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YUCCA MOUNTAIN SITE CHARACTERIZATION PROJECT
STUDY PLAN APPROVAL FORM

Rec'd 6/23/94

Study Pla Number 8.3.1.2.2.4

Study . lan Title Characterization of the Yucca Mountain Unsaturated Zone in the Exploratory Studies Facility

Revision Number 2

Prepared by: U.S. Geological Survey

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Approved:

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Director, Regulatory and Site Evaluation Division / Date

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Director, Quality Assurance Division / Date

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DIRECTIONS

REPLACE: STUDY PLAN APPROVAL PAGE, REVISION 2 WITH
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REPLACE: PAGE iii DATED 12/28/92 WITH
PAGE iii DATED 05/26/94.

REPLACE: PAGE V DATED 12/28/92 WITH
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REPLACE: PAGE 1.1-3 DATED 12/28/92 WITH
PAGE 1.1-3 DATED 03/29/94.

REPLACE: PAGE 1.1-8 DATED 12/28/92 WITH
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DIRECTIONS (continued)

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INSERT: PAGE 2.1-8A BEHIND PAGE 2.1-8

REPLACE: PAGE 3.10-1 DATED 12/28/92 WITH
PAGE 3.10-1 DATED 05/26/94.

INSERT: PAGES 3.10.2 THROUGH 3.10-21 DIRECTLY
BEHIND 3.10-1.

******** DESTROY SUPERSEDED MATERIAL ********

TECHNICAL PROCEDURES FOR ACTIVITY 8.3.1.2.2.4.10

DOCUMENT NUMBER	EFFECTIVE DATE	TITLE
Hydrologic Procedures		
HP-247, R0	04/28/93	Calibration of Thermistors Used for Pneumatic Testing of Unsaturated Zone Boreholes
HP-251, R0	05/19/93	Calibration of Pressure Transducers Used for Pneumatic Testing of Unsaturated Zone Boreholes
HP-271, R0	09/24/93	Gas Flow Rate Calibration Procedure for Unsaturated Zone Borehole Testing Program

Enclosure 2

List of Tables

others are part of the surface-based evaluations. The eight activities in the study were selected on the basis of various factors. Time and schedule requirements were considered in determining the number and types of tests chosen to obtain the required data. Tests were designed on the basis of design and performance parameter needs, available test and analysis methods, and test scale and interference. These factors are described in Sections 2 and 3.

The descriptions and plans for each activity are presented in Section 3. The descriptions include (a) objectives and parameters, (b) technical rationale, and (c) tests and analyses. Alternate test and analysis methods are summarized, and cross references are provided for technical procedures.

Five hydrologic test activities are planned during the ESF construction phase. They are the radial-borehole tests (Activity 8.3.1.2.2.4.4), excavation-effects tests (Activity 8.3.1.2.2.4.5), perched-water tests (Activity 8.3.1.2.2.4.7), hydrochemistry tests (Activity 8.3.1.2.2.4.8), and hydrologic properties of major faults (Activity 8.3.1.2.2.4.10). Revised plans for the first four of these activities were included in Revision 1 of the study plan, in Sections 3.4, 3.5, 3.7, and 3.8, respectively. Plans for the major-faults activity is included in this revision of the study plan. Three other activities will be conducted as part of the *in-situ* testing in the drifts of the ESF: the intact-fracture tests (Activity 8.3.1.2.2.4.1), percolation tests (8.3.1.2.2.4.2), and bulk-permeability tests (Activity 8.3.1.2.2.4.3). The plans for these activities will also be presented in a subsequent revision.

The Calico Hills tests (Activity 8.3.1.2.2.4.6) and the multipurpose-borehole testing (Activity 8.3.1.2.2.4.9) have been dropped from the study, for reasons presented in Sections 3.6 and 3.9, respectively.

Application of the study results is summarized in Sections 1.3 and 4, schedules and milestones are presented in Section 5, and a study-plan reference list is presented in Section 6.

1.1.1 Objectives of the study

Hydrologic evaluation of the unsaturated zone will be conducted as an integrated set of surface-based and ESF activities with a common objective to provide an understanding of the past, present, and future fluid flow characteristics in the unsaturated zone at Yucca Mountain.

Surface-based testing will be conducted on the land surface and in vertical and horizontal holes drilled into the repository host rock and surrounding units. Surface-based borehole studies designed to investigate the deep unsaturated zone are described in YMP-USGS SP 8.3.1.2.2.3 (Unsaturated-zone percolation - surface-based studies), and are integrated with the ESF activities (described in this plan) in terms of technical objectives, spatial locations, and parameter determinations. (Parameter is used in this plan to mean a property, characteristic, and/or the numerical value of a constant that is used to describe the unsaturated-zone hydrologic system).

The north and south ramps, underground drifts, and associated boreholes of the ESF will provide (1) an opportunity to evaluate the in-situ unsaturated-zone hydrologic properties in orientations not achievable from surface-based boreholes, (2) an opportunity to directly inspect the structure and stratigraphy of the rock walls of the ramps and drifts, and (3) an opportunity to evaluate the rock-matrix and fracture-hydrologic parameters for a wide range of test scales. Figure 1.1-2 illustrates the map location of the ESF at Yucca Mountain. Figure 1.1-3 illustrates the conceptual layout of the ESF.

The objective of this ESF unsaturated-zone study is to understand the spatial distribution of present water flow within the unsaturated zone. Plans for studies of past and future unsaturated-zone flow characteristics are described in YMP-USGS SP 8.3.1.2.2.7 (Unsaturated-zone hydrochemistry) and YMP-USGS SP 8.3.1.2.2.9 (Unsaturated-zone modeling and synthesis). Hydrologic studies of infiltration from the land surface (YMP-USGS SP 8.3.1.2.2.1), and site-saturated zone studies (YMP-USGS SP 8.3.1.2.3.1), provide boundary condition information for models of unsaturated-zone percolation. A more detailed discussion regarding the modeling activities associated with this study can be found in the "Characterization of fuild flow in unsaturated, fractured rock" study plan (YMP-USGS-8.3.1.2.2.8). The site-scale unsaturated-zone modeling activities are in study plan YMP-USGS-8.3.1.2.2.9.

The salient conditions to be characterized in the unsaturated zone include the hydraulic and matric potential gradients that extend from the land surface to the water table (350 to 750 m; 1,150 to 2,460 ft beneath Yucca Mountain). These potential gradients may vary discontinuously between geohydrologic units. Figure 1.1-4 shows the relation between the stratigraphic and geohydrologic units at Yucca Mountain. The characterization of flow beneath Yucca Mountain must include, for all geohydrologic units, the determination of flow distribution under a variety of conditions. As flux is difficult to measure at either the infiltration boundary (land surface) or the water table, it must be estimated from either the potential water distribution and the conductive properties of the rocks or by other indirect methods.

From the viewpoint of waste isolation, the most significant site-characterization findings will be to predict the transport of radionuclides from the repository, beneath Yucca Mountain, to the water table. SCP Sections 8.3.5.12 (Ground-water travel time) and 8.3.5.13 (Total-system performance) describe the need for this essential information. The hydraulic-properties data that will be used for these unsaturated-flux calculations will be collected by the USGS in the surface-based and ESF unsaturated-zone percolation studies.

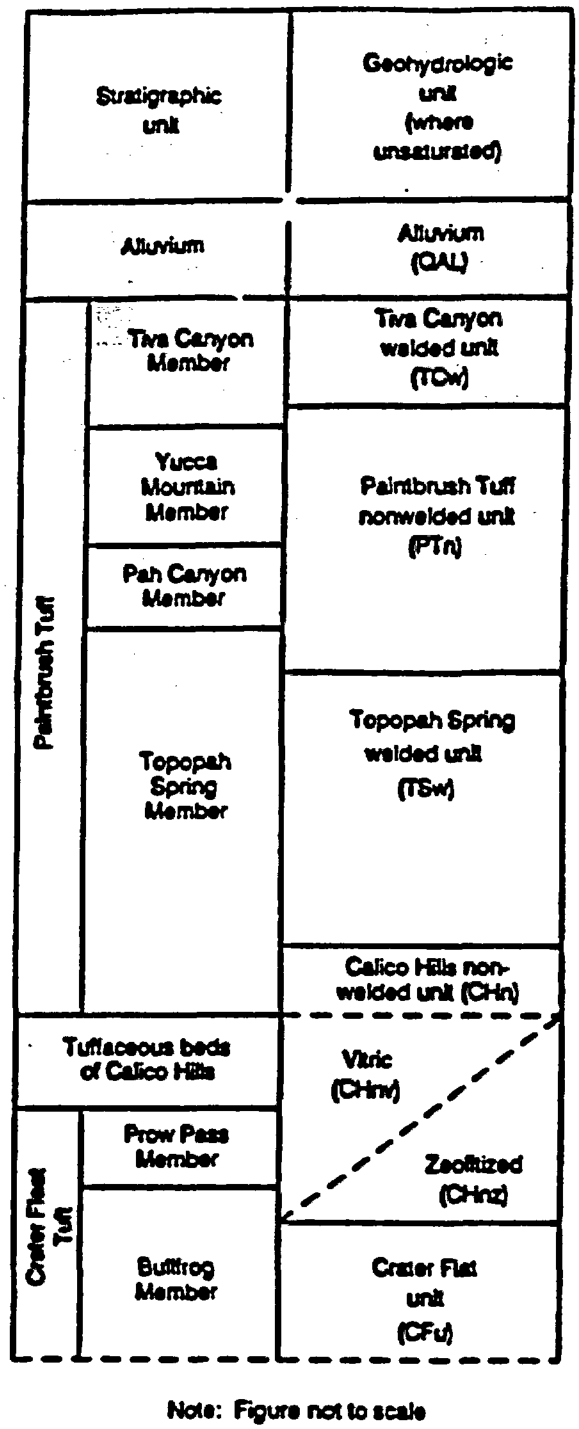

Figure 1.1-4. Diagram showing the relation of geohydrologic units to stratigraphic units (modified from Montazer and Wilson, 1984).

Gas flow in the unsaturated zone has an important hydrologic role, as well as providing a mechanism for transport of gaseous radionuclides to the accessible environment. Whereas the coexisting matrix pores and fractures greatly complicate computations of total-system behavior under present or estimated future conditions, the possible existance of large-aperture fractures provides for large relative gas permeability. Natural gas-phase flow is driven by seasonal atmospheric-density differences between the mountain slopes and mountain summit, and by geothermal heat. Vapor discharges from the air-filled fractures may inhibit water percolation from rain and snow melt because of convective and diffusive vapor discharge to the land surface. If air flow reduces the matrix water content, by drying the matrix immediately adjacent to the fractures, the resulting increased water tension would aid in damping infiltratic pulses that may be channeled in fractures. It is important to be able to quantify vapor flow because it may be opposite in direction to liquid flow, and of similar flux. Current knowledge of and site-characterization efforts for unsaturated-zone gas flow appear in YMP-USGS SP 8.3.1.2.2.6 (Yucca Mountain unsaturated-zone gaseous-phase movement).

Hydraulic, pneumatic, and hydrochemical testing and analysis will be conducted as part of this ESF unsaturated-zone study to provide an understanding of the conditions and processes described above. Integration of this information with the results of other hydrologic studies (Figure 1.1-1) will provide the basis for the development of the unsaturated-zone hydrologic model described in Section 2.

In SCP Table 8.3.1.2-1, activity parameters for the Geohydrology Program are grouped according to parameter categories. The activity parameters associated with activities of this study also appear in the figures and tables of Section 3 of this study plan. Parameter categories serve to group similar types of performance and design parameters supporting performance-assessment and design issues resolutions (SCP Sections 8.3.2 through 8.3.5) and match them with groups of similar types of activity or characterization parameters to be obtained during site characterization. Parameter categories in the SCP were introduced as a classification scheme to aid in assessing the appropriateness and completeness of the data collection program. In Figure 2.1-1, the parameter categories are shown supporting specific model components that make up the site unsaturated-zone model. This figure corresponds to SCP Figure 8.3.1.2-3, and in that document is accompanied by parallel logic diagrams for the surface-water and saturated-zone components of the Geohydrology Program.

In SCP usage, a characterization parameter is a parameter, obtained by a characterization program, that has a logical, direct tie to a performance or design parameter, and for which a testing basis can be defined. Most characterization parameters will be developed from some combination of activity parameters, and will be the products of data reduction, tests and analyses, and modeling. Hydrologic analyses generated in this study can be traced from activity parameters through characterization parameters and to their intended use in satisfying performance-assessment requirements for issues resolutions.

In this and other study plans, it has been useful to group the measured or calculated parameters of the various activities (activity parameters) into a limited set of characterization parameters, more broadly defined parameters that encompass activity parameter data collected in the field and laboratory, or generated by modeling. By introducing these parameters, it becomes easier to understand how the study relates to satisfying the information requirements of parameters in the design and performance issues. The grouping of activity parameters according to characterization parameters is given in Table 2.1-1. Characterization parameters also appear in the logic diagrams accompanying the activity descriptions of Sections 3.4, 3.5, 3.7, and 3.8.

Characterization parameters will be expressed as functions of space and (or) time and will be presented in formats that will facilitate use of the data in resolving design and performance issues. In future SCP progress reports, a testing basis will be developed for each characterization parameter, and will consist of some means of expressing the goals, confidence limits, and accuracy associated with each characterization parameter, so that requirements of performance parameters can be satisfied. An example of a testing basis could be that some statistical measure of the parameter, such as the mean, be known to a specific degree of accuracy.

Table 2.1-1. Association of activity parameters with site characterization parameters

Activity	Characterization Parameter	Activity Parameters Associated with Characterization Parameter
Activity 8.3.1.2.2.4.4 - Radial-borehole tests	Hydraulic conductivity	Permeability, water
	Gas permeability	Permeability, relative, gas, rock matrix Permeability, saturated, gas, rock matrix Pneumatic permeability, bulk, fractured rock Permeability, pneumatic Fault permeability Gas permeability, excavation effects Porosity pore-size distribution, matrix Porosity, bulk, fractured rock Porosity, matrix Porosity Bulk density, rock matrix Grain density, rock matrix Fault characteristics: distribution, aperture, weathering Anisotropy
	Water permeability	Moisture retention, rock matrix Water content, gravimetric, rock matrix Water content, volumetric, rock matrix Permeability, relative, water, rock matrix Porosity pore-size distribution, matrix Porosity, bulk, fractured rock Porosity, matrix Porosity Bulk density, rock matrix Grain density, rock matrix Anisotropy Fracture aperture Fracture permeability
	Hydraulic gradient	Water potential, distribution and fluctuation Water potential, rock matrix, and total fractured rock Pneumatic potential, distribution and fluctuation Pore-gas composition Radioactive isotopes Stable isotopes
	Gaseous diffusion	Gaseous diffusion coefficient, fractured rock units Diffusive tortuosity, fractured rock and rock mass Temperature, distribution and fluctuations

Table 2.1-1. Association of activity parameters with site-characterization parameters (continued)

Activity	Characterization Parameter	Activity Parameters Associated with Characterization Parameter
Activity 8.3.1.2.2.4.5 - Excavation-effects tests	Fracture permeability	Initial fracture permeability around excavations Changes in fracture permeability due to excavation effects Changes in rock stress due to excavation effects Fracture locations Fracture characteristics In-situ rock stress and mechanical property measurements In-situ stress changes, magnitude and direction Fracture deformation Changes in rock stress due to excavation effects Effects of stress changes on fracture aperture Fracture aperture Fracture distribution Fracture orientation Fracture roughness
	Fracture effective porosity	Changes in fracture effective porosity due to excavation effects Rock density Rock porosity Fracture locations Fracture characteristics In-situ rock stress and mechanical property measurements Changes in rock stress due to excavation effects Effects of stress changes on fracture aperture Fracture aperture Fracture distribution Fracture orientation Fracture roughness
	Fracture saturation	Moisture content, in-situ degree of saturation Changes in fracture saturation due to excavation effects Fracture locations Fracture aperture Fracture distribution Fracture orientation Fracture roughness
Activity 8.3.1.2.2.4.7 - Perched-water tests	Hydraulic conductivity	Hydraulic conductivity, perched-water zones Transmissivity Porosity, rock units near ramps and drifts

Table 2.1-1. Association of activity parameters with site-characterization parameters (continued)

Activity	Characterization Parameter	Activity Parameters Associated with Characterization Parameter
Activity 8.3.1.2.2.4.7 - Perched-water tests	Hydraulic gradient	Water potential (total), perched-water zones Hydraulic head, perched-water zones Radioactive isotopes Stable isotopes Water quality Potential
	Ground-water flux	Infiltration rate Discharge rate Flow rates, perched-water zones
	Storage coefficient	Storage coefficient, perched-water zones
Activity 8.3.1.2.2.4.8 - Hydrochemistry tests	Flow paths, ground water and gas	Radioactive-isotope activity Stable isotopes Pore-gas composition Water quality, cations and anions Flow paths, hydrochemical determination
	Travel times, ground water and gas	Radioactive-isotope activity Stable isotopes Pore-gas composition Water quality, cations and anions Travel times, hydrochemical determination
Activity 8.3.1.2.2.4.10 - Hydrologic properties of major faults encountered in the ESF	Hydraulic conductivity	Permeability, water
	Gas permeability	Permeability, relative, gas, rock matrix Permeability, saturated, gas, rock matrix Pneumatic permeability, bulk, fractured rock Permeability, pneumatic Fault permeability Gas permeability, excavation effects Porosity pore-size distribution, matrix Porosity, bulk, fractured rock Porosity, matrix Porosity Bulk density, rock matrix Grain density, rock matrix Fault characteristics: distribution, aperture, weathering Anisotropy

Table 2.1-1. Association of activity parameters with site-characterization parameters (continued)

Activity	Characterization Parameter	Activity Parameters Associated with Characterization Parameter
Activity 8.3.1.2.2.4.10 - Hydrologic properties of major faults encountered in the ESF	Water permeability	Moisture retention, rock matrix Water content, gravimetric, rock matrix Water content, volumetric, rock matrix Permeability, relative, water, rock matrix Porosity pore-size distribution, matrix Porosity, bulk, fractured rock Porosity, matrix Porosity Bulk density, rock matrix Grain density, rock matrix Anisotropy Fracture aperture Fracture permeability
	Hydraulic gradient	Water potential, distribution and fluctuation Water potential, rock matrix, and total fractured rock Pneumatic potential, distribution and fluctuation Pore-gas composition Radioactive isotopes Stable isotopes
	Gaseous diffusion	Gaseous diffusion coefficient, fractured rock units Diffusive tortuosity, fractured rock and rock mass Temperature, distribution and fluctuations

3.10 Hydrologic properties of major faults encountered in the ESF

3.10.1 Objectives of activity

The objectives of this activity are to:

1. measure the pneumatic and hydraulic permeability, porosity, and anisotropy of the major faults and their associated fault zones. In this study plan, fault refers to a planar feature along which movement has occurred. Fault zone refers to the fault and any rock whose fractures and/or other alterations are directly attributed to the fault;

2. conduct long-term monitoring for vertical flow of gas, water vapor, and water in the major faults of the unsaturated zone;

3. conduct tracer tests to estimate the tortuosity and effective porosity of the faults and their associated fault zones.

4. conduct geothermal logging in selected boreholes to determine the nature, if any, of recharge occurring along high-angle faults and fault zones.

3.10.2 Rationale for activity selection

While quantifying the hydrologic properties of the major faults is absolutely necessary for understanding and modeling of the proposed repository site, attempts to quantify the hydrologic properties of large features, such as faults, by testing on a much smaller scale at one, or at the most a few, selected test sites will be far from conclusive. A fault may vary from a simple planar structure with little associated fracturing, to an extensive broken zone (tens of meters wide) where the actual fault plane is no longer identifiable. The faults hydrologic properties are dependent on both random spatial factors and non-random factors such as rock type and depth below land surface. Attempts to extrapolate the fault characteristics measured at one point in one rock type to a larger area should be done only with great care and a large amount of supporting information explaining how and why the extrapolation is justified.

Selection of the fault and fault zone test sites will attempt to address two key issues: (1) identify and test sites that are considered to represent the potentially fastest pathways that could allow rapid transmission of water from the surface to depth and/or rapid transmission of gas and water vapor from depths to the surface, and (2) identify and test sites that are representative of the existing moisture conditions and average permeability of the rock mass. The major fault test sites will be selected at locations where the following conditions exist (listed in descending order of priority):

1. identification of water flow in the fault or fault zone,
2. large open main fault trace,
3. high density of fractures,
4. large aperture fractures,
5. proximity to the proposed repository,
6. fracture mineral coatings,
7. observed changes in rock moisture content over relatively short distances, and
8. temperature gradients.

Yucca Mountain contains and is bounded by west-dipping high-angle normal faults that, depending on location and ambient hydrologic conditions, may serve as pathways for or barriers to gas, vapor, or water flow. As currently conceived, the repository would be excavated mainly in the relatively unfaulted western part of one structural block in the mountain. The repository would be bounded on the west by the Solitario Canyon fault, on the northeast by Drill Hole Wash structure, and on the east and southeast by the western edge of an imbricate normal fault zone. The Ghost Dance fault is expected to approximately bisect the repository area. In the case of dual-ramp access to the underground testing facility (see Reference Configuration Option 30, Figure 3.10-1), the Bow Ridge fault may be intercepted by the north ramp at an approximate distance of 1.5 km from the repository area. These faults are major structural features found typically at intervals of 1 to 2 km and generally have offsets of more than 100 m.

Additional faults of a second type will be encountered at the eastern and southeastern boundary of the repository. Within the structural blocks at Yucca Mountain are numerous steep, west-dipping normal faults. They generally strike north to north-northwest; they are closely spaced and typically have less than 3 m of offset, forming an imbricate pattern.

It is possible that structural flow paths may sometimes be truncated at the contact between the geohydrologic units. It has also been observed that some fault zones contain clay gouge. More ductile rock, like the nonwelded tuffs, typically produces sealing gouge material along fault zones and thus has greater "healing properties." Thus, it is expected that hydraulic conductivity probably varies significantly along fault zones and is perhaps greater in the welded units (e.g., TCw and TSw) than in the nonwelded units (e.g., PTn).

Generalized conceptual models for moisture flow within the unsaturated zone beneath Yucca Mountain have accounted for the presence of these structural features (Montazer and Wilson, 1984; Sinnock et al., 1986). It is generally believed that major faults affect flow significantly in the unsaturated zone. The precise nature of that impact, however, will depend on a number of interrelated hydrologic and geologic parameters. It is conceivable, for example, that under relatively low ambient moisture conditions, faults may impede any lateral moisture flow in the repository block (caused by anisotropy in matrix hydraulic properties or contrasts in such properties at contacts between geohydrologic units). Under such conditions, perched-water bodies may form where the faults transect zones or horizons of significant lateral flow.

Conversely, under conditions of relatively high moisture, faults may serve as highly conductive pathways for vertical water flow. This phenomenon may be especially important in the more competent units TCw and TSw. The conceptual models at Yucca Mountain presently suggest that fractures and faults (especially the high-angle normal faults) are the principal conduits of downwardly transmitted infiltration (see Section 3.4.2).

Under present climatic conditions, the general understanding of the major faults at Yucca Mountain is that they are dry above the water table and therefore dry above and immediately below the repository. This means that if the major faults are highly permeable they may provide a potentially fast pathway to the surface for vapor and other gases from the repository horizon.

Fluid flow in fractures and faults is a complicated phenomenon that is highly sensitive to hysteresis, air entrapment, the presence of fracture coatings, fracture roughness, and a host of other hydraulic and geological parameters. For example, fluid flow is strongly influenced by matric potential. Small increases in bulk saturation may lead to sudden increases in fluid flux through

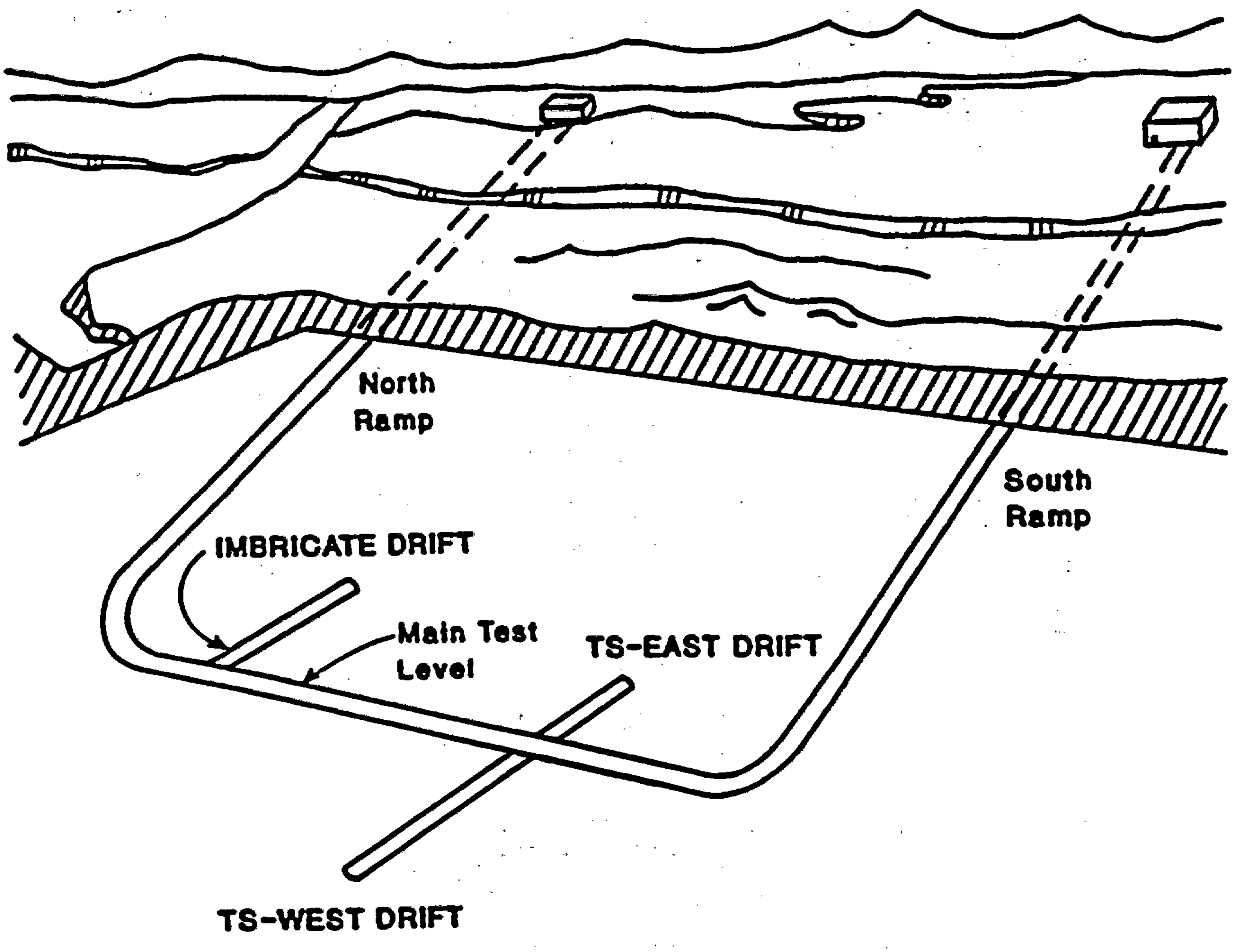

Figure 3.10-1. ESF option 30 configuration.

fractures and faults. Faults may be bounded by zones of extensive disturbance, such as imbricate zones, which may further enhance the conductivity of the overall structure. In more ductile units (e.g., the Paintbrush Tuff nonwelded unit), clay gouge may actually reduce the conductivity of the fault and form an impermeable barrier to flow across the zone of disturbance. Although the amount of fluid flow in major faults is considered to be small under present moisture conditions, additional understanding of the factors controlling that flow must be obtained in order to meet site-characterization requirements. The information gathered from the tests described herein will be used to improve this understanding and refine conceptual models which account for the presence of faults or fault zones.

Prototype testing was conducted to develop equipment and methodology for determining pneumatic and hydraulic properties of structural features such as fractures and faults. One of the specific purposes of prototype testing was to design and evaluate a cross-hole pneumatic and hydraulic test system that could be used in a number of ESF hydrologic tests, including the test described in this study plan. Developing, testing, and refining each of these components during prototype testing increased the likelihood that ESF tests which utilize cross-hole pneumatic and hydraulic tests will be successful in meeting their objectives.

3.10.3 General approach and summary of tests and analyses

Hydraulic and pneumatic properties of the major faults intercepted by the ESF will be quantified by this activity. The proposed dual-ramp access to the ESF (Reference Configuration Option 30) will provide a greater opportunity to inspect and characterize both the geology and hydrology of the major faults than was provided in earlier test plans. It is anticipated that all major faults will be intercepted by either the ramps, main test-level drift, by the east and west access drifts excavated off the main test level, or in any excavations in the Calico Hills nonwelded unit (Calico Hills drifts). Some major faults will be intercepted at more than one location. Such access will provide a higher degree of confidence in the characterization of major faults in and near the repository by allowing tests to be performed at multiple locations along the plane of a fault or fault zone. It may also be possible to visually inspect faults and fault zones at the contacts of geohydrologic units.

The major faults and/or fault zones expected to be tested are:

1.	North Ramp	a) Bow Ridge fault b) imbricate fault zone c) Drill Hole Wash structure
2.	South Ramp	a) Dune Wash fault b) imbricate fault zone c) Abandon Wash fault zone d) Yucca Ridge fault
3.	Main Test Level	a) Ghost Dance fault
4.	TSw East	a) Ghost Dance fault
5.	Calico Hills drifts	a) Solitario Canyon fault b) Ghost Dance fault c) Imbricate fault zone
6.	Imbricate drift	a) imbricate fault zone

Other major faults encountered, particularly those where moisture flow is detected, will also be considered for testing.

If ESF design and construction schedules permit, boreholes drilled specifically for geothermal testing should be drilled to intercept selected major faults and fault zones. This can be accomplished by constructing a small alcove off the ramps or main test level drift and conducting the drilling and testing operations from the alcove. The proposal is to dry drill a near-horizontal (inclined slightly downward) borehole to intersect the fault. The geothermal logging will consist of logging the borehole at an interval of one to two days initially, and weekly thereafter, until the drilling disturbances have subsided and the ventilation in the fault and/or fault zone can be measured. The geothermal logging will involve pushing the temperature probe into the geothermal borehole. The borehole may be either cased or uncased, depending upon borehole conditions. If the borehole is cased, the PI may elect to fill the casing with water to facilitate thermal contact with the surrounding rock. The principal investigator for the geothermal investigations at Yucca Mountain, or his designated representative, will determine the exact location and orientation of any geothermal boreholes drilled in the ESF.

The identification of faults and the characterization of their physical properties comprise a portion of the geologic mapping activity in the ESF (SCP Activity 8.3.1.4.2.2.4 in YMP-USGS SP 8.3.1.4.2.2, Structural features in the site area). Upon identification of major faults by the geologic mapping activity, the PI will determine if the major fault will be tested according to the criteria outlined in Section 3.10.2. If the major faults is selected for testing, one or two test alcoves containing HQ3 boreholes will be installed (see Figure 3.10-2). The borehole drilling will use tracer-tagged air to remove the cuttings. In addition, all fluids used in drilling and/or testing will be tracer-tagged to insure future identification.

In order to quantify the fault and associated fault disturbed zone permeability and porosity, it will be necessary also to quantify the undisturbed tuff. Permeabilities and porosities of the faults, fault disturbed zones, and undisturbed tuff will cover several orders of magnitude. Because the testing requires that all three of these be quantified, the equipment and test configuration was designed to maximize the testing range and allow for modification as more information is obtained. Maximizing the range of the mass flow controllers and sensitivity of the pressure transducers the equipment, will allow single hole testing in rock with permeability ranging from $10^{-18}m^2$ up to $10^{-9}m^2$. Using three boreholes (#1, #2, and #3) in a triangular configuration with approximately 5 meter sides (see Figure 3.10-2), scoping calculations show that, for the gas injection ranges and pressure transducers available, cross-hole testing can be conducted in rock with permeability ranging from approximately $10^{-15}m^2$ to $10^{-11}m^2$ and porosity ranging from .001 to .1. Permeabilities less than $10^{-15}m^2$ would generally require long test times for cross-hole testing and would be limited to single hole testing. Single-hole testing at the high end range of $10^{-9}m^2$ corresponds to the permeability of a permeable gravel, however it is possible that the faults may be more permeable than this. If this is the case and it is determined that accurate measurements of permeabilities greater than $10^{-9}m^2$ are required, then the system will have to be modified to handle higher flow rates and the boreholes located closer together if cross-hole testing is to succeed. Permeability of the undisturbed tuff will be characterized in boreholes #1, #2, and #3, if possible. If it is not possible to characterize the undisturbed tuff in these boreholes, a fourth borehole (#4) will be drilled into undisturbed (minimally fractured and faulted) tuff. This borehole will be drilled away from the fault trace, as shown in Figure 3.10-2.

Following cross-hole testing in the three perpendicular boreholes, two additional 30 meter boreholes (#5 and #6) will be installed. These boreholes will be located from 1 to 3 meters from the main trace of the fault and will be parallel to the fault plane (see Figure 3.10-2). These boreholes will be used to expand testing on the main trace of the fault plane and the rock in the first few meters perpendicular to the main trace. In faults where it is more a fault zone and there is no identifiable main trace, the boreholes will be located at the zone of greatest fracturing with the purpose of testing in the highest permeability zone of the fault. Testing in these boreholes will utilize the same equipment as used in the first three boreholes. Assuming a main trace of the fault is identified boreholes #5 and #6 will be used to conduct tests across the fault or define whether the fault is a constant head or impermeable boundary. Using boreholes parallel to the main trace will allow testing over a larger area of the fault than was possible with the perpendicular boreholes. Preliminary modeling shows that for permeabilities ranging from $10^{-15}m^2$ to $10^{-10}m^2$ the distance from the main trace to the borehole should range from 1 to 3 meters. Assuming that a main trace is identifiable a final 30 meter borehole (#7) will be drilled parallel to and in the main trace. This borehole will allow single hole testing in the main trace and will provide some statistical evaluation of the range of the fault permeability. The equipment for single hole testing has a maximum range of $10^{-9}m^2$. In faults zones where a main trace is not identifiable borehole #7 will not be required.

Figure 3.10-3 summarizes the organization of the testing strategy for major faults. A descriptive heading for each test and analysis appears in the boxes of the second and fourth rows. Below each test/analysis are the individual methods that will be utilized during testing. Figure 3.10-4 summarizes the objectives of the activity, and the activity and site-characterization parameters measured during testing. Cross-references to other studies that provide input to the major-faults testing also appear in both figures.

The two figures summarize the overall structure of the planned activity in terms of methods to be employed and measurements to be made. The descriptions in the following sections are organized on the basis of these charts. Methodology and parameter information are tabulated as a means of summarizing the pertinent relations among (1) the site-characterization parameters to be determined, (2) the information needs of the performance and design issues, (3) the technical objectives of the activity, and (4) the methods to be used.

3.10.3.1 Borehole drilling and coring

Geothermal boreholes, if drilled, should begin at preselected site(s) where the major fault can be intersected. The locations(s) will be selected by the principal investigator or a designated representative. The selection of the site(s) will be determined by the results of the geologic mapping in the ESF. A small drilling alcove will probably be required. The geothermal borehole will be dry drilled to intersect the fault. Core need not be collected if this will shorten the drilling time for the borehole, because time is such a critical element in the geothermal logging. The length of the geothermal borehole will be determined by the geometry of the ESF in relation to the major faults(s) to be tested. The borehole will be inclined slightly downward, approximately 3 to 5 degrees. The geothermal logging will require a borehole that can handle standard

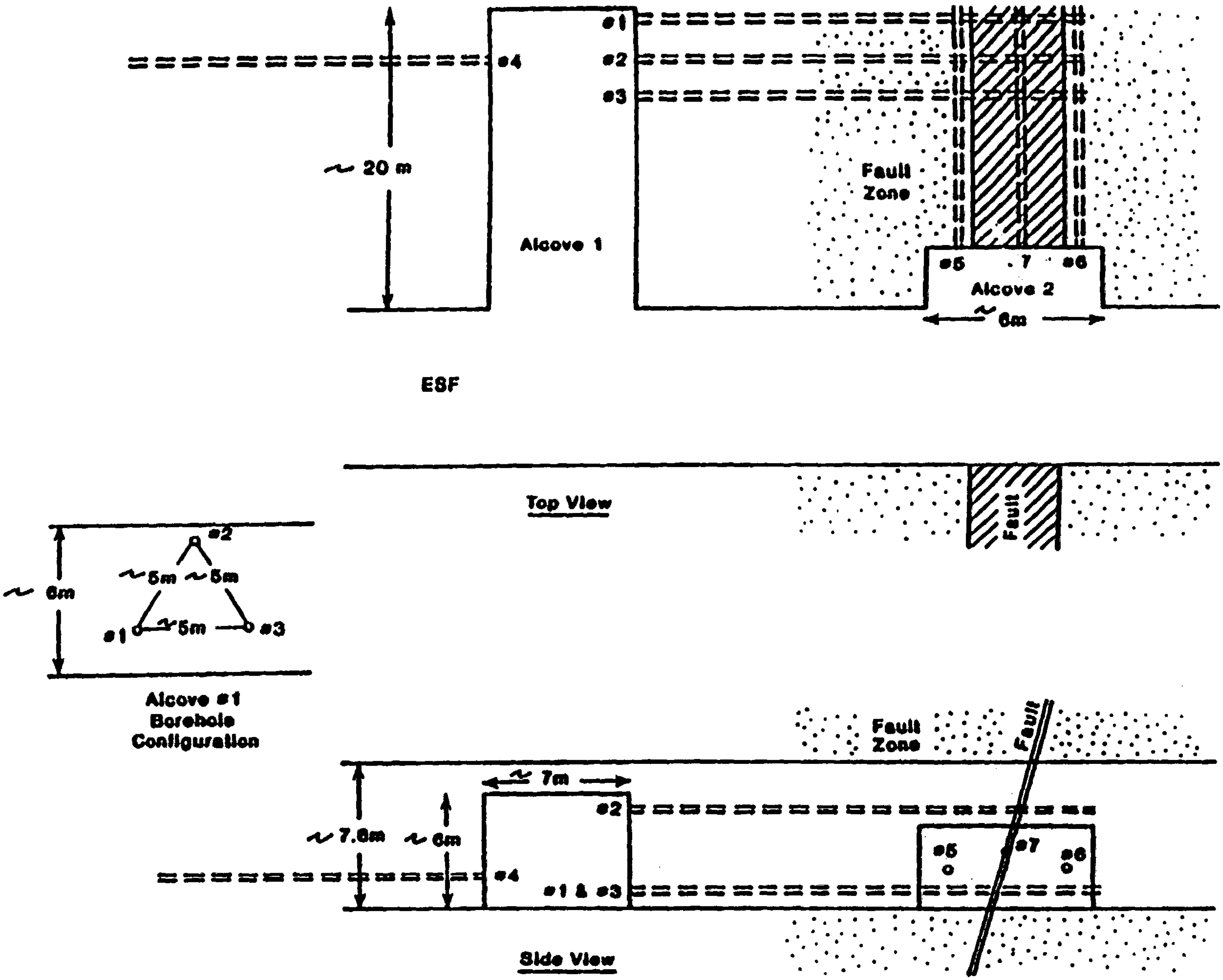

Figure 3.10-2. Schematic of major faults alcoves and borehole configuration.

weight pipe with a minimum 2.5 inch inside diameter: the probe is approximately 2.0 inches in diameter. The pipe may be filled with water to facilitate the thermal contact with the surrounding rock. Keeping the air space between the pipe and the borehole wall to a minimum is also highly desirable in order to minimize any air flow in the borehole.

One or two alcoves will be required at each fault test location in order to provide adequate access to the fault and a suitable area for staging drilling and testing operations off the main drift. The boreholes will be HQ3 size and will provide core. If possible, the core should be oriented. A schematic diagram (Figure 3.10-2) illustrates the desirable configuration for fault testing. The precise configuration of the boreholes, angle, and spacing, will probably vary according to the following local conditions: (1) geometrical relationship between the drifts, alcoves, and the plane of the fault or fault zone; and (2) estimates of the permeability of the fault(s) based on either the geological mapping data or on a preliminary pneumatic injection test performed in a single borehole intercepting the fault. The first alcove will be parallel to the fault. Alcove dimensions will be determined by logistics and the test requirements. Three coreholes, approximately 30 meters long, will be drilled perpendicular to the fault, parallel to each other and in the configuration of an equilateral triangle with approximately 5-m sides. The exact dimensions are still open to discussion and will probably be changed as we obtain more information. The location of the alcove in relation to the fault will depend on the width of the fault zone. It is preferable to locate the alcove outside the fault zone so that the boreholes can be drilled from undisturbed tuff through the fault zone and into the fault. This will allow testing of the fault and the fault zone. However, air-permeability testing equipment limitations will probably restrict the alcove location to within 30 m of the fault. If the width of the fault zone is such that the first alcove is constructed in the fault zone, the fourth borehole will be drilled.

During ESF construction, geologic and fracture mapping will be conducted continuously with ESF construction. This information on lithology, fracture density, and fracture orientation as it relates to the major faults and the associated fault zone will be available to the PI to aid in locating the alcoves and in selecting the final configuration of the boreholes. Information on the fault fillings, fracture density, and fracture fillings will be used to evaluate the applicability of the approximately 5 meter triangular borehole configuration, data on fault orientation will determine the orientation of the boreholes and mapping of the horizontal extent of the fault zone will determine the location of the alcoves. The rock properties where the ramps cross the major faults are expected to have a wide range of welding and therefore the associated fracture zone will be variable. In addition, the amount of fracture and fault filling will vary with rock type. Judging from the large fault displacement seen in the Yucca Mountain area, it is also possible that testing at a major fault site may be conducted in two different stratigraphic units. Such a condition will require a great deal of input in determining the borehole configurations. This input will include results from matrix hydrologic properties testing such as discussed in Section 3.4 of this study plan.

Following completion of the testing in the first alcove, drilling of the boreholes in the second alcove will begin, if, in fact, the second alcove is constructed. The second alcove, if constructed, will be located at the fault. The alcove, if constructed, will extend from a minimum of 2 to 4 meters on both sides of the fault and will be large enough to accommodate testing and instrumentation

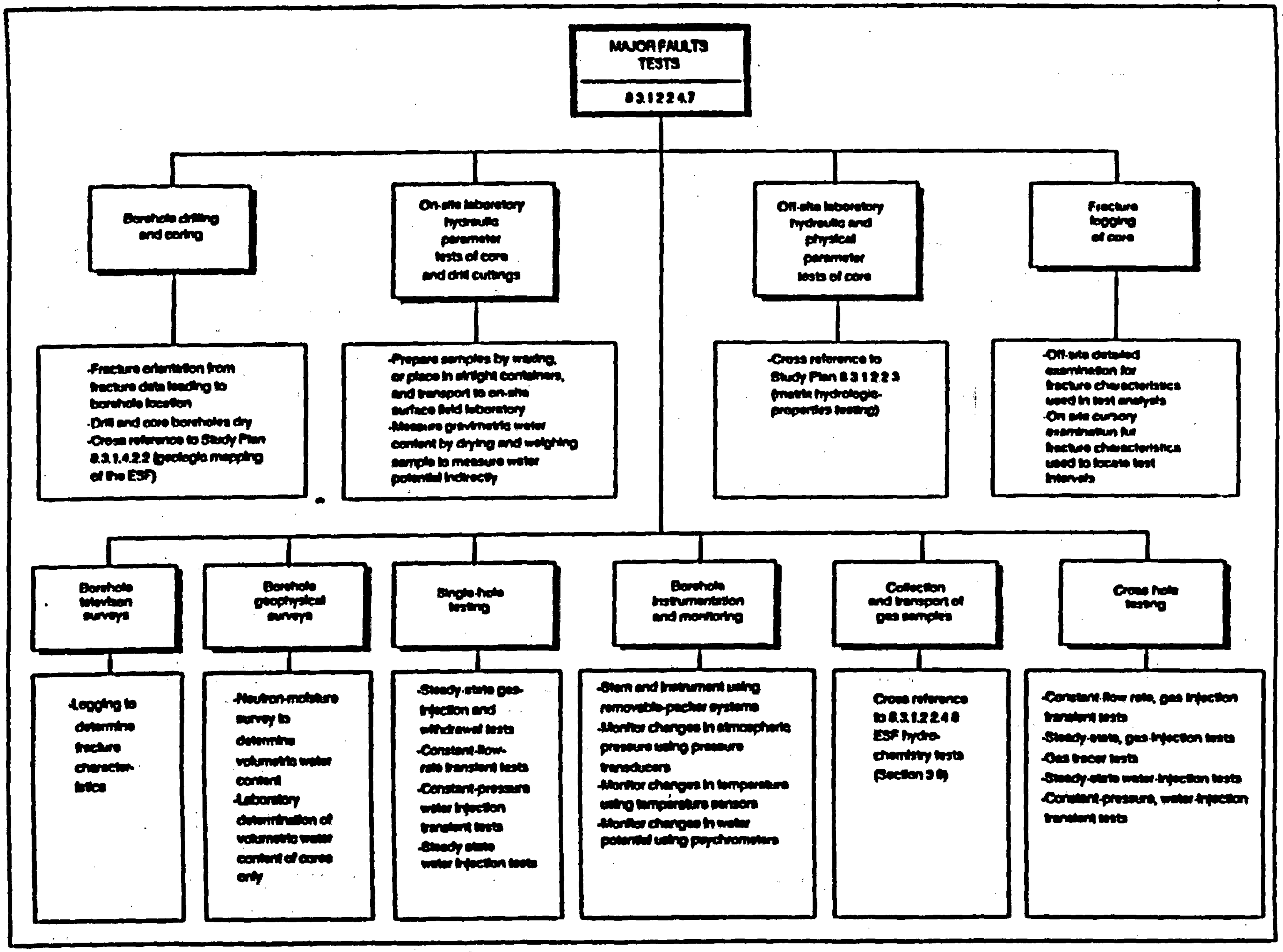

Figure 3.10-3. Organization of the major-fault testing strategy showing tests, analyses, and methods.

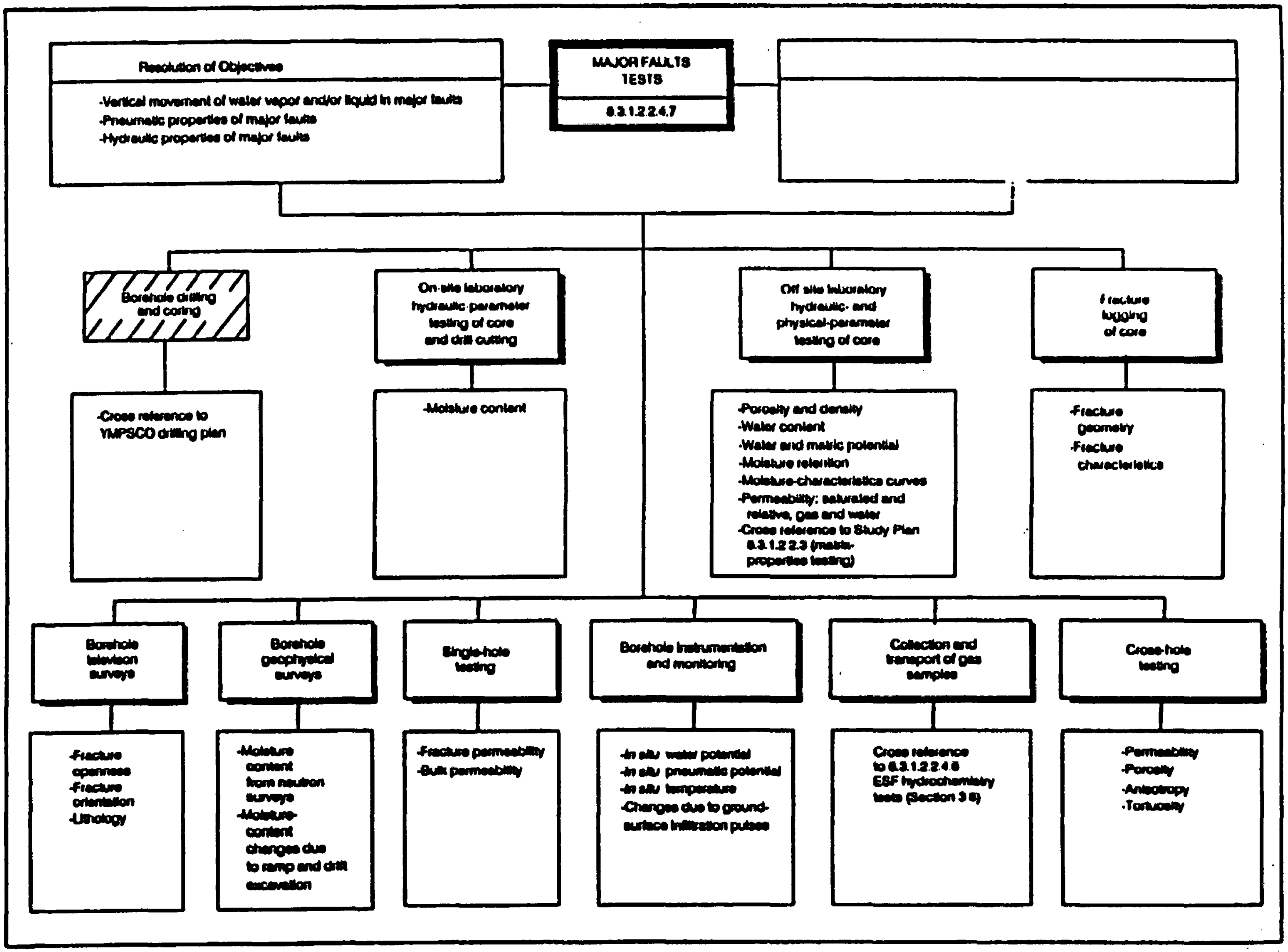

Figure 3.10-4. Organization of the major-fault testing strategy showing tests, analyses, and site parameters. T' › cross-hatched box indicates that no site param-‑'er will be generated.

needs. The alcove, if constructed, will be large enough to allow drilling of two HQ3 approximately 30-meter boreholes (#5 and #6, see Figure 3.10-2), one on each side of the fault at distances of from 1 to 3 meters perpendicular to the fault. The boreholes will be drilled parallel to the fault. Following testing in boreholes #5 and #6, one additional borehole (#7) will be drilled. Borehole #7, HQ3 approximately 30 meters in length, will be drilled parallel to boreholes #5 and #6 and directly along the fault plane (see Figure 3.10-2). If the major fault is more of a fault zone and no real fault plane is identified, the second alcove, if constructed, will be located in the most intensely fractured part of the fault zone and only boreholes #5 and #6 will be required. If there is more than one major fault associated with the fault zone, the principal investigator may request additional alcoves and boreholes similar to the second alcove.

3.10.3.2 On-site laboratory hydraulic-parameter testing of core and drill cuttings

Selected core and drill-cuttings samples obtained during the drilling process will immediately be sealed in wax, or placed in air-tight canisters and transported to a field laboratory, where gravimetric-water content of selected core and cuttings will be determined. Information obtained will be used in the interpretation of gas-injection tests and will serve as baseline data for the newly drilled boreholes. This activity is described in the matrix hydrologic-properties testing activity (Activity 8.3.1.2.2.3.1.) in YMP-USGS SP 8.3.1.2.2.3 (Unsaturated-zone percolation - surface-based studies).

3.10.3.3 Off-site laboratory hydraulic- and physical-parameter testing of core

Core and cuttings samples not utilized during on-site hydrologic testing will be sent off site to laboratories for testing the following properties: volumetric water content, grain density, porosity, bulk density, water potential, matric potential, water retention, saturated water and gas permeability, and relative permeability. The information obtained from these tests will be used in the interpretation of gas injection tests and will serve as baseline data for the newly drilled boreholes. Methods used to measure these important hydrologic parameters are described in the matrix hydrologic-properties testing activity (Activity 8.3.1.2.2.3.1) in YMP-USGS SP 8.3.1.2.2.3 along with possible alternatives.

3.10.3.4 Fracture logs of core

If continuous coring is possible, a cursory examination of the core for fracture characteristics (e.g., type of fracture, depth to fracture, etc.) will be made on site during drilling. In the laboratory, a more detailed examination of the core will be made to develop detailed fracture-characteristic logs. These logs will include fracture frequency, width, coatings and fillings. Fracture data from boreholes will be used in selecting test intervals for single and cross-hole testing along with selection of the long-term monitoring zones. No alternative methods for this activity were identified, although borehole-television cameras will also be used to view fractures in situ.

3.10.3.5 Borehole television surveys

Following completion of drilling all boreholes will be logged with an oriented television camera for fracture characteristics and lithology. The survey will be used for fracture orientation and to determine whether the fractures intersecting the borehole are open or closed. The fracture data will be used to supplement ramp- and drift-wall mapping and to determine the location of test intervals and long-term monitoring zones. An alternative to borehole-television surveys is to maintain orientation of the core during drilling. This would require a special oriented-core barrel. The oriented core could be used to determine fracture orientation; however, it is often difficult to determine from core whether fractures are open or closed, and if they are drilling-induced or natural, especially at greater depths where weathering is not as prominent.

3.10.3.6 Borehole geophysical surveys

Following television logging, all boreholes will be caliper-, natural gamma-, gamma-gamma-, and neutron-logged. Neutron surveys will be conducted on a periodic basis. These data will be used to look at long-term drying or wetting trends. The neutron tool will be calibrated as described in the USGS technical procedure.

3.10.3.7 Single-hole pneumatic testing

The first borehole of Figure 3.10-2 will be used for preliminary single-hole air-injection testing. The hole will be oriented near perpendicular to the plane of the fault and will be counted as one of the three perpendicular boreholes. Constant-rate, steady-state and transient tests will be used to estimate the fault-zone permeability and fault permeability. Single hole pneumatic testing will use a borehole packer-instrumentation system or a SEAMIST borehole liner with a movable injection interval, flow meters, and pressure transducers to conduct pneumatic testing in the fault zone and in the fault. The test zones will be selected based on fracture mapping, core examination, and borehole television and geophysical testing.

The SEAMIST single-hole testing system, if utilized, consists of a borehole membrane and screened injection interval that make up an injection unit (see Figure 3.10-5). The membrane is a balloon type unit that unfolds down the borehole in an inversion installation technique. The inversion installation allows the liner to be essentially blown down the borehole thereby eliminating any need to drag or push packers into the borehole. To conduct single-hole injection tests, first the injection screen is installed at the desired test interval and then the membrane is averted down the borehole. The screened interval is on rollers and can be installed at any location. The membrane forms a seal covering the entire borehole except where the screened interval prevents the membrane from contacting the borehole. Gas injection to the injection interval is through a special injection line that connects the injection interval to the alcove yet will not interfere with the membrane. The system will allow the entire length of the borehole to be tested and is superior to packers because the membrane eliminates the potential of the injected air to short-circuit and flow back out the borehole. Because the SEAMIST system is new technology and has had limited field testing, there is the possibility that the system might not operate as hoped. If this happens, the SEAMIST system will be replaced with a standard borehole-packer instrumentation system.

Prototype testing has determined that several gas-injection and -withdrawal methods will be utilized during the single hole testing. They include: (1) single-hole, constant-flow-rate, transient tests, and (2) single-hole, steady-state, gas-injection and -withdrawal tests.

Because the pneumatic permeability of the rock is dependent on the moisture content, it is important to evaluate the influences the air injection may have on the moisture content. Present theory on

Yucca Mountain holds that the matric potential is generally dry suchthat the fractures and/or large pores that are responsible for most permeability are dry and therefore the testing will provide good estimates of the rock permeability. As a general rule, the injection pressures will be limited to 1.0 bars and therefore will not change the permeability of any rock with a matric potential less than -1.0 bars. If the laboratory matric potentials of the core samples show matric potentials greater than 1.0 bars, testing pressures will be lowered to less than the matric potentials.

Single-hole fluid injection or withdrawal (production) field tests are commonly used to evaluate reservoir or aquifer permeability. These tests utilize only one active well and no observation wells. Rock parameters are evaluated from data (flow rates and pressure collected from a single borehole (Earlougher, 1977; Govier, 1977). The two single-hole methods listed above are briefly described below. A thorough treatise on each method can be found in the references accompanying each description.

Steady-state gas-injection and -withdrawal tests will be used to determine the permeability of individual fractures and faults (Govier, 1977). Steady-state tests consist of injecting gas into or withdrawing gas from the rock until the downhole pressure and uphole measured injection (withdrawal) flow rates remain constant. Trautz (1984) used this method to characterize fractures in unsaturated fractured tuffs. Schrauf and Evans (1984) also used this method to evaluate the relation between the gas conductivity and geometry of natural fractures in the laboratory.

The single-hole constant-rate transient test consists of injecting gas into the rock at a constant rate and at the same time monitoring the transient pressure response (i.e., change in pressure with time). Constant-production-rate transient tests are commonly used in the oil industry to evaluate gas-reservoir parameters (Earlougher, 1977). An alternative to this method, which is listed in Table 3.10-1, is a constant-pressure transient test. As the name implies, gas is injected or produced from the rock at a constant pressure while the change in gas-flow rate is monitored with time. Such a test is seldom made because it is much easier to measure pressure accurately than it is to accurately measure flow rate (Earlougher, 1977). Constant-rate tests, however, may inadvertently become constant-pressure tests, and so it is desirable to be able to analyze both types of tests.

The results of the initial single-hole tests will be compiled with the information obtained from core, video logs, borehole geophysics, and geological mapping. Estimates of fracture permeability will then be used to plan the optimal borehole configuration for subsequent borehole drilling and cross-hole tests. Although ramp excavation effects are believed to be minimized by the 20-m depth of the alcove, the effects of excavation in the vicinity of the ramp and alcove will be considered in the preliminary analyses. Methods and data that are required to compensate for these effects will be provided in the excavation effects test, as described in Section 3.5. The results of a single-hole test, as just described, can be heavily influenced by wellbore conditions, making it difficult or impossible to calculate effective porosity. In addition, it is impossible to characterize the anisotropic nature of a rock using a single-hole test. For these reasons, the data obtained from the exploratory hole will have limited usefulness in site characterization. Its purpose will be realized chiefly in providing input for scoping calculations that can be used to optimize subsequent test strategies at each testing location in the ESF.

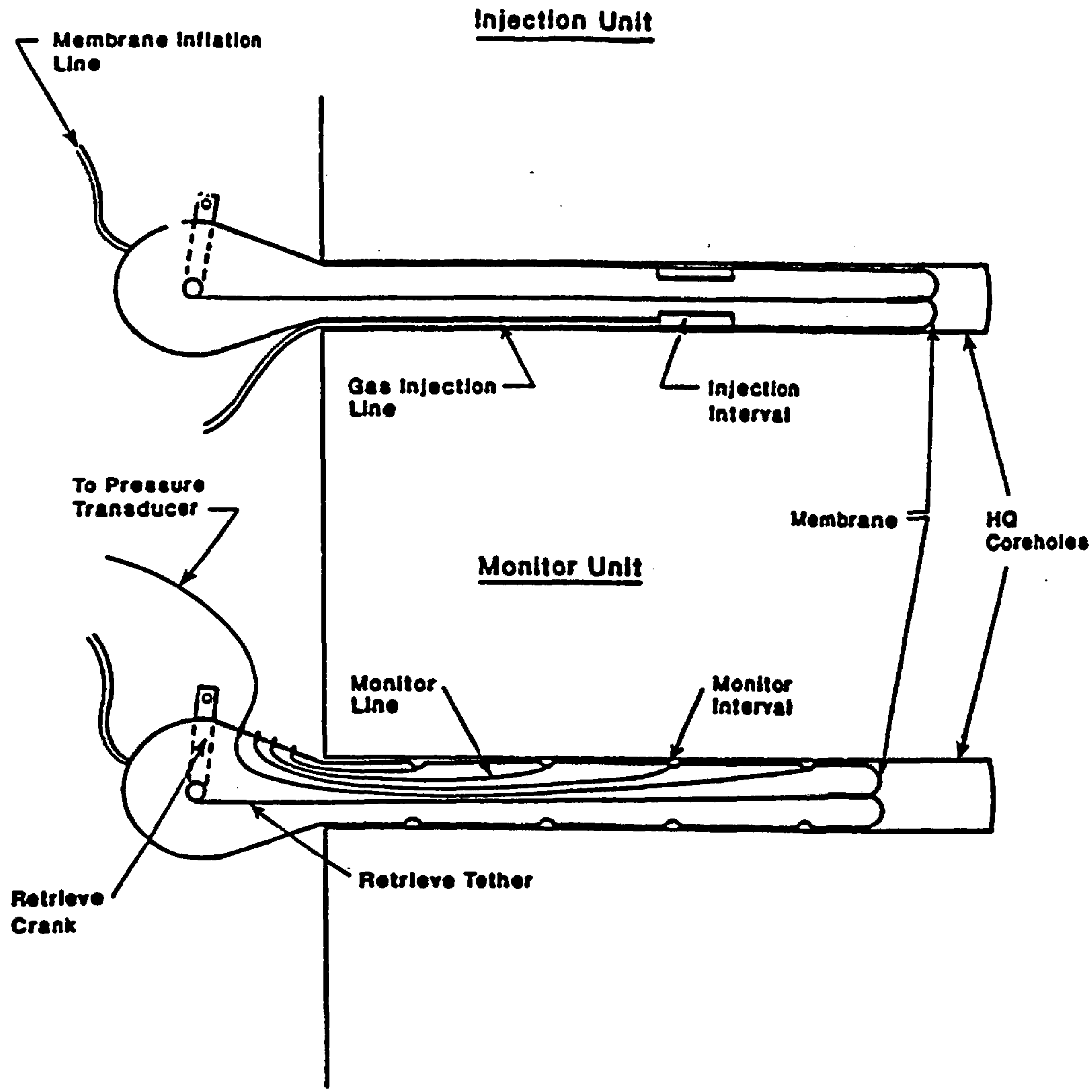

Figure 3.10-5. Schematic of SEAMIST system showing injection and monitor units.

In addition to fracture data, rock-matrix lithology and hydrologic properties will be determined for the core obtained from the initial exploratory hole. The physical properties that will be determined from core samples include matrix pore geometry, welding, grain density, bulk density, and porosity. Fracture or fault geometry data will include orientation, roughness, and, in the event of multiple faults, spacing. Mineralization along fracture or fault walls will also characterized if present. The hydrologic properties that will be determined from the core samples include moisture content (gravimetric and volumetric), water potential, matrix potential, and moisture retention.

All core will be examined on site immediately before it is sealed in wax or placed in air-tight canisters (for shipment to the surface field laboratories). Some samples will also be sent to laboratories off the site for more complicated analyses (e.g., water potential, matric potential, moisture retention, saturated water and gas permeability, and relative permeability). This work is included in the matrix hydrologic properties testing activity (Activity 8.3.1.2.2.3.1) of Study 8.3.1.2.2.3.

An additional source of information will be the planned natural gamma, gamma-gamma, neutron-moisture, and caliper geophysical logs. In all boreholes, this suite of geophysical logs will be used to aid in the location of fault zones and the determination of moisture-content distributions. Periodic temperature logs will also be made in some boreholes to help determine the thermal gradient across the fault zone.

Although a one-point sample taken from a single borehole is an inadequate representation of a large planar structure, some information obtained from the matrix-properties and geophysical-log testing will be immediately useful in assessing the hydrologic significance of a fault or fault disturbed zone under consideration. Such an assessment would be used only in guiding decisions pertaining to the scheduling and implementation of subsequent testing activities and not for actual site characterization. For example, a moisture-content profile obtained from the core may provide information on the recent history, if any, of moisture flow through the specified fault. Structures, such as fracture coatings, which provide immediate evidence of significant moisture flow (especially if it is determined to be recent) will be given a relatively higher priority in the ESF test scheduling. Water flow, if present, will be measured using the techniques described in the perched water test (Section 3.7).

3.10.3.8 Cross-hole pneumatic, hydraulic and tracer testing

Following the single-hole testing and preliminary data evaluation, the location and drilling of the second and third boreholes will be completed. Following completion of the drilling, the second and third boreholes will be single-hole tested. All previously given drilling and single-hole testing requirements apply to the second and third boreholes.

Once the boreholes have been cored, fracture mapped (with video camera), and logged with the suite of geophysical probes, preparations will begin for cross-hole pneumatic (air or nitrogen) testing. Cross-hole testing will be conducted between each of the boreholes. The cross-hole testing will use the single-hole equipment plus an additional two SEAMIST borehole monitor units. The SEAMIST monitor units consist of a borehole membrane with up to 15 monitor intervals (see Figure 3.10-5). The membrane operates the same as the injection interval membrane but differs in that the membrane has up to 15 monitor screens that are permanently installed in the membrane. The monitor screens are connected to the alcove by small diameter tubing. These monitor screens allow the pressure response at the monitor interval to be monitored in the alcove by connecting a pressure transducer to the tube. The tube can also be used to withdraw gas samples from the monitor intervals. Once the monitor unit is installed in a borehole, the borehole changes from a single line source to 15 point sources. As with the injection unit, if the SEAMIST monitor unit does not operate as needed, the system will be replaced with an inflatable packers system. The single-hole-testing SEAMIST injection unit will then be used to conduct cross-hole testing between injection and monitoring intervals on the same side of the fault, in the fault, and on opposite sides of the fault. (See Sections 3.4 and 3.10.3.1 through 3.10.3.7 of this study plan.)

The exact spacing and orientation of the holes will be determined from analysis of data obtained from fracture mapping, borehole television and geophysical logging, and the results of pneumatic tests from the single-hole testing. The boreholes will be oriented to maximize the number of fracture intersections. The boreholes will be spaced in order to maximize the distance between the boreholes while still allowing a pressure transient response between boreholes in a reasonable period of time. It is anticipated, however, that an expected minimum spacing of 5 m between the holes will be required.

Cross-hole pneumatic and hydraulic field tests, commonly referred to as "interference tests" in the petroleum industry, are used to evaluate reservoir permeability and storativity, determine the location of structural features such as faults, no-flow and recharge boundaries, and evaluate homogeneous versus anisotropic conditions in reservoirs (Earlougher, 1977) and fractured aquifers (Hsieh and Neuman, 1985; and Hsieh and others, 1985). Cross-hole testing is a descriptive phrase used to describe a multiple-well test. Multiple-well tests require at least one active (producing or injecting) well and at least one observation well; however, only one active well will be utilized at any given location and time during this study. Gas will be injected or produced from an isolated test interval in one of the boreholes, and the response of the formation to the change in fluid pressure will be monitored in numerous nearby observation intervals located in other boreholes. The test results, namely active- and observation-well fluid pressures, and injection or production-flow rates, will be used to calculate reservoir or aquifer parameters. Analysis of the test results is dependent upon flow-domain boundary conditions, the type of fluid injected into the formation, the saturation state of the formation, and the type of test conducted (e.g., steady-state or transient).

The methods described with regard to single-hole tests apply equally to cross-hole testing. The greatest difference between the two test configurations is the quality of results that can be determined from the test data. Single-hole test results can be heavily influenced by wellbore conditions (i.e., skin effects caused by wellbore damage or improvement), making it difficult or impossible to calculate reservoir parameters. In addition, it is impossible to characterize the anisotropic nature of a reservoir using a single-hole test. The cross-hole tests provide a convenient test configuration for estimating the permeability anisotropy of the fault and fault zone. Types of cross-hole tests to be conducted include (1) constant-rate transient gas-injection and recovery tests, and (2) steady-state gas injection and withdrawal. A possible alternative to these methods could be constant-pressure gas-injection tests.

Following pneumatic testing, cross-hole tracer testing will be conducted. Tracer travel times between selected intervals can be compared to velocities calculated from conductivities and porosities and used to estimate tortuosity. Tracer testing will be conducted in cooperation and under guidelines of the geochemistry staff, using methods described in Section 3.8.

Following pneumatic and tracer testing, several test sites will be selected for hydraulic testing. Faults that were tested at more than one location should have one test site selected for hydraulic testing. Pneumatic and hydraulic test results will differ due to gravity, air entrapment, Klinkenberg effect, and other possible influences. However, an opportunity to compare pneumatic and hydraulic test results is important in the site characterization program. If reliable techniques can be derived for estimating permeability (and hydraulic conductivity) from air- and water-injection test data at the field scale (that scale which corresponds to the zone which is evaluated in the air- or water-phase testing), then pneumatic testing results may be more efficient and provide a more comprehensive assessment of the permeability of the formations containing faults or fault zones than an estimate provided by laboratory experiments. It will be necessary to perform cross-hole pneumatic tests followed by hydraulic tests at select locations in order to determine the usefulness of effective air permeability in calculating hydraulic conductivity. A full discussion of the use of multiple testing approaches for estimating hydraulic conductivity is included in Section 2.1.2 of this study plan.

Obviously, sites chosen for a comparative analysis of hydraulic and pneumatic testing should be representative of other fault-testing locations in both welded and nonwelded units. However, they should also be situated away from areas where water might interfere with other test activities. The selected hydraulic test sites should provide the confidence needed for correlating pneumatic and hydraulic parameters.

Hydraulic testing will also allow for long-term monitoring following water injection. Because some of the hydraulic test sites have alternate sites where no water will be injected, this will allow long-term monitoring of the same fault following air versus water injection.

3.10.4 Long-term instrumentation and monitoring of boreholes

A final phase of testing major faults or fault zones consists of instrumenting and monitoring for long-term observation of *in-situ* hydrologic properties. The long-term monitoring will last from 5 to 7 years. Packers will be used to isolate selected monitoring intervals in the fault and fault zone. Monitoring will be done in at least one borehole at all major-fault test sites and one borehole will be left for future logging and possible testing. Monitoring will include pressure transducers for pneumatic pressure, thermistors for temperature, and thermocouple psychrometers for relative humidity. Prototype testing by the USGS has shown that thermocouple psychrometers can be calibrated with salt solutions to a sensitivity of 0.05 bars and accuracy of 0.7 bars over a range of -1 to -75 bars. Prototype thermistor testing has developed thermistors with sensitivity of 0.001 C°, and accuracies of 0.005 C° over a range of 10 to 50 C°. Prototype pressure transducer testing and development has resulted in units with sensitivities of 10.0 Pascals, and accuracies of 20.0 Pascals over a range of 0.5 to 1.5 atms.

Long-term monitoring in selected boreholes will monitor changes in pressure, temperature and relative humidity in the faults and may allow detection of any water pulses that might percolate through the unsaturated zone. This type of information will be especially valuable if one or more of the major-fault test sites is also a geohydrologic unit-contact site. This will provide an opportunity to investigate the hydraulic continuity of the major vertical structures passing through the geohydrologic unit contacts.

The long-term monitoring just described is based on the premise that during infiltration events, percolation of water will disturb the *in situ* matrix potential and temperature.

3.10.5 Methods summary

The parameters to be determined by the tests and analyses described in the above sections are summarized in Table 3.10-1. Also listed are the selected and alternate methods for determining the parameters and the current estimate of the parameter-value range. The alternate methods will be utilized only if the primary (selected) method is impractical to measure the parameter(s) of interest. In some cases, there are many approaches to conducting the test. In those cases, only the most common methods are included in the tables. The selected methods were chosen wholly or in part on the basis of accuracy, precision, duration of methods, expected range, and interference with other tests and analyses.

The USGS investigators have selected methods which they believe are suitable to provide accurate data within the expected range of the site parameter. The test results will be used to develop models and analytical techniques that describe the site flow system. The expected ranges of the site parameter have been bracketed by previous data collection and computer modeling and are shown in Table 3.10-1.

3.10.6 Quality assurance

The USGS quality-assurance program plan for the YMP (USGS, 1989) requires documentation of technical procedures for all technical activities that require quality assurance.

Equipment requirements and instrument calibration are described in the technical procedures. Lists of equipment and procedures for the use and calibration of equipment, limits, accuracy, handling, and calibration needs, quantitative or qualitative acceptance criteria of results, description of data documentation, identification, treatment and control of samples, and records requirements are included in these documents.

Table 3.10-1. Summary of tests and methods for the major-fault activities (SCP 8.3.1.2.2.4.10) in the Exploratory Studies Facility.

Methods (selected and alternate)	Site-characterization parameter
On-site laboratory hydraulic parameter testing of core and drill cuttings	
Measure gravimetric water content by drying and weighing sample (selected)	Water content, gravimetric, rock matrix
Off-site laboratory hydraulic- and physical-parameter testing of core	
Matrix hydrologic properties testing (selected)	Bulk density, rock matrix
•	Grain density, rock matrix
•	Moisture retention, rock matrix
•	Permeability, relative, gas, rock matrix
•	Permeability, relative, water, rock matrix
Matrix hydrologic properties testing (selected)	Permeability, saturated, gas, rock matrix
•	Pneumatic permeability, bulk, fractured rock
•	Porosity pore-size distribution, matrix
•	Porosity, bulk, fractured rock
•	Water potential, rock matrix, and total fractured rock
Fracture logging of core	
Off-site detailed examination for fracture characteristics used in test analysis (selected)	Fracture characteristics: distribution, aperture, alteration
On-site cursory examination for fracture characteristics used to locate test intervals (selected)	Fault characteristics: width, coatings
Borehole television surveys	
Television logging to determine fracture characteristics	Fracture characteristics: distribution, aperture, alteration
•	Fault characteristics: width, orientation, coatings

Table 3.10-1. Summary of tests and methods for the major-fault activities (SCP 8.3.1.2.2.4.10) in the Exploratory Studies Facility. (continued)

Methods (selected and alternate)	Site-characterization parameter
On-site laboratory hydraulic parameter testing of core and drill cuttings	
Borehole geophysical surveys	
Neutron-moisture survey to deter- ine volumetric water content (selected)	Water content, volumetric, rock matrix
Laboratory determination of volumetric water component of cores only (selected)	"
In-site pneumatic testing	
Single-hole and multihole, steady-state, gas-injection and -withdrawal tests (selected)	Permeability, pneumatic
"	Anisotropy
"	Fault aperture
Single-hole and multihole, gas-injection, constant-flow-rate, transient tests (selected)	Permeability, pneumatic
"	Anisotropy
"	Porosity
"	Fault permeability
Single-hole and multihole, gas injection, constant-pressure, transient tests (alternate)	Permeability, pneumatic
"	Anisotropy
"	Porosity
"	Fault permeability
Gas tracer testing	Tortuosity

Table 3.10-1. Summary of tests and methods for the major-fault activities (SCP 8.3.1.2.2.4.10) in the Exploratory Studies Facility. (continued)

Methods (selected and alternate)	Site-characterization parameter
On-site laboratory hydraulic parameter testing of core and drill cuttings	
Borehole instrumentation and monitoring	
Monitor pressure changes within test intervals using pressure transducers (selected)	Pneumatic-potential distribution and fluctuation
Monitor changes in chemical composition of rock-unit gases (selected)	Diffusive tortuosity, fractured rock and rock mass
•	Gaseous diffusion coefficient, fractured rock units
Monitor changes in temperature within borehole using temperature sensors (selected)	Temperature, distribution and fluctuations
Monitor changes in water potential within boreholes using psychrometers (selected)	Water potential, distribution and fluctuation
Collection and transport of gas samples	
Cross reference to 8.3.1.2.2.4.8 ESF hydrochemistry tests (selected)	Pore gas composition
•	Radioactive isotopes
•	Stable isotopes
Cross-hole hydraulic testing	
Cross-hole, steady-state, water-injection tests across geohydrologic-unit contacts (selected)	Permeability, water
Cross-hole, constant-rate, water-injection, transient tests across geohydrologic-unit contacts (selected)	•
Cross-hole, constant-pressure, water-injection, transient tests across geohydrologic-unit contacts (alternate)	•

Department of Energy
Office of Civilian Radioactive Waste Management
Yucca Mountain Site Characterization Office
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Las Vegas, NV 89193-8608

WBS 1.2.9.1.1
QA: N/A

APR 21 1994

Linda J. Desell, Chief, Regulatory Integration Branch, Systems and Compliance, HQ (RW-331) FORS

SUBMITTAL OF PARTICIPANTS' MONTHLY STATUS REPORTS (SCP: N/A)

The U.S. Nuclear Regulatory Commission (NRC) has requested to be put on distribution to receive a copy of the Yucca Mountain Site Characterization Project participants' monthly status reports on a regular basis. Therefore, the enclosed Civilian Radioactive Waste Management System Management and Operating Contractor, EG&G Energy Measurements, Inc., Los Alamos National Laboratory, Lawrence Livermore National Laboratory, Sandia National Laboratories, and U.S. Geological Survey monthly status reports are submitted to your office for formal transmittal to the NRC.

If you have any questions, please call me at (702) 794-7622.

Carl J. Hader for
April V. Gil, Team Leader
Licensing Team
Assistant Manager for
Suitability & Licensing

AMSL:AVG-3149

Enclosure: (NOT RECORD MATERIAL)
List of Status Reports w/encls