Study Plan for
Study 8.3.1.15.2.1

Characterization of the Site Ambient Stress Conditions

1

Revision 0

January 1989

U.S. Department of Energy
Office of Civilian Radioactive Waste Management
Washington, DC 20585

Prepared by
U.S. Geological Survey

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Prepared by:
U.S. Geological Survey

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ABSTRACT

This study plan discusses the in situ determination of ambient stresses as part of the thermal and mechanical rock properties program. The planned overcore stress activity will be done during construction of exploratory shaft ES-1. The elastic strain recovery activity, also included in this study, will be detailed in a subsequent revision of this plan.

Tests are planned at two levels in the densely welded Topopah Spring Member of the Paintbrush Tuff--in a lithophysal zone (upper level) and in a nonlithophysal zone (lower level); tests are also planned in an alcove near the base of the shaft. The tests will be done in breakout rooms at least 8 m from the shaft. Some of the tests will be done within 1-6 m of the breakout-room walls to define the zone in which stresses have been changed by the excavation, others as deep as 20 m to measure undisturbed stresses.

The test methods are as follows. First, three noncoplanar exploratory NQ (3-in.) holes are cored to determine the best locations for the overcore holes; the cores are logged for lithology and fracture data, and core is selected and stored for rock-fabric analysis. In each exploratory borehole, a borehole TV camera is used to survey and record fractures, and dilatometer tests are done to estimate the deformational properties of the rock mass. When suitable locations have been found, three pilot EX (1.5-in.) holes are cored in increments of about 1 m, parallel to the exploratory holes and about 0.2-1 m from each hole. For each pilot hole, the core is logged and the borescope is used to survey fractures. The USBM (U.S. Bureau of Mines) borehole deformation gauge is then installed, and about three to five overcore stress-determination tests are done in each pilot hole. For the overcore tests, an interval of about 0.5 m of the pilot hole containing the USBM gauge is overcored, and the overcore specimen is removed; the biaxial elastic modulus test is done, and samples are selected and stored for rock-fabric examination. At the base of the shaft, low-volume hydraulic-fracturing tests also may be conducted.

Elastic anisotropy tests are conducted on samples from oriented overcores and on selected NQ cores. Thin sections are taken parallel and perpendicular to the borehole axis from the overcore specimens, and microfracture orientation and abundance are determined by standard universal-stage methods.

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STUDY PLAN 8.3.1.15.2.1: CHARACTERIZATION OF THE SITE AMBIENT STRESS CONDITIONS

This study plan summarizes and supplements the discussion of section 8.3.1.15.2.1 of the SCP. The study plan describes plans for characterizing the ambient stress conditions at Yucca Mountain. The study comprises two activities--

- 8.3.1.15.2.1.1--Anelastic strain recovery experiments in core holes
- 8.3.1.15.2.1.2--Overcore stress experiments in the exploratory shaft facility

Because the overcore stress activity will be started during construction of the exploratory shaft, it is discussed in detail in this study plan. The anelastic strain recovery activity will be detailed in subsequent revisions of this plan.

This study is one of ten planned to characterize preclosure rock properties. Figure 1-1 shows the relation of the study to other studies in the thermal and mechanical rock properties program (Program 8.3.1.15), and figure 1-2 shows the design issues and the other characterization programs for which the study provides information.

1 PURPOSE AND OBJECTIVES OF THE STUDY

1.1 Information to be obtained and how that information will be used

The main objective of this study is to obtain a set of spatially distributed stress measurements to characterize the ambient state of in situ stress representative of undisturbed conditions in the repository host rock. Specific uses of the information for meeting design and performance goals and regulatory requirements are discussed in sections 1.2 and 3.2.9; uses of the information for supporting other studies are discussed in section 4.

Objectives specific to Activity 8.3.1.15.2.1.2 are discussed in section 3.2.

1.2 Rationale and justification for the information to be obtained: why the information is needed

This section explains why the information to be obtained in this study is needed (1) to predict the performance of the repository relative to the tentative goals associated with performance measures and (2) to satisfy regulatory requirements.

Data on ambient stress conditions are needed to specify initial and boundary conditions for repository design calculations. Specifically, information from the study is needed to evaluate the response of the rock to thermal loading and to the excavation of emplacement boreholes and drifts. Figure 1-2 shows the design issues and other site characterization programs that require information from the study.

Information from this study is needed to predict the performance of the repository relative to performance or design goals for three design issues--1.11, 1.12, and 4.4 (SCP table 8.3.1.15-1). Table 1-1 shows these goals and the performance measures with which they are associated. The table is taken from SCP sections 8.3.2.2 (Issue 1.11), 8.3.3.2 (Issue 1.12), and 8.3.2.5 (Issue 4.4). The terms and concepts in the table are defined in those sections and in the SCP glossary (vol. VII).

For issue 1.11, information from the study is needed to measure the predicted performance of the repository against one or more of three performance goals (table 1-1) in order to demonstrate that the repository and its engineered barriers would comply with 10 CFR 60.133 (SCP table 8.2-2). The study will measure deformation and elastic properties of intact rock in thermal/mechanical unit TSw2 (nonlithophysal Topopah Spring; SCP, fig. 2-5) in order to provide information on the maximum and minimum horizontal stresses in the rock mass of the unsaturated zone (SCP table 8.3.1.15-1); those stresses, in turn, will be used to evaluate the initial stress state in the primary area and extensions (SCP table 8.3.2.2-5). Specifically, an estimate of the ambient stress condition is needed to: design the layout and engineered barriers to contribute to performance (Part 60.133(a)(1)); accommodate site specific conditions (Part 60.133(b)); reduce deleterious rock movement (Part 133(e)(2)); select excavation methods that limit preferential pathways (Part 60.133(f)); and predict thermal and thermomechanical response of the rockmass (Part 60.133(i)).

For Issue 1.12, information from the study is needed to measure the predicted performance of the repository against one or more of five design goals (SCP tables 8.3.1.15-1, 8.3.3.2-1. 8.3.3.2-4) in order to demonstrate that the shaft and borehole seals would comply with 10 CFR 60.134 (SCP table 8.2-2). The study will measure deformation and elastic properties of intact rock in units TCw (welded Tiva Canyon) and TSw2 (nonlithophysal Topopah Spring) in order to calculate the maximum and minimum horizontal stresses in the rock mass of those units in the primary area (SCP table 8.3.1.15-1), so as to contribute to information on the ambient stresses at potential seal locations (SCP, p. 8.3.3.2-32). The ambient stress conditions are relevant to this issue because the nature and extent of preferential pathways resulting from the excavation and operation of the repository will depend in part on the ambient conditions. The structural and hydrologic behavior of the rock/seal interface will also depend on the ambient stress conditions and the redistribution of the stress field around the openings. That information is needed to ensure that the anchor-to-bedrock plugs and seals, the general fill, and the station plugs limit the flow of water into the underground facility; that the drift backfill seal reduces the potential for subsidence; and that the borehole seals reduce the potential for radionuclide transport through boreholes (SCP table 8.3.3.2-1).

For issue 4.4, information from the study is needed to predict the performance of the repository in terms of the performance goal that accessways and drifts remain usable for 100 yr; the licensing strategy calls for that goal to be attained with high confidence (SCP table 8.3.2.5-2). The assessments will be based in part on analytical and empirical evaluations that require an estimate of the ambient stress conditions at the site and the redistribution of the stresses around the openings. (This performance goal is also a performance measure for Issue 4.2 (nonradiological health and safety; SCP, sec. 8.3.2.4); resolution of that issue presumably would also depend on information from the study.) Information from the study is needed to measure the deformation modulus of the rock mass in unit TSw2 and to measure deformation and elastic properties in intact rock of unit TSw2; those measurements will allow for calculation of the ratio of the maximum and minimum horizontal stresses to the vertical stress and for determination of the bearing of the horizontal stresses in the rock mass of unit TSw2 in the primary area (SCP tables 8.3.1.15-1 and 8.3.2.5-2).

Information from this study is also needed to address regulatory requirements of 10 CFR 60 (Disposal of High-Level Radioactive Wastes in Geologic Repositories) and 10 CFR 960 (General Guidelines for the Recommendation of Sites for the Nuclear Waste Repositories): the information is needed to characterize the present and expected characteristics of the host rock and surrounding units, so as to determine compatibility with containment and isolation as required by 10 CFR 60(c)(1)(ii)(C) and 10 CFR 960.4-2-3 (postclosure rock characteristics). In addition, information from the study is needed to characterize the host rock and surrounding units so as to evaluate if construction, operation, and closure of the repository are feasible, as required by 10 CFR 60.122(c)(21) and 10 CFR 960.5-1 (system guidelines) and by 10 CFR 960.5-2-9 (preclosure rock characteristics). Estimates of the rock-mass deformation modulus are needed to confirm geotechnical and design parameters during repository construction, as required by 10 CFR 60.141(a), (b), and (c). The estimates from this study, coupled with observations of fracture frequency, will supplement the estimates of modulus from Study 8.3.1.15.1.7. The in situ state of stress is needed to contribute to the evaluation of possible tectonic phenomena at Yucca Mountain, to determine if construction, operation, closure, and decommissioning of the repository are feasible, as required by 10 CFR 60.122(c)(13) and 10 CFR 960.4-2-7 (postclosure tectonics) and by 10 CFR 960.52-11 (preclosure tectonics).

2 RATIONALE FOR SELECTING THE STUDY

The two activities in this study were chosen as complementary means for obtaining the required information on ambient stress conditions. The bases for selecting the types of tests comprised in each activity are discussed below. The actual plans for the tests are discussed in section 3.2.1.

2.1 Activity 8.3.1.15.2.1.1: Anelastic strain recovery experiments in core holes

The rationale for choosing the tests in this activity will be detailed in subsequent revisions of this study plan.

2.2 Activity 8.3.1.15.2.1.2: Overcore stress experiments in the exploratory shaft facility

2.2.1 Rationale for types of tests selected

The planned tests (table 3.2-2) were chosen from alternative types of tests discussed in this section for the reasons below. In some cases, alternatives to the selected tests are also being conducted, either as part of this activity or as additional activities, to complement and support the information gathered by this activity. In combination, the planned borehole and laboratory tests will provide data to identify locations for performing the stress measurements.

2.2.1.1 Borehole inspection

Borehole inspection is needed to locate relatively intact intervals for overcore stress measurements. Because borescope and borehole television observations give limited information on fracture filling, roughness, and displacement, the alternative method of examining core also will be used. Inspection needs could probably not be met solely through the alternative of examining core--especially, small-diameter (EX) core from the pilot boreholes. Such core often contains induced fractures; it is often incomplete, and joint fillings may have been washed away. Accordingly, fracture information for the pilot (EX) and exploratory (NQ) boreholes will be obtained both from inspection of the boreholes and from inspection of the cores. Oriented cores from the 6-in. overcore holes also will be inspected for fractures after stress measurements and will be sampled for thin sections.

Geophysical logs (e.g., natural gamma, gamma density) may be used as indices for comparing rock-mass properties. Crosshole techniques (e.g., seismic tomography) may be used to investigate the rock mass between drill holes. These methods could be used for reconnaissance prior to overcoring or for correlating properties between the NQ reconnaissance holes and the overcoring pilot holes.

2.2.1.2 Borehole dilatometer tests

The borehole dilatometer will be used mainly to characterize deformability as a function of distance from the excavation and to support the selection of intervals for overcoring by identifying zones of higher modulus, which suggest less fractured volumes of rock. The measurements will also be used to estimate the distance from the excavation that the deformation modulus of the rock has been altered. Alternatives to the borehole dilatometer include the Goodman jack and the Menard pressuremeter. The Menard pressuremeter is not well adapted to rocks having relatively high modulus, such as the welded tuff. The chief advantage of the Goodman jack over the dilatometer is its ability to apply directed uniaxial loads to the borehole and, after repeated tests in different orientations in the borehole, to yield information on the anisotropic response of the rock. The chief disadvantage of the Goodman jack is its sensitivity to platen-borehole mismatch and attendant theoretical problems in data reduction. To overcome this problem, nonroutine boreholes must be drilled to exacting specifications with regard to diameter of the borehole, a practice that is both time consuming and costly. The dilatometer, on the other hand, will function satisfactorily in boreholes obtained by routine drilling practices.

2.2.1.3 Overcore stress measurements

To obtain information on the present three-dimensional state of stress in the immediate vicinity of the exploratory shaft, the stress-relief technique has been selected as the primary method. This passive method of obtaining data on the in situ stress state in shallow boreholes (<50 m or 160 ft) has witnessed steady progress in development and application, is firmly based in theory, is supported by extensive literature spanning more than two decades, and has met with general acceptance in the rock-mechanics community. Its chief alternative is the active method of hydraulic fracturing.

Another method for measuring the stress state is the diametral deformation method (Serata and Kikuchi, 1986). This method is subject to uncertainty of interpretation associated with preexisting fractures, anisotropy of mechanical properties, and borehole orientation. Although the diametral deformation method is not planned for this study, it will be considered if fracture conditions at any test level prove incompatible with the overcoring method.

Various techniques are available for monitoring stress changes in response to environmental influences (e.g., Gloetzel cells, flatjack pressure cells, IRAD rigid-inclusion stressmeter), but they are not standard techniques for measuring the preexisting in situ state of stress.

To induce stress relief, an instrumented volume of rock is removed from its surroundings; in practice, the rock is removed by coring over and around a strain-monitoring instrument contained in a centered coaxial pilot hole. Upon removal, the core of rock expands or contracts owing to loss of confinement, and the attendant displacements or strains are recorded. The three principal candidate instruments are the U.S. Bureau of Mines (USBM) deformation gauge, the Australian (CSIRO) hollow-inclusion cell, and the doorstopper method. The USBM and doorstopper methods both require three noncoplanar boreholes for a complete determination of the stress state; the CSIRO method requires only one borehole. The USBM and CSIRO methods of measurement require that the length of the recovered core be at least twice its diameter to allow for complete stress relief and for measurement of its elastic properties as described in section 2.2.1.4. The doorstopper method typically requires a smaller diameter borehole than the other methods. The CSIRO and doorstopper instruments must be cemented to the borehole wall, introducing potential difficulties in getting satisfactory bonding; and the bonding material could conceivably interfere with subsequent chemical testing. Both methods also require the use of numerically or experimentally derived geometrical or strain-coupling constants for data interpretation.

Notwithstanding the advantages of the doorstopper and CSIRO methods, the USBM method was selected as the primary method, principally because of its inherent simplicity and relative stability. The USBM gauge is wedged and oriented in the pilot hole; because of its circuit design (full Wheatstone bridge), it is less affected by heat conduction to the pilot hole during overcoring. The CSIRO cell is encapsulated with epoxy and oriented in the pilot hole; because of its circuit design (quarter Wheatstone bridge), it is more sensitive to heat-induced expansion in the pilot hole, which cannot be flushed with cooling fluid during overcoring (Swolfs, 1982). The selection of the USBM or CSIRO method (displacement or strain measurement) is based on the prevailing site and rock conditions in the shaft. The USBM gauge will be the primary instrument, but the CSIRO cell may be used as a secondary instrument if stresses are sufficiently high and if the thermal response of the cell is sufficiently low to allow accurate measurements.

2.2.1.4 Biaxial elastic modulus tests

The biaxial elastic modulus test is required to interpret the strain-relief data from the USBM gauge or CSIRO cell. Most of the rock is expected to be reasonably isotropic. If the rock is isotropic or nearly so, then this technique of modulus determination is adequate for data interpretation using standard methods. Its chief advantage is that the modulus measurements can be made in the field immediately after overcoring and performed at pressures in the biaxial device that approximate the stress level in the rock prior to overcoring. If biaxial testing reveals significant anisotropy, then the alternative of laboratory triaxial core testing on oriented samples cored from test overcores will be used to determine the required anisotropic elastic parameters (Aggson, 1977).

The additional laboratory alternative of polyaxial testing techniques (Swolfs and Nichols, 1987) will be used to fully characterize the elastic properties of rock that is highly anisotropic. By testing cubes obtained from the annular portion of the oriented overcores, values of Young's modulus and Poisson's ratio may be obtained in three orthogonal directions. These property measurements can then be used in a data-analysis procedure (Hooker and Johnson, 1969) that assumes the rock to be orthotropic; that is, the rock is assumed to have three mutually perpendicular planes of elastic symmetry, with the overcore perpendicular to one of these planes. Extreme anisotropy is sometimes caused by a fracture contained in an overcore annulus that otherwise remains intact; results from such tests will be discarded as not representative of in situ stress conditions, since the overcore sample is not representative of relatively homogeneous material where stress relief can be applied.

2.2.1.5 Hydraulic fracturing

Low-volume hydrofracture tests may be performed in unwelded tuff in an alcove near the base of the ESF (fig. 3.2-3) in order to provide independent measurements of the ambient stresses for comparison with the overcore results. Hydraulic fracturing is not well suited for the rock expected at the upper test levels--highly fractured welded tuff above the water table; consequently, hydraulic fracturing will be used only at the lower level.

2.2.1.6 Rock-fabric analysis

Microscopic rock-fabric analysis will supply detailed three-dimensional information on fracturing and mineral grains; that information will be used to evaluate variations observed in the elastic rock parameters needed for interpreting the overcoring data. Directional variation of intact rock modulus is caused primarily by microscopic fractures, which this analysis will identify (McWilliams, 1966). The standard petrographic techniques to be used for rock-fabric analysis have no reasonable alternatives.

2.2.2 Rationale for the number, location, duration, and timing of the selected tests

The number and location of the tests is based on the objectives of the study and the needed confidence specified in the SCP performance allocation process (see sec.

1.2). The number and locations (summarized in table 3.2-3) vary depending on the test method. The testing program identified in the table is considered adequate but is conditional, and additional tests may be required if conditions result in a significant number of unsuccessful tests or if the data variability exceeds the specified confidence level.

2.2.2.1 Number

The number of tests of each type is discussed below. In general, the number of tests will be guided by experience and by standard methods (ISRM, 1987a, b). However, depending on specific rock conditions in the shaft and the experience gained during prototype testing of these or related field methods in G-tunnel, the number of tests of each type may be modified. Therefore, the actual number of tests of each type will depend on the observed variability of the rock mass in the shaft: if the rock is highly fractured or heterogeneous, larger numbers of tests may be run in order to delimit the range of test results and thereby help to ensure representativeness of results. Additional tests may be performed--for example, in intervals where the deformation modulus changes abruptly.

Borehole inspection.--One inspection will be made in the 3-in.-diameter (NQ) exploratory borehole for each dilatometer test in order to log the fractures in the hole, and one borehole inspection will be done in the 1.5-in.-diameter pilot (EX) hole prior to each overcore stress test. Each inspection will be detailed enough to ensure that the overcore stress tests are made in the least fractured intervals of the borehole.

Borehole dilatometer tests.--Nine 3-in.-diameter (NQ) dilatometer test holes are planned for the exploratory shaft: one dilatometer hole will be cored parallel to each of the three required overcore test holes at each of the three test levels in the shaft (figs. 3.2-1, 3.2-2). To obtain a representative characterization of relative deformability as a function of distance from the excavation and to support the selection of intervals for overcoring, dilatometer tests will be run continuously in each hole, sampling approximately 2-ft intervals. Similar tests may be performed in the EX pilot holes as they are extended along each overcore test hole in advance of each overcore test.

Overcore stress tests.--Three noncoplanar drill holes are required to calculate the principal in situ stress magnitudes and directions. For each drill hole (fig. 3.2-2), two overcore tests will typically be run in the zone of redistributed stresses (as near to the excavation as rock conditions permit) and three tests in the zone of undisturbed stresses.

Biaxial elastic modulus tests.--One test will be performed on each overcore stress test sample. A single test is standard practice, because the elastic modulus should be measured immediately after the overcore is removed from the borehole.

Hydraulic fracturing test.--About three or four tests will be made in each of the three 3-in.-diameter (NQ) dilatometer drill holes in the alcove near the base of the shaft (fig. 3.2-3).

Rock fabric analysis.--Typically, about three thin sections will be studied for each overcore sample; that number will ensure that the microfracture populations at overcore locations are adequately sampled. Study of those microfractures will identify anisotropy in the samples, as described in section 3.2.1.

2.2.2.2 Location

The tests are to be conducted in the exploratory shaft because it allows the first opportunity to make detailed in situ measurements of stresses above and within the repository host rock (fig. 3.2-3). The test results will provide the only available approximation of stress conditions in the host-rock mass until further testing is done.

The levels for testing are dictated by the design of the shaft (fig. 3.2-3); at each level, testing will be done in breakout rooms adjacent to the shaft. Some of the tests will be done within 1-6 m of the breakout-room walls to define the zone in which stresses have been changed by the excavation, others as deep as 20 m to measure undisturbed stresses. However, stresses will be measured at least 8 m from the shaft so as to avoid the effect of *shaft* excavation on the measured stresses (for linear elastic rock-mass response, this corresponds to a distance of at least two shaft diameters from the shaft wall).

At each level, overcore testing requires three noncoplanar holes--two subhorizontal and one vertical (see sec. 2.2.2.1 and fig. 3.2-2). Hydrofracturing tests are to be conducted if the shaft penetrates unwelded tuff near its base; the welded tuffs exposed higher in the shaft are likely to be too highly fractured to be suitable for hydrofracturing tests.

2.2.2.3 Duration

The planned tests were selected because individual tests are appropriate for the information needs and because the overall test program can be accommodated within the anticipated excavation schedule for the ESF. The duration of test series for individual holes will depend on the complexity of fractures and heterogeneities within each drill hole: enough time will be taken to ensure that the test results are representative of the desired parameters and can be readily and adequately interpreted. Current estimates are that the test series will require about 21 days per level (sec. 5).

2.2.2.4 Timing

The tests were planned to obtain in situ stress measurements early in the ESF development program, both to allow for subsequent planning and to avoid interference from mining activity and other excavations. The timing will be determined in part by other simultaneous testing (e.g., excavation-effects tests) at each level and by the resumption of shaft sinking. The tests will be done in the sequence shown in table 3.2-4. At the upper two levels (fig. 3.2-2), the overcore stress tests will be conducted either immediately after the demonstration breakout rooms (DBR's) have been constructed or after completion of shaft construction. The ES construction schedule has not been finalized at this time. It is recommended that the stress measurements be made as soon as possible after breakout room construction to avoid introducing additional uncertainty related to time-dependent effects. At the lower level, tests will be conducted after shaft completion in a drilling alcove extending laterally from the shaft near its base (fig. 3.2-2).

2.2.3 Constraints: factors affecting selection of test methods

None of the factors considered below provided a strong basis for choosing the planned test methods rather than alternative methods discussed in section 2.1; for all factors, alternatives to the selected tests were essentially the same as the selected tests. For example, alternatives to the planned tests would all have negligible impacts on the site, so impact was not a basis for choosing between alternatives.

2.2.3.1 Impacts on the site

No detrimental effects on site performance are anticipated from the planned tests. The greatest impact would be due to the low-volume hydraulic-fracturing tests at the base of the shaft. The artificial hydraulic fractures produced in those tests are not expected to significantly affect the site: they will close after testing and are not expected to add significantly to the natural fracture population (Zoback and Pollard, 1978).

In terms of short-term impacts, the amount of fluid lost to the rock during drilling and overcoring will be minimized through the use of dry drilling wherever feasible. Fluid loss during the low-volume hydrofracturing tests will be small because each test typically injects about 2-3 gallons, or less, of water into the rock. Both selected and alternative tests require mined rooms; determination of ambient stress away from the openings requires drilled holes, which slightly alter the rock mass within 10-15 m of these openings at the three established levels.

In terms of long-term impacts, the tests are not expected to impact performance of the site, based on analyses and considerations described in section 8.4.3 of the SCP. The relatively short borehole lengths (20 m or less) are not expected to create preferential pathways to the accessible environment. If a borehole intersects a fault or fracture zone identified as being important to waste isolation, the borehole will be sealed.

2.2.3.2 Simulation of repository conditions

Overcore stress testing would simulate repository conditions as well as or better than alternative test methods. For example, at many locations, the flatjack method (Deklotz and Boisen, 1970) and other stress-cancellation methods would be unable to reach into the shaft or drift wall to a depth where stress conditions are relatively undisturbed by the excavation, making it impossible to measure ambient stresses.

2.2.3.3 Required accuracy and precision

The planned test methods differ negligibly from alternative methods in terms of test accuracy. The planned USBM overcoring method is considered one of the most accurate and reliable methods for stress measurements in tuff. The planned tests should meet the tentative goals for accuracy shown in table 1-1. We anticipate measurement error limits of ± 1 MPa for vertical stresses and ± 2 MPa for horizontal stresses. These error limits will bound the required accuracies.

2.2.3.4 Limits of analytical methods

The planned test methods use standard elastic solutions, as well as solutions which account for rock anisotropies (Becker and Hooker, 1967; Swolfs and Nichols, 1987). The limitations of standard elastic solutions include assumptions of rock elasticity and homogeneous continuity. They also are generally restricted to two-dimensional, plane stress or plane strain analyses. However, nearby fractures or altered zones may give rise to nonlinear inelastic and anisotropic or combined responses during overcoring. Borehole TV, core, and dilatometry observations may not always detect the presence of such fractures, and models for continuum behavior may not explain their effects. Accordingly, the planned methods differ negligibly from alternative methods.

2.2.3.5 Capability of analytical methods

Capabilities of analytical methods were not a basis for selecting test methods. The planned methods were selected largely because the methods for gathering and reducing data are well established. The overcore method of in situ stress determination with the USBM gauge was chosen in part because of its wide acceptance in the geomechanics community and its history of successful operation in many rock types (Tullis, 1981; Lang et al., 1986; Nishimatsu et al., 1986). The instrument has been manufactured commercially for many years, and it has been used to investigate rock stresses for surface and underground construction in rock, including potential nuclear-waste-storage facilities. As stated in section 2.2.1.4, if the Yucca Mountain rock is strongly anisotropic, the data-analysis procedure of Hooker and Johnson (1969) can be used.

2.2.3.6 Time constraints

Time constraints did not affect the choice of test methods: the planned test methods would provide the required information in the time available at least as well as alternative methods. The planned methods are faster than more labor intensive large-scale tests such as the flatjack stress-cancellation method. Section 8.3.1.15.1 of the SCP addresses these concerns.

2.2.3.7 Scale and applicability

The results of the planned tests are expected to provide reasonable estimates of the initial boundary conditions of in situ stresses in the rock mass surrounding the exploratory shaft. The test results will not be widely extrapolated; rather, they will be combined with the results of other studies (see sec. 4.3) to characterize the stress state at Yucca Mountain. The borehole dilatometer tests will be used only to provide data on relative deformability near boreholes extending away from the excavated openings; the results will be used mainly to locate adjacent overcore test intervals.

2.2.3.8 Interference with other tests

The overcoring stress test and associated supporting tests are expected to have negligible interference with other tests in the ESF. This minimal interference is independent of the type of test; hence, it was not a basis for choosing the types of tests. The planned boreholes will alter the stress state for only two or three borehole diameters (about 0.5 m) beyond the borehole wall, and instrumentation used in other ESF tests can readily be located outside this stress-redistribution zone. Hydraulic permeability may increase locally because of fracturing induced by overcoring or by stress redistribution, and moisture content may increase if water is used in drilling or decrease because of evaporation from air circulation in the boreholes. But hydrologic studies can readily be conducted well outside the locations of the boreholes (e.g., several meters), and tracers will be added to all water used in the tests so as to identify potential interference with subsequent hydrologic and hydrochemistry tests. The volumes of drilling fluid and of water for the hydrofracturing tests will be minimized so as to reduce interference with other tests. The hydraulic fracturing tests will be done only at the base of the shaft so as to avoid interference with other tests on the main test level.

2.2.3.9 Interference with exploratory shaft

Both the planned tests and any reasonable alternatives would affect the design and construction of the exploratory shaft. The planned tests are expected to require 35 days per level (sec. 5); alternative tests would result in similar or greater impacts to the schedule.

3 DESCRIPTION OF TESTS

This section describes the tests planned for Activity 8.3.1.15.2.1.2--Overcore stress experiments in the exploratory shaft facility. The tests for Activity 8.3.1.15.2.1.1--Anelastic strain recovery experiments in core holes--will be described in subsequent revisions of this plan.

3.1 Activity 8.3.1.15.2.1.1: Anelastic strain recovery experiments in core holes

The tests in this activity will be described in subsequent revisions of this study plan.

3.2 Activity 8.3.1.15.2.1.2: Overcore stress experiments in the exploratory shaft facility

The objectives of this activity are to determine the ambient in situ state of stress in three dimensions at three predetermined levels--above and within the repository host rock--in that part of the repository block penetrated by the ESF, and to evaluate the extent to which the ambient stresses are changed by the excavations. Table 3.2-1 shows how the information from this activity will be used. Secondary objectives of the activity are to relate the observed in situ stress parameters (magnitude, orientation, stress differences, and variability) to rock-mass fabric and structure and to estimate the extent of the region surrounding the underground openings where the deformation modulus of the rock has been altered. Specific uses of the information for meeting design and performance goals and regulatory requirements are discussed in sections 1.2 and 3.2.9; uses of the information for supporting other studies are discussed in section 4.

3.2.1 General approach

In situ stress determinations and related tests are planned at three levels in the ESF. (The construction of the ESF is described in sec. 8.4 of the SCP.) Specifically, tests are planned at each of the two breakout levels in the densely welded Topopah Springs Tuff--in a lithophysal zone at the upper level and in a nonlithophysal zone at the lower level; tests are also planned in an alcove near the base of the shaft (fig. 3.2-3). An integrated analysis of borehole-measurement data, core mechanical properties test data, and rock-mass fracture data will be used at each site to characterize in situ stresses at each level. The principal tests in this activity are the overcore stress test and the biaxial elastic modulus test; the remaining tests provide field and laboratory support data for those tests. The tests and the information obtained are summarized in table 3.2-2. Table 3.2-1 shows how the information will be used to support the design, performance, and characterization needs.

At all three levels, testing will be done in breakout rooms at least 8 m (two shaft diameters) from the shaft; to measure both the redistributed stresses around the excavations and the undisturbed ambient stresses, the tests will be done throughout an interval extending from about 2 m to as much as 15 or 20 m (about four breakout-room radii) from the breakout-room walls. At each of the three levels, tests will be done in the sequence shown in table 3.2-4. First, three noncoplanar exploratory NQ holes will be cored to determine the best locations for the overcore holes; the cores will be logged for lithology and fracture data, and core will be selected and stored for rock-fabric analysis. In each exploratory borehole, the borehole TV camera will be used to survey and record fractures, geophysical logs may be run to identify rock conditions suitable for testing, and dilatometer tests will be done to estimate the deformational properties of the rock mass. A combination of data from the borehole inspection activities, core logs, geophysical logs, and borehole dilatometer tests will be used to identify possible locations for performing the stress measurements. When suitable locations have been found, three pilot EX holes will be cored in increments of about 1 m, parallel to the NQ exploratory holes and about 0.2-1 m from each NQ hole. For each pilot hole, the core will be logged and the borescope used to survey fractures. (Dilatometer tests will generally not be done in the pilot holes, so as not to damage the rock to be overcored.) If the pilot hole proves satisfactory, the USBM gauge will then be installed, and about three to five overcore stress-determination tests will be done for each of the three pilot holes (fig. 3.2-2). For the overcore tests, an interval of about 0.6 m of the pilot hole containing the USBM gauge will be overcored, and the overcore specimen will be removed; the biaxial elastic modulus test will be done, and samples will be selected and stored for rock-fabric examination. At the base of the shaft, NQ (3-in.) holes will be cored, dilatometer tests will be done, and about three or four low-volume hydraulic-fracturing tests will be conducted in each hole to provide additional confirmation to the overcoring results.

Elastic anisotropy tests will be conducted on samples from oriented overcores as well as on selected NQ (3-in.) cores as judged necessary to aid in the analysis of field measurements and in interpretation of spatial variability of rock mass properties that influence the stress distribution and measurements. (The theoretical effects of fractures on in situ stresses are considered by Lemos and Brady [1983]).

In order to evaluate microfractures as potential causes of anisotropy, oriented thin sections will be taken parallel and perpendicular to the borehole axis from the overcore specimens. Microfracture orientation and abundance will be determined by standard universal-stage methods and compiled on appropriate diagrams for comparison with overcore strains and biaxial moduli.

For all the tests, data reduction will be done by standard methods (sec. 3.2.7).

3.2.2 Test methods

Standard methods defined in the references to this study plan will be used for all tests in this activity (table 3.2-2). The technical procedures for the tests are shown in table 3.2-5. Technical procedures will be available for review and approval before testing is begun. Prior to ESF testing, prototype overcore tests may be performed in the G-tunnel at the Nevada Test Site. This experience in fractured welded tuff may lead to worthwhile modification of some tests, for the reasons given in section 2.2.2.1.

3.2.3 QA level assignment

All tests for activity 8.3.1.15.2.1.2 have been assigned QALA I, as detailed in SIP-6923G-01 and summarized in Appendix A of this plan.

3.2.4 Required tolerances, accuracy, and precision

Tentative goals for the accuracy of the design parameters to be derived from this study are shown in SCP table 8.3.1.15-1. Preliminary testing in G-tunnel (Zimmerman and Vollendorf, 1982) suggests that the actual measurements will vary considerably (i.e., ±1.5 MPa) because of factors such as the variability of fracturing in the rock units in which the tests are made. Sections 2.2.3.3 and 2.2.3.4 address this concern. Careful selection of locations and intervals for overcoring is expected to reduce the variability of the stress measurements relative to those previously made in G-tunnel. Tentative parameter goals for Issue 4.4 are that the magnitudes and orientations of the stresses have the expected values shown in section 3.2.5 with medium confidence; for Issue 1.11, that the vertical stress be known with an accuracy of ±1 MPa with medium confidence and that the horizontal stresses be known with an accuracy of ±2 MPa with medium or low confidence; for Issue 1.12, that they be known with an accuracy of ±2 MPa with low confidence.

The accuracy of the stress determinations will depend on measurement error, on the assumptions used in reducing the data, and on uncertainties due to variations in the properties and conditions of the rock being tested. The measurement error will be quantified by regular calibration of the instruments and other components involved. Error introduced during testing will be minimized, in part, by following the procedures developed for each test method. Uncertainties due to analytical assumptions are discussed in section 3.2.8.

3.2.5 Range of expected results

Surface-based hydraulic fracturing data at Yucca Mountain (Stock and others, 1985) indicate that the minimum principal stress is nearly horizontal and trends N. 60° W. to N. 65° W.; its magnitude is somewhat less than the vertical gravity-induced stress. Near-surface stress values are expected to be slightly modified by topographic effects, as discussed by Savage and Swolfs (1986) and Swolfs and Savage (1986). The maximum principal stress is expected to be nearly vertical and approximately equal to the overburden pressure. Expected values of stresses and mechanical properties, based on available data, are summarized in table 3.2-6.

Stresses are expected to be redistributed within a radius or two of mined openings. In linear elasticity theory (Obert and others, 1960), stresses are increased by about 20 percent within approximately one radius of a circular excavation opening and by 5 percent with two radii (plane stress; hole in plate; uniaxial stress field). The actual extent of such modifications will depend on the heterogeneity, nonlinearity, and inelasticity of the rock mass.

3.2.6 Equipment

All of the equipment to be used for the tests is conventional off-the-shelf equipment comprising standard components (table 3.2-7).

3.2.7 Data-reduction techniques

Standard data-reduction techniques will be used for the tests, as specified by the references shown below.

U.S. Bureau of Mines overcore stress determination tests: ISRM, 1987a; Swolfs and Powers, 1985

Biaxial elastic modulus tests: Becker and Hooker, 1967

Dilatometer tests: Roctest, 1985; ISRM, 1987b

Hydraulic fracturing: ISRM, 1987a

These techniques of stress analysis assume plane stress (two dimensional) and a linear elastic, homogeneous, isotropic medium. If the rock is strongly anisotropic, the techniques described in section 2.2.1.4, in Becker and Hooker (1967), and in Amadei (1983) will be used. If the rock is nonlinearly elastic, Aggson's (1977) procedures for analyzing nonlinearly elastic stress-relief overcores will be used.

The statistical uncertainty of the stress data will be calculated using a least-squares analysis suggested by Becker (1968). Classical statistical and geostatistical methods will be used to analyze the data from the support activities.

Rock-fabric information will be plotted on histograms and on equal-area stereonet diagrams. Television borehole fracture data will be obtained using the algorithm method described by Mahtab and others (1973). These data will then be analyzed using graphical and analytical approaches (e.g., plotted on equal-area diagrams and compared with similarly plotted stress data) to assess the potential effect of the fractures and rock fabric on the measured stresses.

3.2.8 Representativeness of results

The data from this activity are expected to be representative of the ambient state of stress within the volume defined by the boreholes. Characterization of stress throughout the host rock will be based on further measurements in the ESF and from the surface (notably, the anelastic strain-recovery experiments of activity 1 of this study). Whether the measurements in this activity can be extrapolated with confidence to the rock mass between test levels will depend on the consistency of the results and on how well these results compare with other tests, such as hydrofracture tests. The identification of geologic controls on stress variations will also increase confidence in projections of stresses. Borehole dilatometer and petrofabric data will provide supplemental information on whether the observed stress variations can be correlated with small-scale rock properties. (See also sec. 2.2.3.7.)

In addition to the uncertainties intrinsic in the stress measurements themselves (sec. 3.2.4), further uncertainties arise from the combined effects of excavation and of spatial variation in rock properties. The petrofabric analyses, modulus tests, and additional laboratory tests will establish how closely the rock approximates the assumptions used in the analyses. While these tests will provide the basis for identifying and quantifying the effects of most deviations from the assumed properties and conditions, minor deviations may be noted but no correction made in the analysis.

3.2.9 Relations to performance goals and confidence levels

This activity will contribute to the tentative goals associated with performance measures for design issues 1.11, 1.12, and 4.4, as outlined in section 1.2 and table 1-1 and as detailed in SCP tables 8.3.1.15-1, 8.3.2.2-4, 8.3.2.2-5, 8.3.3.2-1, 8.3.3.2-4, and 8.3.2.5-2. The tests of this activity are expected to provide the confidence levels specified for in situ stress information in table 1-1, but additional tests may be required if the conditions encountered result in a large number of unsuccessful tests or if data variability exceeds specified confidence levels (these levels may be changed as a result of changes in performance allocation).

4 APPLICATION OF RESULTS

This section tells how the results of the study of ambient stress conditions will be used in performance-assessment and design studies and in other characterization studies. Section 1.2 describes how the results of the study will be used to measure the predicted performance of the repository against tentative goals associated with established performance measures for resolving performance and design issues. Figure 1-2 shows the design issues and site-characterization programs that will use information from this study.

The study will support the thermal and mechanical rock properties program (program 8.3.1.15), contributing directly to the resolution of issues 1.11, 1.12, and 4.4 and indirectly to the resolution of Issues 1.10 and 4.2. The characterization of stresses in this study will contribute to geomechanical and thermal-mechanical models of the Yucca Mountain site. These models are two of four components of a three-dimensional rock characteristics model of the site (SCP fig. 8.3.1.4-1). The other two components are the geologic and geohydrologic models. The in situ stress and the deformation and elastic moduli are the parameters addressed by this study. These can be grouped together at a higher level as two site characterization parameters, in situ stress state and rock mechanical properties. This structure of information flow exists so that the data collected in the site characterization activities making up this study (and the other studies in the preclosure rock characteristics program) can be traced upward to the geomechanical and thermal-mechanical models, and finally to the three-dimensional rock characteristics model. This highest-level computer-based representation of rock mechanical properties at the site can then provide input for performance assessment and design computer analyses of the repository involving hydrologic, thermal, thermomechanical, and geomechanical processes.

Information from this study will be used in the thermal and mechanical properties program (Program 8.3.1.15) which includes the ambient stress and temperature conditions in the rock mass. The ambient in situ stress state is required input for numerous assessments of site performance and repository design including room stability, worker safety, changes in rock mass permeability around openings, retrieval, seals, and waste package environment. The data are necessary boundary conditions and input parameters in the numerical and empirical analyses supporting resolution of the issues identified in section 1.2.

The ambient stress state determines, in part, the behavior of the rock mass when changes (such as the creation of underground openings or the addition of heat) occur in the system. The response to these changes includes movement of intact blocks of rock, creation of new fractures, and changes in the condition of existing fractures. The response of the rock mass influences the stability of the openings, the ground support required, and the magnitude and extent of changes in the hydrologic behavior.

4.1 Application to performance-assessment studies

The results of this study will not be used directly for any of the performance-assessment studies.

4.2 Application to design studies

The results of this study will be used for resolving design issues 1.11, 1.12, and 4.4, as discussed in section 1.2. The estimates of the ambient stress state will be used in analytical and empirical models to assess the behavior of the rock mass to the construction and operation of a nuclear waste repository. Preliminary models used to develop the conceptual design of the repository are discussed in section 6.4 of the SCP and in the appendices Site Characterization Plan Conceptual Design Report (SCP-CDR). Models used to assess the changes in the hydrologic behavior in the stress redistribution zones are discussed in section 8.4 of the SCP.

4.3 Application to characterization studies

The results of the overcore stress tests (Activity 8.3.1.15.2.1.2) may be used to supplement in situ stress data collected in the excavation effects tests of Study 8.3.1.2.2.4 (unsaturated-zone percolation, exploratory shaft facility).

Some of the mechanical properties data from the study (e.g., deformation modulus and elastic anisotropic moduli) may supplement the mechanical properties data measured in Study 8.3.1.15.1.3 (the laboratory determination of mechanical properties of intact rock).

In situ stress measurements from the study will support the shaft-convergence activity (8.3.1.15.1.5.1) of the excavation investigations in the exploratory shaft (8.3.1.15.1.5). The in situ stress data from the present study will help to define initial and boundary conditions for mechanical and thermomechanical analyses of the effects of shaft excavation. The stress data may also be used in the demonstration breakout-room activity (8.3.1.15.1.5.2), to evaluate the deformations caused by repository-sized excavations in the welded tuff. Finally, stress data from the study may be used as baseline data for the sequential drift-mining activity (8.3.1.15.1.5.3), as a basis for evaluating changes in ambient stress caused by sequential drift mining.

Although not explicitly stated in the SCP, in situ stress data from the present study could contribute to Study 8.3.1.17.4.8 (Stress field within and proximal to the site area) and supplement the in situ stress data from borehole measurements in Activity 8.3.1.17.4.8.1, thus contributing to the assessment of the vertical and lateral variability of in situ stress at the site.

5 SCHEDULE AND MILESTONES

5.1 Activity 8.3.1.15.2.1.1: Anelastic strain recovery experiments in core holes

The schedule and milestones for this activity will be described in subsequent revisions of the study plan.

5.2 Activity 8.3.1.15.2.1.2: Overcore stress experiments in the exploratory shaft facility

5.2.1 Schedule for performing the tests

The schedule for performing the ambient stress tests described in this activity depends on the duration of the various tasks and their interrelationship with the ESF construction activities and the execution of other studies. The estimated completion time for performing stress measurememts in a breakout room is approximately 35 days, assuming testing is performed two shifts per day.

5.2.2 Milestones for the tests

There are two milestones associated with this activity: the start of the overcore stress experiments in the upper breakout room; and completion of the report on the results of the testing. The milestones are tied to the ES-1 construction schedule as illustrated in the figure below. The estimates are based on figure 8.5-1 in the SCP and the level 2 schedule for the ES-1. The overcore stress experiments begin shortly after the upper breakout room is completed. Obviously any delay in the completion of the upper breakout room will impact the milestones for the overcore stress experiments. The milestones for other tests in the upper breakout room are also shown. The milestone dates for the ES-1 construction have not been finalized at this time and, therefore, no dates can be given for the overcore stress milestones.

```
                           C E
Milestone A        B  D F                    G
          |-------|--|-|--------|-------------|------|----
     Year                       1                    2
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A: M652 Start construction of exploratory shaft ES-1

B: M088 Complete excavation to upper breakout room

C: M089 Complete upper breakout room in ES-1

D: M688 Begin demonstration breakout room testing

E: M602 Begin overcore stress experiments in exploratory shaft

F: M882 Begin excavation effects test

G: M687 Complete report on overcore stress tests

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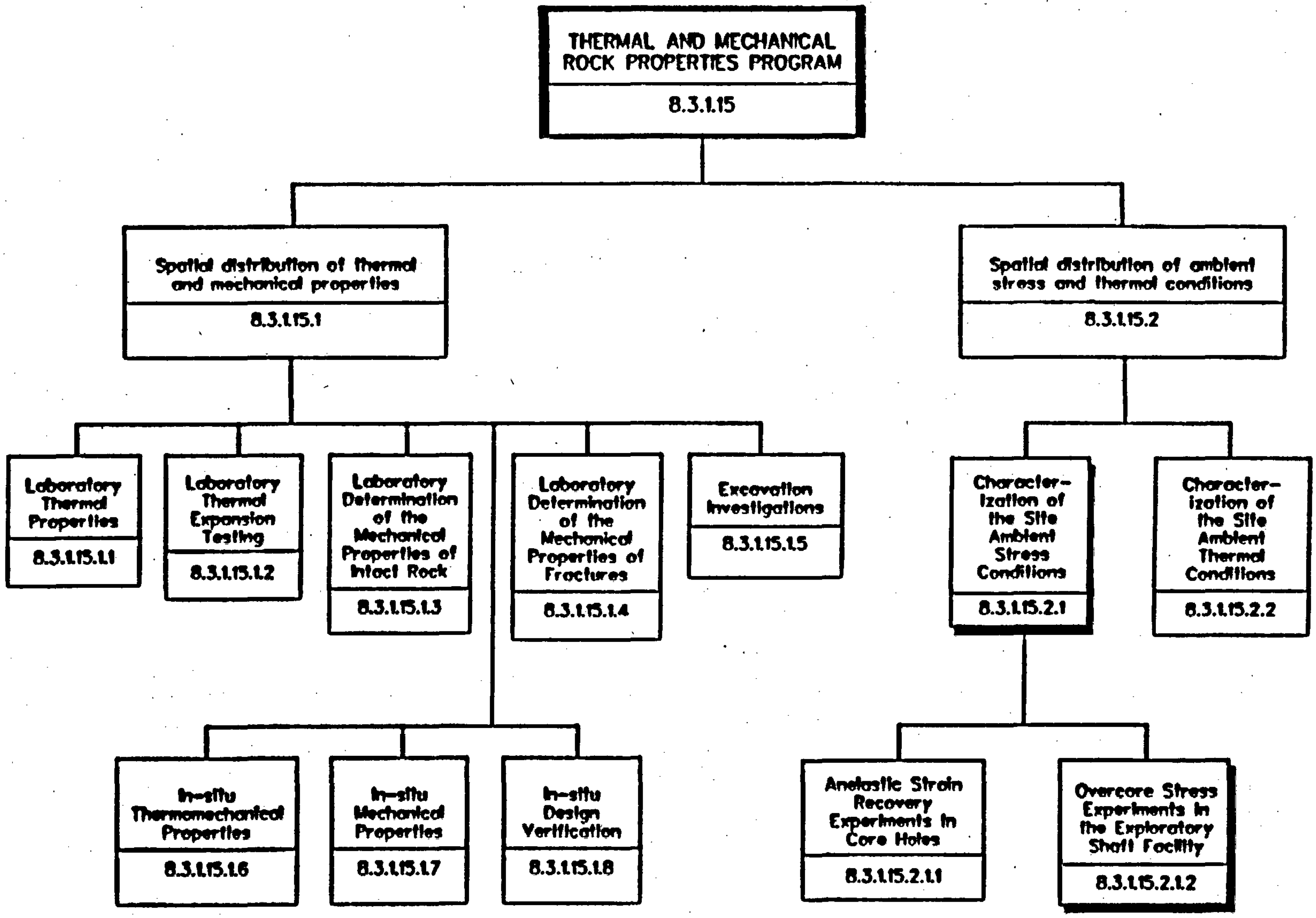

Figure 1-1.--Position of Study 8.3.1.15.2.1. (highlighted) in the Thermal and Mechanical Rock Properties program (Program 8.3.1.15).

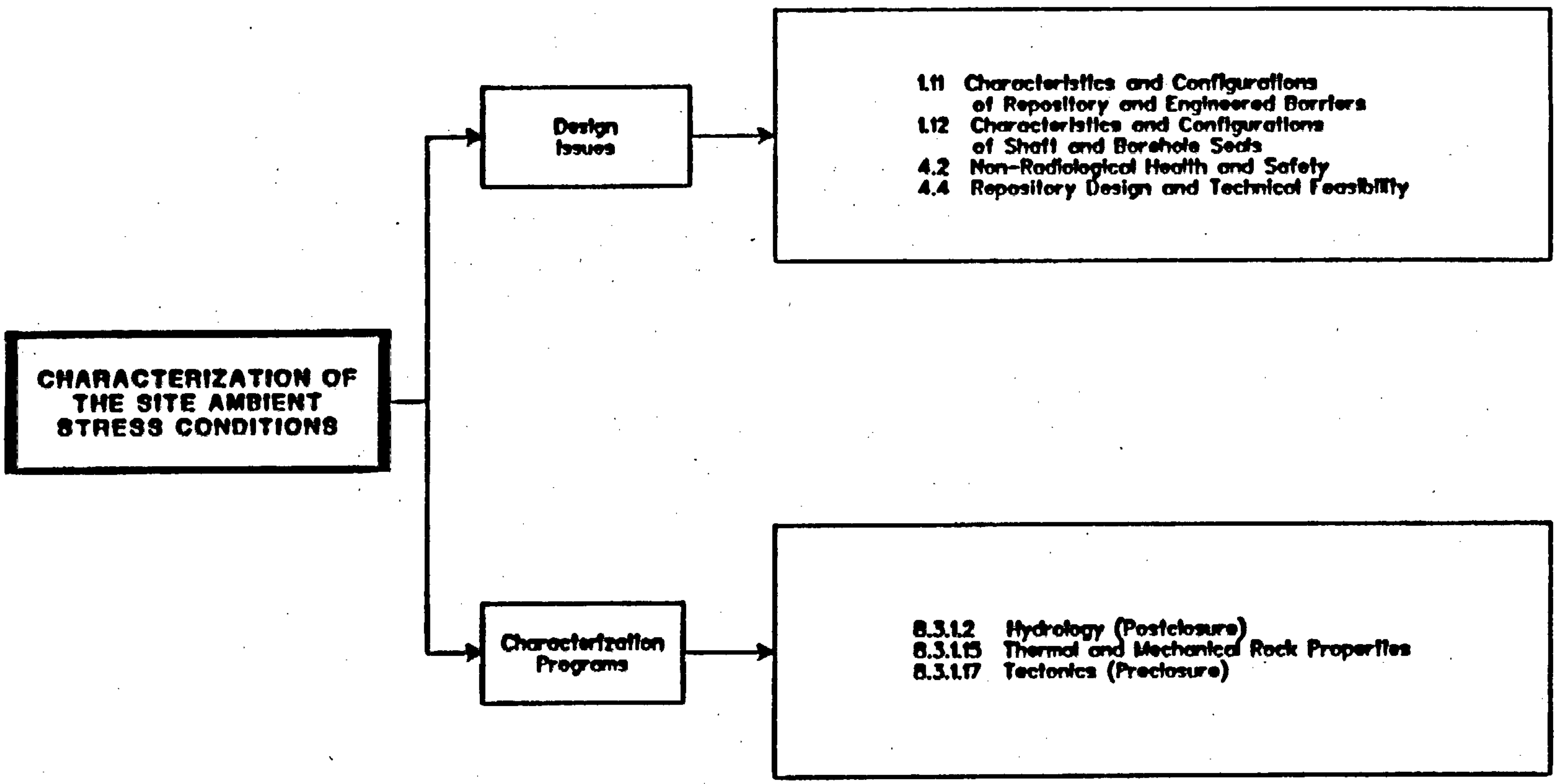

Figure 1-2.--Uses of information from the study for resolving design issues and supporting other characteriztion programs.

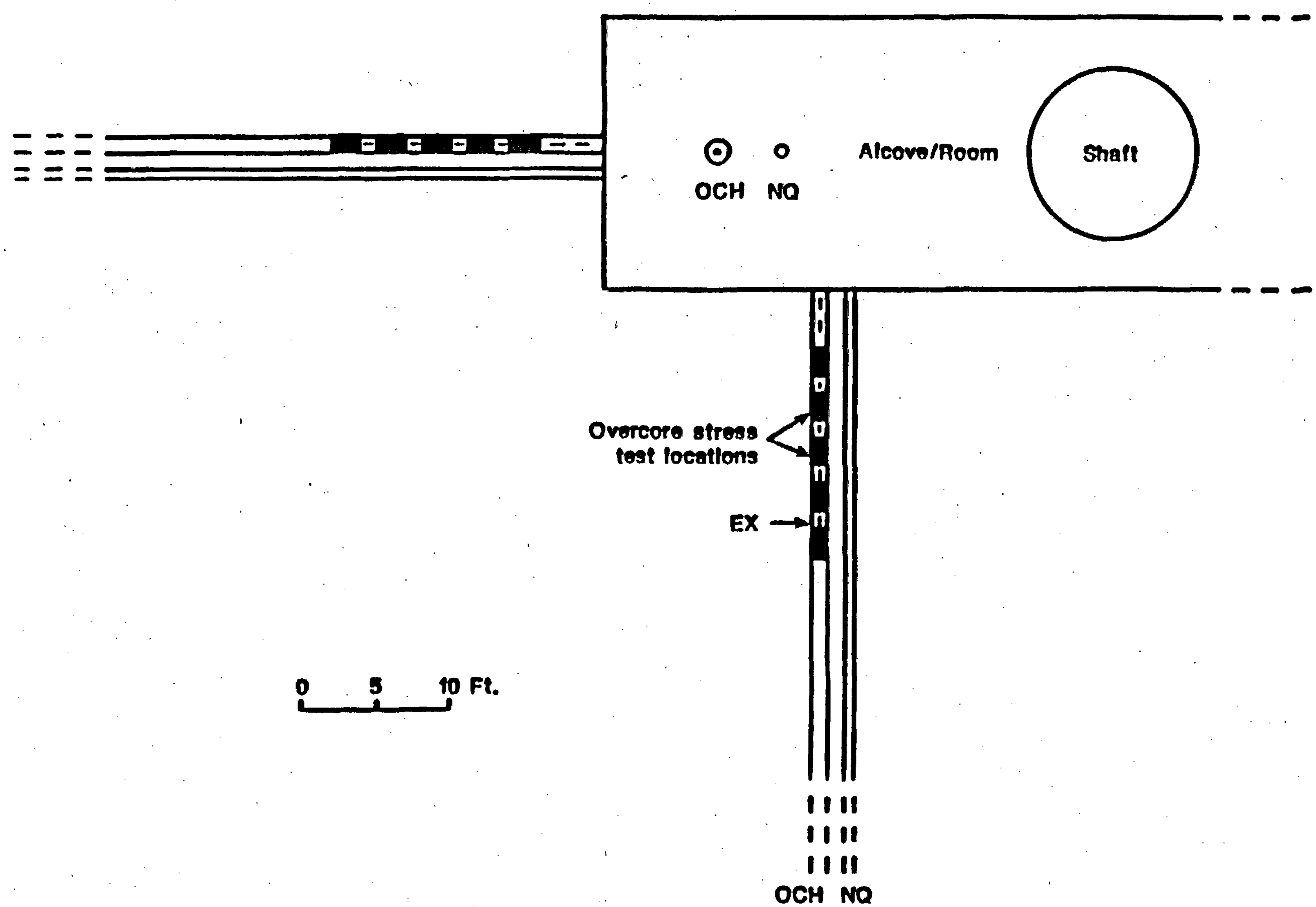

Figure 3.2-1.--Schematic plan view of layout for overcore stress tests in the breakout rooms and in the alcove near the base of the exploratory shaft, showing typical locations of exploratory (NQ) and adjacent, parallel overcore (OCH) holes surrounding pilot (EX) holes.

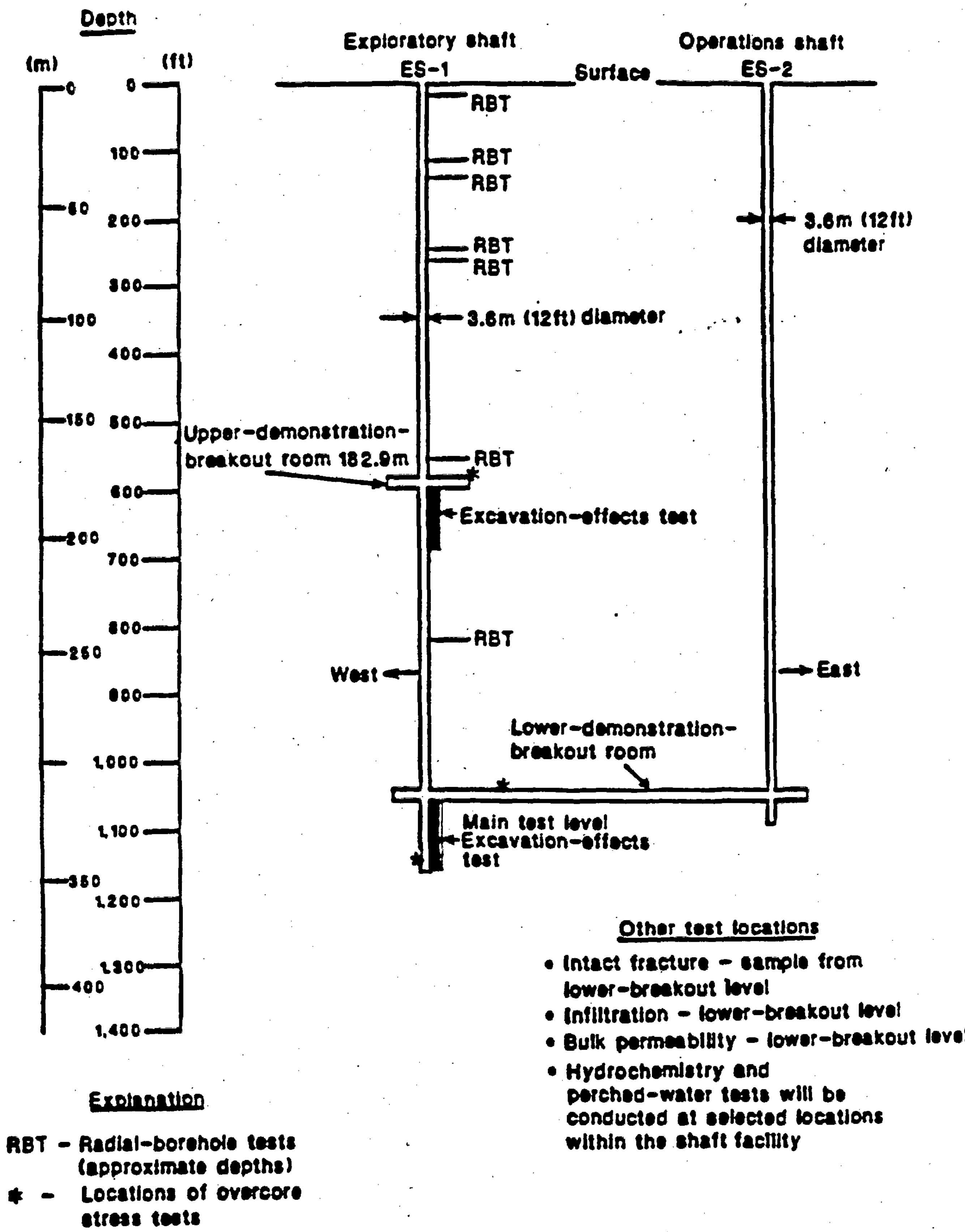

Figure 3.2-2.--Schematic cross section of exploratory shaft, showing locations of overcore stress tests. Modified from SCP figure 8.4-12.

Table 1-1. Design parameters requ... g information from Study 8.3.1.15.2.1, showing performance measures, associated goals and confidence levels, and associated processes and functions

Design parameter requiring information from study(1)	Tentative goal of performance or design parameter	Performance goal	Needed confidence	Performance measure	Process	Function
<u>Issue 1.11</u>						
Minimum and maximum horizontal stresses in rock mass of unsaturated zone in primary area and extensions	Accurate to ±2MPa	Relative motion at top of TSw1(2) <1 m - No intact rock failure - No continuous joint slip	Medium	Potential for significant displacement	Limit deleterious rock movement or preferred pathways	Design thermal loading, taking into account performance objectives and themomechanical response of host rock
"	"	Surface uplift < 0.5 cm/yr	Low	Surface uplift	Limit impact on surface environment	"
"	"	Boreholes that do not load container beyond limits imposed under Issue 1.10	High	Stress, deformation, factor of safety, and potential rockfall	Limit potential for borehole collapse	"
<u>Issue 1.12</u>						
Minimum and maximum horizontal stresses in rock mass of units TCw, TSw2, and CHn1 in primary area	Accurate to ±2MPa	Limit surface waters entering shaft to 1,700 m^3/yr from 0 to 500 yr and 23,000 m^3/yr at the end of the sealing period	High	Quantity of water	Water entering the upper portion of the shaft or ramp	Anchor-to-bedrock plug/seal: reduce amount of water that could potentially reach waste disposal rooms

Table 1-1. Design parameters requiring information from Study 8.3.1.15.2.1, showing performance measures, associated goals and confidence levels, and associated processes and functions (continued)

Design parameter requiring information from study[1]	Tentative goal of performance or design parameter	Performance goal	Needed confidence	Performance measure	Process	Function
=	=	Restrict flow	Low	Quantity of water	Infiltration of surface and subsurface waters reaching base of shafts	General fill: reduce amount of water that could potentially reach waste disposal rooms
=	=	Limit surface and subsurface waters from entering the underground facility to 1,000 m^3/yr from 0 to 500 yr and 14,000 m^3/yr at end of sealing period	High	Quantity of water	Water passage from base of shaft to waste emplacement drifts	Station plugs: reduce amount of water that could potentially reach waste emplacement rooms
=	=	Backfill to within 0.5 m of roof	Low	Amount of fill	Failure of rock mass above drifts	Drift backfill: reduce potential for subsidence
=	=	Control potential for vertical flow through boreholes to 1% or less of potential for vertical flow through entire rock mass	Low	Percentage of flow	Preferential ground water flow through repository, Calico Hills unit and saturated zone	Calico Hills exploratory borehole seal: reduce potential for water-transported radionuclides to be preferentially transported through boreholes

Table 1-1. Design parameters requiring information from Study 8.3.1.15.2.1, showing performance measures, associated goals and confidence levels, and associated processes and functions (continued)

Design parameter requiring information from study(1)	Tentative goal of performance or design parameter	Performance goal	Needed confidence	Performance measure	Process	Function
<u>Issue 4.4</u>						
Deformation modulus in rock mass of unit TSw2 in primary area	11-19 GPa	Accessways and drifts usable for 100 yr	High	Usable openings of required size		Provides physical properties adequate for construction and operation of stable (safe) underground accesses, drifts, emplacement boreholes, and support facilities for normal and credible abnormal conditions (subsurface system element)
Ratio of minimum and maximum horizontal stress to vertical stress, and bearings of horizontal stresses in rock mass of unit TSw2 in primary area	Minimum horizontal stress ratio 0.3-0.8 Maximum horizontal stress ratio 0.3-1.0 Bearing of minimum horizontal stress between N 45 W and N 65 W Bearing of maximum horizontal stress between N 25 E and N 40 E	"	"	"	"	"

(1) Design parameters and associated goals taken from SCP Table 8.3.1.15-1. Other information from SCP Tables 8.3.2.2-4 and 8.3.2.2-5 (for Issue 1.11), 8.3.3.2-1 and 8.3.3.2-4 (for Issue 1.12), and 8.3.2.5-2 (for Issue 4.4).

(2) TCw - Welded, devitrified Tiva Canyon; TSw1 - Lithophysal Topopah Spring; TSw2 - Nonlithophysal Topopah Spring; CHn1 - Calico Hills ash flows, bedded units, tufaceous beds.

Table 3.2-1.--Information to be obtained from overcore stress activity (Activity 8.3.1.15.2.1.2) and how that information will be used

Information to be obtained	How the information will be used
The magnitude (including the standard deviation) and orientation of the principal in situ stress components at three ESF levels (from the overcore stress tests)	For repository design and for stability evaluation of excavations and engineering structures. To define initial and boundary conditions for mechanical and thermomechanical analyses and models used in repository performance assessment.
The magnitude and orientation of the secondary principal stress components normal to each overcore test hole as a function of distance from the excavation (from the overcore stress tests)	To estimate the boundaries of the disturbed zone surrounding the excavations and for excavation design and stability analysis
The deformation moduli of the overcore samples and the anisotropy of these deformation moduli normal to the overcore axis (from the biaxial elastic-modulus tests)	To properly determine the in situ stress state from the borehole deformation data
Estimates of the rock-mass deformation modulus (from each borehole dilatometer measurement)	To assess spatial variation in rock-mass variability and relate it to variability in stress data
Description and tabulation of fractures (from borehole inspection)	To aid in evaluating variability of borehole deformation measurements
Elastic and mechanical properties data (from core tests)	To aid in evaluating rock-mass variability
Estimated magnitude and direction of least principal stress (from low-volume hydraulic fracturing measurements)	To verify the overcore results by an independent method
The existence and magnitude of heterogeneities in the rock mass	To estimate the effect of rock-mass heterogeneities on the stress state

Table 3.2-2.--Types of tests planned for overcore stress activity (Activity 8.3.1.15.2.1.2) and types of information to be obtained from the tests

Type of test	Type of information to be obtained from test
Borehole inspection with TV borehole camera and borescopes	Fracture characteristics
Borehole dilatometer tests	Small-scale deformational properties of the rock mass
Overcore stress determination tests	Stress-relief borehole deformation data
Biaxial elastic modulus tests	Deformation modulus of stress-relief overcores
Hydraulic fracturing	Estimated magnitude and direction of least principal stress
Rock-fabric analyses with petrographic microscope and U-stage	Relation of rock fabric to stress state and to anisotropy in deformation modulus

Table 3.2-3.--Location and number of tests planned for overcore stress activity (Activity 8.3.1.15.2.1)

Test method	Location	Number of tests	Total
Overcoring	183 m (upper breakout room)	5 tests per borehole	15
	323 m (lower breakout room)	5 tests per borehole	15
	355 m (bottom of shaft)	5 tests per borehole	15
Hydraulic fracturing	355 m (bottom of shaft)	4 tests per borehole	12
Biaxial pressure test	Same as overcoring	Same as overcoring	45
Borehole inspection	183 m depth	Entire length of borehole	6
	323 m depth	Entire length of borehole	6
	355 m depth	Entire length of borehole	6
Core logging	Same as borehole inspection	All core	18
Geophysical logging	Same as borehole inspection	Entire length of exploratory (NQ) boreholes	9
Dilatometer	Same as borehole inspection	Entire length of exploratory (NQ) boreholes	[1]270
Rock fabric	183 m depth	3 per overcore sample	45
	323 m depth	3 per overcore sample	45
	355 m depth	3 per overcore sample	45

[1]Assumes boreholes of maximum length (20 m)

Table 3.2-4.--Sequence of tests for overcore stress activity (Activity 8.3.1.15.2.1.2)

1. Three noncoplanar NQ-diameter exploratory holes are cored; core is logged for lithology and fracture data
2. Borehole TV camera is used to survey and record fractures in exploratory boreholes
3. Borehole dilatometer tests are conducted in acceptable boreholes
4. Core is selected and stored for petrographic (rock-fabric) analysis
5. EX diameter hole is cored parallel to each acceptable exploratory borehole; core is logged for lithology and fracture data
6. Borescope is used to survey fractures in EX borehole
7. USBM gauge is installed and overcore test performed
8. Biaxial test is conducted on removed overcore specimen
9. Samples are selected and stored for petrographic examination
10. Steps 5-9 are repeated for each overcore hole
11. Near base of the shaft, hydraulic fracture tests are conducted at selected intervals in NQ-diameter dilatometer holes following dilatometer testing
12. Rock fabric analysis is performed

Table 3.2-5.--Methods and technical procedures for overcore stress activity (Activity 8.3.1.15.2.1.2)

Method	Technical procedure		
	Number	Title	Date
Borehole drilling coring	TBD[1]	NQ, EX, and overcore hole drilling	TBD
	TP-1	Procedure for diamond drilling holes for instrumentation	TBD
Borehole video surveys	GP-10, R0		TBD
	TP-14	Procedure for inspection of boreholes using borehole TV camera and borescope	TBD
Borehole overcore deformation measurement	TP-3	Overcore stress testing	TBD
Installation and use of borehole deformation gauges	TP-17	Procedure for installation and operation of borehole deformation gauges	TBD
Field biaxial stress testing	TP-4	TBD	TBD
Rock fabric analysis	TBD	TBD	TBD
Low-volume hydrofracturing stress measurements	TBD	TBD	TBD
Borehole dilatometer measurements	TBD	TBD	TBD

[1]TBD = to be determined; procedures will be in place at the appropriate time and will be available to the NRC 30 to 60 days before start of work

Table 3.2-6--Stresses and mechanical properties expected at Yucca Mountain

Expected stresses

[Source: SCP table 6-10]

Parameter	Mean value	Range
Vertical stress (MPa)		
Upper breakout room	3.8	2.5 to 5.5
Lower breakout room	6.8	4.0 to 9.5
Bottom of shaft	7.7	4.5 to 10.5
Minimum horizontal to vertical stress ratio	0.5	0.3 to 0.8
Bearing of minimum horizontal stress	N. 57 W.	N. 60 W. to N. 65 W.
Maximum horizontal to vertical stress ratio	0.6	0.3 to 1.0
Bearing of maximum horizontal stress	N. 33 W.	N. 25 E. to N. 40 E.

Expected mechanical properties (intact rock)

[Source: SCP table 2-7]

	Young's modulus (GPa)	Poisson's ratio	Tensile strength (MPa)
Upper breakout room (1)	31.7 ± 17.9	0.25 ± 0.7	21.1 ± 4.6
Upper breakout room (2)	15.5 ± 3.2	0.16 ± 0.03	1.0
Lower breakout room and shaft alcove	30.4 ± 6.3	0.24 ± 0.06	15.2

Table 3.2-7.--Instrumentation, equipment, and materials for overcore stress activity (Activity 8.3.1.15.2.1.2)

Item	Quantity
1. Drill rig and equipment for EX, NQ, and 15.2-cm (6-in.) coring	1
2. EX double tube swivel-type core barrel	2
3. 15.2-cm- (6-in.-) diameter core barrels and bits	10
4. Instruments and tools to conduct overcore borehole deformation measurements	1 set
5. Three-component borehole deformation gauges	3
6. EX and NQ borehole dilatometers	3 each
7. Low-volume hydraulic-fracturing system and accessory equipment	1
8. Borehole TV-camera system	1

APPENDIX A: QALA'S AND QA MATRIX

The tests in this study have been assigned Quality Level I in accordance with procedure USGS QMP-3.02, as shown in table A-1. The test results may be used in the license application, as indicated in section 1 of this study plan. Table A-2 shows the criteria from NQA-1 that apply to this study and the procedures and other documents that satisfy those criteria.

Table A-1.--Quality assurance level assignment sheets for overcore stress activity (Activity 8.3.1.15.2.1.2)

[Table follows--pp. A-3 and A-4]

NNWSI - USGS QUALITY LEVELS ASSIGNMENT SHEET (QALAS) — NNWSI-QALA-6923G-01-01, RO

Activity - Overcore Stress Tests —

Method - Stress Determination Using USBM Overcore Method

Method/Item Breakdown	QA Level	NQA-1 Criteria Requirements*	Justification of Level & QA Criteria Exceptions
Coring operations NX (7.6 cm) and EX (3.8 cm)	III		Standard operating procedure; meets none of the attributes of Levels I & II on the logic diagram.
15.2 cm. diameter overcore drilling operations	I	1,2,3,4,5,6,7,8 10,12,13,15,16, 17,18	Meets step No. 4 of the QA Level Checklist wherein this item is the first step in providing data to evaluate stress. The item will be conducted under direction of USGS scientist in charge and according to written procedure. Criteria excluded: 9 - not a special process; 11 - no tests or research involved; 14 - not part of the USGS QA Program.
Borehole TV fracture logging	I	1,2,3,4,5,6,7,8, 10,12,13,15,16, 17,18	Meets step No. 5 of the QA Level Checklist wherein this item provides fracture data for efficient test planning and execution, and will be utilized during data analysis to evaluate alternative interpretations. Criteria excluded: 9 - not a special process; 11 - no tests or research involved; 14 - not part of the USGS QA Program.

*LEGEND OF 18 QA CRITERIA of NQA-1 as incorporated in NVO-196-17

1 ORGANIZATION	7 CONTROL OF PURCHASED MAT'L, EQUIPMENT, SERVICES	13 HANDLING, STORAGE & SHIPPING
2 QA PROGRAM	8 ID & CONTROL OF MATERIALS, PARTS & SAMPLES	14 INSPECTION, TEST, & OP. STATUS
3 DESIGN & SITE INVESTIGATION CONTROL	9 CONTROL OF SPECIAL PROCESSES	15 CONTROL OF NONCONFORMING ITEMS
4 PROCUREMENT DOCUMENT CONTROL	10 INSPECTION (SURVEILLANCE)	16 CORRECTIVE ACTION
5 INSTRUCTIONS, PROCEDURES & DRAWINGS	11 TEST & EXPERIMENT/RESEARCH CONTROL	17 QA RECORDS
6 DOCUMENT CONTROL	12 CONTROL OF MEASURING & TEST EQUIPMENT	18 AUDITS

APPROVALS

Fitzhugh T. Lee	7/31/87	J. Willmon	7/31/87	A. Handy	7/31/87
Originator (F. Lee)	Date	Quality Assurance Manager (J. Willmon)	Date	Chief, Branch of NNWSI (A. Handy, for L. Hayes)	Date
J Blaylock	10/26/87	M. Blanchard	10/30/87	10-30-87	
WMPO Quality Assurance	Date	WMPO Technical	Date	Effective Date	

NNWSI - USGS QUALITY LEVELS ASSIGNMENT SHEET (QALAS)
Activity - Overcore Stress Tests
Method - Stress Determination Using USBM Overcore Method

Method/Item Breakdown	QA Level	NQA-1 Criteria Requirements*	Justification of Level & QA Criteria Exceptions
Borehole dilatometer measurements	I	1,2,3,4,5,6,7, 10,12,13,15,16, 17,18	Meets step No. 4 of the QA Level Checklist wherein this item produces data to aid in evaluating alternative interpretations regarding variability in field stress measurements. Criteria excluded: 8 - no samples required; 9 - not a special process; 11 - no tests or research involved; 14 - not part of the USGS QA Program.
Overcoring borehole deformation measurements	I	1,2,3,4,5,6,7, 10,12,13,15,16, 17,18	Meets step No. 5 of the QA Level Checklist wherein this item provides the fundamental field data for determination of in-situ stress. Criteria excluded: 8 - no samples required; 9 - not a special process; 11 - no tests or research involved; 14 - not part of the USGS QA Program.
Biaxial loading tests of overcore samples	I	1,2,3,4,5,6,7,8, 10,12,13,15,16, 17,18	Meets step No. 4 of the QA Level Checklist wherein this item is an important step providing test results required to convert borehole deformation data to stress values. Criteria excluded: 9 - not a special process; 11 - no tests or research involved; 14 - not part of the USGS QA Program.
Overcore sample identification, marking, and storage	I	1,2,3,4,5,6,7,8, 10,12,13,15,16, 17,18	Meets step No. 4 of the QA Level Checklist wherein this item is an important step providing core identification and marking directly affecting subsequent testing and data analysis. Criteria excluded: 9 - not a special process; 11 - no tests or research involved; 14 - not part of the USGS QA Program.
Low-volume hydraulic-fracturing measurements	I	1,2,3,4,5,6,7, 10,12,13,15,16, 17,18	Meets step No. 5 of the QA Level Checklist wherein this item provides an alternate method of estimating in-situ stress and confirming overcore results. Criteria excluded: 8 - no samples required; 9 - not a special process; 11 - no tests or research involved; 14 - not part of the USGS QA Program.
Core index tests 1. indirect tensile strength 2. direct compressive strength 3. unconfined compression for elastic modulus 4. petrographic rock-fabric studies	I	1,2,3,4,5,6,7, 10,12,13,15,16, 17,18	Meets step No. 4 of the QA Level Checklist wherein this item produces data to aid in evaluating alternative interpretations regarding variability in field stress measurements. Criteria excluded: 8 - no samples required; 9 - not a special process; 11 - no tests or research involved; 14 - not part of the USGS QA Program.

Table A-2.--Applicable NQA-1 criteria for Study 8.3.1.15.2.1 and how they will be satisfied

NQA-1 criteria	Documents that satisfy those criteria
1. Organization and interfaces	The organization of the OCRWM program is described in the Mission Plan (DOE/RW-005, June 1985) and further described in section 8.6 of the SCP. Organization of the USGS-YMP is described in the following: QMP-1.01 (Organization Procedure)
2. Quality assurance program	The Quality Assurance Programs for the OCRWM are described in YMP-QA Plan-88-9 and OGR/83, for the Project Office and HQ respectively. The USGS QA Program is described in the following: QMP-2.01 (Management Assessment of the YMP-USGS Quality Assurance Program) QMP-2.02 (Personnel Qualification and Training Program) QMP-2.05 (Qualification of Audit and Surveillance Personnel) QMP-2.06 (Control of Readiness Review) QMP-2.07 (Development and Conduct of Training) Each of these QA programs contains Quality Implementing Procedures further defining the program requirements. An overall description of the QA Program for site characterization activities is described in section 8.6 of the SCP.

3. Scientific investigation control and design	This study is a scientific investigation. The following QA implementing procedures apply: QMP-3.02 (USGS QA Levels Assignment [QALA]) QMP-3.03 (Scientific and Engineering Software) QMP-3.04 (Technical Review of YMP-USGS Publications) QMP-3.05 (Work Request for NTS Contractor Services (Criteria Letter)) QMP-3.06 (Scientific Investigation Plan) QMP-3.07 (Technical Review Procedure) QMP-3.09 (Preparation of Draft Study Plans) QMP-3.10 (Close-out Verification for Scientific Investigations) QMP-3.11 (Peer Review)
4. Administrative operations and procurement	QMP-4.01 (Procurement Document Control) QMP-4.02 (Acquisition of Internal Services)

5. Instructions, procedures, plans, and drawings	The activities in this study are performed according to the technical procedures listed in section 3.2 of this study plan, and the QA administrative procedures referenced in this table for criterion 3 QMP-5.01 (Preparation of Technical Procedures) QMP-5.02 (Preparation and Control of Drawings and Sketches) QMP-5.03 (Development and Maintenance of Management Procedures) QMP-5.04 (Preparation and Control of the USGS QA Program Plan) QMP-5.05 (Preparation and Issuance of Tentative Technical Procedures (Replaces QMP-11.01))
6. Document control	QMP-6.01 (Document Control)
7. Control of purchased items and services	QMP-7.01 (Supplier Evaluation, Selection and Control)
8. Identification and control of items, samples, and data	QMP-8.01 (Identification and Control of Samples) QMP-8.03 (Control of Data)
9. Control of processes	Not applicable
10. Inspection	Not applicable
11. Test control	Not applicable
12. Control of measuring and test equipment	QMP-12.01 (Instrument Calibration)
13. Handling, shipping, and storage	QMP-13.01 (Handling, Storage, and Shipping of Instruments)
14. Inspection, test, and operating status	Not applicable
15. Control of nonconforming items	QMP-15.01 (Control of Nonconforming Items)

16. Corrective action	QMP-16.01 (Control for Corrective Action Reports)
	QMP-16.02 (Control of Stop-Work Orders)
	QMP-16.03 (Trend Analysis)
17. Records management	QMP-17.01 (YMP-USGS Records Management)
	QMP-17.02 (Acceptance of Data Not Developed Under the YMP QA Plan)
18. Audits	QMP-18.01 (Audits)
	QMP-18.02 (Surveillance)