

**U.S. DEPARTMENT OF ENERGY  
OFFICE OF CIVILIAN RADIOACTIVE WASTE MANAGEMENT**

**NUCLEAR WASTE TECHNICAL REVIEW BOARD  
EBS PANEL MEETING**

**SUBJECT:       LARGE-BLOCK TEST  
                  STATUS AND PLANS**

**PRESENTER:     DALE G. WILDER**

**PRESENTER'S TITLE  
AND ORGANIZATION:   TECHNICAL AREA LEADER  
                          LAWRENCE LIVERMORE NATIONAL LABORATORY  
                          LIVERMORE, CA**

**PRESENTER'S  
TELEPHONE NUMBER:   (510) 422-6908**

**PLEASANTON, CALIFORNIA  
MARCH 10-11, 1994**

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# **"A Critical Issue..."**

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**"...DOE's theoretical, untested understanding of the magnitude and consequences of..evaporation and condensation...of moisture...adjacent to the emplaced waste,..."**

**Sixth Report to the U.S. Congress and The U.S. Secretary of Energy,  
Nuclear Waste Technical Review Board, Dec. 1992**

# Test Scale Strategy

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(see slide in 10/93 TRB presentation)

**Lab scale**

**Block Scale**

**In Situ**

**ESF scale**

**Combined location for large scale**

**Repository scale**

# **Specimens of Candidate Container Materials Will Be Exposed During Large Block Test**

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- **Specimens exposed at different locations corresponding to different temperatures and humidities**
- **Plan to expose specimens of carbon steel and copper, candidate materials for outer barrier of container**
- **Measure general corrosion and oxidation by weight change; observe attack pattern (uniform or localized) and analyze corrosion products**
- **Exact exposure locations and specimen configurations are being worked out**

## Justification for LBT

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- **Model confidence-building & testing separate of characterization & ESF monitoring**
- **3-D characterization & monitoring**
- **Geochemical sampling**
- **Schedule demands**

# **Large Block Test Goals:**

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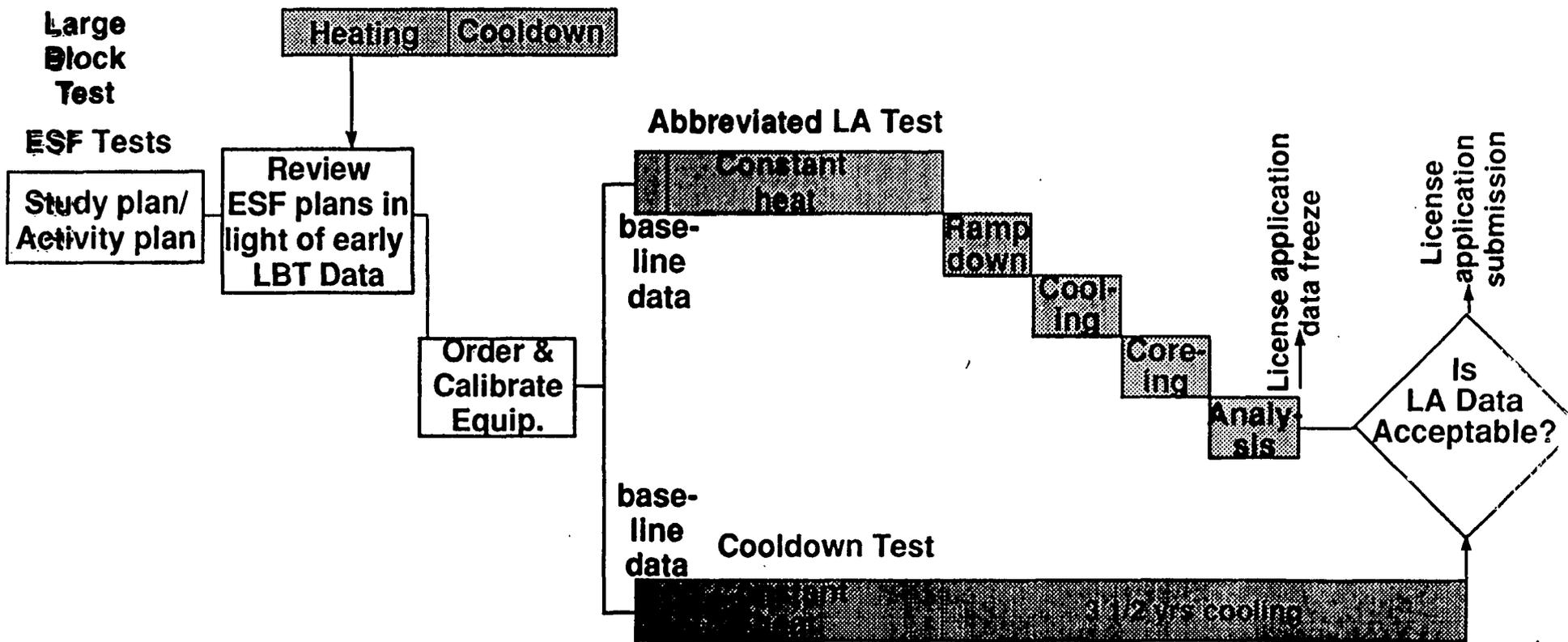
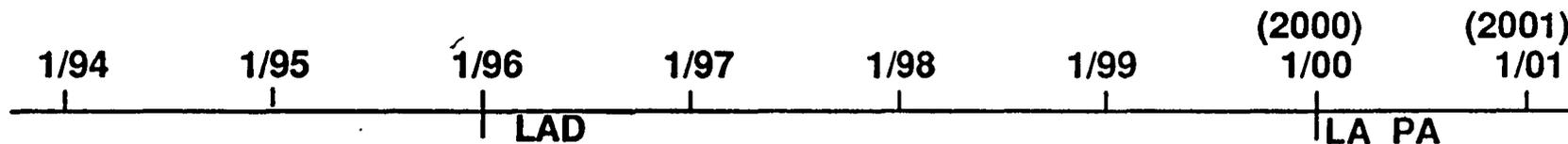
- **Initial validation of thermo-hydrologic models**
  - dehydration/rehydration
  - heat transport (conduction/convection)
  - condensate movement
- **Initial validation of geochemical model**
  - characterize fractures before and after test
  - geochemical sampling during test
- **Monitor coupling of hydrological, geochemical, and geomechanical processes**
- **Monitor Geomechanical Responses**
  - fracture deformation and initiation

# **Large Block Test Goals (cont.)**

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- **Methodology-monitoring technique development**
  - **Instrumentation**
  - **Mini-prototype testing**
  
- **Specific Questions**
  - **refluxing of water in the saturated zone**
  - **condensate drainage/shedding**
  - **effects of the coalescence of drying fronts on coupled processes**

# Strategy Using Large Block Test



Long duration test  
(Performance Confirmation)

Constant heating  
(6 yrs. heating, 6-12 yrs cooldown)

## **Issues requiring testing prior to ESF**

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- **Validation test independent from those used for characterization (property values etc.) data, and developing or testing models.**

**Developing and testing require "tweaking knobs" in the models to understand physics. For characterization the physics must be appropriate prior to testing.**

- **Early decisions based on model predictions (e.g., thermal loading, MPC, emplacement strategy) require incorporation in models of processes important to the outcomes. The models have not been adequately demonstrated.**
- **ESF test planning.**
  - Confidence in models used for planning of ESF tests, instrument and technique evaluation prior to ESF test, and evaluation of scaling effects**

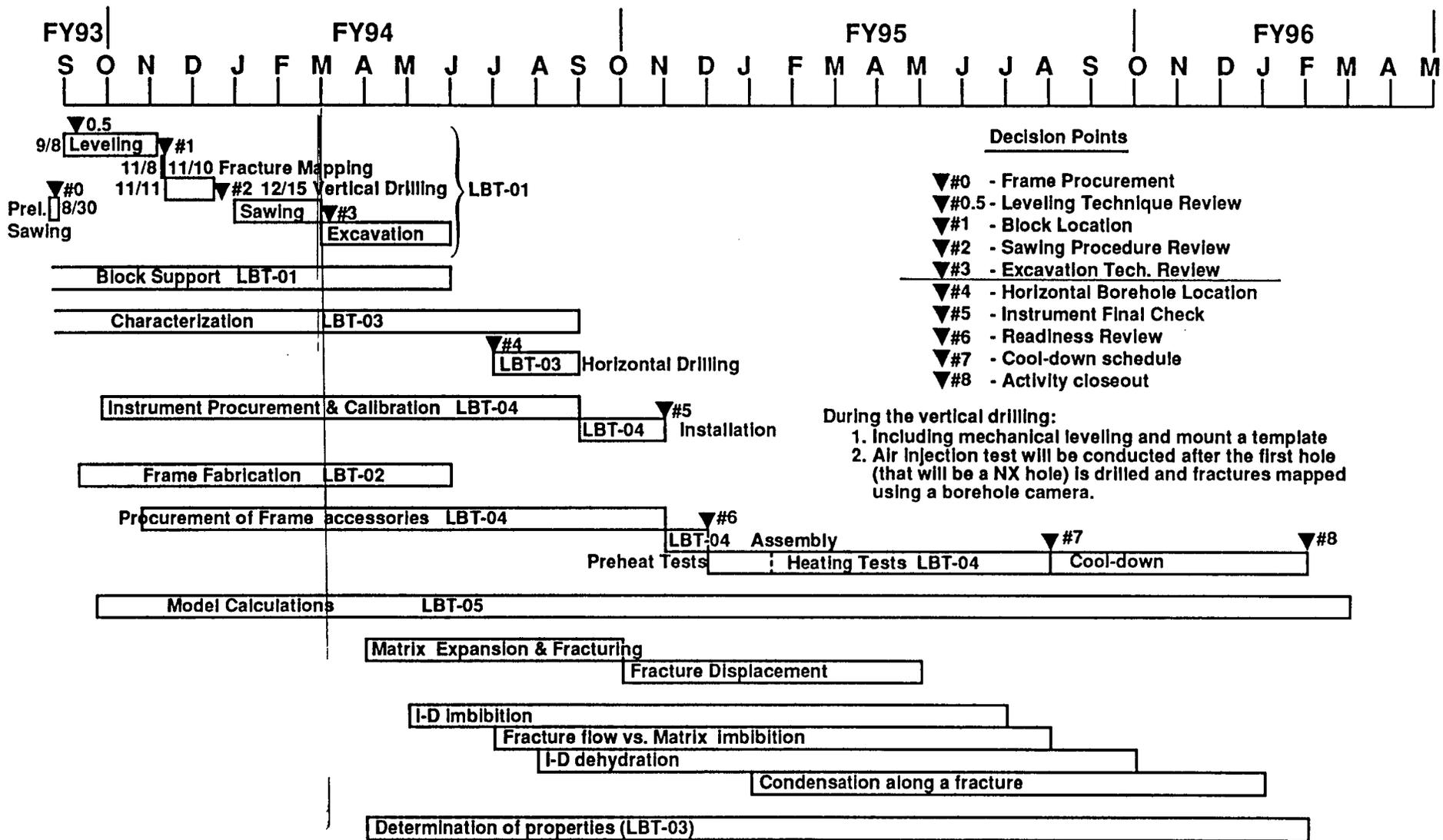
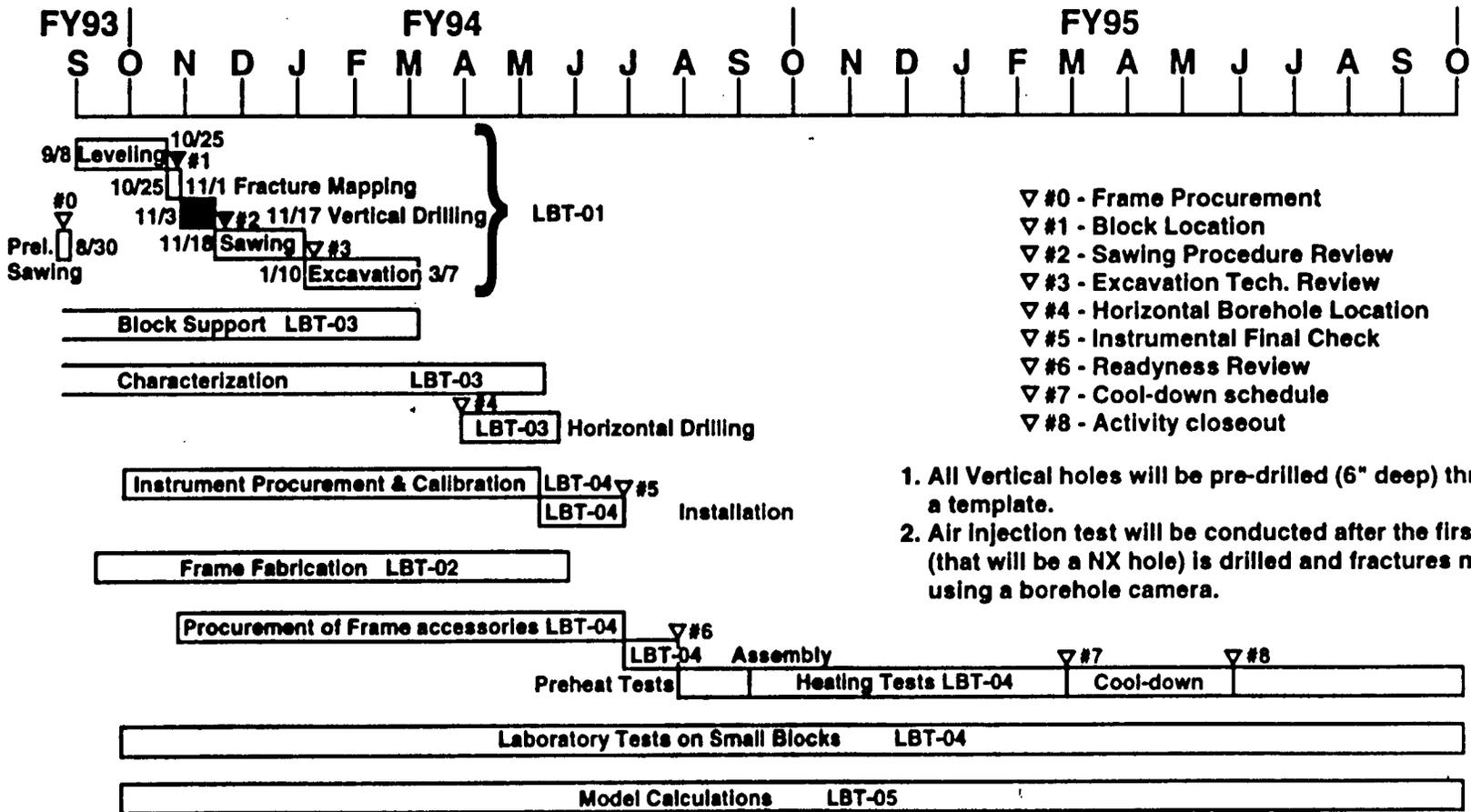


Figure 26. Schedules of activities in the LBT.



- ▽ #0 - Frame Procurement
- ▽ #1 - Block Location
- ▽ #2 - Sawing Procedure Review
- ▽ #3 - Excavation Tech. Review
- ▽ #4 - Horizontal Borehole Location
- ▽ #5 - Instrumental Final Check
- ▽ #6 - Readiness Review
- ▽ #7 - Cool-down schedule
- ▽ #8 - Activity closeout

1. All Vertical holes will be pre-drilled (6" deep) through a template.
2. Air Injection test will be conducted after the first hole (that will be a NX hole) is drilled and fractures mapped using a borehole camera.

# Review of Status

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**Test Concept and Location specifications completed**

**Test Planning and Controls**

**SIP Approved 11/93**

**ESF Study Plan in final comment resolution**

**Activity Plan in approval cycle**

**QA grading of Activities**

**Continuing planning meetings**

**Work Orders, Job Packages, & Test Planning pkg on track**

**Construction**

**Benching and sump completed**

**Sawing completed 2/25**

**Test Frame under construction--June**

**Accessories under design**

**Vertical Boreholes completed**

**Block support in design**

**Foam construction support**

**Excavation methods tested**

## **Review of Status, cont.**

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### **Characterization**

**Fracture Mapping of surface completed**

**Scoping test of saturation from surface samples completed**

**Vertical boreholes logged-core samples selected**

**Permeability Testing of Vertical Holes completed**

**Neutron Gage Measurements of Vertical Holes completed**

**analyses waiting on receipt of core**

**Block samples collected for cutting penetration analyses**

### **Instrument Procurement**

**Instrument development underway**

**Instrument specifications and orders in prep**

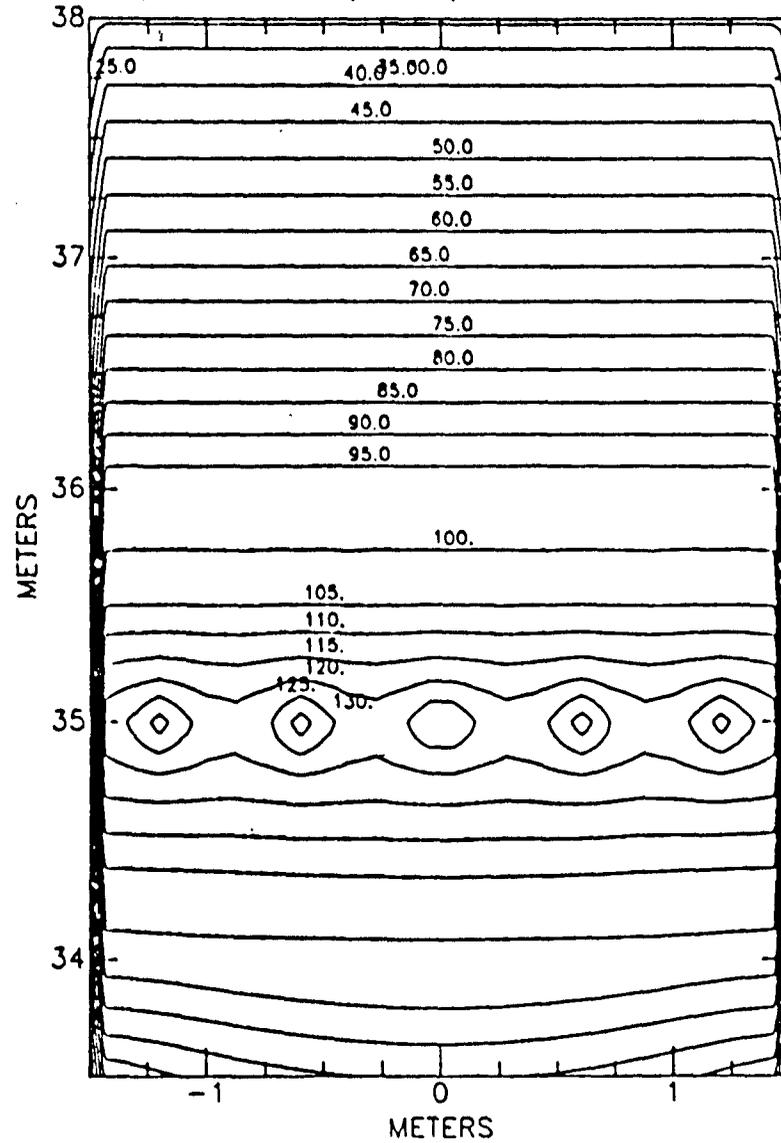
**DAS system orders placed**

**Technical support identified--working on obtaining**

### **Scoping Calculations performed**

# Large Block Test, Run No. 2, x-z Model, 5-23-93

TEMPERATURE (C)  
TIME(DAYS) = 120



(BEST AVAILABLE COPY)

DCLLNLDW25 125.NWTRB/7-13/14-93

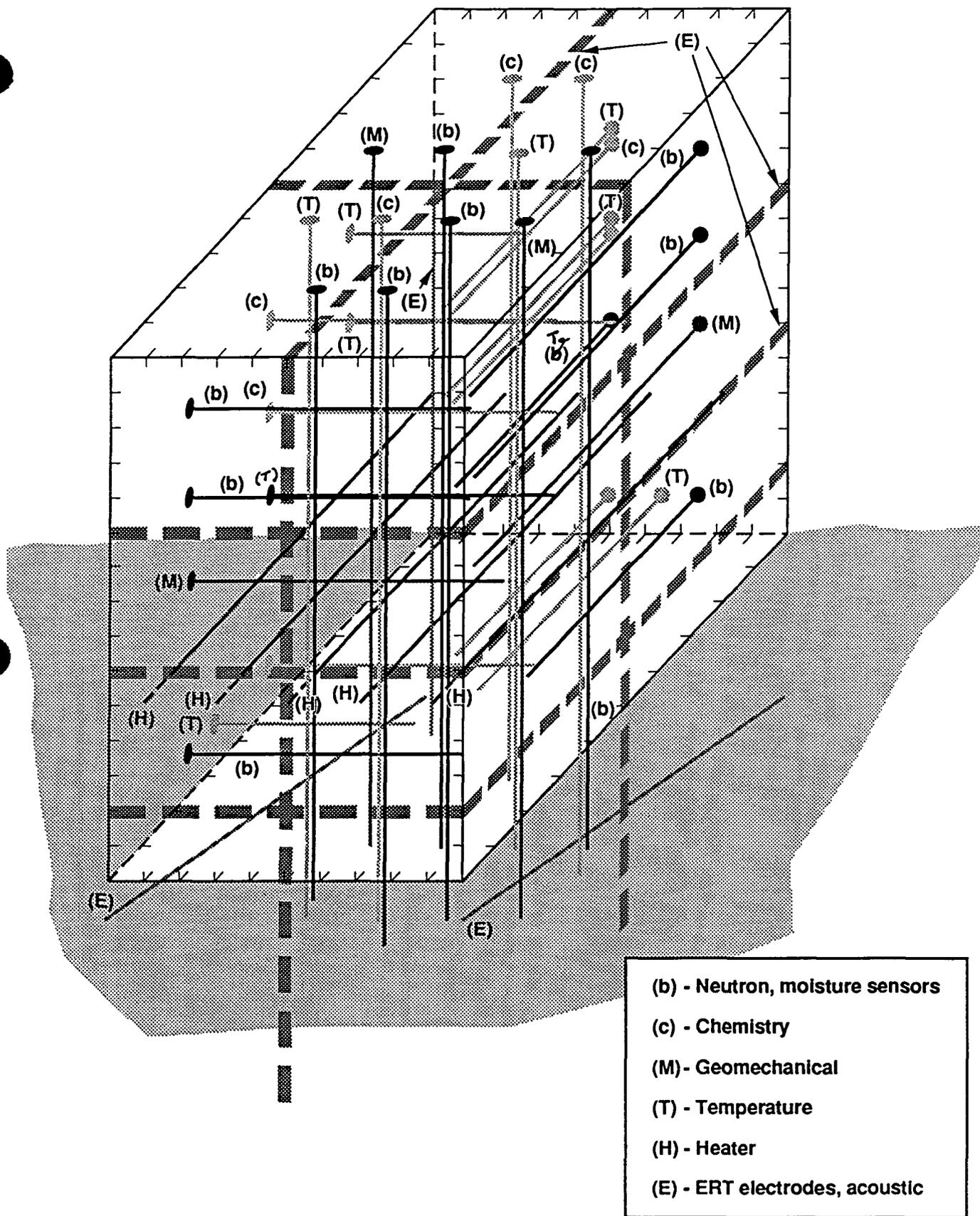
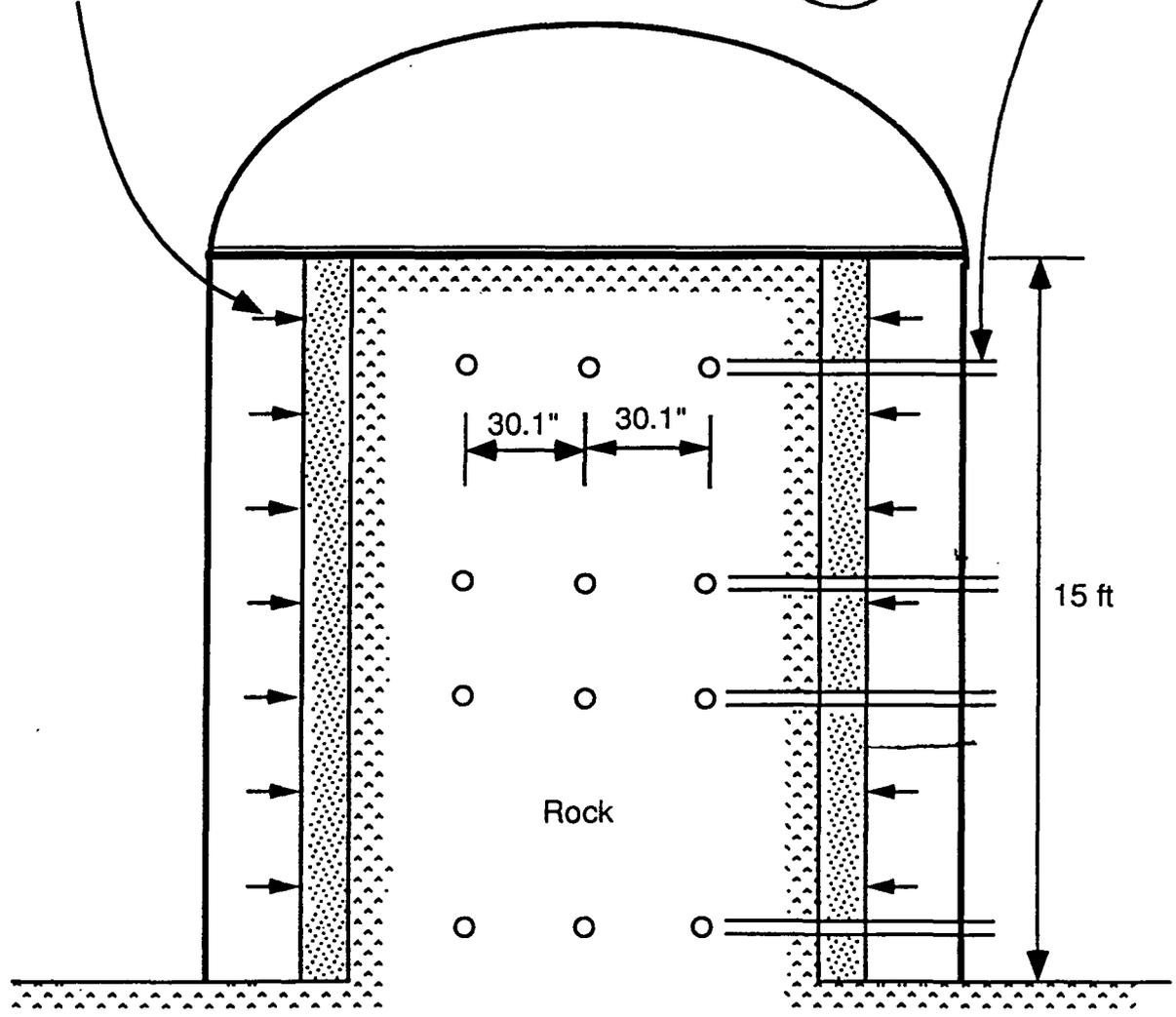
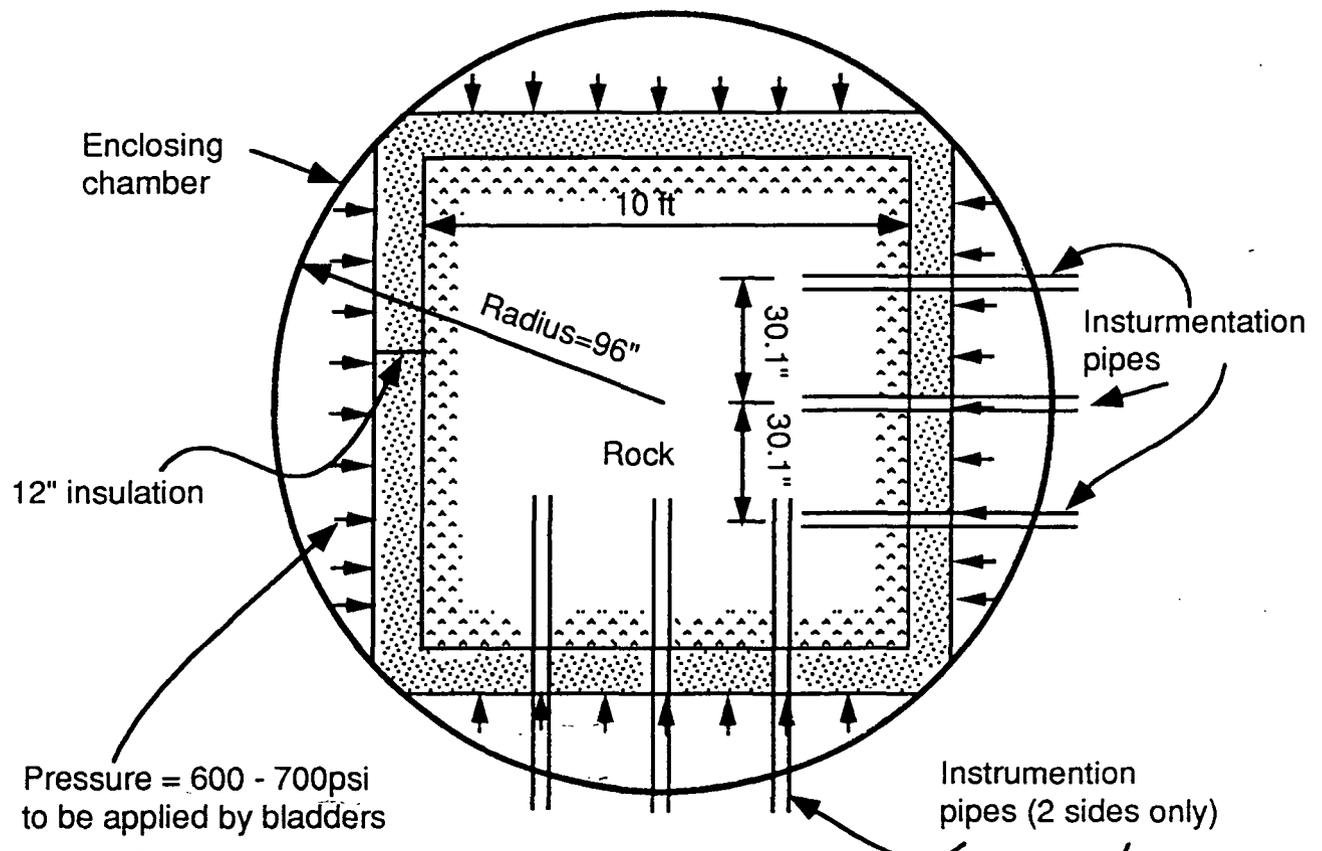


Figure 6. Instrumentation holes in the large block.



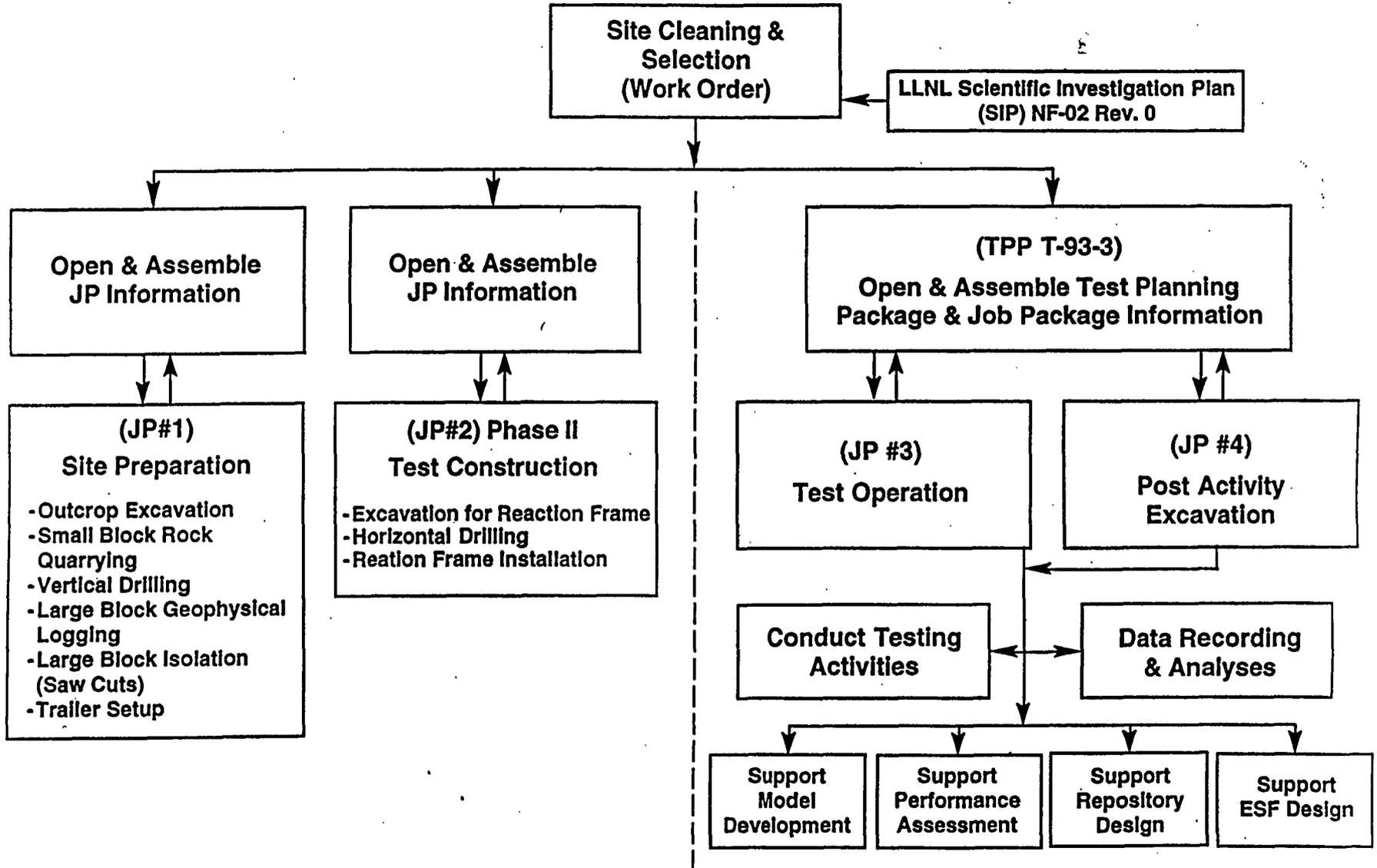
# Quality Assurance

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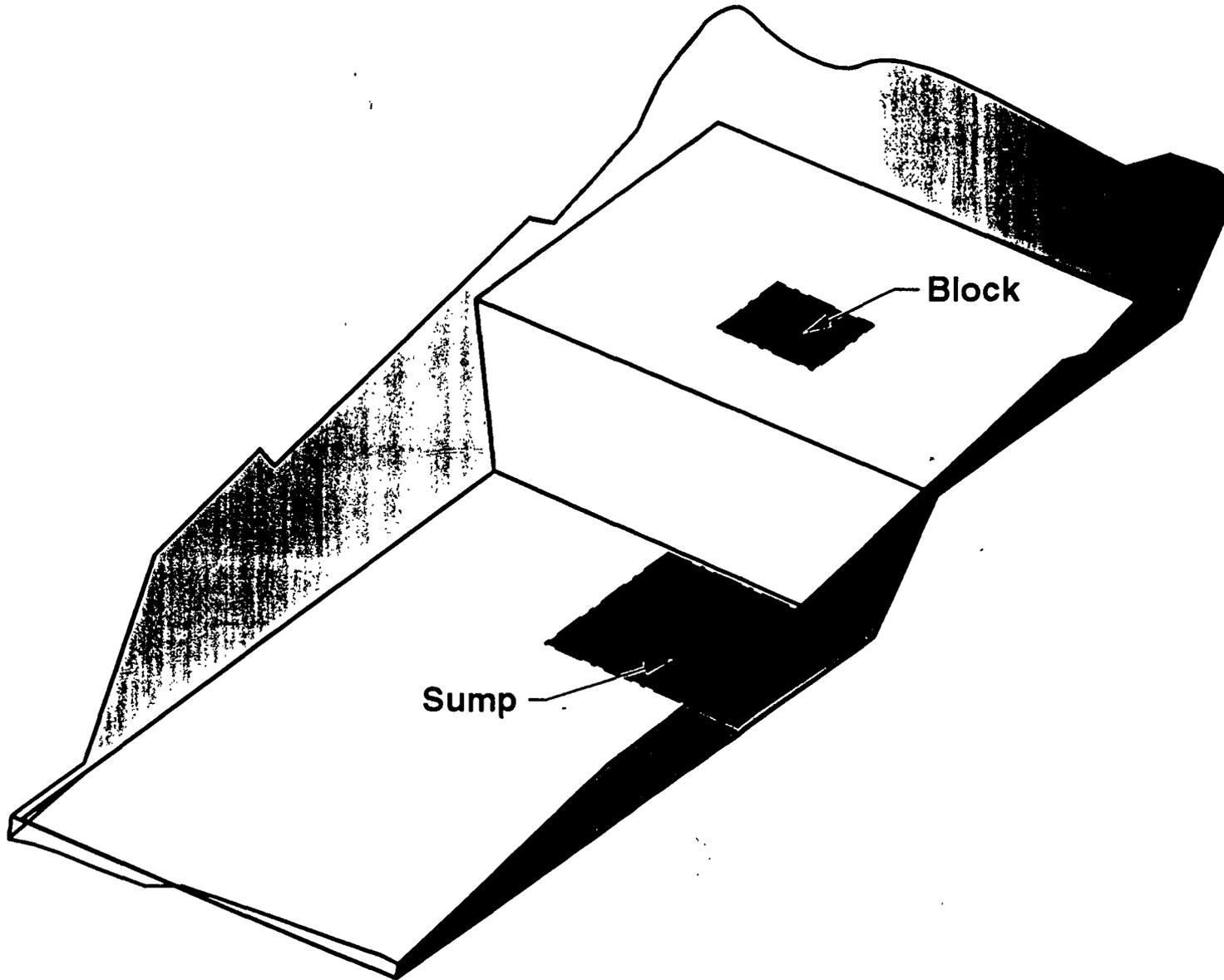
Grading of 8 activities completed

<b>Activity</b>	<b>Date</b>	<b>Q A?</b>
LBT-01 Collect or Isolate Rock blocks	4/1/93	No
LBT-02 Design & Fabrication of a Loading Frame	8/10/93	No
LBT-03.1 Scoping Property Determination for Test Design & Planning Document	9/23/93	No
LBT-03.2 Characterization of Blocks	8/20/93	Yes
LBT-04.1 Scoping Laboratory Tests on Small Blocks	9/20/93	No
LBT-04.2 Main Testing of the Coupled TMHC Processes	8/20/93	Yes
LBT-05.1 Pre-Test Model Calculations	8/20/93	No
LBT-05.2 Post-Test Model Calculations	8/20/93	Yes

# Test Control Logic Diagram



# Benching For Large Block Test



**Sawing**

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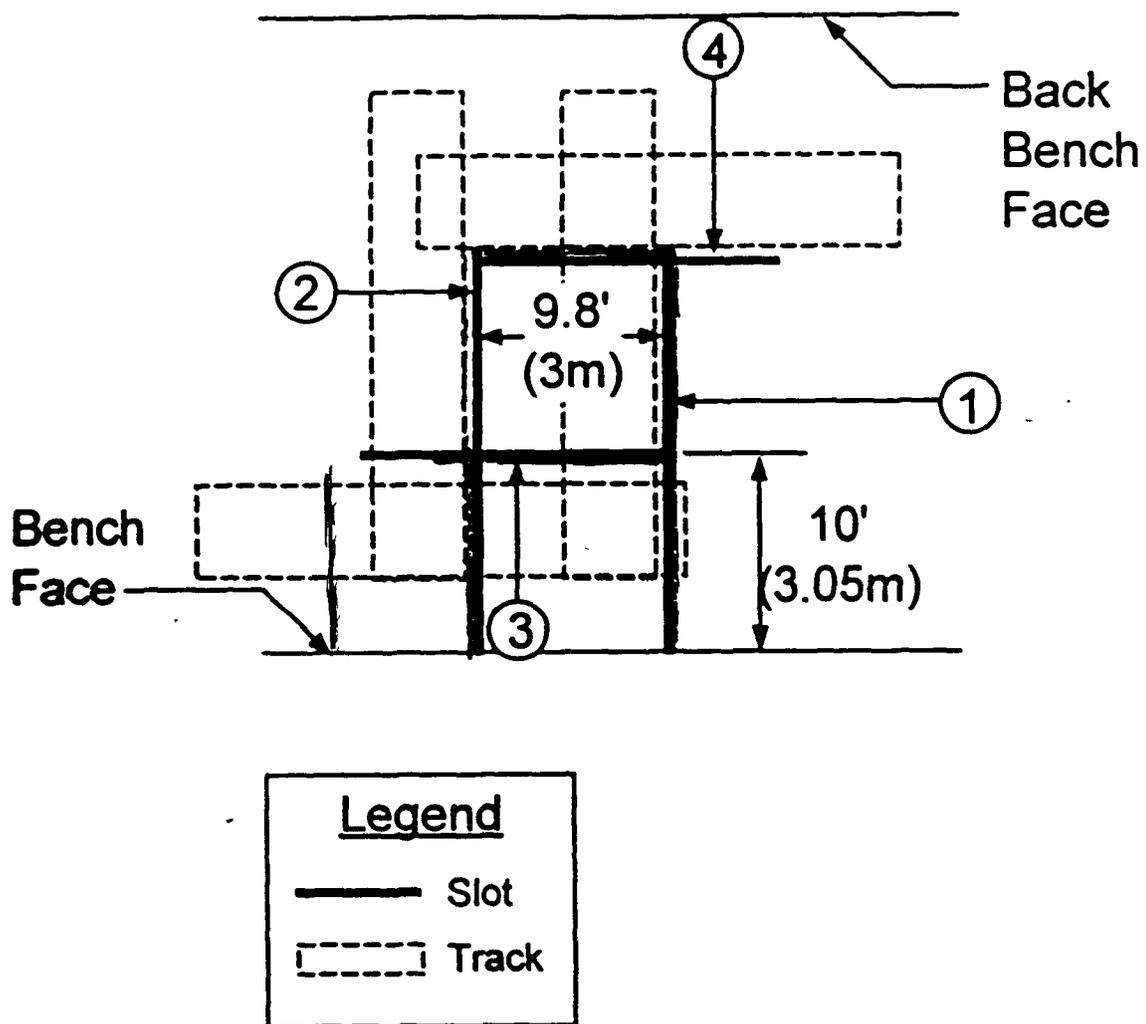
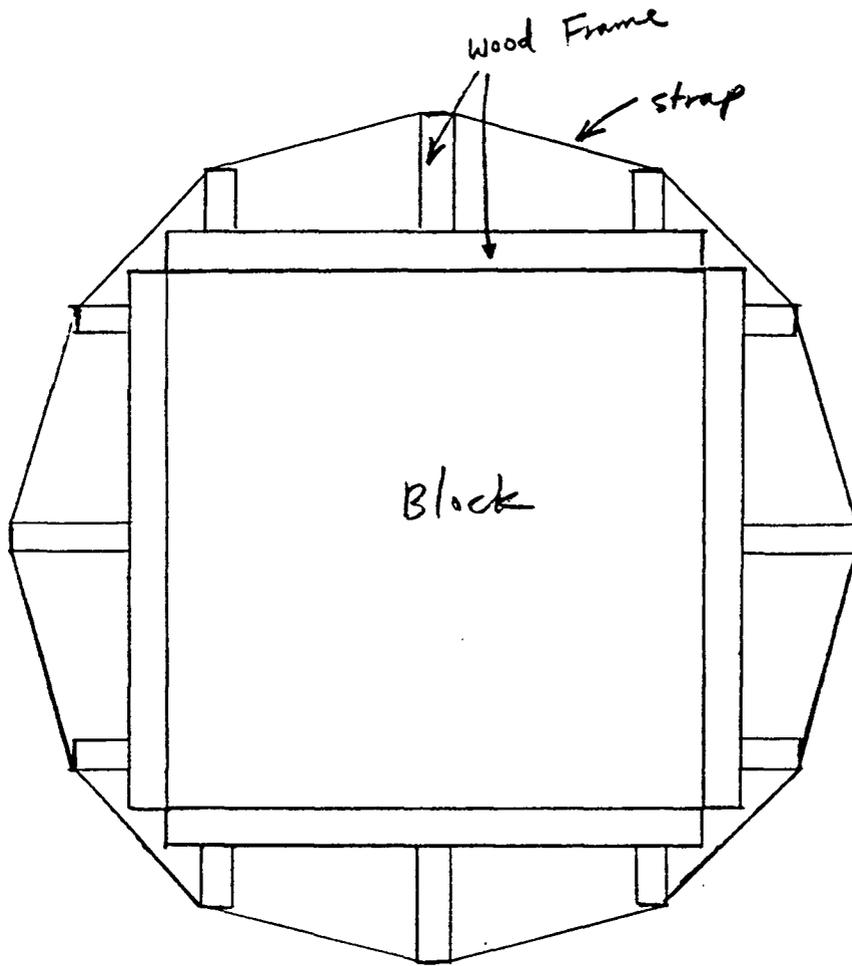


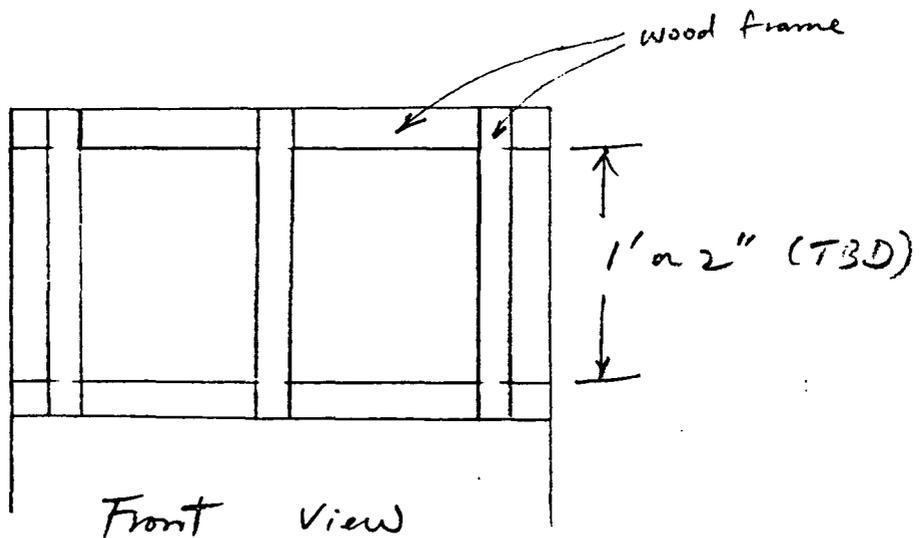
Figure 4. Illustration of Outcrop Area and Planned Sequence of Slot Cutting

Concepts of keeping the block together

TOP View



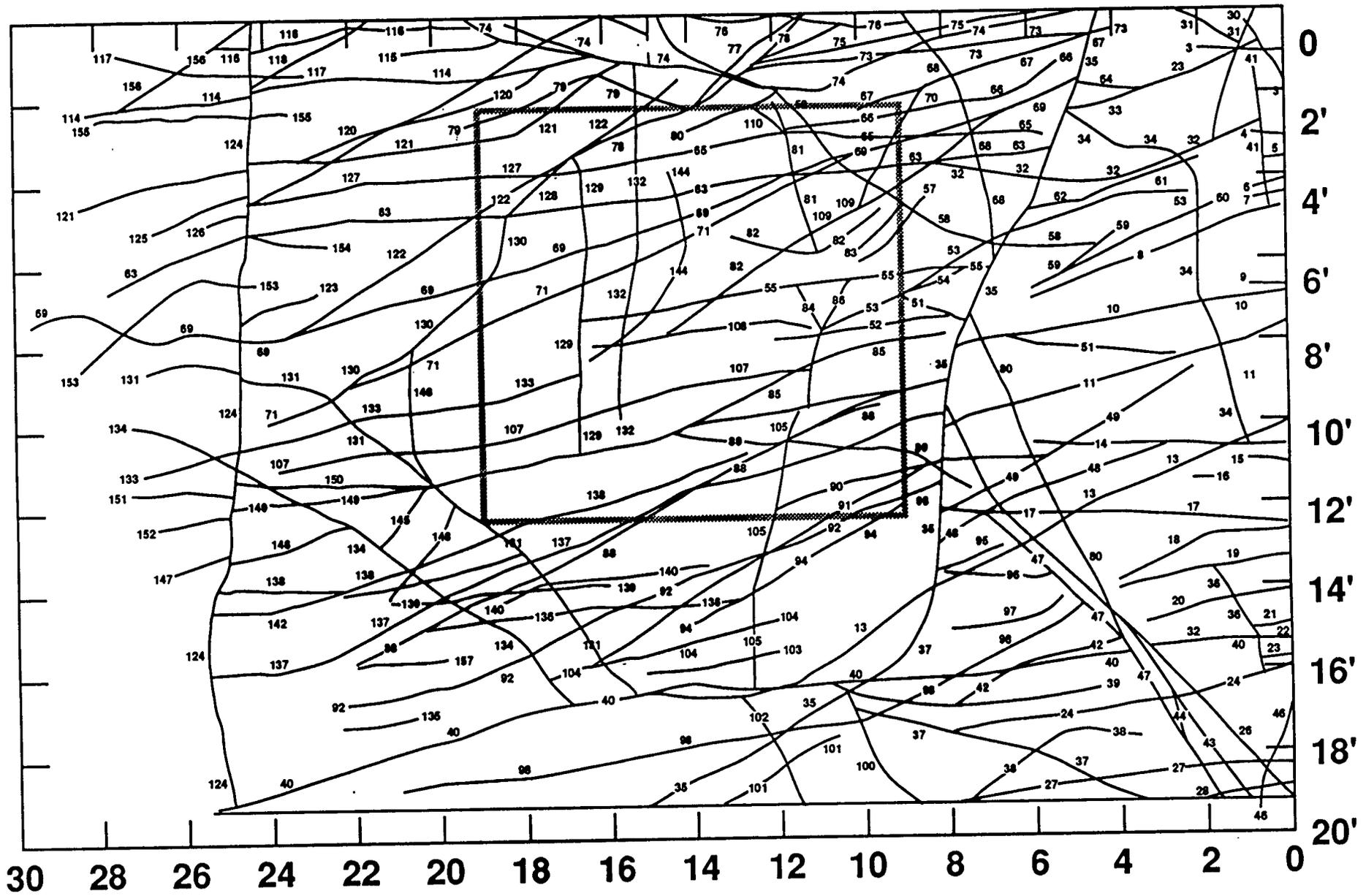
Max. load on  
the entire surface  
of each side is  
31,000 lb



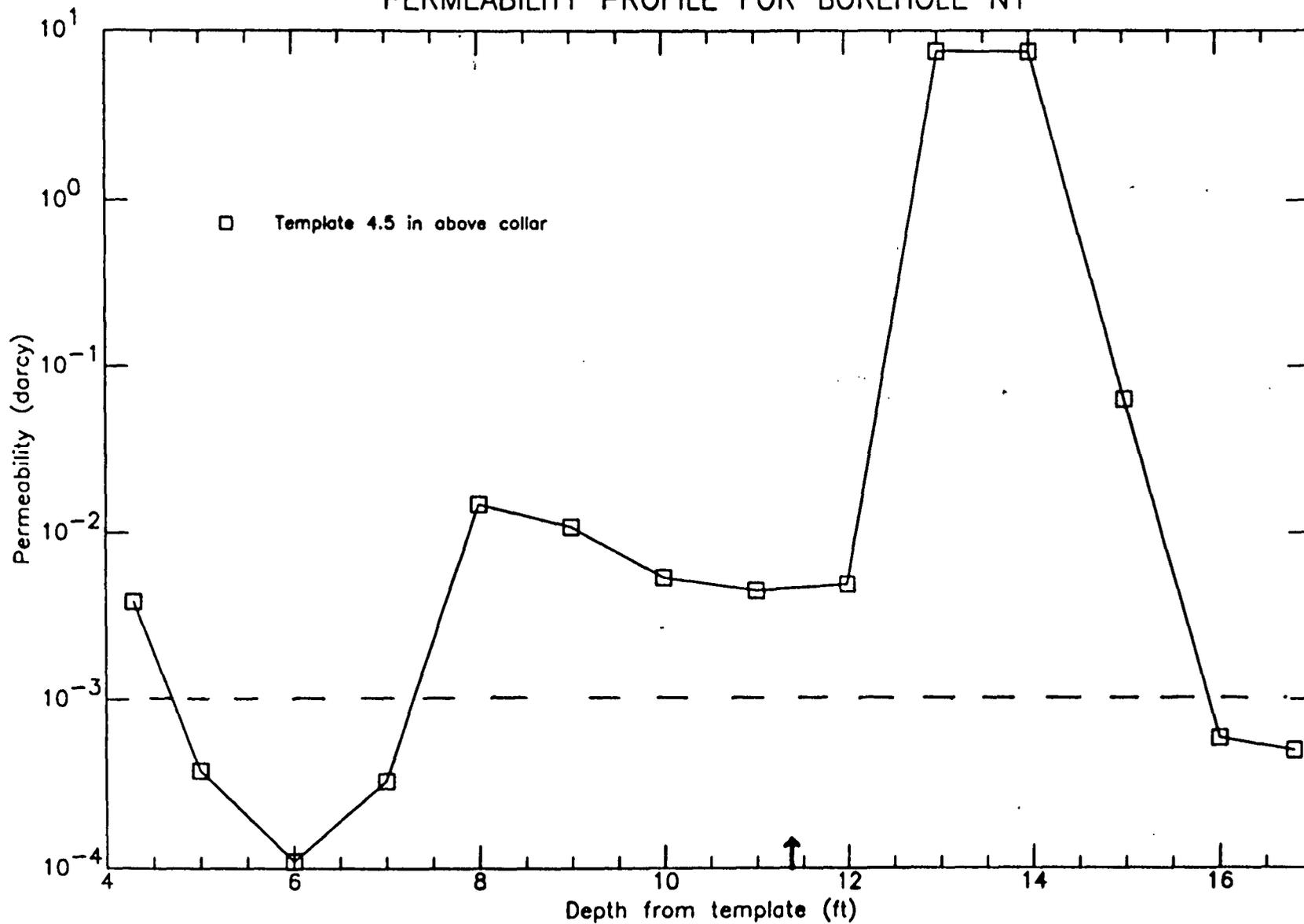
# Block Characterization

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**Fracture Mapping**  
**Pole diagrams**  
**3-D representation**



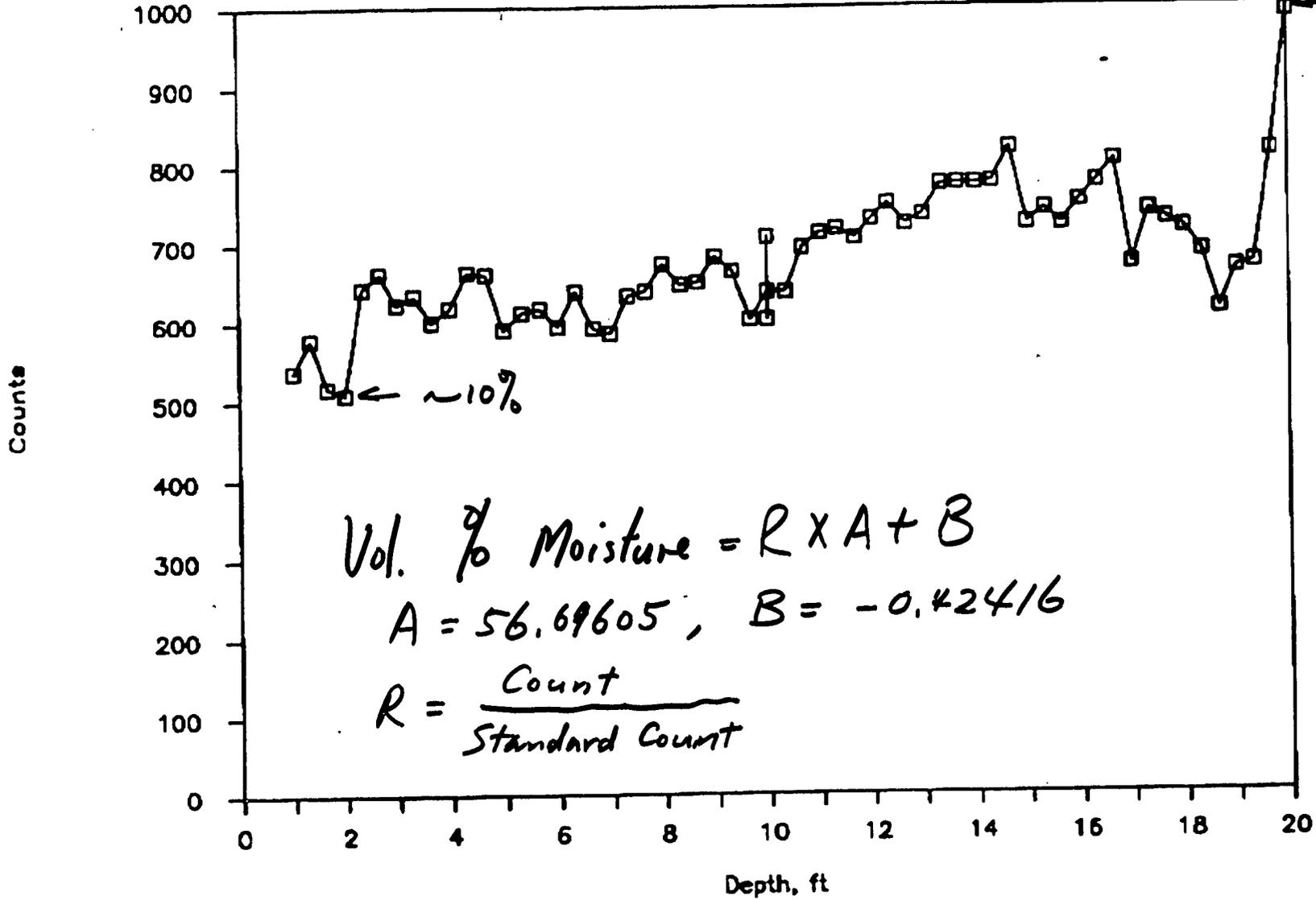
YMP Large Block Test  
Preliminary Air Injection Test Results  
PERMEABILITY PROFILE FOR BOREHOLE N1



# LBT Neutron Logging

Hole E4, 12/20/93

01-07-1994 11:38



# Instrumentation

- Temperature Measurements
- Displacement Measurements
- Electrical Resistivity Tomography
- Acoustic Emissions
- Confinement Pressure and Temperature Control
- Heat Exchanger System Monitor and Control
- Assorted Geomechanical / Geochemistry Measurements

# Calibration

- Plan to use EG&G/REEC Co calibration facilities
  - Traceable to NIST
- Concern over possible closures

# Data Acquisition

- 900 Channels
- Using "Dual Benefit" approach
  - SMIDS
    - LLNL Special Initiative under the Weapons Program to digitize data and expand the networking capabilities
  - EG&G support

## Instrumentation

- Temperature Measurements
- Displacement Measurements
- Electrical Resistivity Tomography
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## Temperature Measurements

- 340 channels measuring internal block thermal gradients
- 240 channels measuring outer surface boundary temperatures
- 100 channels measuring geochemistry experiments
  - Ambient to 130 Degrees Celsius temperature range
  - +/- 1 Degree Celsius Accuracy
  - 0.1 Degree Celsius Resolution
- A new inexpensive Temperature sensor is being evaluated to replace the standard thermocouple. The Resistance Temperature Device (RTD) will provide higher accuracy and fewer instrumentation connections. The RTD requires no isothermal reference. In many locations a "standard" conversion coefficient will return the required systematic accuracy.

## Displacement Measurements

- Three boreholes with four anchor locations
  - 12 data channels
- Measurement maximum distance 4.5 meters
- Resolution 0.1 mm
- A new instrument technology is under development to incorporate laser distance measuring techniques to monitor rock displacements.

## Electrical Resistivity Tomography

- Noted here because of the implications on all other measurements
- The DAS system must tolerate:
  - 300 volts of switched DC current across the block
  - Transient current spikes from the ERT experiments

## Acoustic Emissions

- Noted here because of the implications on all other measurements
- Transient acoustic recorders will be provided by others

## Confinement Pressure Measurement and Temperature Control

- Measurement of the pressure of confinement bladders
  - Estimated 40 channels
  - 600 psig +/- 14 psig pressure range
- Measure heat flux at block boundary
  - Control heaters to establish zero heat flux at block boundaries
  - Estimated 40 channels

## Heat Exchanger System Monitor and Control

- Serial computer interface
  - Monitor exchange fluid temperature
  - Establish set point temperature
- Monitor temperature channels to calculate exchanger set point

## Assorted Geomechanical / Geochemistry Measurements

- Pore Pressure measurements
  - 10 channels
  - 50 +/- 0.5 psig
- Humidity
  - 25 channels
- Geochemistry Sensors
  - 36 channels
- Fracture Movement Monitors
  - To Be Determined

## Data Acquisition System

- Computer Processor System will be the SMID System developed in support of the LLNL Containment Program.
- Multitasking DEC processor can handling simultaneous control and monitor operations
- Graphical interfaces requires minimum operator training
- Power fail and recovery capabilities are built in
- Highly modular with ethernet support to LLNL
- Rewriteable Optical Disk provides flexibility, size, and reliability to the data archives system
- File transfer system is compatible with desktop Macintosh applications
- Data base will support instrument tracking and engineering conversions
- Pass word protected for data security

## Front End Hardware

- Hewlett Packard relay scanner system provides channel isolation from ground loops as well as protection from the ERT experiment
- External Digital Multimeter provides system configuration flexibility
  - Interchangeability with minimum downtime
  - Rotation of multimeter for calibration
  - Simple upgrades with new requirements and accuracy

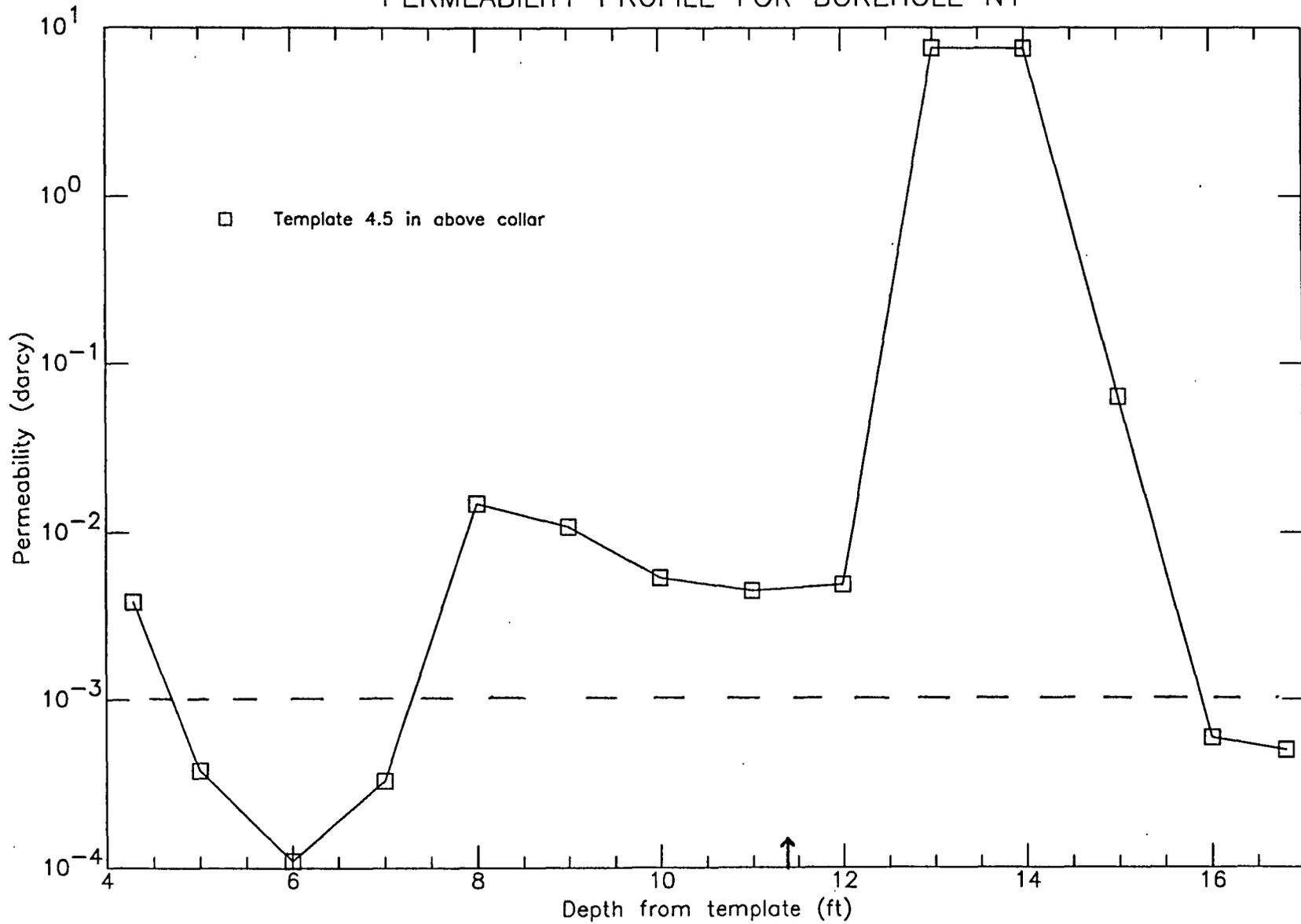
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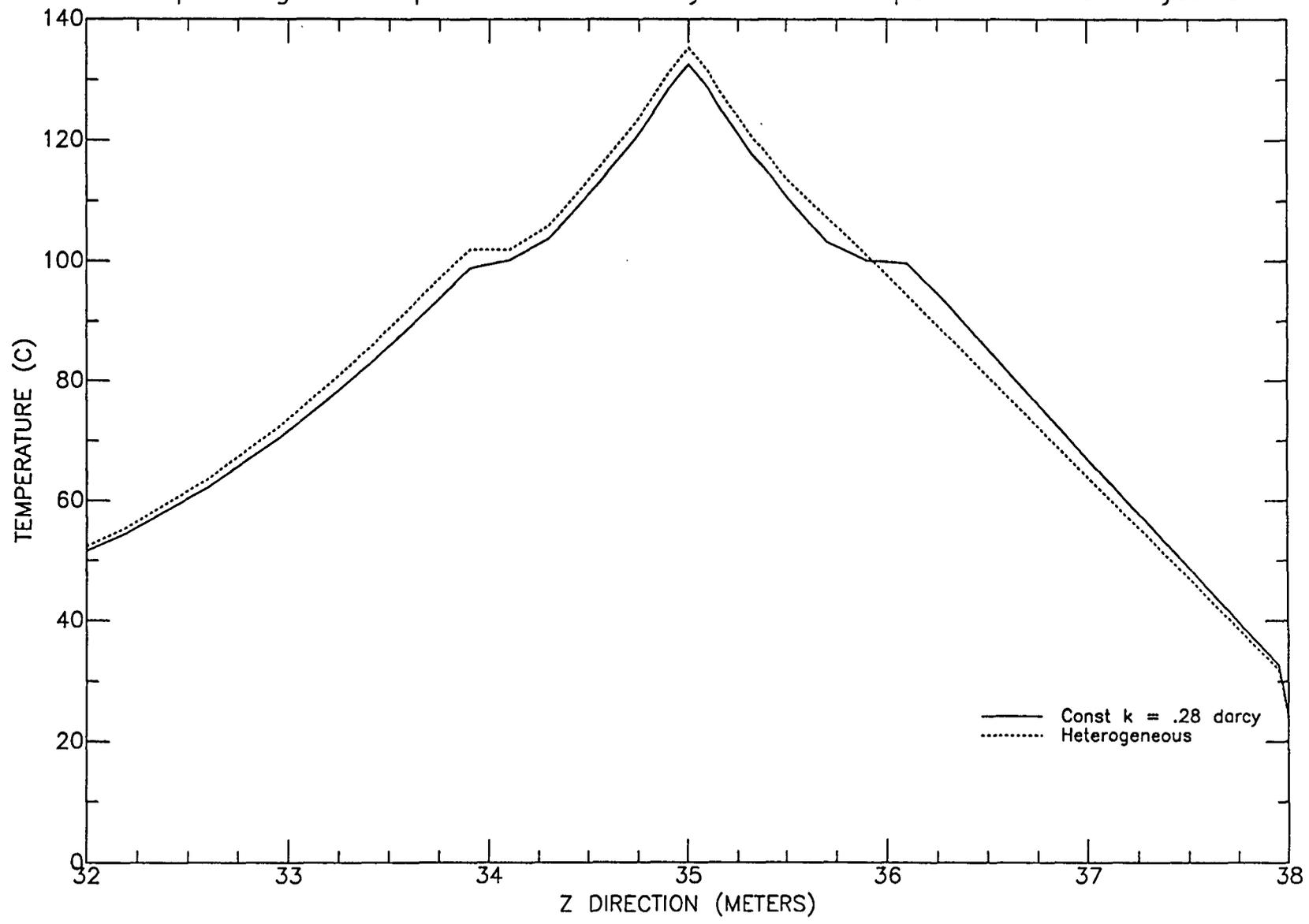
- Plan to use EG&G/REECO calibration facilities
  - Traceable to NIST
- Concern over possible closures

YMP Large Block Test  
Preliminary Air Injection Test Results  
PERMEABILITY PROFILE FOR BOREHOLE N1



\*Large Block Test, Run 6, x-z Model, 6-21-93\*  
EFFECT OF PERMEABILITY ON TEMPERATURE AT 120 DAYS

Temp using const perm of .28 darcy and heter perm from air injection



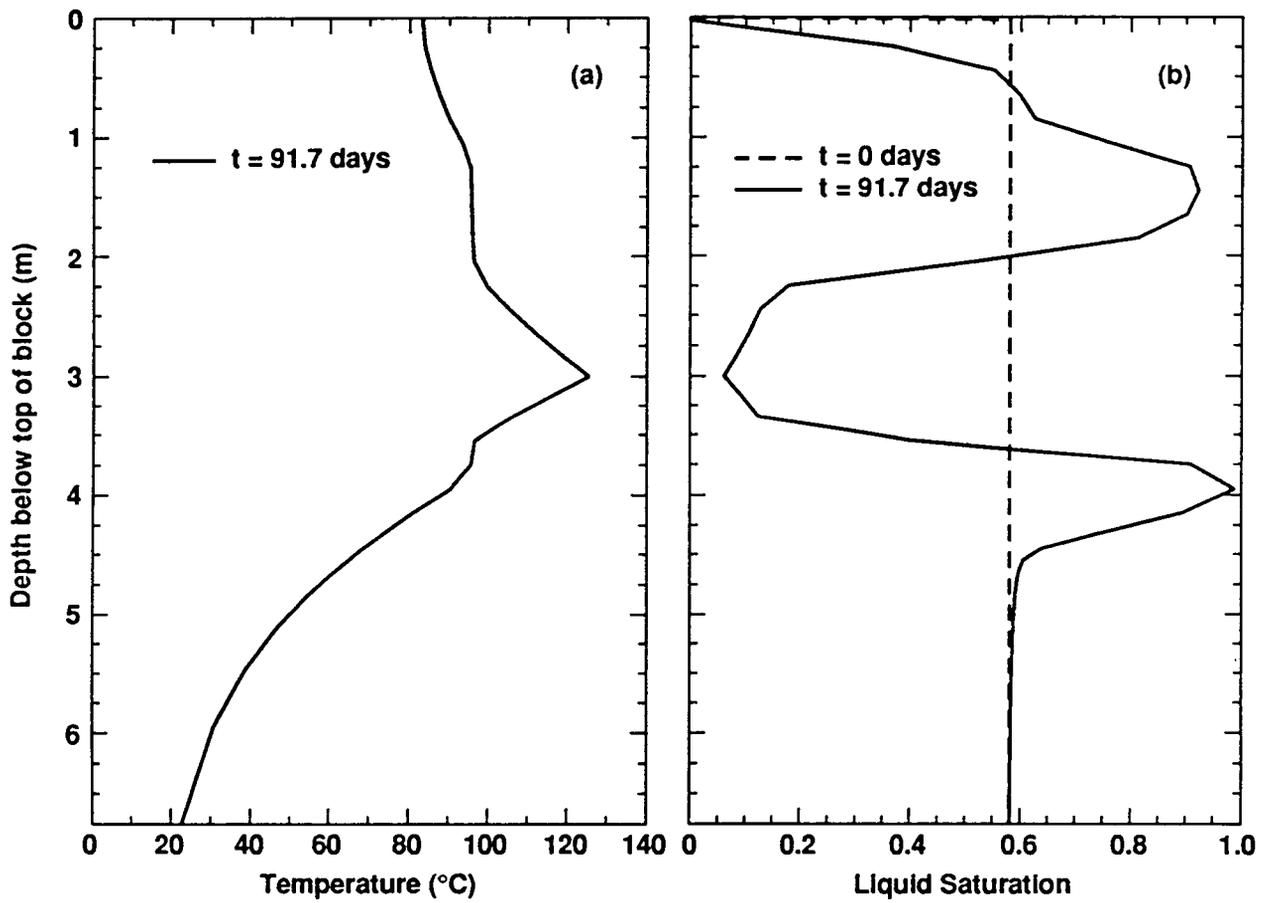


Figure 25. Vertical temperature profile (a) and liquid saturation profile (b) along the midline of the large-block test with 5 300-W heaters and a bulk permeability of 280 millidarcy at  $t = 91.7$  days.

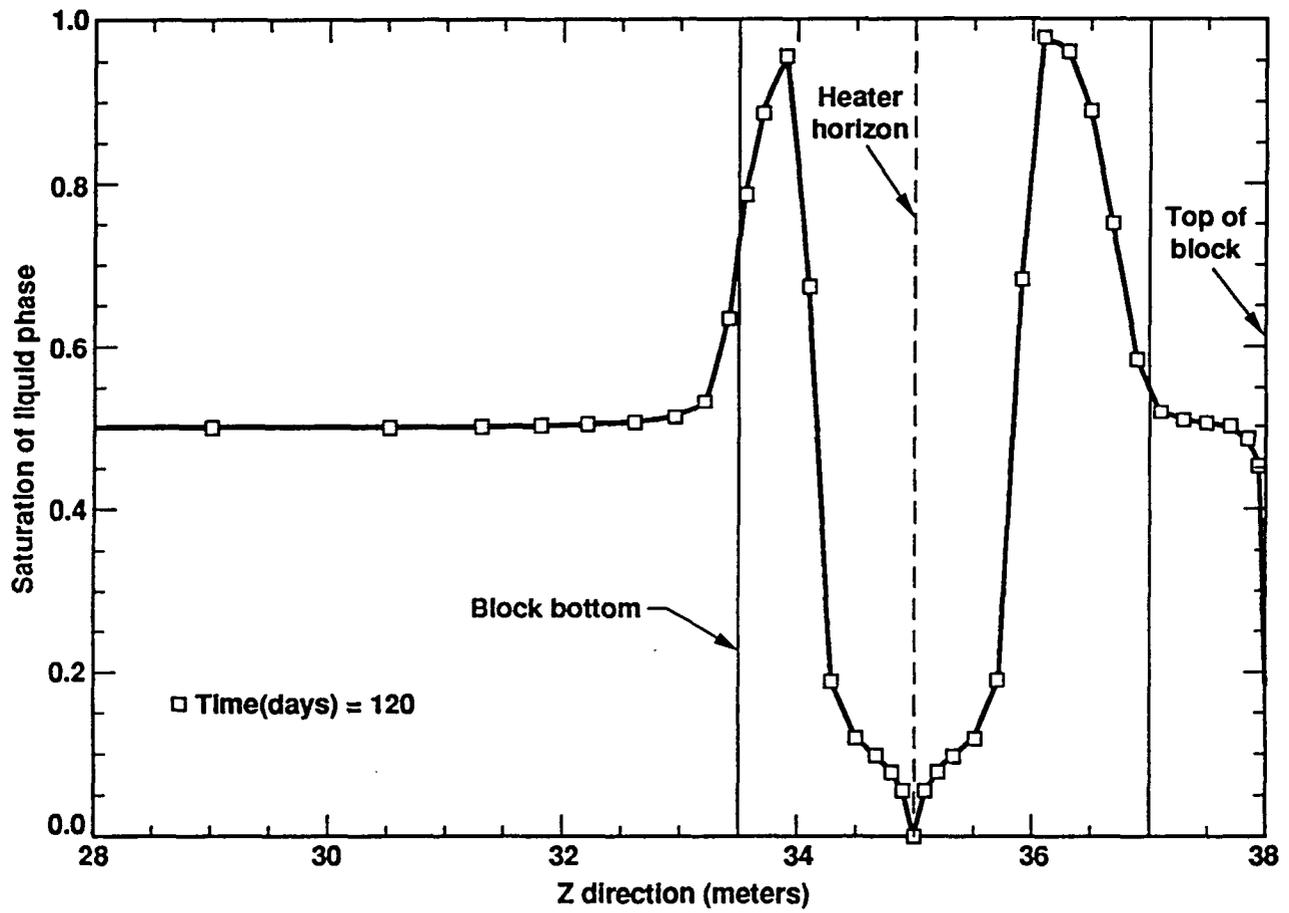
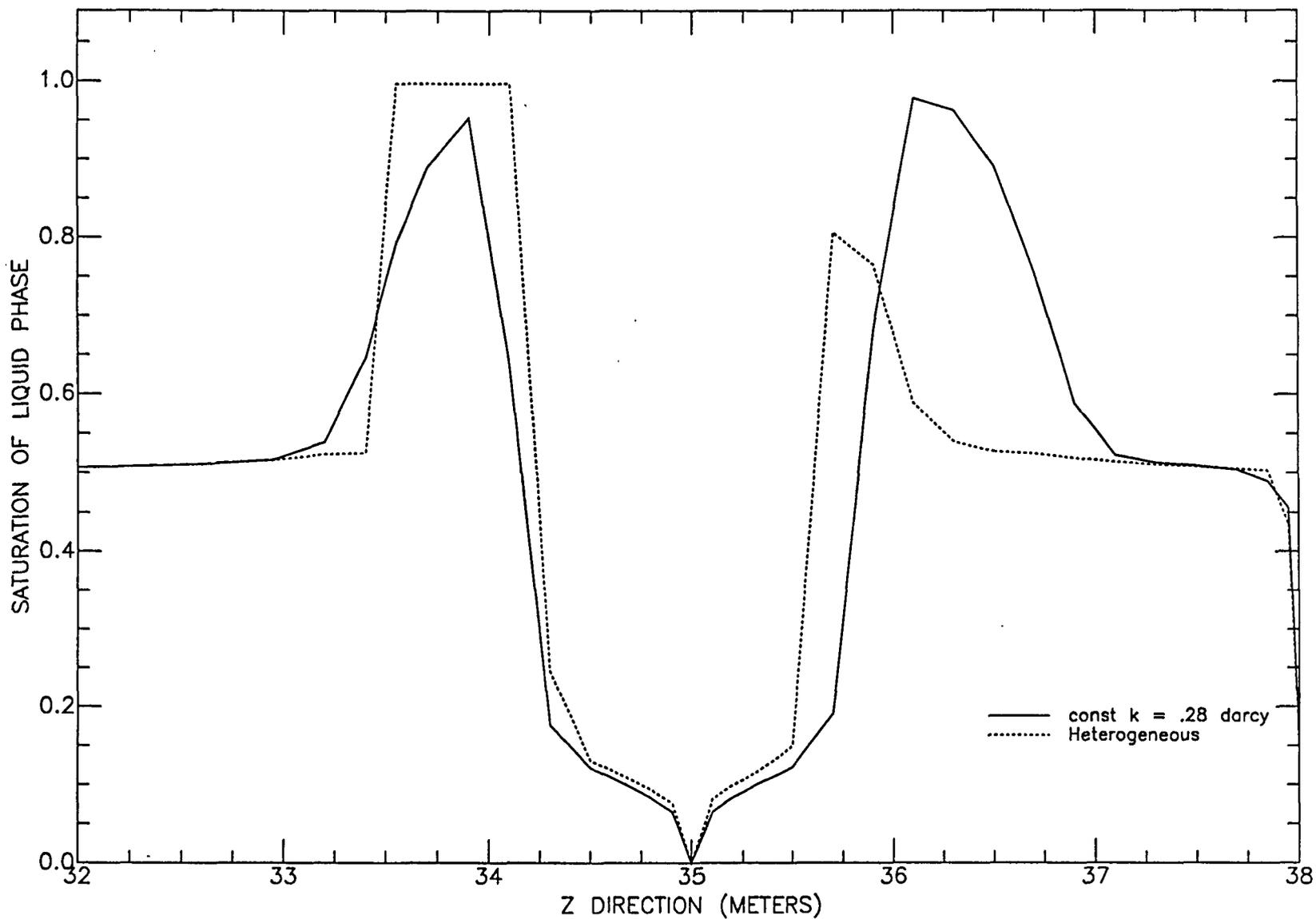


Figure 24. The preliminary result of the pre-test model calculation of the moisture distribution in a square column model.

\*Large Block Test, Run 6, x-z Model, 6-21-93\*

EFFECT OF PERMEABILITY ON WATER SATURATION PROFILE AT DAY 120

Saturation using const perm of .28 darcy and heterogeneous perm from air inj.



THE TESTING OF  
THERMAL-MECHANICAL-HYDROLOGICAL-CHEMICAL  
PROCESSES USING A LARGE BLOCK

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(510) 422-7162

## ABSTRACT

The radioactive decay heat from nuclear waste packages may, depending on the thermal load, create coupled thermal-mechanical-hydrological-chemical (TMHC) processes in the near-field environment of a repository. A group of tests on a large block (LBT) are planned to provide a timely opportunity to test and calibrate some of the TMHC model concepts. The LBT is advantageous for testing and verifying model concepts because the boundary conditions are controlled, and the block can be characterized before and after the experiment. A block of Topopah Spring tuff of about 3 x 3 x 4.5 m will be sawed and isolated at Fran Ridge, Nevada Test Site. Small blocks of the rock adjacent to the large block will be collected for laboratory testing of some individual thermal-mechanical, hydrological, and chemical processes. A constant load of about 4 MPa will be applied to the top and sides of the large block. The sides will be sealed with moisture and thermal barriers. The large block will be heated with heater in boreholes and guard heaters on the sides so that a dry-out zone and a condensate zone will exist simultaneously. Temperature, moisture content, pore pressure, chemical composition, stress and displacement will be measured through out the block during the heating and cool-down phases. The results from the experiments on small blocks and the tests on the large block will provide a better understanding of some concepts of the coupled TMHC processes. The progress of the project is also presented in this paper.

## I. INTRODUCTION

A major concern for the disposal of high level nuclear wastes in deep geological formations is the quantity and quality of water (both liquid and vapor) that may contact waste packages. The Yucca Mountain Site

Characterization Project (YMP) is investigating the Topopah Spring tuff at Yucca Mountain, Nevada, for its suitability as a host rock for the disposal of high level nuclear wastes. The host rock at the potential repository horizon is a partially saturated, fractured, densely welded, nonlithophysal tuff. Work to date suggests that the host rock at the potential repository horizon has a mean matrix porosity of 14% and a mean water saturation of 65%.<sup>1</sup> Therefore, the pores of the host rock are filled with both air and water.

The expected development of the near-field environment in a repository is discussed in the next two paragraphs. The radioactive decay heat from waste packages will increase the temperature in the rock mass in the near field of the repository. The temperature in the rock mass depends on the thermal load in the repository. Results from a heater test in G-Tunnel, Nevada Test Site<sup>2</sup> and model calculations<sup>3</sup> indicate that, above an areal power density (APD) threshold, the near-field environment of a nuclear waste repository will consist of a boiling/dry-out zone and a condensate zone. The rock in the near field will be subject to thermal loading that may change the fracture porosity and connectivity. Laboratory studies<sup>4</sup> and a field investigation<sup>5</sup> indicate that fractures are the main flow path for vapor/steam. Most of the water vapor will condense where temperatures are sufficiently low. A region of increased saturation is expected to form adjacent to and outside of the dryer region due to this condensation. In regions above the heater, for example, the drainage water may be evaporated, flow upward, be condensed, and flow downward again (refluxing).<sup>3</sup> In regions to the sides of the heaters, the condensed water may be shed.<sup>6</sup> In the condensate region and in the refluxing zone, rock-water interaction may occur. And the rock-water interaction will cause dissolution and re-deposition, which, in turn, will affect the movement of fluids within the rock mass.<sup>7,8,&9</sup>

These coupled thermal-mechanical-hydrological-chemical (TMHC) processes have to be understood before models can provide meaningful description of the near-field environment and predictions of the quantity and quality of water in the waste package environment.

Experiments are being designed to test, verify, calibrate, and validate some model concepts of the TMHC processes in the laboratory and in the field. A logical experimental sequence begins with experiments on small laboratory scale cores (usually a few centimeters in size), continues with laboratory experiments on small blocks (of a few tens of centimeters in size) and field experiments on large block (a few meters in size), and ends with in situ field experiments in Exploratory Studies Facility (ESF) (several tens of meters in size), as shown in Figure 1. Laboratory tests on small samples of intact rock and samples with single fractures are being conducted to test and develop conceptual models, such as dehydration and rehydration behavior, vapor diffusion, and liquid water imbibition, under controlled boundary conditions. Larger-scale tests that can incorporate more inhomogeneities, such as fractures, are needed to confirm and validate conceptual and numerical models. Eventually, in situ field tests in ESF will be performed to confirm models that will be used to predict the performance of an entire repository. Some of the tests shown in Fig. 1 may be performed concurrently. This paper presents the progress to date of the large block test (LBT). The LBT is designed to study some of the TMHC processes under controlled boundary conditions.<sup>10</sup> Therefore, it will provide a better and timely understanding of some concepts related to the coupled TMHC processes.

## II. PURPOSE AND OBJECTIVES OF THE LBT

The LBT is designed to create controlled boundary conditions so that some of the coupled TMHC processes can be observed and some conceptual models can be tested. We will make observations on: 1) dominant heat transfer mechanism, 2) coincidence (or lack thereof) of the dry-out zone and the boiling-point isotherm, 3) re-wetting of the dry-out zone and the cooling of the region, 4) refluxing of the condensate water above the heated zone, 5) the effect of rock-water interactions and the thermal-mechanical processes on the movement of fluid.

The LBT will provide tests on a block of rock which is closer in scale to the repository than previous heater test blocks,<sup>11</sup> will be able to be characterized from five exposed surfaces and multiple boreholes, and will be dismantled after testing for further characterization, especially for studying rock-water interactions. The LBT will also provide an opportunity for testing the performance of waste package materials in the thermal-hydrological-chemical environment of the block.

The LBT is expected to meet three objectives:

- 1) It will improve understanding of the coupled TMHC processes included in models that 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.

The LBT will not replace the EBSFT. Neither will it simulate the in situ conditions in a repository, such as mechanical stresses, mineralogical composition on fracture surfaces, etc. Therefore, the evaluation of testing methodology and instruments will be at risk because the instruments will not be in the environment expected to exist in ESF. The LBT will not simulate emplacement modes either.

## III. DESCRIPTION OF THE LBT

The LBT consists of two parts: (1) laboratory tests on small blocks of intact rock and blocks with single fractures, quarried from the region adjacent to the large block, to study the thermal hydrological, mechanical, and chemical processes and (2) an attempt at integrated macroscopic simulation and evaluation of the coupled TMHC processes in a large block.

### A. Block Size Determination and Site Selection

A block size is chosen to be 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, that sufficient number of fractures are included in a test region<sup>12</sup> and that it allows for a zone of condensate to form above the coalesced boiling front above heater zone. If fracture densities at Fran Ridge are similar to those in the potential repository horizon, a block of about 3 m on a side will include at least 10 fractures.

Pre-test calculations have been performed for a block with five horizontal heated holes, each containing a 2.44-m-long, 300-watt heating element, spaced by 0.61 m in a horizontal plane located about 1.5 m from the bottom of the block. The result shows (see Figure 2) that a dry-out zone of about 0.75 m immediately above and below the heater plane can be generated after full-power heating for about 4 months with adiabatic conditions on the sides and a constant 20°C on the top. The maximum temperature attained is about 135°C. A condensate zone about 1.25 m thick will exist adjacent to the dry-out zone. We expect that condensate refluxing may occur along fractures in the condensate zone above the heater plane. Based on these a block size of 3 m square and 4.5 m tall is determined.

While a larger block would be desirable, the thickness of load-retaining frame plates becomes excessive for blocks greater than 3 m in size.

A site at Fran Ridge was selected for the large block. Three considerations were applied in the site selection: the rock type, fracture characteristics, and accessibility. The rock type exposed at Fran Ridge is the same as the densely welded, fractured, Topopah Spring tuff just below the lithophysal/nonlithophysal contact. The fracture density, as observed on the outcrop, is at least one fracture per 30 cm. Both of these two characters meet the criteria for a large block site. An outcrop at the southeastern end of Busted Butte, just south of Fran Ridge, was also inspected. The rock type at the Busted Butte site is closer to that at the potential repository horizon, and the fracture density is also similar. But the accessibility of the Fran Ridge site is superior to the Busted Butte site. Figure 3 shows the location of the Fran Ridge site. The large block is located north of Pit #1 of the US Geological Survey Fracture Mapping site.

#### B. Isolation of the Large Block

A belt saw will be used to saw four vertical slots that will form the boundary of the large block. The rock surrounding the block will be excavated, so that a 3 x 3 x 4.5 m block will be free standing, as shown in Figure 4.

The techniques of using a belt saw in the field have been developed by Sandia National Laboratories at Albuquerque, New Mexico. A preliminary sawing using a 2 m-long cutting bar was very successful. A commercial belt saw with a 4.9 m-long cutting bar will be used to saw four vertical slots. Each slot will be about 3 m long, 4.9 m deep, and about 4.4 cm wide. In order to use the belt saw, a work area of about 12 x 12 m will be leveled to within 15 cm. A wall of about 4.9 m in height will be created roughly parallel to one of the sides of the block, as shown in Figure 5. Controlled blasting was used to level the work area. The block location was chosen, based on the fracture distribution and configuration. In deciding the block location, the stability of the block after the sawing and excavation was the main concern.

Pre-test model calculations indicate that the bulk permeability of the block should be at least  $10^{-15} \text{ m}^2$  in order to create a dry-out zone by heating from the heaters within the block. Air injection tests were conducted after the first vertical hole was drilled. The results indicate that for most parts of the block (in term of depth) the permeability is above  $5 \times 10^{-15} \text{ m}^2$  (5 mDarcy).

After all 17 vertical holes were drilled, neutron logging was conducted in some of the holes to estimate the moisture content in the block. Neutron logging will be

performed later at various stages of the block preparation to estimate the initial moisture content of the block before the experiment starts. According to pre-test model calculations, a water saturation level of at least 50% by volume is required in order to maintain condensate refluxing. Water may be added to the block if its initial moisture content is not enough.

A sawing procedure has been developed to minimize the adverse effect of sawing on the integrity of the block (see Job Package JP-93-10, YMP). Dunnage bags will be put in the slots during the sawing to protect the block, if necessary. The sawing will start from the previously described high-wall (Fig. 5) so that the water carrying the cuttings can be drained. After the sawing, the rock surrounding the block will be excavated. Mechanical excavation methods will be used to remove the rock near the block. The block will be supported as the excavation progresses. Some small blocks of rock, about 30 cm in size, will be collected from region adjacent the large block for laboratory tests.

#### C. Characterization of the Block

The large block will be characterized as completely as possible. The distribution of fractures, mineralogical composition of the matrix and the fracture coating, mechanical and hydrological properties, and the initial moisture content will be characterized. The fracture traces on the five surfaces and on the drill cores from the instrument holes will be used to determine the distribution of fractures within the block. The coating on the fractures extending beyond the block will be analyzed, so that the mineralogical composition of the coating on the fractures within the block can be inferred. The properties of the matrix to be determined include porosity, permeability, moisture retention curves, electrical resistivity vs moisture content, stress-strain curves, and acoustic wave velocity. The initial moisture content of the block will be determined using neutron logging.

#### D. Tests on Small Blocks

Blocks of Topopah Spring tuff collected during the excavation will be used for laboratory experiments to investigate thermal-hydrological, thermal-chemical, and thermal-mechanical processes. Blocks of the tuff with sizes up to several tens of centimeters will be machined that can be joined together to form block-assemblies containing a single saw-cut with controlled aperture. Blocks with a suitable natural fracture will also be used. One block assembly will be used at a time for the experiment. These experiments include: 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. The following paragraphs contain greater detailed explanations of these experiments.

For the fracture flow vs. matrix imbibition experiment, water will be applied to a fracture, and the wetting front will be determined both along the fracture and in the matrix by using electrical resistivity tomography (ERT)<sup>4</sup> and x-ray tomography.<sup>13,14</sup> The experiment will be done for various fracture apertures and various initial moisture contents, at room temperature, elevated uniform temperature, and under a thermal gradient. Water that flowed through the fracture will be collected for chemical analyses to determine pH; Cl<sup>-</sup>, HCO<sub>3</sub><sup>-</sup>, F<sup>-</sup>, Si, Na, and K. The fracture surfaces will be examined before and after the experiment for evidence of rock-water interaction.

In the one-dimensional imbibition experiment, a block assembly with controlled fracture aperture will be brought in contact with water at one end of the fracture. The experiment will be conducted at elevated temperatures. The moisture distribution will be determined using ERT and x-ray tomography. The imbibition direction will either be against gravity, with gravity, or perpendicular to gravity.

There are three types of experiment in the investigation of the dehydration process: one-dimensional dehydration in both intact and fractured samples and condensation of vapor along a fracture. 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. A sample with known initial moisture content will be heated from the end opposite the open end. Temporal and spatial distributions of temperature, moisture content, and pore fluid pressure will be monitored. 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. ERT and x-ray tomography will be used to monitor the moisture distribution 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 or fractured rock will be put under constant triaxial loads and heated either uniformly or from one end. Stress-strain curves will be determined. Displacement of the matrix and across fractures during the heating phase will be measured. Acoustic emissions will be monitored to detect thermal fracturing. The fracture surfaces will be examined before and after heating for evidence of changes in the fracture properties.

## E. Large Block Tests of the Coupled TMHC Processes

Tests in the large block will be used to investigate the macroscopic phenomena of the coupled TMHC processes that are affected by multiple fractures, fracture connectivity, scale, and matrix heterogeneities. The large block will first be characterized for its fracture intensity and configuration, as described earlier. Horizontal heater holes and instrument holes will be drilled. Figure 6 shows the instrument holes and heater holes in the block. Instruments will also be installed outside the holes. Installation of instruments, data acquisition, test procedures, and data analyses will be discussed next.

1. Installation of Instruments. Resistance temperature devices (RTD) will be used to measure temperature in the block. A bundle of RTDs will be grouted with cement in temperature holes that are 3.8 cm in diameter. Some of the RTDs will be put in thin-walled stainless steel tubes so that they can be calibrated or replaced during the test. The Rapid Evaluation of K and Alpha (REKA) thermal probe, to be used to determine the thermal conductivity and thermal diffusivity,<sup>15</sup> will also be installed in some of the temperature holes. Extensometers, displacement transducers, stress transducers, and acoustic emission transducers will be either grouted or mounted on a SEAMIST membrane in the geomechanical holes (both 7.6 and 3.8 cm in diameter). Humidity sensors (including resonant cavities and Humicap) and pressure transducers will be installed in a packer system in the moisture content hole (7.6 cm in diameter). The moisture content hole will also be used to measure air permeability. Microelectrode array sensors will monitor pH, Eh, Cl<sup>-</sup>, and water sampling discs will be mounted on the outer surface of a SEAMIST membrane and pushed against the wall in the geochemistry holes (both 7.6 and 3.8 cm in diameter). Coupons of the waste package material, such as carbon steel and copper, will also be instrumented with the chemical sensors and put in the geochemistry holes. The neutron logging holes (3.8 cm in diameter) will be kept open by using a Teflon tube liner. The annular space between the liner and the borehole wall will be sealed with cement grout. One 2.44-m-long, 300-watt heating element will be installed in each heater hole (3.8 cm in diameter). Coupons of the waste package material will be put in the heater holes. The opening of the heater holes will be plugged to prevent heat loss and develop a hydrological sink. ERT electrodes will be grouted in the ERT holes (both 7.6 and 3.8 cm in diameter).

In addition to the instruments in the holes, the following devices will be mounted on the block surfaces: a temperature control/moisture collecting system at the top, and ERT electrodes, acoustic transducers, and guard heaters

on the sides of the block. The guard heaters will be used to maintain a boundary condition as close to adiabatic as possible.

After installation of the instruments and heaters, the block will be sealed with thermal and moisture barriers on its four side surfaces. Flat jacks will be used as a loading device on the top, and bladders will be used to load the sides. The prefabricated load-retaining frame will be assembled around the block section by section. The electrical wires of instrument and high pressure lines will be brought out through pre-drilled holes in the load-retaining frame and also through trenches under the frame.

2. Data Acquisition. There are two data acquisition modes: automated data acquisition by a data acquisition system (DAS) and individual data acquisition. The data to be acquired by the DAS include temperature, pressure, displacement, wattage, voltage output from chemical sensors and Humicaps, etc. Data to be collected individually include neutron logging, REKA, resonant cavity, acoustic emission and velocity, ERT, and air permeability. Water sampling will also be conducted manually.

3. Test Procedures. The DAS will start collecting data at least one week before loads are applied to the block. The DAS will continue throughout the test duration. In the preload period at least one set of the manual data will be obtained. Then the block will be loaded with a peak stress of about 4 MPa, both vertically and horizontally, at ambient temperature. At least one set of the manual data will be acquired when the block has reached an equilibrium to the loads. Also in this period, at least one set of stress-strain curve of the block will be obtained. Then the heaters within the block will be energized at full power for at least 6 months, followed by a natural cool-down period, in which the heaters are turned off. The block is considered cooled when its maximum temperature decreases to within 5°C above the ambient temperature. The natural cool-down phase may take several months. During the heating phase, the temperature at the top of the block will be maintained at about 80°C. Pre-test model calculations indicate that the maximum temperature in the heater zone will be about 135°C. One of the criteria for determining the heating duration, the maximum temperature, and the temperature at the top of the block is to establish a dry-out region, a condensate region, and a relatively undisturbed region simultaneously in the block for at least 2 months, so that enough data and samples can be acquired. During the heating phase, a constant load will be maintained on the block. The manual data and water samples will be collected every two weeks. Vapor that exits the block will be collected for measuring its amount and chemistry. The

external loads on the block will be released after the block is cooled.

After the test the block will be mechanically 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.

4. Data Analyses. Data reduction and analysis will begin when the data are available and will continue throughout the testing duration. The chemical effect of all man-made materials on the test will be studied and included in the data analyses.

Post-test model calculations will also be performed to analyze the test results. In this case V-TOUGH and NUFT will be used to model thermal-hydrological processes. The results of this experiment will also be used for model concept development and to verify model calculations using thermal-hydrological-chemical codes, such as EQ3/6, BASIN II, and PRECIP. A thermal-mechanical model, such as Fast Lagrangian Analysis of Continua (FLAC), will be used to analyze the observed thermal-mechanical responses. A physical model will be set up to interpret the coupled processes.

#### IV. CURRENT STATUS AND DISCUSSION

The load-retaining frame is expected to be delivered in the middle of May 1994. All scientific planning documents of the LBT are in place. All vertical instrument holes have been drilled. Air injection tests indicate that the permeability of the block will be sufficient for generating a dry-out zone in the time frame of the experiment, based on the pre-test model calculations. Sawing of the block will start in early January of 1994. A tentative schedule is shown in Figure 7.

The information obtained so far indicates that the LBT will provide an earlier (relative to EBSFT) opportunity for testing some numerical models used to understand the coupled TMHC processes. For model calibration and verification, the LBT has advantages over in situ field testing in that the experimental conditions can be better controlled, there is easier three-dimensional accessibility to the test region, and the test region (the block) can be better characterized both before and after the testing.

#### ACKNOWLEDGEMENTS

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## REFERENCES

1. 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)
2. Ramirez, A. L. (1991), *Prototype Engineered Barrier System Field Test (PEBSFT) Final Report*, Lawrence Livermore National Laboratory, UCRL-ID-106159. (NNA.910711.0047)
3. 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)
4. 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)
5. 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)
6. 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)
7. 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)
8. 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)
9. 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)
10. Lin, W. (1993), *Technical Basis and Programmatic Requirements for Large Block Testing of Coupled Thermal-Mechanical-Hydrological-Chemical Processes*, Lawrence Livermore National Laboratory, Livermore, CA, UCRL-ID-112834
11. Zimmerman, R. M., and M. K. Blanford (1986), "Expected Thermal and Hydrothermal Environments for Waste Emplacement Holes Based on G-Tunnel Heater Experiments," in *27th U.S. Symposium on Rock Mechanics*, H. Hartman, Ed., (Society of Mining Engineers, Inc., Littleton, CO), pp. 874-882. NNA.891212.0018.
12. 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)
13. 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)
14. 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)
15. Danko, G., and P. F. Mousset-Jones, (1991), "A Probe Method for Measuring In Situ Thermophysical Properties," in *Proceedings, 2nd International High Level Radioactive Waste Management Conference, Las Vegas, NV, April 28-May 3, 1991*, American Nuclear Society, La Grange Park, IL, pp. 555-563.

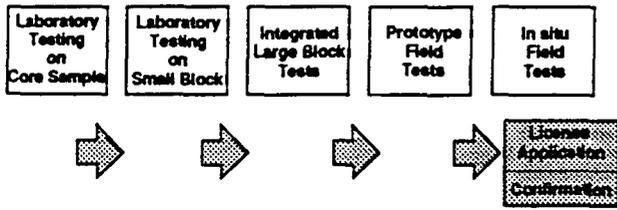


Figure 1. Logical testing sequence leading toward license application and confirmation of a repository

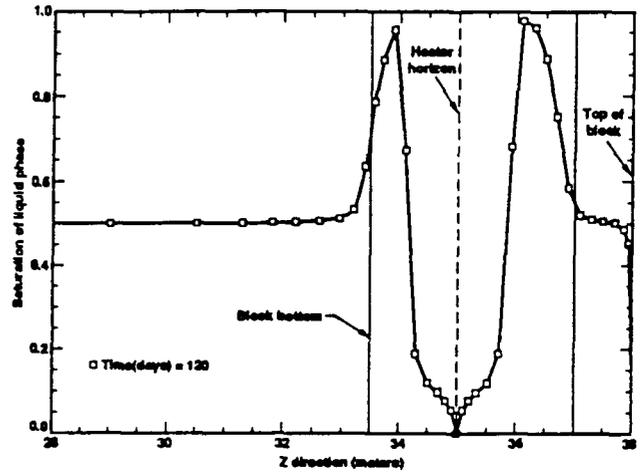


Figure 2. The preliminary result of the pre-test model calculation of the moisture distribution in a square column model.

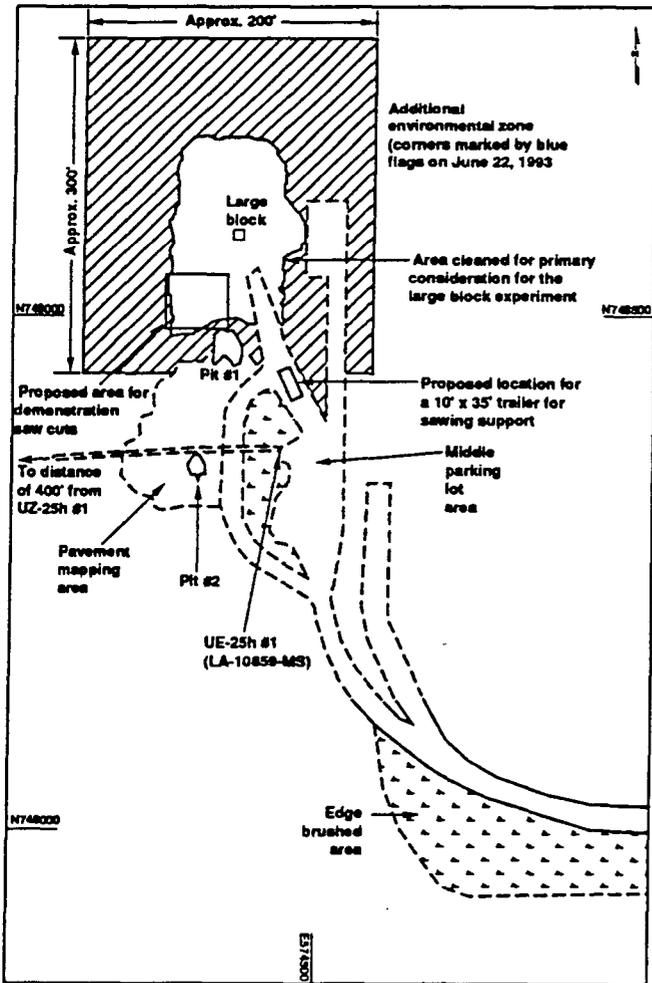


Figure 3. Location of the Fran Ridge Site.

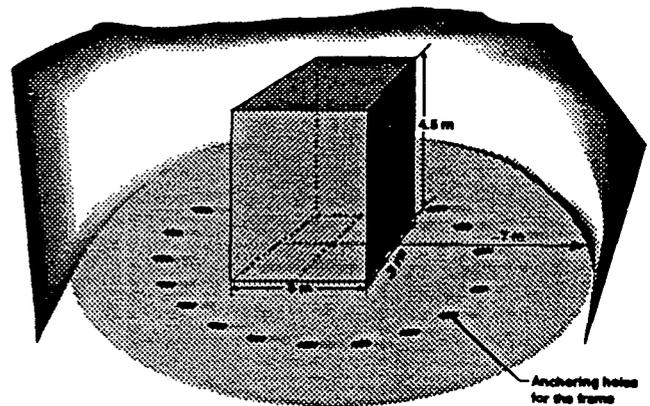


Figure 4. Diagram showing the block and its surrounding area.

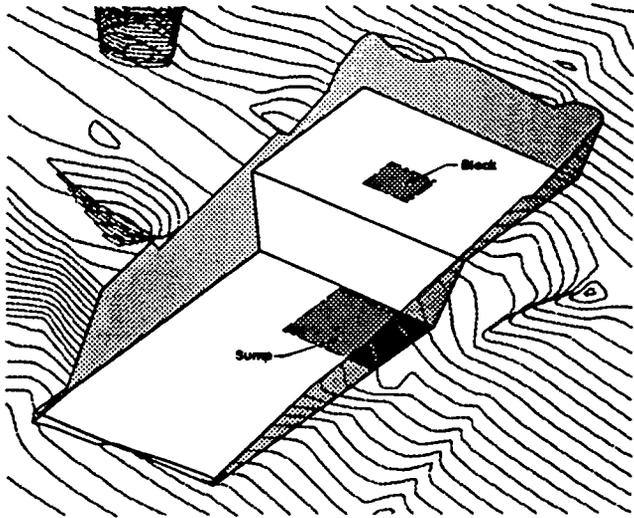


Figure 5. Sketch of the outcrop area after leveling.

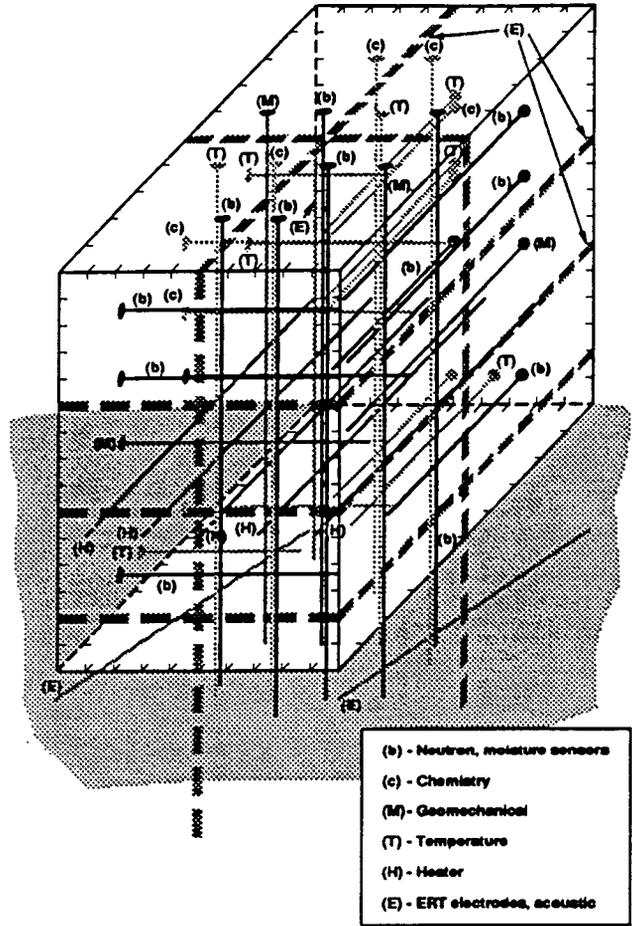


Figure 6. Instrumentation holes in the large block.

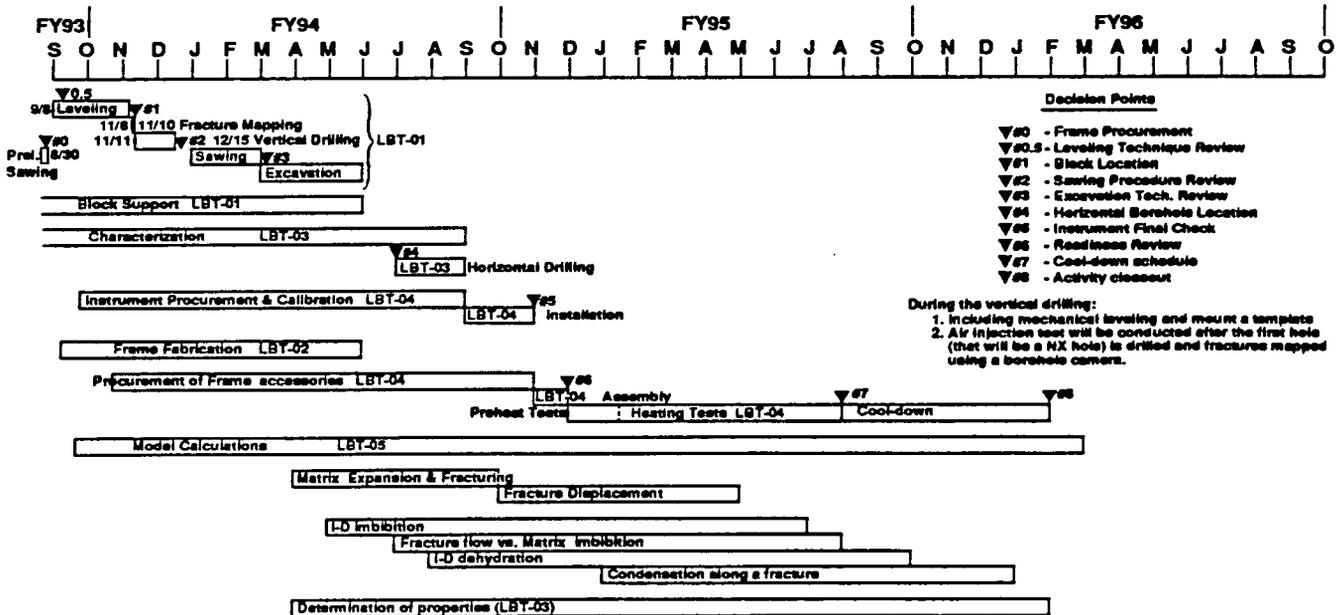


Figure 7. Schedules of activities in the LBT.