5.2.1 Borehole Instrumentation

Possible instrument choices for measuring temperature, moisture content, pore pressure, and rock mass deformation and stress changes are listed in Table 1. Temperature measurements will be made with thermocouples or thermistors or both. Measurement of moisture content and pore pressure in unsaturated media, and of rock mass deformations and stress changes, however, is more difficult. Wilder et al. (1982) documented a number of experiences with geotechnical instrumentation relevant to applications in heated environments, and LLNL has accrued a considerable amount of instrumentation and testing experience during the conduct of the Spent Fuel Test-Climax (e.g., Ganow, 1985; and Glenn and Butler, 1983). The instrument types listed in Table 1 are tentative selections based on these experiences. Instruments that are selected for use in these tests must be able to withstand the rigors of the thermally perturbed conditions for the duration of the tests, or must be replaceable during testing without loss of data. Additional evaluation, testing, and development will lead to final selection and preparation of instruments.

Evaluation of instrument types and measurement techniques for use in the tests is in progress; prototype testing of selected devices will be done prior to actual use in the ES. Instrument calibration is discussed in the section on data acquisition and management, below. All instrument locations will be surveyed, but actual locations of heater and instrument holes will be selected in the ES test drifts on the basis of the geology encountered, and the results of the drift mapping efforts. Core recovered from instrumentation holes will be retained and used by LLNL until completion of the Waste Package Environment Tests and will be subsequently be archived in the project core library.

Table 1. Types of Measurements to Be Performed During the Waste Package Environment Tests.

<u>MEASURED PARAMETER</u>	<u>POSSIBLE METHOD</u>	<u>EXPECTED RANGE OF VALUES</u>
Temperature	Thermocouples and resistance temperature devices	25°C - 250°C
Moisture content	Neutron probe logging	0 - 10% by volume
Pore water pressure or tension	Psychrometer/Tensiometer	0.7 - 2.5 bars
Presence/absence of water in fractures	High-frequency electromagnetic geotomographic imaging between boreholes	To be determined
Water chemistry	Analytical chemistry in laboratory	<u>See Table 2</u>
Permeability	Laboratory mass flow rate testing	3 - 12 μ da
Rock Chemistry and Mineralogy	Microprobe, X-Ray, scanning electron microscope (SEM)	NA
Rock mass displacement	Borehole extensometers	0 - 5 mm
Rock mass stress changes	USBM borehole deformation gauges	< 30 MPa

NOTES: 1. Actual measurement techniques will be selected on the basis of data needs and usage in keeping with the types of instruments available for obtaining the needed data.

2. Value ranges are estimated from LLNL experiences with the Spent Fuel Test--Climax (Patrick et al. 1982, 1983, 1984) and from scoping calculations now in progress.

5.2.2 Geophysical Measurements

High frequency electromagnetic (HFEM) geotomography is being evaluated as a method to obtain two-dimensional fluid-flow profiles (Ramirez and Daily, 1984). This technique involves monitoring variation with time of electromagnetic wave attenuation between transmitting and receiving antennas positioned in boreholes surrounding the heater unit. Images of water saturation in the host rock can then be constructed from the measured signal attenuations. Two-dimensional images from differing orientations can be used to visualize the fluid migration in three dimensions. Previous experience using electromagnetic probes to map water distribution underground at three different sites gave encouraging results (Ramirez et al., 1982). This technique may be particularly useful for mapping water which occupies fractures; it is being evaluated by LLNL in field trials at G Tunnel and at Livermore for use in the Waste Package Environment Tests.

The images constructed from electromagnetic wave attenuation induced by fluid-filled porosity are called geotomographs. HFEM measurements near the heater tests will require several 5 cm diameter boreholes similar to those shown in Fig. 4. If used, HFEM imaging will be carried out three times as a minimum: before heating, during heating, and after the formation temperature has dropped below 100°C. For Tests II and III, imaging will be performed several times during the cooling period to monitor details of water movement as the 100° isotherm collapses. Real time data processing of color coded tomographs will allow expedient evaluation of the test.

Use of HFEM methods in the waste package environment tests will require: (1) Construction of antennas from ceramic insulated cables for use at temperatures to 200°C; (2) Laboratory measurements of complex dielectric constants in samples of the Topopah Spring Member as a function of water content, temperature, and clay content; and (3) Modeling of signal reflections from the heater and other metallic objects (e.g., thermocouples) in the host rock to determine distortion effects on the geotomographs. Rock bolts and other ground support components will not penetrate the test zones in order to minimize the problem with reflected signals. Each geotomograph might include

a total of about 1800 data points, requiring about six hours of data collection and data processing. Scoping calculations indicate that such a tomograph would have a 3-5 cm spacial resolution.

Other geophysical methods will be used to obtain redundancy in moisture measurements during the tests. The neutron probe methods for measuring moisture content, for example, are not temperature-sensitive (although certain probe components may be). When a neutron source is placed in a medium containing hydrogen (as in water), the flux of neutrons at any point in the medium depends strongly on the hydrogen content. Although the flux also depends somewhat on the bulk density of the medium and (especially in the case of thermal neutrons) on the elemental composition, this dependence is unimportant in our situation because the density and elemental composition will remain relatively constant throughout the tests. Neutron methods therefore complement the HFEM method well.

Neutron probes are most sensitive at low water content. To take advantage of this sensitivity, the probes must be calibrated in the medium in which they will be used. Such calibrations are required to eliminate data sensitivity to elemental composition, and should be repeated each time the probes are used to compensate for changes in electronics and decay of the radioactive sources. Blocks of tuff from the Topopah Spring member with known water content should be used to calibrate the probes. If this is not possible, then samples of the tuff must be crushed and reconstituted with known water content and used for calibration. Because of the high sensitivity of the neutron method at volume fractions of water below 0.10, it is likely that the accuracy of the measured water content in the ES tests will be limited by the accuracy of our knowledge of the water content in the calibration blocks.

5.2.3 Petrologic and Geochemical Studies

In Tests II and III, the water added to the waste package environment might be sufficient to allow selected dissolution of minerals in the zones penetrated by hot fluids, and concomitant precipitation of the dissolved material as the water migrates to cooler portions of the rock. This is a

potential mechanism for inducing changes in permeability in the near-field and should be evaluated in situ as well as in laboratory experiments (Lin and Daily, 1984). Table 2 lists water chemistry data for background information; detailed information on rock chemistry is summarized by Knauss (1984).

Preliminary laboratory experiments in temperature gradients (Morrow et al., 1983) suggest that major changes in permeability are unlikely, but other experiments (Lin and Daily, 1984) have encountered fracture healing phenomena. Changes in permeability could be either beneficial or detrimental. For example, mineral coatings (e.g., amorphous silica) deposited along fracture surfaces may lower retardation values for the bulk rock, providing reduced isolation capabilities. Filling of presently open fractures with silicate minerals could provide a seal against penetration of water into the near field following the thermal pulse, or conversely it may provide a seal around the canister which will hold water that might otherwise have drained away. The relative importance of these various scenarios will be evaluated based on the test results. Detailed near-field geochemical and petrologic studies of both pre- and post-test samples using scanning electron microscope and microprobe techniques will allow determination of changes in solid rock material. It is important to determine the spacial dimensions over which the rock is altered to provide the basis for extrapolation to repository-scale processes.

Uncertainty in our understanding of the relationships between matrix permeability and fracture permeability under unsaturated flow conditions requires that small-scale laboratory experiments receive field confirmation. Macroscopic processes may be different and should fractures and joints become healed by precipitation of mineral phases during or shortly after the thermal pulse, it is possible that a number of waste packages could be exposed to locally "perched" water. The occurrence of perched water can be included in waste package design and reliability analyses if it is confirmed, but field studies are required to determine the likelihood that such an event will occur.

Table 2. Estimate of Steady-State Water Chemistry for the
Topopah Spring Tuff - J-13 Water System (Oversby, 1984b)

Element	Concentration in ppm at			
	25°C*	90°C	120°C	150°C
Al	0.01	0.4	1.2	1
B	0.13	0.1	0.1	0.1
Fe	0	0	0	0
Si	27	49	81	122
Ca	12.5	8	3.5	3
Mg	1.9	0.2	0.1	0.1
K	5.1	9	9	9
Na	44	40	45	40
F	2	2	2	2
Cl	7	7	7	7
NO ₃	9	9	9	9
SO ₄	18	18	18	18

* ambient J-13 water

6.0 LOCATION OF TESTS

The reference horizon for a potential repository at Yucca Mountain is the densely welded, devitrified portion of the Topopah Spring Member of the Paintbrush Tuff (Vieth, 1982). The water table at Yucca Mountain is more than 500 m below the central portion of the mountain; as a result, the Topopah Spring Member lies entirely within the unsaturated zone. The matrix porosity of the welded tuff is approximately 13 percent, and the rock has a fracture frequency of 0.8 to 3.9 fractures per meter (Dudley and Erdal, 1982).

The Waste Package Environment Tests will be located in the drifts described in ESTP Part I, Chapter 6, at a depth of about 365 m (1200 ft) in the Exploratory Shaft. The tests will be installed using boreholes and alcoves such as shown in Fig. 1. The tests will be separated from one another by at least 6.1 m (20 ft) based on initial scoping calculations and the need to avoid interaction of the individual tests. This planned minimum separation will be refined as scoping and design calculations proceed. The actual test locations within the access drift will be very dependent on local geology.

7.0 DATA ACQUISITION AND MANAGEMENT

Periodic scanning of instruments measuring temperature, pressures, displacements, and stress changes around the heater emplacement holes will be required. Measurements must be made at surveyed locations in the rock mass in addition to measurements within the emplacement holes adjacent to the heaters. Planned locations of the rock mass displacement and stress change measurements will be specified in the detailed engineering test plan, but will be modified in the field to suit local conditions.

Table 3 summarizes the expected types, numbers, and resolutions of the principal transducers to be used. The maximum and steady-state scan rates are shown together with the periods of time during which those rates will be operational. Based on previous field test experiences, permissible downtimes are given for both the steady-state and the more critical ("maximum scan")

TABLE 3 TRANSDUCER SCANNING REQUIREMENTS

Transducer Type	Number of Transducers ^a	Range	Resolution	Scan Rate		Scan Period ^d	Permissible Downtime	
				Maximum ^b	Steady ^c	Steady ^c	Maximum ^b	Steady ^c
				Scan Rate	State		Scan Rate	State
Thermocouple	486	25°C-250°C	0.1°C	15 min	60 min	18 months	1 hr	24 hr
Resistance temperature device	42	25°C-250°C	0.01°C	"	"	"	"	"
USCM cell	72	0-30 MPa	0.2 MPa	30 min	4 hr	"	8 hr	24 hr
Borehole extensometer	144	0-5 mm	10 μ m	30 min	4 hr	"	8 hr	24 hr
Prototype moisture instrumentation	72	0.7-2.5 bars $\pm$ 5%		15 min	60 min	"	1 hr	24 hr

Notes:

- a Includes all three waste package environment tests, but 151 separate control channels are not shown.
- b "Maximum scan rate" refers to the critical stages (of 10 to 30 days) immediately preceding and immediately following changes in thermal load patterns.
- c "Steady state" refers to the relatively long periods of monitoring following adjustments in heater energy levels.
- d This period could be extended if necessary for long term monitoring.

times during which rapid responses of the rock and packing materials are anticipated. The permissible downtime figures apply to discrete events which are widely separated in time. An overall system availability of 90% or better is required.

Connection boxes will be mounted in the drifts near the tests. Transducers and wiring from the instruments to the boxes will be provided and installed by LLNL and its subcontractors; point-to-point wiring from the boxes to the data alcove will be provided as part of the ES facilities. Current plans assume that appropriate data scanners and digital multimeters (DMMs) will be provided by the Integrated Data System (IDS). These systems will handle both analog and digital signals. The facility uninterruptible power supply (UPS) should be adequate for the Waste Package Environment Tests. However, large variable loads (such as heaters) will not be connected to the instrumentation UPS unit since this practice would jeopardize overall IDS performance. The heaters will therefore be provided with a separate power source that can be interrupted for a maximum of one hour.

Instruments will be grounded at the individual transducers. DMMs will not be grounded since this would create ground loops which introduce noise in the acquired data. Grounded cable trays will be provided for the physical and electromagnetic shielding of all wires that carry data signals. A copper ground buss will provide equal ground potential throughout the experimental area. Separate trays will be provided for signal and power cables; these trays will be separated by a minimum of two meters. Cabling provided as part of the IDS will consist of individually shielded twisted pairs with an overall shield and drainwire referenced to ground.

The IDS will supply temperature and voltage standards for on-site use. All on-site calibrations will use the "systems" philosophy. Thus, calibration data is acquired through the IDS just as normal test data is acquired. Calibration of commercial DMMs; system standards such as current, voltage, and resistance sources; temperature calibration baths; and similar devices will be in accordance with manufacturers specifications or with standards traceable to those of the National Bureau of Standards (where they exist). Results of calibrations will be entered into IDS data conversion

software. Calibrations will be performed both before and after each of the tests. Specific sensor calibration procedures and designs of sensor installations will be provided as part of the detailed engineering test plans.

All test data and related information will be incorporated into summary reports, and raw data will be stored in NNWSI project files according to QA procedures (LLNL, 1985). Raw data will be retained permanently since this is the purest form in which the data exists. From raw data, any reconversion scheme may be applied without compounding errors present in converted data. Therefore, LLNL will independently archive raw data (copies of IDS magnetic data tapes) from the Waste Package Environment Tests.

Although raw data will be permanently archived, raw data will be converted to engineering units on the IDS. Data reduction software will be ready for use prior to the start of Test I. This approach will permit data analysis and responses to instrument and control system malfunctions in close to real time. The IDS will provide remote alarming capability for selected test status and control instruments. This capability will be made available through dial-up modem connections between LLNL-Livermore and the IDS, or may utilize the generally more reliable leased-line connections.

8.0 DATA ANALYSIS

Numerical models for predicting rock mass thermomechanical and hydrothermal responses will be adapted from those available in the NNWSI program. ADINA and ADINAT are finite element codes that will be used to model the thermomechanical behavior in the near-field waste package environment. HFEM data will be processed using data reduction codes available at LLNL. Geochemical models such as EQ3/6 (Wolery et al., 1984) will be used to establish probable changes in rock and water chemistry. Observed rock and water chemistry will then be modeled in an iterative mode to determine the basis for any differences between measured and anticipated response. In this manner, an understanding of near-field hydrothermal processes will be developed. Knowledge of these processes is critical for extrapolation of near-field results to repository scale behavior of rock and water after waste package emplacement, as described in Section 3.0, Purpose and Rationale.

Current plans for scoping calculations also include use of the WAFE code (Daniels, et al., 1982), or a similar hydrothermal transport code, to calculate two-component, two-phase mass and heat transport in porous media. WAFE solves the conservation equations for mass (air, vapor and liquid) and energy (in the fluid and in the solid matrix). Velocity fields are modeled using nonlinear flow equations, and condensation and evaporation are included. The code can be used to provide the time dependent evolution of pressure, temperature and saturation fields for a heat source and boundary conditions. Material properties needed for input to the WAFE code include permeability (saturated), porosity, grain density, average grain size, thermal conductivity (dry), specific heat (dry), relative permeability (air and liquid) vs. water saturation, and matric potential vs. water saturation. These properties will be available from laboratory measurements. The field monitoring of the temperature, moisture, and pressure values will then be used for code calibration. The WAFE code does not include thermomechanical effects. However, field monitoring of stresses and displacements will permit these effects to be included in revised or coupled codes, if necessary. Fracture flow has not yet been explicitly included in WAFE or any similar code for NNWSI.

Preliminary WAFE calculations suggest that vapor pressures on the order of 0.8-0.9 MPa may occur in the 170°C to 200°C temperature range under conditions of no migration of water and steam. Further results from this code and from thermomechanical modeling will be used to guide placement of instrumentation around the heater emplacement holes, and after the tests are completed the codes will be useful for modeling the results for comparison of predictions and observations.

9.0 QUALITY ASSURANCE

As specified in the Waste Package Task Quality Assurance Plan, all activities will follow requirements and procedures established in the LLNL Nuclear Waste Management Project (NWMP) Quality Assurance Program Plan. The results of the Waste Package Environment Tests tentatively are designated as

being Quality Level I, because of their role in site characterization and in evaluating waste package performance.

As the detailed engineering test plan is developed for these tests, quality level assignments will be made for individual activities and items using LLNL Procedure 033-NNWSI-P. 20.0, Quality Level. This will be done working backwards through the activity sequence; using the quality level of the end result as a starting point. As an example, the site characterization data obtained from a borehole instrument may be assigned to the Level I category. Instrument calibration might also be a Level I activity because of its direct impact on the data. Surveying of the instrument location within the borehole may also be Level I, but instrument installation might be Level II and borehole drilling might be Level III because of their relative roles with respect to the quality of the data.

Procedures will be developed as needed to fulfill the quality requirements so as to assure that the required levels of quality are attained by the test activities. These quality requirements are grouped into broad categories such as are listed below:

033-NNWSI-R. 3.0	Design Control
033-NNWSI-P. 4.0	Procurement Document Control
033-NNWSI-P. 5.0	Instructions, Procedures and Drawings
033-NNWSI-R. 6.0	Document Control Drawings
033-NNWWI-R. 7.0	Control of Purchased Materials, Equipment and Services
033-NNWWI-R. 8.0	Identification and Control of Materials, Parts and Components
033-NNWSI-R. 9.0	Control of Processes
033-NNWSI-R. 10.0	Inspection
033-NNWSI-R. 11.0	Test Control
033-NNWSI-R. 12.0	Control of Measuring and Test Equipment
033-NNWSI-R. 13.0	Handling, Storage and Shipping

033-NNWSI-R. 14.0	Inspection, Test, and Operating Status
033-NNWSI-P. 15.0	Nonconformances
033-NNWSI-P. 16.0	Corrective Action
033-NNWSI-P. 17.0	Quality Assurance Records
033-NNWSI-P. 18.0	Audits
033-NNWSI-P. 19.0	Software Quality Assurance
033-NNWSI-P. 20.0	Quality Level
033-NNWSI-P. 21.0	Training
033-NNWSI-P. 22.0	Technical Review of Publications

10.0 SAFETY

Safety aspects of the Waste Package Environment Tests will in general be covered by ES standard operating procedures. Any safety-related issues that are identified during development of the detailed engineering test plan (or later in other stages of the work) that are not covered by established procedures will be dealt with by means of revision of the operating procedures or by developing a new procedure. There are no special safety related concerns that are unique to these tests.

11.0 ENVIRONMENTAL EFFECTS

No environmental consequences are anticipated beyond those associated with the whole Exploratory Shaft activity.

12.0 REPORTS

Several types of reports will be used to document and disseminate the progress and results of the Waste Package Environment Tests. In addition to weekly, monthly, and quarterly progress reports, technical presentations, and papers in refereed technical publications, the following reports (which are subject to 033-NNWSI-P. 22.0) will be used:

- conceptual test plan in the NNWSI ESTP (this document)
- detailed engineering test plan
- preliminary results of test under ambient moisture conditions
- preliminary results of test under simulated recharge conditions
- preliminary results of test including packing material
- final report of Waste Package Environment Test results

The reports of preliminary results and the final report will document the data resulting from the tests, its reduction and analysis, and the interpretation of the results. These interpretations will answer the questions raised in section 3.0 on test purpose and rationale.

Releases of unchecked, unreduced data may be required by agreement between DOE and NRC; these will be treated separately.

13.0 ORGANIZATIONAL RESPONSIBILITIES AND INTERFACES

The Waste Package Environment Tests will be conducted by LLNL. Test support will be provided as required by the NTSO contractors. Interfaces to the Integrated Data System (IDS), which is a Los Alamos National Laboratory (LANL) responsibility, are currently included in the test plan, and will continue to be defined as the work of the Exploratory Shaft Test Plan Committee progresses toward issuance of a final Test Plan. After that time, interfaces will be handled by the experimenters and the IDS representatives. ES in situ test scheduling will be coordinated by Science Applications International Corporation (SAIC) through PERT-type networks; periodic update information will be furnished to SAIC for this purpose. Other interfaces include those with the USGS for geologic and hydrologic data, and with SNL for comparison of thermomechanical measurement data. Test results will be used in LLNL's waste package performance assessment, which interacts with the SNL repository performance assessment.

14.0 REFERENCES

Daniels, W. R., et al, 1982. Summary Report on the Geochemistry of Yucca Mountain and Environs, LA-9328-MS, Los Alamos National Laboratory, Los Alamos, NM.

Dudley, W. W., Jr, and B. R. Erdal, 1982. "Site Characterization for Evaluation of Potential Nuclear Waste Isolation at Yucca Mountain, Nevada," in Proceedings of the 1982 National Waste Terminal Storage Program Information Meeting, DOE/NWTS-30, pp. 10-12.

Ganow, H. C., 1985. The Negative Hysteresis Problem Associated with the U.S. Bureau of Mines Borehole Deformation Gauge, Lawrence Livermore National Laboratory, in final preparation.

Glenn, H. D. and L. S. Butler, 1983. Evaluation of the Irad Sonic Extensometers for Application in the Canadian Underground Research Laboratory, UCID-19982, Lawrence Livermore National Laboratory, Livermore, CA.

Goodman, R. E., 1980. Introduction to Rock Mechanics, John Wiley & Sons, New York, NY.

Gregory, E. C. and K. Kim, 1981. "Preliminary Results from the Full-Scale Heater Tests at the Near-Surface Test Facility," in Proceedings of the 22nd U.S. Symposium on Rock Mechanics, pp. 137-142.

Johnstone, J. K. and Hadley, G. R., 1980. "In Situ Tuff Water Migration/Heater Experiment", in Proceedings of the 1980 National Waste Terminal Storage Program Information Meeting, ONWI-212, pp 355-358.

Knauss, K. G., 1984. Petrologic and Geochemical Characterization of the Topopah Spring Member of the Paintbrush Tuff: Outcrop Samples Used in Waste Package Experiments, UCRL-53558, Lawrence Livermore National Laboratory, Livermore, CA.

Lin, W. and W. Daily, 1984. Transport Properties of Topopah Spring Tuff, UCRL-53602, Lawrence Livermore National Laboratory, Livermore, CA.

Lawrence Livermore National Laboratory (LLNL), 1985. Quality Assurance Program Plan, Nevada Nuclear Waste Storage Investigations.

Montan, D. N. and W. E. Bradkin, 1984. Heater Test 1, Climax Stock Granite, Nevada, UCRL-53496, Lawrence Livermore National Laboratory, Livermore, CA.

Morrow, C. A., Moore, D. E., and Byerlee, J. D., 1983. "Permeability and Fluid Chemistry of Some Nevada Test Site Tuffs", MRS Meeting, Boston, Nov. 1983 (abstract).

Nuclear Regulatory Commission (NRC), 1983. 10 CFR Part 60, Disposal of High-Level Radioactive Wastes in Geologic Repositories.

O'Neal, W. C., D. W. Gregg, J. N. Hockman, E. W. Russell, and W. Stein, 1984. Preclosure Analysis of Conceptual Waste Package Designs for a Nuclear Waste Repository in Tuff, UCRL-53595, Lawrence Livermore National Laboratory, Livermore, CA.

Oversby, V. M., 1984a. Reference Waste Forms and Packing Material for the Nevada Nuclear Waste Storage Investigations Project, UCRL-53531, Lawrence Livermore National Laboratory, Livermore, CA.

Oversby, V. M., 1984b. Reaction of Topopah Spring Tuff with J-13 Water at 120°C, UCRL-53574, Lawrence Livermore National Laboratory, Livermore, CA.

Patrick, W. C., L. B. Ballou, T. R. Butkovich, R. C. Carlson, W. B. Durham, G. L. Hage, E. L. Majer, D. N. Montan, R. A. Nyholm, N. L. Rector, D. G. Wilder, and J. L. Yow, Jr., 1982. Spent Fuel Test-Climax: Technical Measurements Interim Report Fiscal Year 81, UCRL-53294, Lawrence Livermore National Laboratory, Livermore, CA.

Patrick, W. C., L. B. Ballou, T. R. Butkovich, R. C. Carlson, W. B. Durham, G. L. Hage, E. L. Majer, D. N. Montan, R. A. Nyholm, N. L. Rector, D. G. Wilder, and J. L. Yow, Jr., 1983. Spent Fuel Test-Climax: Technical Measurements Interim Report Fiscal Year 82, UCRL-53294-82, Lawrence Livermore National Laboratory, Livermore, CA.

Patrick, W. C., T. R. Butkovich, R. C. Carlson, W. B. Durham, H. C. Ganow, G. L. Hage, E. L. Majer, D. N. Montan, R. A. Nyholm, N. L. Rector, F. J. Ryerson, H. Weiss, and J. L. Yow, Jr., 1984. Spent Fuel Test-Climax: Technical Measurements Interim Report Fiscal Year 83, UCRL-53294-83, Lawrence Livermore National Laboratory, Livermore, CA.

Ramirez, A. L., Deadrick, F. J., and Lytle, R. J., 1982. Cross-borehole Fracture Mapping using Electromagnetic Geotomography, UCRL-53255, Lawrence Livermore National Laboratory, Livermore, CA.

Ramirez, A. L. and W. D. Dailly, 1984. Preliminary Evaluation of Alterant Geophysical Tomography in Welded Tuff, UCID-20289, Lawrence Livermore National Laboratory, Livermore, CA.

Roseboom, E. H., 1983. Disposal of High-Level Nuclear Waste Above the Water Table in Arid Regions, USGS, Geological Survey Circular 903.

Van Sambeek, L. L., R. G. Hickney, and R. A. Wagner, 1980. "Thermomechanical Assessment of In Situ Heater Tests in Dome Salt at Avery Island, Louisiana," in Proceedings of the 21st U.S. Symposium on Rock Mechanics, pp. 175-182.

Vieth, D. L., 1982. "Nevada Nuclear Waste Storage Investigations Project Overview," in Proceedings of the 1982 National Waste Terminal Storage Program Information Meeting, DOE/NWIS-30, pp. 9-10.

Wilder, D. G., F. Rogue, W. R. Beloff, E. Binnall, E. C. Gregory, 1982. Executive Committee Report, Geotechnical Instrumentation Working Group Meeting, UCRL-87183, Lawrence Livermore National Laboratory, Livermore, CA.

Wolery, T. J., D. J. Isherwood, K. J. Jackson, J. M. Delany, and I. Puigdomenech, 1984. EQ3/6: Status and Applications, UCRL-91884, Lawrence Livermore National Laboratory, Livermore, CA.

Yow, J. L., Jr., 1985. Field Investigation of Keyblock Stability, UCRL-53632, Lawrence Livermore National Laboratory, Livermore, CA.

Zimmerman, R. M., 1983. "First Phase of Small Diameter Heater Experiments in Tuff", in Proceedings 24th U.S. Symposium on Rock Mechanics, pp. 271-282.