Scientific Investigation Plan

For

Large Block Testing of Coupled Thermal-Mechanical-Hydrological-Chemical Processes

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WBS 1.2.2.2.4
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ENCLOSURE 1

SCIENTIFIC INVESTIGATION PLAN

FOR

YMP WBS ELEMENT 1.2.2.2.4

LARGE BLOCK TESTING OF COUPLED THERMAL-MECHANICAL-HYDROLOGICAL-CHEMICAL PROCESSES

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1.0 Purpose and Objectives

The purpose of this Scientific Investigation Plan (SIP) is to describe tests to be performed on a large block of welded rhyolitic tuff, from the same rock formation as that in the potential repository horizon at Yucca Mountain, Nevada. The tests are intended to gather preliminary data to evaluate critical concepts relating to the coupling of thermal, mechanical, hydrological, and chemical processes, in order to develop models of the performance of a nuclear waste repository. These models will provide the basis for design of tests to be performed in the Exploratory Studies Facility as part of the Engineered Barrier System Field Tests (EBSFT). Data and models developed through the EBSFT will be used to predict actual repository performance. This group of tests will be identified by the Work Breakdown Structure (WBS.) element 1.2.2.2.4, Large Block Tests (LBT) of Coupled Thermal-Mechanical-Hydrological-Chemical (TMHC) Processes. This SIP is intended to contain concepts and plans of the LBT. Detailed description of testing activities, requirements, and constraints will be included in Activity Plans (AP). Detailed information of construction related activities will be included in Job Package (JB) and Test Planning Package (TPP). This SIP contains schedule information for planning purpose only. Official cost and schedule of the LBT are in PACS.

The LBT will provide a series of tests on a block of rock which is closer in scale to the repository than previous heater test blocks, will be able to be characterized from five exposed surfaces, and will be dismantled after testing for further characterization. Knowledge of the fracture characteristics is essential for developing an understanding of the coupled TMHC processes, especially the geochemical processes.

The large block test will meet three objectives:

1) It will improve understanding of the coupled TMHC processes needed to develop models to predict the long-term, near-field performance of a nuclear waste repository.

2) It will provide preliminary data for the development of those models, which will be more rigorously tested under full Quality Assurance controls in the EBSFT.

3) It will develop and evaluate measurement systems and techniques to be used in the EBSFT, which will be controlled by study plan 8.3.4.2.4.4 that has been prepared separately.

The LBT consists of two parts: 1) laboratory testing and validation of some coupled process concepts on small blocks quarried from the region adjacent to the large block, and 2) an attempt at integrated simulation and evaluation of the coupled TMHC processes in a large, in situ block. The LBT first requires the identification of a block of suitably fractured rock at least three meters square, and at least 4.5 meters tall, which will be isolated in the field. This block will be fitted with thermal and moisture barriers, a load retaining frame capable of duplicating repository-level stresses, heater assemblies, and instruments to monitor temperature, moisture content, relevant chemical parameters, stress, and displacement. Tests on the small blocks will be started before the test on the large block. Information obtained from the small block tests will be fed into the large block test design and operation.

The TMHC responses will be monitored at ambient temperature and pressure, then through a sequence of pressurization, heating, cooling, depressurization and return to ambient conditions. Infiltration of water into the heated block will be investigated at a boundary condition of what could occur in a repository. Fluid (liquid and gas) will be sampled at intervals across the block and through time. Rock block and fracture properties will be determined before and after the tests.

Smaller blocks measuring up to a few tens of centimeters in each dimension will be removed from the rock directly adjacent to the large block. These will be tested in the laboratory to measure thermal-mechanical processes such as thermal fracturing characteristics, fracture propagation, and fracture surface variations. They will also be used to test concepts of thermal-hydrological and geochemical processes not readily investigated in the large block, such as one-dimensional dehydration and rehydration, fracture-matrix interaction, condensation along fracture walls, and refluxing of water in fractures. Geochemical studies will include rock-water interactions along fractures and in the matrix.

The critical hypotheses to be addressed in the LBT and EBSFT are the following:

1) Does heat conduction dominate heat flow?

2) Are fracture density and connectivity sufficient to promote rock dry-out due to boiling and condensate shedding?

3) Does rewetting of the dry-out zone back to ambient saturation, by the moisture driven away during the boiling/dry-out period, significantly lag behind the end of the boiling period?

4) Do geochemical and geomechanical processes alter the thermal-hydrological performance?

The LBT provides a bridge between the laboratory tests (on core and small block samples) and in situ field tests. Figure 1 shows a logical testing sequence for disposal of nuclear wastes in a deep geological repository. The scale of the LBT is one step closer to that of in situ field tests so that the effect of scale on the laboratory test result can be evaluated. The block will be large enough for studying the effects of multiple fractures and inhomogeneities on the coupled TMHC processes; this is not possible in the laboratory testing of small samples. As shown in Fig. 1, currently prototype field tests are not in official plans, therefore the LBT will serve the purpose of testing methodologies and instrumentation that will be used in field tests at some risk since the LBT environment is different than that of the ESF. However, the

LBT can not replace either the accelerated testing portion of the prototype field test or the in situ field tests.

Results from the heater test in G-Tunnel (Ramirez, 1991) and model calculations (Buscheck, et al 1993) indicate that, above an areal power density (APD) threshold, the near-field environment of a nuclear waste repository will consist a boiling/dry-out zone and a condensate zone. The rock in the near field will be subject to thermal loading that may create new fractures and displacement on existing fractures. This thermal-mechanical process will affect the movement of moisture. The dehydration and rehydration process will affect rock-water interaction. In turn, the rock-water interaction will affect the mechanical and hydrological properties of the rock. The coupled TMHC processes must be understood in order for models to correctly predict the near-field environment. Experience from the G-Tunnel test called for a 3-dimensional coverage of a test region with sensors in order to obtain useful information for understanding the processes. The LBT is designed to create a controlled experimental condition so that some of the coupled TMHC processes can be observed and some model concepts can be tested. Specifically, the LBT will try to determine the bulk heat transfer mechanism, to monitor the relationship between dry-out and boiling of pore water, to monitor condensate refluxing and its effect on geochemistry, and to determine the time lag between the dry-out and re-wetting of the rock in the block.

The maximum temperature in the block will not exceed 130°C; the steady state vertical thermal gradient will be no more than

1.8°C/m. These conditions can simulate all thermal loading strategies in which the near-field temperature is above the boiling point of water.

For the larger-block testing, the effect of scale, inhomogeneities, and fractures on coupling the processes observed in the testing of smaller blocks will be studied. A block will be chosen that contains appropriate fractures and that measures at least 3 m on each side and at least 4.5 m tall. The dimensions were determined by applying similar criteria that will be used for the EBSFT. The geometric scale and duration of testing for the EBSFT will be determined based on (1) sufficient volume of rock heated to include about 100 fractures, (2) sufficient time so that tests will not be excessively overdriven - allows for geochemical equilibrium to be established, and (3) establishment of zones adequate for geochemical sampling. Based on these criteria, the tentative design of the EBSFT includes a volume of rock heated above the boiling point of water of at least 20 m diameter with a test duration of 5-7 years (Wilder 1993). This size is not feasible for the LBT, and the LBT duration of 5-7 years would defeat its purpose because the results will not be obtained in time to be of use in the EBSFT, which is scheduled to begin in 1996. Therefore, the criteria for the LBT are that a block of sufficient size be tested to include: (1) at least 10 fractures to allow for the widely observed ratio of less than 10% of fractures accounting for 90% of flow in fractured rock (a minimum of 10 fractures should be included in the test area so that at least one major fracture can be expected), (2) that will allow for a zone of condensate (where refluxing can be established) to form above the coalesced boiling front above multiple heaters, and (3) where condensate drainage between heaters can be monitored. If fracture densities are similar for Fran Ridge and for the potential repository horizon, a block of about 3 m on a side will include at least 10 fractures. Preliminary field observations indicate that fracture densities at Fran Ridge will result in about 10 - 20 fractures. With heaters spaced approximately 0.6 m apart (reflection of extraction ratios for a repository), at least 3 heaters could be included in a block of 3 m size. While a larger block would be desirable, the thickness of loading frame plates becomes excessive for blocks greater than 3 m in size.

The block will be isolated on an outcrop in the field. Figure 2 shows an idealized testing setup. Thermal and moisture barriers will be installed around the outside of the block so that the movement of moisture in the block is similar to a one-dimensional problem. A load-retaining frame will be assembled around the block; the frame will allow loading with a stress similar to the in situ principal stress at the repository horizon. Loading the block with the approximate in situ stresses is not to return the physical conditions in the surface outcrop rock to that at the potential repository horizon at Yucca Mountain. The purposes of loading the block are as follows: (1) The mechanical responses of the block interior to heating and subsequent cool-down will be subjected to similar mechanical constraints as at the potential repository horizon. (2) The stress at contact points on fracture surfaces in the block will be similar to that in situ, so that the effects of stress on rock-water interaction in the block will be similar to those in situ.

Fluid in the block will be sampled and fluid transport in fractures will be monitored. Heater assembly(s) will be installed in boreholes in the block. However, the LBT will not simulate emplacement modes, rather will create a controlled experimental condition for testing some model concepts. We can select a ratio of the heater hole diameter to the heater diameter so that it simulates drift emplacement. As such, although it may look like horizontal borehole emplacement, it is typical of the current trend towards drift (horizontal) emplacement. Instruments installed in the rock block will monitor such parameters as temperature, moisture content, pH, concentration of some chemical species (such as oxygen, Cl^-, F^-, HCO_3^-, Si, Na, K, and CO_2), and stress and strain. The chemical monitoring can be done by installing probes in the block or collecting fluid samples. The mechanical responses, moisture movement, and chemical processes will be measured during heat-up and subsequent cool-down of the block. Results of the first test will be evaluated to determine subsequent tests, including infiltration of water into the heated block, to be done on the block. Rock and fluid (water and gas) will be sampled, and fracture geometry measurements will also be made before and after the tests. The block will be characterized before and after the tests to investigate the effect of heating on mineralogy, fracture surfaces, and hydrological properties. Figure 3 shows a tentative schedule of the activities of the LBT. These activities are described in Section 5. Activities beyond FY95 will depend on the test results. This is for planning purpose only. Official schedule and cost are in the

PACS. The schedule will be updated within the PACS database; this SIP will not be revised as the schedule evolves.

2.0 Relationships to Programmatic Objectives

2.1 Information Needs

The Site Characterization Plan (SCP) is divided into a series of issues and information needs (INs) that address those issues. One issue is identified as 1.10 (Waste Package Characteristics-Postclosure), which deals with the service environment of the waste package. Section 8.3.4.2 of the SCP states:

> 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.

IN 1.10.4. (Post Emplacement Near-Field Environment) will receive information from several studies, including SCP Study 1.10.4.4 (EBS Field Tests). The laboratory and field tests described in this SIP (the LBT) are a precursor investigation to SCP Study 1.10.4.4. In addition, information from the LBT will provide input to other INs. All of these INs are given in Table 1.

Information from the LBT will be used to quantify the uncertainties of characterizing the near-field environment, which, in turn, will be input to the issue resolution strategy for Issue 1.4: Will the waste package meet the performance objective for containment as required by 10 CFR 60.113?

Information obtained from the LBT will also be used in the issue resolution strategy for Issue 1.5: Will the waste package and repository engineered barrier system meet the performance objective for radionuclide release rate as required by 10 CFR 60.113? The estimation of radionuclide release rate from the engineered barrier system needs information of the quantity and quality of water that may contact the engineered barrier. The rate of both container degradation as well as the rate of waste form dissolution and transport depend on the quantity and geochemistry of water or vapor. The LBT will provide validation of some model concepts that will be used for predicting the quantity and chemistry of water, as well as temperature, that may contact the EBS.

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 radioactive nuclide release from the waste package and engineered barrier system (Section 8.3.5.10.3)
1.5.4	Release rates of radioactive nuclides 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)

1.10.4 Service environment of the waste package (Section 8.3.4.2)

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 LBT will provide data on near-field hydrological, thermal, mechanical, and chemical phenomena during a complete, accelerated thermal cycle in the rock block. Movement of water and steam in pores and fractures in the near-field 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 hydrological behavior and because of possible effects on components of the engineered barrier system. The need for this information is specified in the issue resolution strategy for Issues 1.4: Will the waste package meet the performance objective for containment as required by 10 CFR 60.113? and 1.5: Will the waste package and repository engineered barrier system meet the performance objective for radionuclide release rate as required by 10 CFR 60.113?.

The objective of the LBT regarding geochemical characteristics is to identify relevant geochemical phenomena and build confidence in, or test, to the extent practical, the concepts of models that characterize rock-water interactions, including synergistic effects that may be present at larger scale and were not identified during laboratory testing of core-size and small block samples. Laboratory studies on core-size or small block samples are described in SIP-7, Nevada Nuclear Waste Storage Investigation: Waste Package Environment and in the draft Study Plan for the Characterization of Chemical and Mineralogical Changes in the Post Emplacement Environment Study (SCP 8.3.4.2.4.1), WBS 1.2.2.2.1 which is in revision. The need for this information is specified in the issue resolution strategy for Issues 1.4 and 1.5, where the quality of water that may contact the waste packages is discussed.

For characterizing thermal-hydrological processes the objective of the LBT is to identify the relevant physical phenomena and build confidence in, or validate, to the extent practical, the results of laboratory studies that characterize hydrological properties, including any synergistic effects present at larger scale that were not identified during laboratory testing of core-size samples. These laboratory studies on core-size samples are described in SIP-7, Nevada Nuclear Waste Storage Investigations: Waste Package Environment and in the draft Study Plan for Laboratory Study of Hydrological Properties of the Near Field Environment (SCP 8.3.4.2.4.2), WBS 1.2.2.2.2 which is in revision. The need for this information is specified in the issue resolution strategy for Issues 1.4 and 1.5, where the quantity of water that may contact the waste packages is discussed. The information gained in these activities will be used to characterize the near-field hydrological properties of the tuff under anticipated and unanticipated conditions as required in Issue 1.10.

Regarding thermal-mechanical characteristics, the objectives of the LBT is to investigate the effect of the thermal-mechanical responses of the block on hydrological and geochemical properties. The mechanical attributes studies are described in the Study Plan for Geomechanical Attributes of the Waste Package Environment (SCP 8.3.4.2.4.3), WBS 1.2.2.2.3. The need for this information is specified in the issue resolution strategy for Issues 1.4 and 1.5, where limits are placed on the failure of waste containers.

2.2 Applicable Regulations

The objective of the LBT is to provide information on the environmental processes affecting the near-field host rock (where the waste package will raise the temperature significantly above pre-emplacement ambient temperatures) after waste package emplacement. This objective is dictated by requirements contained in Section 135(a) of NRC Rule 10 CFR 60 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, radioactive nuclide 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, fractured, densely 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 loads and may impose radiation loads on the rock mass. The near-field environment created by the thermal load of waste packages will be described in the following paragraphs. The thermal load will increase the near-field temperatures and create a region of hot and potentially dry rock around the emplacement drifts or boreholes (Ramirez, 1991). 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 masses. 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 the 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 local fracture aperture. The effect of gravity on the flow of liquid water in vertical fractures above the waste packages may cause refluxing of water in the fractures. On the other hand, gravity flow may shed water away from the waste packages (Buscheck, et al, 1993). The prediction of moisture movement in the rock mass is further complicated by changing properties due to temperatures. As an example, surface tension of water decreases with temperature so that capillary effects (imbibition) decrease. This may enhance fracture flow (drainage). While some laboratory studies have been performed (Daily and Lin, 1991) testing at the LBT will allow evaluation of effectiveness of the inclusion in models of these phenomena in accounting for the effects as they actually occur in the rock mass. 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.

The activities described below will provide tests of model concepts that will be used to predict the coupled TMHC processes in the near-field rock mass after the emplacement of waste packages. They will also provide input data to the model calculations.

Construction of underground facilities (including ramps, drifts, alcoves, and boreholes) and emplacement 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 an impact on the fracture porosity and connectivity of the rock mass as well as structural integrity. The change in fracture porosity and connectivity may affect the rock-water interaction and the movement of water and steam described in previous paragraph.

The hydrologic environment around a heater during thermal loading is expected to develop in the following manner. With time, the heat will dry the originally partially saturated rock near the heaters. The water vapor formed will be driven by vapor pressure gradients through the matrix until it intersects a fracture; it will then move down the pressure gradient along the fracture as noted in laboratory work performed by Daily et al. (1987) and in the field (Daily and Ramirez, 1989). Some of the vapor will be imbibed into the matrix along the fracture, but the amount will not be significant (Lin, 1992). Most of the water vapor will condense where 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 due to gravity. 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 the matrix. In regions above the heater, for example, the down-flowing water may be evaporated, flow upward, be condensed, and flow downward again (refluxing). In regions to the sides of the heaters, the condensed water may be shed (Lin et al., 1991). In the condensate region and in the refluxing zone, rock-water interaction may occur, and the water chemistry may therefore be changed.

When the dried region is allowed to cool, it is expected to re-wet slowly because of pore pressure and saturation gradients that develop in the rock around the heater. The time scales of dry-out and re-wetting will be determined to test models that predict those times for physical scales ranging from the block to the ESF to a full scale repository.

As stated previously, the flow of vapor in the fractures away from the waste packages will result in condensation along the fracture walls in the cooler region. It is necessary to determine whether this liquid condensation will attain water saturation sufficient to result in liquid-phase mobility within the fracture, or whether the condensation will be pulled into the rock matrix by capillary suction. The outcome depends on the condensation rate, capillary suction gradient, liquid-phase permeability in the matrix and fractures, and the effect that secondary minerals along fracture surfaces may have on the imbibition of water. Laboratory results indicate that imbibition of water into the tuff during the flow of vapor is much slower than when the vapor is condensed into liquid water (Lin, 1992). Model predictions of the amount and distribution of vapor condensation in a fracture need to be validated. Laboratory tests on heated blocks with certain fracture patterns are needed to determine the distribution of water and temperature for validating model calculations.

Chemical processes during the rock-water interaction may have a significant effect on the hydrological properties of the rock mass. Lin and Daily (1989 and 1990) and Lin (1991) reported laboratory results that show that flowing liquid water or steam in fractured Topopah Spring tuff samples at temperatures greater than 90°C may cause fractures to heal, resulting in a drastic decrease in permeability. However, Lee and Ueng (1991) reported an increase in air permeability in the heater borehole after heating the rock mass to about 240°C in a field test in G-Tunnel, at the Nevada Test Site. The effect of moisture movement on the hydrological properties of fractured rock mass in the near field must be determined in order to develop numerical models that can properly characterize near-field hydrological processes.

The design of the LBT will focus on determining the three-dimensional temperature field, the stress and displacement on fractures, distribution of moisture around the heaters, and the variation of water and gas chemistry in the block during heating and cool-down.

4.0 Activities

Work performed in support of the LBT has been divided into the following activities for quality assurance grading. Once these activities are graded they will be controlled by the appropriate QA procedures as identified in the grading reports. The description of the activities is contained in Section 5.0 of this SIP. The details of implementation including specifics of how the test will be conducted, instrumentation used, and test parameters will be contained in the Activity Plan(s) that will be developed after approval of this SIP. The activity plan will also identify the test controls and documentation requirements as well as the approval required for modifications etc.

Activity Number	Title & Scope
LBT-01	Collect and isolate rock blocks. This activity includes locating a rock outcrop where the large block will be isolated, collecting smaller blocks, and cutting and preparing the block(s).
LBT-02	Design and fabricate of a load retaining frame. This activity includes designing and constructing a steel frame that is big enough to accommodate the large block and strong enough to retain the stresses that will be loaded on the large block.
LBT-03	Characterize the blocks. This activity includes determining the physical and

hydrological characteristics of the large block and the smaller blocks. The physical characteristics include, but are not limited to, dimensions, fracture density and configuration, fracture aperture, mechanical properties, and thermal properties. The hydrological characteristics include, but are limited to, moisture content, effective porosity, suction potential, saturated permeability.

LBT-04 Conduct the main tests. This activity includes testing on the large block of the coupled TMHC processes, and the tests of model validation on smaller blocks made of the same material as the large block. Data acquisition, analysis, and reporting are also included in this activity. A detailed description of the tests is given in the next section.

LBT-05 Perform model calculations in support of the design of the test, and analyze the test results.

5.0 Description of Activities

The following sections provide a general description of the activities of the LBT. Where specific details are required, activity plans and/or implementing procedures will be prepared in accordance with the requirements of the LLNL-YMP QA procedures governing control of scientific investigations.

5.1 Collect and Isolate Rock Blocks (LBT-01)

This activity includes identifying an outcrop area suitable for obtaining rock blocks, cutting the blocks, and preparing them for laboratory testing. The criteria for a suitable outcrop area are rock type and accessibility. A desirable criteria would be for the fractures to be similar in spacing, aperture, and geochemical/mineralogical characteristics to those expected at the potential repository horizon. However, this is not possible for outcrops which are under quite different stress conditions and which often are either weathered or filled with surficial secondary materials. Thus, the selection of an outcrop area is a compromise that emphasizes the rock type and accessibility. The desired rock type for the LBT is the nonlithophysal, densely welded, fractured Topopah Spring tuff. The mineralogical characteristics of the outcrops are considered to be similar to that of the host rock at the potential repository horizon to the extent that similar minerals will be present (although the relative abundances may vary). There are two areas near Yucca Mountain where major outcrops of the Topopah Spring tuff exist: the eastern slope of Fran Ridge, Nevada, and the southern slope of Busted Butte, Nevada. The Fran Ridge site is where the fracture mapping pits of the U. S. Geological Survey are located. This site has excellent outcrops of

Topopah Spring tuff and a good access road. The exposed rock at the Fran Ridge site is near the interface between the lithophysal and nonlithophysal units of the Topopah Spring tuff. The Busted Butte site has outcrops of the Topopah Spring tuff closer to the potential repository horizon. However, surface material at the Busted Butte site needs to be removed before a sufficient area of the rock can be exposed. And, most important, accessibility to the Busted Butte site is poor.

We consider that the rock type at the Fran Ridge site is mineralogically acceptable for the LBT. We have selected the Fran Ridge site mainly because of its good accessibility. The location of the site will be determined based on selection of a block containing sufficient fracture density but without stability problems. After selection the coordinates (North and East) will be determined by surveying and documented in a LBT record package.

A block of the Topopah Spring tuff with a dimension of at least 3 m on each side and at least 4.5 m tall will be isolated in the field. Initial plans for cutting the block are to use a belt saw such as that developed by the Sandia National Laboratories (SNL) in New Mexico, although other methods such as large hole drilling may be considered. The corners of the block may be cut about 0.3 m into the block to make room for installing thermal insulation material. A slot may be cut under the block for installing a steel plate with built-in instruments and fluid sampling devices or a series of instrumentation holes if deemed appropriate by the principal investigator (PI), based on the practicality of inserting such a plate, its effect on the stability of the block, and the availability of alternative methods for monitoring and sampling under the block. The rock outside of the block will be removed by a method yet to be determined that will cause minimal disturbance to the block and not preclude us from obtaining small blocks for testing. Possible methods include cutting with the belt saw, splitting with a swelling agent, and mechanical splitting. Geotechnical instruments, such as stress meters and extensometers, will be installed in the rock before the sawing and excavation start to determine the effect of these quarrying activities on the block. An additional, and possibly a major, potential impact is addition of water to the system. This is not as easy to monitor. However, these tests do not require a specific initial saturation. They require that the change in saturation be observable. The most significant impact would be on the saturation distribution. It is likely that most saturation changes would occur near excavation face and in fractures. It is not know (and will not until laboratory tests are completed) whether there will be sufficient time from cutting until testing for these localized effects to dissipate. Scoping calculations will be performed and determination made as to possible effects. Efforts will be made to minimize water. Additional efforts to homogenize the saturations (possibly even pre-test infiltration) will be discussed in activity plan. The main block may need protection during the process of cutting and removing the surrounding rock from its sides. Block protection techniques and procedures will be developed by the scientists and engineers in charge of the quarrying with consultation with the PI, and will be documented in the implementing procedures such as activity plans, test planning package, and job package. The rock removed from the sides of the block will be collected for use in the activity of characterization of blocks (LBT-03) and some parts of the main testing activity (LBT-04).

Wet cutting of the faces and drilling of instrument/heater holes will be permitted. Initial measurements on small loose surface blocks indicate that the large block will be about 50% saturated with water; additional water may be added to the block prior to testing if deemed appropriate by the PI based on the initial moisture content measurements of the block and the surrounding rocks. Vertical holes will be drilled in the block prior to cutting the faces; these holes can be used to obtain direct measurements of the initial moisture content, such as by neutron logging.

5.2 Design and Fabrication of a Load-Retaining Frame (LBT-02)

A steel load-retaining frame will be assembled outside of the block of Topopah Spring tuff at Fran Ridge (Figure 4). The frame must sustain a minimum internal vertical load of about 10 MPa and a horizontal load of about 5 MPa. These loads are the approximate in situ stresses at the potential repository horizon. The approximate in situ stresses are required so that the block will deform (during heating and cool-down) under the influence of similar mechanical conditions as in situ. And rock-water interaction will be affected by similar stress on fracture surfaces as the in situ conditions. The stresses will be loaded on the rock block by flat jacks or any loading device as deemed appropriate by the PI, which will be inserted between the rock block and the load retaining frame. The criteria for selecting a loading device are load capacity, displacement capability, temperature rating, and adaptability to the configuration of the frame. The frame will have circular openings for easy access of instruments to the block. The load-retaining frame will be designed by engineers in the Mechanical Engineering Department of LLNL and fabricated by LLNL or an outside vender. It will be anchored to the ground around the block using techniques and procedures determined by the engineers and documented in the design documentation.

5.3 Characterization of Blocks (LBT-03)

It is necessary to determine the physical, hydrological, and mineralogical characteristics of the main (large) block and the material removed from the sides of the block. For the main block itself, the fractures must be characterized as completely as possible. All fractures and their orientation on each surface will be determined by geologic mapping techniques, (e.g. line surveys or other techniques) as determined by the PI. The technique should be appropriate for determining fracture locations and apertures on the block surface. Connectivity of the fractures within the block will be determined based on surface features and other geophysical methods, such as acoustic tomography, electrical resistivity tomography, etc. The averaged bulk properties of the large block (such as density, effective porosity, saturated permeability, electrical resistivity, mechanical (elastic) and thermal properties.) will be estimated based on data obtained from smaller samples taken from the material removed from its sides.

To properly characterize the bulk properties of the block samples will be obtained from the material removed from all sides of the large block as close to the block as practical. The number of samples will be determined by the scientist in charge of the characterization largely based on how uniform the results of the testing are. Samples will be removed in accordance with criteria that will be specified in the Job Package for Activity LBT-01. The number of samples will be strongly dependent on the uniformity of the block. As a minimum, the following parameters will be determined for the matrix of the rock: Density, total and effective porosity, saturated permeability, moisture retention curves, electrical resistivity as a function of moisture content, Klinkenberg coefficients, and initial moisture content. The relative importance of these parameters, and thus the amount of effort expended in measuring each of them, will be determined by sensitivity studies during scoping calculations and by the results of the tests themselves. Therefore, the extend of testing will be determined by the PI based on detailed planning as reflected in the Implementation Plans (e.g. Activity Plans). To determine the initial moisture content, pieces of the rock must be preserved as soon as they are available on site. Moisture content will be determined from blocks of sufficient size that the effect of moisture in fractures is not significant. The fracture surfaces in the pieces of rock removed from each side of the large block will also be examined for their roughness, coatings, and mineralogy. This information will be used to characterize the fracture surfaces in the large block.

5.4 The Main Tests (LBT-04)

The main tests include model validation experiments on smaller blocks and testing of the coupled TMHC processes on the large block. The experiments on the smaller blocks will be done in the laboratory because they require controlling the aperture of fractures as well as carefully constrained boundary conditions. The tests on the large block will be done in the field where the large block is located.

5.4.1 Model Concept Validation (Small Block) Experiments

Blocks of Topopah Spring tuff quarried during the isolation of the large block will be used for these model concept validation experiments. The experiments include investigation of thermal-hydrological, thermal-geochemical, and thermal-mechanical responses. Blocks of the tuff with sizes up to several tens of centimeters will be obtained that can be joined together to form block-assemblies with a single fracture or multiple fractures with designed fracture patterns and aperture. Blocks with suitable natural fractures will also be used. One block assembly at a time will be used for the experiment. The remainder of this section describes hydrological, geochemical, and geomechanical experiments which will be conducted on the block assemblies: Experiments on fracture flow vs. matrix imbibition as a function of the fracture aperture, one-dimensional imbibition and dehydration, condensation along fractures, and geomechanical responses to heating. If other experiments are added, they will be described in Activity Plans which are subordinate to this document.

The purpose of the fracture flow vs. matrix imbibition experiment is to determine parameters that affect fracture flow vs. matrix imbibition of Topopah Spring tuff. These parameters include fracture aperture, moisture content, surface coating, roughness, pore size distribution, and temperature. For this experiment, water will be applied at the top of a fracture, and the wetting front will be determined both along the fracture and in the matrix by using electrical resistivity tomography (Daily et al., 1987) and x-ray tomography (Tidwell and Glass, 1992; Foltz et al., 1992). The experiment will be done for fractures of different apertures and blocks with various initial moisture contents. The experiments will be done at room temperature, elevated uniform temperature, and under a thermal gradient. Thermocouples and moisture sensors will be mounted at strategic locations in the fracture and matrix to measure temperature and moisture distributions as a function of time and space. The moisture sensors to be used in these tests described in this SIP include resonant cavity and electro-optic liquid sensor. Both can be used under elevated temperatures above the boiling point of water. The water flux through the top of the sample will be controlled. Water that has flowed through the fracture will be collected for chemical analyses to determine pH; concentration of oxygen (using selective ion electrodes); Cl^-, HCO_3^-, F^-, Si, Na, K, and CO_2 (using inductively coupled plasma analysis and ion chromatography). The fracture surfaces will be examined before and after the experiment for evidence of rock-water interaction.

In the one-dimensional imbibition experiment our goal is to study the relative imbibition rate in the matrix and into an intersecting fracture. This experiment will simulate a model that predicts condensate along a vapor-conducting fracture intersecting the dry-out zone will be imbibed into the matrix and fractures intersecting the conducting fracture. A block assembly with a certain fracture aperture will be brought in contact with water at one end of the fracture. The surface of the end of the block contacting water will simulate the fracture surface that water flows through. The water front will be determined using appropriate techniques, e.g., electrical resistivity tomography or x-ray tomography. The imbibition direction will either be against gravity, with gravity, or perpendicular to gravity. The effect of the intersecting fracture aperture on the relative imbibition rate will be studied. The effect of temperature on imbibition will also be studied. In this case, the sample will be sealed with a moisture barrier on the outside surfaces. Thermocouples and moisture content sensors will be mounted in the matrix and on the joint surfaces to monitor the distribution of temperature and moisture as a function of time and space.

There are three types of experiment in the investigation of dehydration process: one-dimensional dehydration in intact sample, one-dimensional dehydration in fractured sample, and condensation along a fracture during dehydration. In the first two experiments both intact blocks and block assemblies with controlled fracture aperture will be used. The sample will be sealed with a moisture barrier on all of the outside surfaces except one side, which will serve as the moisture exit from the sample. The sample will be heated from the end opposite the open end without a controlled thermal gradient. Thermocouples, moisture sensors, and pressure transducers will be mounted in strategic locations in the sample to monitor the temporal and spatial distributions of temperature, moisture content, and pore fluid pressure. The experiment will be started with samples of known initial moisture content. In the experiment to investigate condensation along a fracture, a thermal gradient will be maintained in the sample so that condensation along the fracture can occur. Fracture flow and matrix imbibition of the condensate will be studied. Electrical resistivity tomography and x-ray tomography will be used to monitor the drying front in the sample. The fracture surfaces will be examined before and after the experiment for evidence of rock-water interactions.

For the study of thermal-mechanical responses, a block of intact rock or fractured rock will be heated either uniformly or from one end. Stress meters, strain gauges, and other geotechnical instruments will be used to measure stress in the block and strain on fractures. Acoustic emission will be monitored to detect thermal fracturing. The fracture surfaces will be examined before and after heating for evidence of change in the fracture properties.

5.4.2 Large Block Tests of the Coupled TMHC Processes

Tests in the large block will be used to confirm the results from the experiments on the small block(s) and to investigate the macroscopic phenomena of the coupled TMHC processes that are affected by multiple fractures, fracture connectivity, scale, and heterogeneities. The large block will first be characterized for its fracture intensity and configuration, as described in Section 5.3. Heater holes will be drilled in the middle of the block or at other appropriate locations as determined by pre-test model calculations. The number of heater holes will be determined by the pre-test calculations such that coalescence of drying fronts between the holes can be observed. Thermocouple holes will be located so that thermocouples can be installed to determine a three-dimensional temperature distribution in the block. The thermocouples will be distributed in the block so that the dominant heat transfer mechanism, conduction or convection, can be determined. These two thermal transfer mechanisms will generate different thermal gradients in the block. Thermal transfer models will be used to analyze the measured thermal gradient in the block. Conduction-dominated heat transfer is one of the essential factors of the extended dry repository concept (Buscheck, et al. 1993). Additional thermocouples will be installed on exposed surfaces of the block just under the surface so that the thermal gradient in the block near its surfaces can be determined during the test. The thermal gradient data will be used to calculate heat flux away from the block when the block is heated.

Some candidate nuclear waste package materials will be used to make the heater assembly(s). This will provide an opportunity to study the responses of the materials to an environment similar to that expected in the near field of a waste repository. If it is not practical to use a candidate waste package material to make the heater assembly, then coupons of the material will be put in heater holes, near, but not in contact with, the heater. Other coupons of the same materials may also be placed in holes to intersect either condensate drainage or reflux areas. Details will be in the activity plan. The material will be examined before and after the test for property changes.

Other instrumentation holes will be drilled for installing stress meters, strain gauges, acoustic emission transducers, moisture sensors (including resonant cavities, psychrometers, electro-optic liquid sensors, etc.), calibrated selective ion probes for chemical monitoring for pH, oxygen, Cl^-, F^-, HCO_3^-, Si, Na, K, and CO_2, chemical sampling tubes to sample water for chemical analyses of the elements mentioned previously, pressure transducers, etc. All instruments and sensors will be calibrated before installation. The number of these sensors and instruments and their exact locations will be determined after the block has been fully characterized, because their locations will be dictated by the fracture pattern in the block. Details will be contained in implementation plans (e.g. activity plans). Electrodes for electrical resistivity tomography will be mounted on the outside surfaces of the block and in a borehole. The number of electrodes will be determined on site because it depends on the final dimension of the block and the heater location in the block. Every instrument will be tested after installation to make sure that it functions properly. After installing the instruments and sensors, the holes will be sealed with a sealant that will have minimal chemical impact on the water, gas, and rock in the block. The heater holes will either be sealed or blocked with packers. The holes for neutron logging will be lined, and the annular space between the lining and the hole-wall will be sealed with a sealant. The total volume of the heater holes and instrumentation holes will be about 0.4% of the block volume. These holes will be distributed throughout the block. They should not have significant impact on the test. Details of the block/instrumentation geometry will be described in Activity Plan LBT-04.

After installation of the instruments and heaters, the block will be sealed with a thermal barrier and a moisture barrier on its four side surfaces. A temperature controlling heat exchange device will be installed on the top block surface so that the temperature on the block top can be maintained at a value determined by the PI while the block is being heated from inside. A water vapor collecting device will also be installed on the block top. Flat jacks or other loading devices such as bladders will be installed on the outside surfaces of the block. The prefabricated load-retaining frame will be assembled around the block section by section. The wires, instrument leads, and high pressure lines will be brought out through pre-drilled holes in the load-retaining frame or through other appropriate means designed by the engineers and scientists in charge. If flat jacks are used, filling material will be used to fill the space between the block and the load-retaining frame. The filling material should be able to transmit an almost uniform load on the load-retaining frame. The design engineers of the load-retaining frame (Section 5.2, Activity LBT-02) will select the most suitable filling material in consultation with geochemists to avoid unwanted rock/water interaction impacts. Details on filler material will be contained in Activity Plans.

Data will be collected at ambient conditions for at least one week before the block is loaded with predetermined stresses. Data acquisition at ambient temperatures will continue once the block is stressed, but before the heaters are energized until the PI is satisfied that transient responses are eliminated. Multiple loading cycles may be required to achieve proper joint responses. Then the block will be heated at constant power for a period of time (determined by the PI) followed by a period in which the heater power will either be ramped down (a controlled cool-down) or turned off (a natural cool-down). The maximum power output of the heaters, the constant power heating period, the controlled cool-down schedule, and the natural cool-down duration will be determined by pre-test calculations (Section 5.5, Activity LBT-05). One of the criteria for determining these parameters is to establish a dry-out region, a condensate region, and a relatively undisturbed region that exist simultaneously in the block for as long a period as possible. During the heating phase, the load on the block may increase due to the thermal expansion of the block. This increase of load will be monitored by pressure gauges connected to the flat jacks or loading bladders. We will make sure that capability is included to adjust pressure in the flat jacks or the bladders. The loading conditions will be specified in Activity Plans. Data acquisition will continue throughout the entire heating and cool-down cycle. Samples of water and gas will be collected periodically. The temperature on the top block surface will be adjusted so that the vertical thermal gradient in the block is suitable for condensate refluxing to occur, according to the pre-test calculations. Vapor that exits the block will be collected for measuring its amount and chemistry. At 100°C the rock-water interaction rates are sufficient for concentrations of most of the dissolved species to approach steady state in a few months (Knauss, et al. 1987). One of the purposes of the LBT is to determine what species reach equilibrium. The external loads on the block may be released when the temperatures in it are not significantly higher than ambient values. Data acquisition will continue after the temperatures drop until data indicate a static condition.

Data from the thermally loaded cycle of the LBT are expected to demonstrate refluxing of water in the condensate zone above the heaters, the coincidence of the drying front and the boiling front, the dominant heat-transfer mechanism, and (possibly) shedding of the condensed water. These are the main factors related to the concept of an extended dry repository (Buscheck, et al. 1993). As mentioned, monitoring will continue during cool-down phase to evaluate return of moisture and the delay between temperature collapse and moisture return, what potion of condensate "halo" can return, and also to determine whether there is a change in which fractures are dominant pathways for moisture movement during heating as well as cool-down. It may be necessary to introduce water during cool-down phase. This will be determined based on laboratory tests and model calculations. The cool-down phase tests relate to potential return of moisture to the waste package area after temperatures decay.

After the test or a series of tests, the block will be dismantled so that the fracture surfaces and some portions of the matrix can be examined for evidence of chemical processes and alterations due to the heating and cooling. Instruments that can be recovered will be re-calibrated. Data reduction and analysis will begin when the data are available and will continue throughout the testing duration. The experimental results will be analyzed and reported. The chemical effect of all man-made materials on the test will be studied and included in the data analyses.

Based on results, the block may be re-assembled inside of the load-retaining frame to evaluate the impact of more broken or fractured rock on the responses and to allow better pre-test geochemical characterization. This would be followed by a series of tests similar in nature to those described.

5.5 Model Calculations (LBT-05)

Pre-test calculations similar to those done for the field test in G-Tunnel at the Nevada Test Site, Nevada, will be conducted for this test (Buscheck and Nitao, 1991). The scoping calculations will determine the required power output of the heaters, the full-power heating duration, the power ramp-down duration, and the cool-down duration so that a dry-out region, a condensate region, and a relatively undisturbed region will co-exist in the block during the test. Because it is unrealistic to expect that there will be no heat loss from the block during the test, the model calculations will take into consideration certain amounts of heat loss. Possibly, the thermal load from the heaters can be designed (by varying the maximum power level and heating duration) so that the relatively undisturbed region in the block will be big enough for the heat loss to become insignificant, without sacrificing the goal of having a measurable dry-out region and a condensate region.

The model calculations will also include post-test modeling to analyze the test results. In this case V-TOUGH will be used to calculate temperature distribution and moisture content distribution as a function of time in an equivalent continuum model. The calculated result will be compared with the observed one so that a physical model can be established to explain the experimental result. Discrete fracture model may also be used to understand generic relationship between the fracture and matrix responses to the thermal-hydrological process.

5.6 Limitations

The large block test is not intended to simulate either the repository or the large scale field test of the EBSFT. The power loading and power decay will occur far faster for the LBT than for a repository, or even for the EBSFT, because of the size limitations for a block that can be reasonably fully characterized. Pre-test calculations will be used to investigate various scenarios for heating, cooling, and maximum power output, in order to optimize observation of coupled processes. The LBT will be designed on the basis of such pre-test calculations. The test is intended to determine whether the current model includes all relevant processes, and describes them adequately. So, the test must be designed to produce a dry-out zone, a condensate zone, and a relatively undisturbed zone coexisting in the block for long enough for meaningful measurements to be made. Thus, the thermal history of the experiment will be strikingly different from that of the EBSFT, and of the repository. This intrinsic limitation controls the range of environmental conditions that can be imposed on the block. The inability to control the thermal properties of the rock (e.g. thermal conductivity) cannot be entirely mitigated by selecting rock as similar to the repository horizon as possible.

Because the initial power loadings (kilowatts per meter of heater) will be smaller than the power loading planned for the waste packages in a repository, and the heat will be imposed for months, the volume of rock dried out will be much smaller than for the repository drying period of thousands of years. The effects of fractures and other discontinuities may be substantially different. It is hoped that designing the experiment so that at least one fracture intersects the heater borehole will result in early manifestation of the effect of fractures on drying out of the rock. As the focus is on process understanding, the scale effects may be resolvable as testing moves on to the larger ESF test.

Another significant limitation due to the scale and duration of the test is that maximum temperatures are likely to be lower than expected in a repository. Thus, temperature-dependent processes, such as the precipitation, dissolution or alteration of minerals in the rock may proceed differently in this test than they would be in the repository. The small block tests associated with the LBT will be used to examine the effects of higher temperatures and different time scales on geochemical and petrological processes. These will provide relevant data for analytical modeling, again directed at understanding of relevant processes.

There are no plans to emplace radioactive sources in the initial tests, because previous work (Durham, et al., 1986) indicates that gamma radiation has no significant effect on the strength and elasticity of granitic rocks similar in composition to the rhyolitic tuff. Therefore, the potential limitations that might be imposed by the need for new licensing and safe-handling procedures will not affect the test. Any radiation effect on rock and mineral properties will be studied in the laboratory. If these plans change, the SIP will be revised.

5.7 Contingency Plans

Potential cause of failure in the LBT is in the construction of the block that includes, but not limited to, using the belt saw to isolate (cut) the block and supporting the block. The belt saw has been used in dimension quarry routinely and has been demonstrated being able to cut densely welded tuff boulders. However, the fracture in the Topopah Spring tuff rock mass may cause the cutter bar to be stuck in slots. If it occurs, procedures for freeing the bar have been included in the job package (JP-1). If the belt saw can not be successful in isolating the block at all we plan to use other methods, including line drilling along the block perimeter, cutting with water jet, etc. These methods require closer interactions between cutting the block and excavation of the surrounding rocks.

Detailed procedures for supporting the block will be included in the AP. If we can not support the block then the alternative is to do tests in other configurations, such as testing on outcrop with one or two free vertical faces and testing in a shallow tunnel. But these alternatives can not provide a 3-dimensional coverage of the testing region with instruments and do not allow characterization of the test region from five free surfaces. The test objective will be very different. It will require a decision at higher level in YMP and a revised SIP.

The outcrop indicates that the rock mass contains very few lithophysae. During excavation, additional observations can be made to verify that the block is located where lithophysae are acceptable. If the excavated surfaces have extensive lithophysae, the test may have to be relocated.

6.0 Application of Results

Information will be obtained from the following activities during the course of the smaller block laboratory experiments and the larger block integrated tests:

- Recording of data from the various instrument readout systems.
- Analysis of rock samples for rock properties (analysis to be performed under WBS 1.2.2.2.2).
- Evaluation of equipment and instrument performance.
- Physical examination of boreholes.
- Obtaining 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 of geomechanical responses (model development to be performed under WBS 1.2.2.2.3).
- Obtaining rock/water/sealant samples for geochemical analysis of the impact of man-made materials (to be performed under WBS 1.2.2.2.5).
- Material testing of the candidate waste package materials (to be performed under WBS 1.2.2.3.2).

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 analyses of the data, a conceptual model will be constructed that describes the coupled thermal, hydrological, chemical, and mechanical responses 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 models.

To determine the dominating heat transfer mechanism, the temperature distribution in the block as a function of time will be compared with the temperatures measured at fractures and the temperature distribution expected from a thermal conduction model. Based on the results of a field test in G-Tunnel, Nevada Test Site (Ramirez, 1991), we expect that heat conduction will be the dominant heat transfer mechanism; convection along fractures will only decrease the local temperatures slightly (Lin et al., 1991).

Physical examination of boreholes will provide information on the fracture and porosity parameters for the heat and mass transport models. Analysis of rock samples will provide information on chemical and mineralogical properties, porosity, and moisture content at various distances from the heater holes that have undergone thermal, hydrological, geochemical, and mechanical disturbances.

The above information, in conjunction with laboratory studies of (1) dehydration/rehydration processes, rock/water interactions, and fluid composition, and (2) mechanical fracture properties of smaller blocks, will provide input to the characterization of factors affecting the hydrological properties of tuff under anticipated repository conditions.

Evaluation of equipment and instrument performance and methodology of testing for future use in the EBSFT 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, neutron logging, and point moisture content measurement.

(3) Various methods of using one of a kind or developmental sensors will be evaluated. For example, thermocouples can be either grouted shut in boreholes or placed in thin-walled tubings. The LBT will evaluate these two different methodologies.

The results of the testing of candidate waste package materials that will be put in the heater holes will provide input information for the study of material degradation and corrosion in the near-field environment of the nuclear waste repository.

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8. References

Buscheck, T. A., and J. J. Nitao (1991), *Modeling Hydrothermal Flow in Variably Saturated, Fractured, Welded Tuff During the Prototype Engineered Barrier System Field Test of the Yucca Mountain Project*, Lawrence Livermore National Laboratory, Livermore CA, UCRL-ID-106521. (NNA.911212.0238)

Buscheck, T. A., D. G. Wilder, and J. J. Nitao (1993), "Large-Scale In Situ Heater Tests for Hydrothermal Characterization at Yucca Mountain", in *High Level Radioactive Waste Management, Proceedings of the Fourth Annual International Conference, Las Vegas, Nevada, April 26 - 30, 1993*, American Nuclear Society, La Grange Park, IL, also Lawrence Livermore National Laboratory, UCRL-JC-112445. (NNA.930217.0046)

Daily, W. and W. Lin (1991), "Laboratory Determined Suction Potential of Topopah Spring Tuff at High Temperatures," in *High Level Radioactive Waste Management, Proceedings of the Second Annual International Conference, Las Vegas, Nevada, April 28-May 3, 1991*, American Nuclear Society, La Grange Park, IL, pp. 583-588, also, Lawrence Livermore National Laboratory, UCRL-JC-102127. (NNA.910304.0097)

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. (NNA.900123.0064)

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. (NNA.910326.0097)

Durham, W. B., J. M. Beiriger, M. Axelord, and S. Trettenero (1986), "The Effect of Gamma Irradiation on the Strength and Elasticity of Climax Stock and Westerly Granites," *Nuclear and Chemical Waste Management*, Vol. 6, pp. 159-168. (Readily Available)

Foltz, S. D., V. C. Tidwell, R. J. Glass, C. A. Kelsey, and R. R. Eaton (1992), "An Experimental Investigation of Matrix Interaction on Fracture Flow," *EOS Transactions, 1992, Fall Meeting, American Geophysical Union, San Francisco, CA, December 7-1*, p.223. (Abstract-readily available)

Knauss, K. G., W. J. Beiriger, and D. W. Peifer (1987), *Hydrothermal Interaction of Solid Wafers of Topopah Spring Tuff with J-13 Water at 90 and 150°C Using Dickson-Type, Gold-Bag Rocking Autoclaves: Long-Term Experiments*, Lawrence Livermore National Laboratory, Livermore, CA, UCRL-53722. (NNA.870713.0081)

Lee, K., and J. Ueng (1991), "Permeability Tests," Chapter 3 of *Prototype Engineered Barrier System Field Test (PEBSFT) Final Report*, A. Ramirez, Sci. Ed., Lawrence Livermore National Laboratory, Livermore, CA, UCRL-ID-106159, pp. 40-50. (NNA.910711.0047)

Lin, W. (1991), "Variation of Permeability with Temperature in Fractured Topopah Spring Tuff Samples," in *High Level Radioactive Waste*

Management, Proceedings of the Second Annual International Conference, Las Vegas, Nevada, April 28 - May 3, 1991, American Nuclear Society, La Grange Park, IL, pp. 988-993. (NNA.910523.0105)

Lin, W. (1992), "Hydrologic Properties," Chapter 2 of *Preliminary Near-field Environment Report, Volume II: Scientific Overview of Near-Field Environment and Phenomena*, D. Wilder, Sci. Ed., Lawrence Livermore National Laboratory, Livermore, CA, UCRL-LR-107476, pp. 2-5. (NNA.920501.0002)

Lin, W., and W. Daily (1989), "Laboratory Study of Fracture Healing in Topopah Spring Tuff - Implications for Near Field Hydrology," *Proceedings of the Topical Meeting on Nuclear Waste Isolation in the Unsaturated Zone, Focus '89*, American Nuclear Society, La Grange Park, IL. (NNA.900711.0241)

Lin, W., and W. Daily (1990), "Hydrological Properties of Topopah Spring Tuff under a Thermal Gradient -- Laboratory Results," *Int. J. Rock Mech. Min. Sci. & Geomech. Abstr.* Vol. 27, No. 5, pp. 373-385. (Readily Available)

Lin, W., A. L. Ramirez, and D. Watwood (1991,) "Temperature Measurements," Chapter 7 of *Prototype Engineered Barrier System Field Test (PEBSFT) Final Report*, A. L. Ramirez, Sci. Ed., Lawrence Livermore National Laboratory Livermore, CA, UCRL-ID-106159, pp. 82-93. (NNA.910711.0047)

Montazer, P. M., and W. E. Wilson (1984), "Conceptual hydrologic model of flow in the unsaturated zone, Yucca Mountain, Nevada," USGS-84-4345 *Water Resources Investigative Report*, U.S. Geol. Survey, Denver, CO. (NNA.890327.0051)

Ramirez, A. L. (1991), *Prototype Engineered Barrier System Field Test (PEBSFT) Final Report*, Lawrence Livermore National Laboratory, UCRL-ID-106159. (NNA. 910711.0047)

Tidwell, V. C., and R. J. Glass (1992), "X-ray and Visible Light Transmission as Two-dimensional, Full-field Moisture-sensing Techniques: A Preliminary Comparison," *High Level Radioactive Waste Management, Proceedings of the Third International Conference, April 12-16, 1992*, American Nuclear Society, La Grange Park, IL, and American Society of Civil Engineers, New York, NY, pp. 1099-1110. (NNA.930205.0015)

Wilder, D. G. (1993), "Alternative Strategies -- A Means for Saving Money and Time on the Yucca Mountain Project," in *High Level Radioactive Waste Management, Proceedings of the Fourth Annual International Conference*, Las Vegas, Nevada, April 26-30, 1993, American Nuclear Society, La Grange Park, IL, pp. 1263-1270, also Lawrence Livermore National Laboratory, UCRL-JC-111652. (NNA.930224.0019)

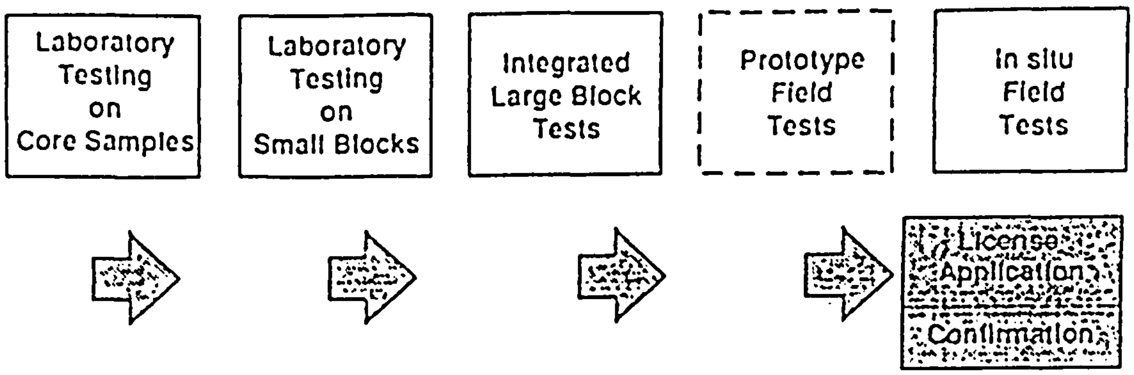

Figure 1. Logic l testing sequence leading toward license application and confirmation. Protolye Field Tests are not in official plan.

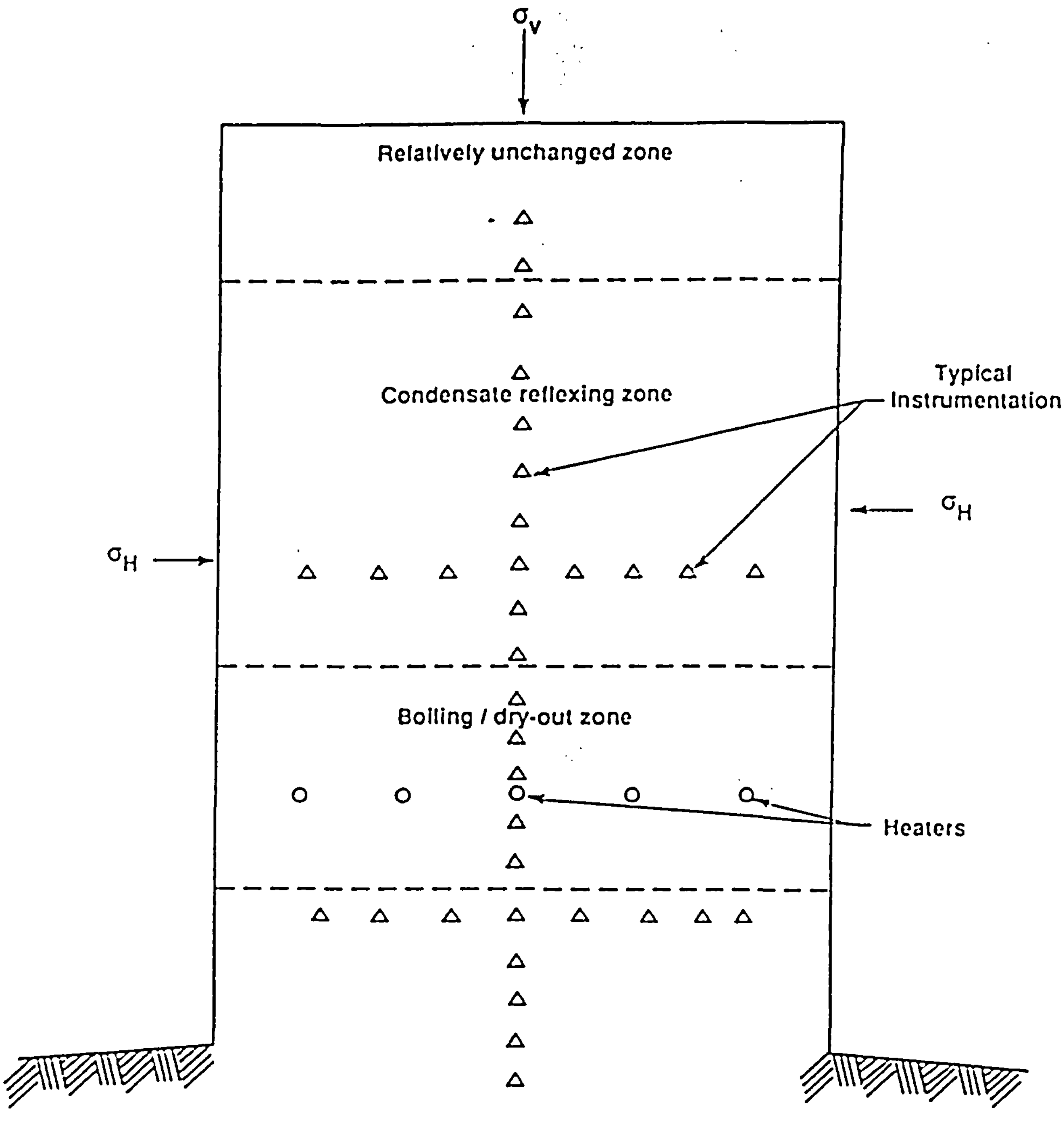

Figure 2. A schematic sketch of the testing setup. σ_H and σ_V are horizontal and vertical stresses respectively.

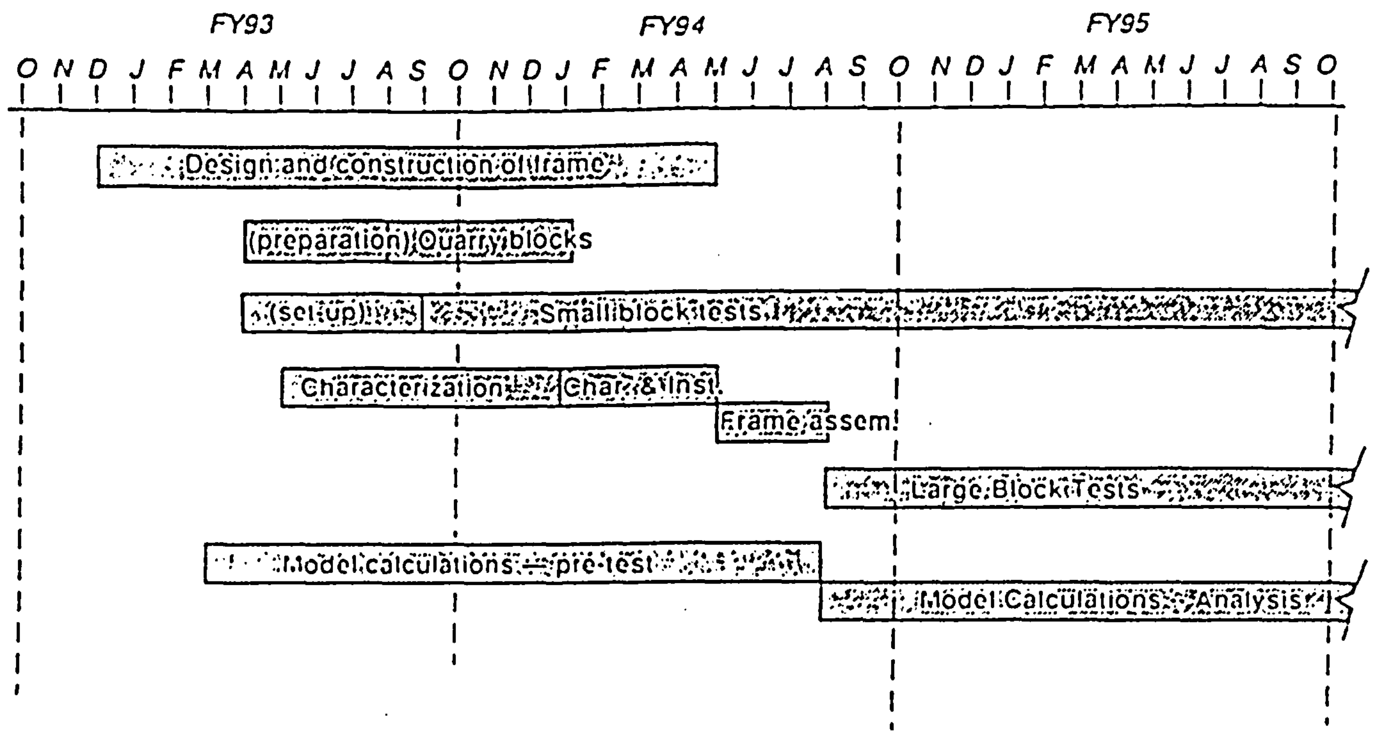

Figure 3. Tentative schedule of the LBT activities. Official schedules are in the PACS.

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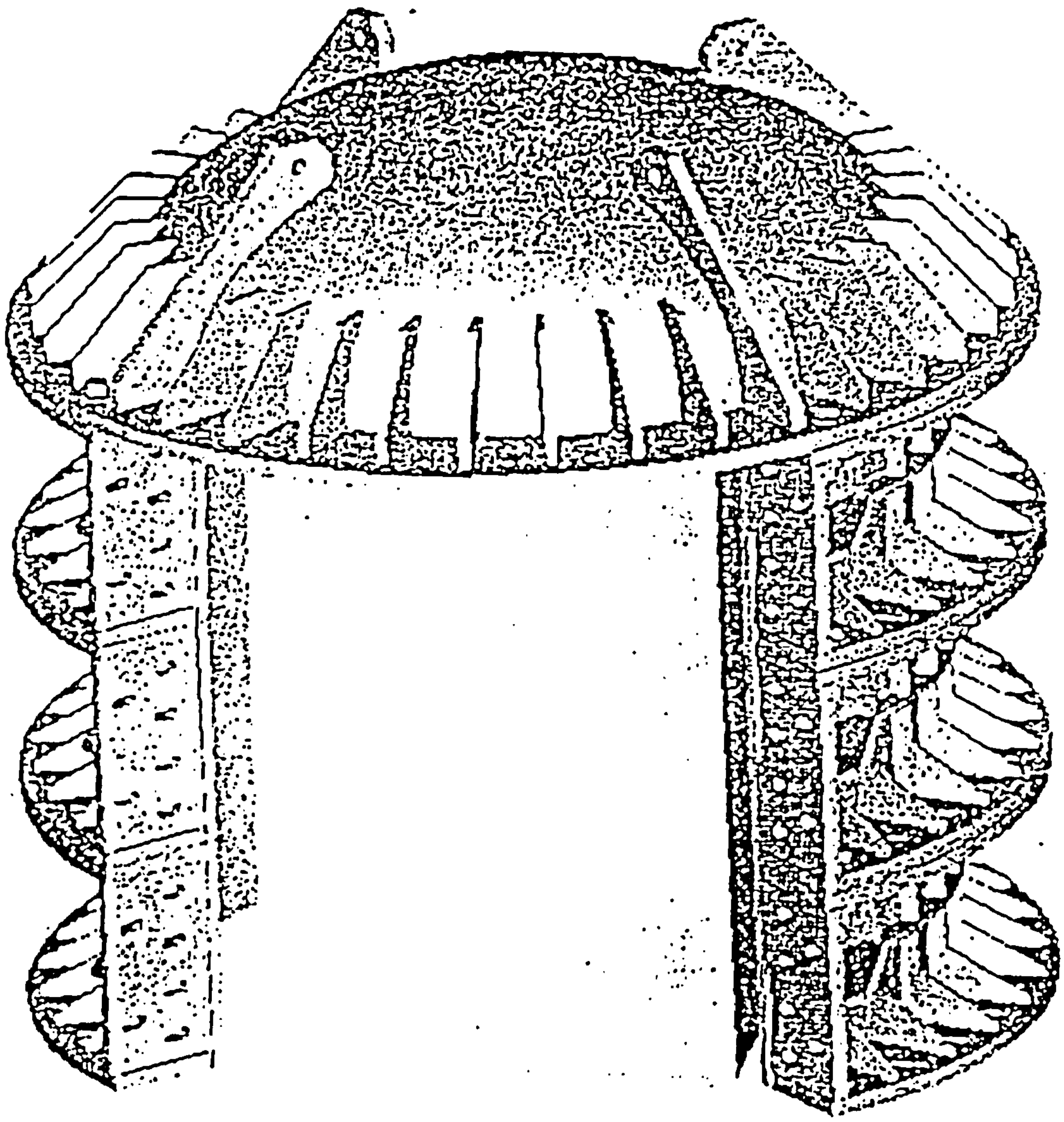

Figure 4. A conceptual drawing of a load-retaining frame on a large block.