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Dinesh Gupta
U.S. Nuclear Regulatory Commission
Division of Waste Management
Washington, D.C. 20555

"NRC Technical Assistance for Design Reviews"
Contract No. NRC-02-85-002
FIN D1016

Dear Dinesh:

Enclosed with this letter is our draft of "Suggested Review Approach to In-Situ Testing at Yucca Mountain (Section 8.3.2, Planned Tests, Analyses, and Studies—Repository Program)". We expect to send a companion part covering Section 8.3.3 next week.

In preparting these sections, it became evident that there were questions on which NRC guidance would be desirable.

1. Questions Concerning Acceptance Criteria

The Acceptance Criteria section could be treated either very broadly or narrowly.

Very Narrowly: This document is intended for guidance on SCP review. The authority for this review rests on 10CFR60.17, NWPA 1982, Section 113 and Regulatory Guide 4.17—and only these documents.

Very Broadly: SCP is written in preparation for license application and, hence, all 10CFR60 sections relevant to license application and repository performance are relevant and need to be referenced under Acceptance Criteria.

Guidance from NRC is requested as to whether the section on Acceptance Criteria should be written in a very narrow or in a very broad sense.

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2. Questions regarding the detail in which the 10CFR60 is to be quoted

   Example §60.21 — quote entire §?
   — quote a few directly applicable sections?

3. How closely tied should the document be to present NNWSI seal design/test plans (e.g., should it discuss Fernandez (1985) in detail?)?

We look forward to discussing these drafts at our 18 December 1986 meeting in your offices. In the meantime, please do not hesitate to contact myself, Jaak Daemen, or Roger Hart if you have any questions.

Sincerely,

Loren Lorig

Loren J. Lorig

cc: D. Tiktinsky

Encl.
ljl/ks

DRAFT

SUGGESTED REVIEW APPROACH TO IN-SITU TESTING AT YUCCA MOUNTAIN
(Section 8.3.2, Planned Tests, Analyses, and Studies — Repository Program)

TABLE OF CONTENTS

TABLE OF CONTENTS (continued)

PAGE

TABLE OF CONTENTS (continued)

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SUGGESTED REVIEW APPROACH TO IN-SITU TESTING AT YUCCA MOUNTAIN

I. AREAS OF REVIEW

NNWSI Repository Program Status (September 1986)

The NNWSI Repository Program has been detailed by MacDougall (1985) and Jackson (1984). Additional information is available from meeting documents ("Subsurface Design Concepts for the NNWSI", Parsons Brinkerhoff, February 1986) and from NRC/ NNWSI correspondence. Some proposed testing relating to the repository program is described in NNWSI documents (e.g., Vieth et al, 1985).

Review Preliminaries

Review of Section 8.3.2, Repository Program, will require familiarity with a number of directly-related sections—in particular,

Section 1.6, Drilling and Mining — This section will discuss the behavior of excavations at the NTS (particularly, the G-Tunnel) as well as near-by mines.

Chapter 2, Geoengineering

Section 6.1.1, Repository Design Requirements — This section will present the technical requirements and assumptions established as a basis and rationale for repository design.

Section 6.2.6, Subsurface Design

Section 6.3, Assessment of Design Information Needs—in particular,

6.3.2, Design of Underground Openings
6.3.4, Strength of the Rock Mass
6.3.6, Construction

II. ACCEPTANCE CRITERIA

A. Basic Acceptance Criteria

The applicable rules and basic acceptance criteria pertinent to the areas of this section of the SCP are given below.

<u>10CFR60.17, Contents of Site Characterization Plan</u>

This rule requires the applicant to

(1) describe the extent of planned excavations [(a)(2)(i)]; and

(2) describe plans to apply QA to data collection, recording and retention [(a)(2)(v)].

<u>10CFR60.21, Safety Analysis Report</u>

The license application will include a Safety Analysis Report which, in turn, must include a description and assessment of

(i)(C) the geomechanical properties and conditions, including pore pressure and ambient stress conditions;

6(i)(F) The anticipated response of the geomechanical, hydrogeologic, and geochemical systems to the maximum design thermal loading, given the pattern of fractures and other discontinuities and the heat transfer properties of the rock mass and groundwater.

The assessment shall include:

ii(F) "Analyses and models that will be used to predict future conditions and changes in the geologic setting shall be supported by using an appropriate combination of such methods as field tests, in situ tests, laboratory tests which are representative of field conditions, monitoring data, and natural analog studies."

10CFR60.111, Performance of the Geologic Repository Operations Through Permanent Closure

This rule [point (b)] requires the applicant to design the geologic repository operation area "to preserve the option of waste retrieval throughout the period during which wastes are being emplaced and thereafter, until the completion of a performance confirmation program and Commission review of the information obtained from such a program. To satisfy this objective, the geologic repository operations area shall be designed so that any or all of the emplaced waste could be retrieved on a reasonable schedule, starting at any time up to 50 years after waste emplacement operations are initiated...."

10CFR60.122, Siting Criteria

Potentially-adverse conditions relating to geomechanics are described in 10CFR60.122(c). An adverse condition exists if complex measures are required in the design and construction of the underground facility—or, if there are geomechanical properties which do not permit design of the underground openings through to permanent closure.

10CFR60.133, Additional Design Criteria for the Underground Facility

This section details the design criteria for the entire underground facility. Specific parts of interest are reproduced here.

> "(b) Flexibility of The underground facility shall be designed with sufficient flexibility to allow adjustments where necessary to accommodate specific site conditions identified through <u>in situ</u> monitoring, testing, or excavation.
>
> (c) Retrieval of waste. The underground facility shall be designed to permit retrieval of waste in accordance with the performance objectives of §60.111.
>
> (e) Underground openings.
>
> (1) Openings in the underground facility shall be designed so that operations can be carried out safely and the retrievability option maintained.

(2) Openings in the underground facility shall be designed to reduce the potential for deleterious rock movement of fracturing of overlying or surrounding rock.

(f) Rock excavation. The design of the underground facility shall incorporate excavation methods that will limit the potential for creating a preferential pathway for ground water or radioactive waste migration to the accessible environment.

(i) Thermal loads. The underground facility shall be designed so that the performance objectives will be met taking into account the predicted thermal and thermomechanical response of the host rock and surrounding strata, ground water system."

<u>Nuclear Waste Policy Act of 1982, Section 113, Site Characterization</u>

This Policy Act describes the requirements for the general site characterization plan. Specifically, the Act requires, in A,

"(i) a description of such candidate site;
(ii) a description of such site characterization activities, including the following: the extent of planned excavations, plans for any onsite testing with radioactive or nonradioactive material, plans for any investigation activities that may affect the capability of such candidate site to isolate high-level radioactive waste and spent nuclear fuel, and plans to control any adverse, safety-related impacts from such site characterization activities;

(iii) plans for the decontamination and decommissioning of such candidate site, and for the mitigation of any significant adverse environmental impacts caused by site characterization activities if it is determined unsuitable for application for a construction authorization for a repository;

(iv) criteria to be used to determine the suitability of such candidate site for the location of a repository, developed pursuant to section 112(a); and

(v) any other information required by the Commission.

Regulatory Guide 4.17

The minimum required information for the SCP is presented in Reg. Guide 4.17 as interpreted and agreed to by NRC/DOE in the annotated outline for SCPs (Rev. 4, Feb. 15, 1985).

This regulation requires that information presented in the SCP must be complete and thoroughly documented. The next sections describe criteria which the NRC staff may use to assess whether the information presented in the SCP with regard to planned test analyses and studies is sufficiently complete or documented to determine if the results of planned tests, analyses, and studies will assist in the licensing process.

U.S. Nuclear Regulatory Commission Generic Technical Position on Design Information Needs in the Site Characterization Plan (Final), December 1985

"This Generic Technical Position (GTP) addresses the type and level of detail of design information that needs to be included in the SCP" (p. 3, 2nd paragraph).

U.S. Nuclear Regulatory Commission Generic Technical Position on In-Situ Testing During Site Characterization for High-Level Nuclear Waste Repositories (Final), December 1985

This GTP discusses:

(1) "the background and regulatory framework for insitu testing";

(2) NRC's "technical position on insitu testing"; and

(3) "such items as the rationale and description of specific types of testing."

B. Specific Technical Criteria

Specific technical criteria required to address potential licensing issues covered by 10CFR60 are as follows.

8.3.2 PLANNED TESTS, ANALYSES, AND STUDIES — REPOSITORY PROGRAM

This section summarizes the repository test program and provides an overview of the research and development and engineering activities required to ensure that the repository is capable of satisfying applicable performance objectives. The primary areas of focus for specific acceptance criteria in Section 8.3.2.2 through Section 8.3.2.5 are:

(1) limitations and uncertainties of test methods and data analysis;

(2) representativeness, precision and accuracy of proposed test methods and data analysis; and

(3) significant options or alternative methods and data analyses to those proposed.

8.3.2.1 Overview

The overview section will state the purpose of the repository program and provide an overview of the repository program. Of particular concern to the NRC reviewer will be the interrelations and sequencing of the primary activities. The reviewer should determine if spatial or temporal proximity of tests will interfere with obtaining or analyzing results. In addition, the reviewer should assess whether the sequencing of tests progresses in a logical manner.

The following discussion addresses general considerations which should be kept in mind when reviewing the overview section. Discussion areas are:

(1) Zone of Influence;

(2) End Effects;

(3) Test Sequencing

(4) Scoping Calculations; and

(5) Flexibility in Testing Approach.

Zone of Influence — The concept of zone of influence is important in the site characterization process because it may provide considerable simplification in the interpretation of results. The discussion of this concept with regard to mechanical stress which follows is based largely on Brady and Brown (1985). The essential idea of a zone of influence is that it defines a domain of significant disturbance. It differentiates between the near field and far field of a perturbation. The perturbation may be a change in stress conditions (i.e., generation of an opening) or a change in thermal conditions (i.e., introduction of a heat source). The extent of an opening's effective mechanical near-field domain can often be examined using a two-dimensional elastostatic analysis. For example, the stress distribution around a long circular hole of radius r in the hydrostatic stress field of magnitude p is given by the Kirsch solution as

$$\sigma_{rr} = p \left[1 - (a/r)^2 \right]$$

$$\sigma_{\theta\theta} = p \left[1 + (a/r)^2 \right]$$

Using the Kirsch solution, it is readily calculated that, for

$$r = 5A,\ \sigma_{\theta\theta} = 1.04p, \text{ and } \sigma_{rr} = 0.96p$$

(i.e., on the surface defined by r = 5a), the state of stress is not significantly different (within ± 5%) from the field stresses. The general rule is that openings lying outside one another's zones of influence can be analyzed by ignoring the presence of all others. For example, for circular openings of the same radius, a, in a hydrostatic stress field, the mechanical interaction between openings is insignificant if the distance between their centers is greater than or equal to 6a. It is important to note that, in general, the zone of influence of an opening is related to both excavation shape and pre-mining stresses. It should also be noted that, in markedly anisotropic rock, or for plastic discontinuous behavior, the influence zone could be larger than predicted by elastic analysis.

Similar considerations can be made for the zone of influence of heat sources, although the problem is not as straight forward for thermoelasticity because temperatures and stresses are a function of time. Nevertheless, results for simple problem geometries are easily obtainable and useful in assessing the zone of influences. For example, Hart (1981) presents analytical criteria for temperature, stresses, and displacements due to exponentially-decaying or constant, infinite line heat sources. Nowacki (1962) presents the analytical solution for the case of an instantaneous point heat source in an infinite region. Temperatures and stresses at a time of 10 years, shown in Fig. 1, result from application of a point pulse heat source for 0.1 years. The figure shows that, for this very particular case, the zone of influence is limited to about 2 meters.

For more complex problem geometries, determination of the zone of influence can be based on numerical analysis.

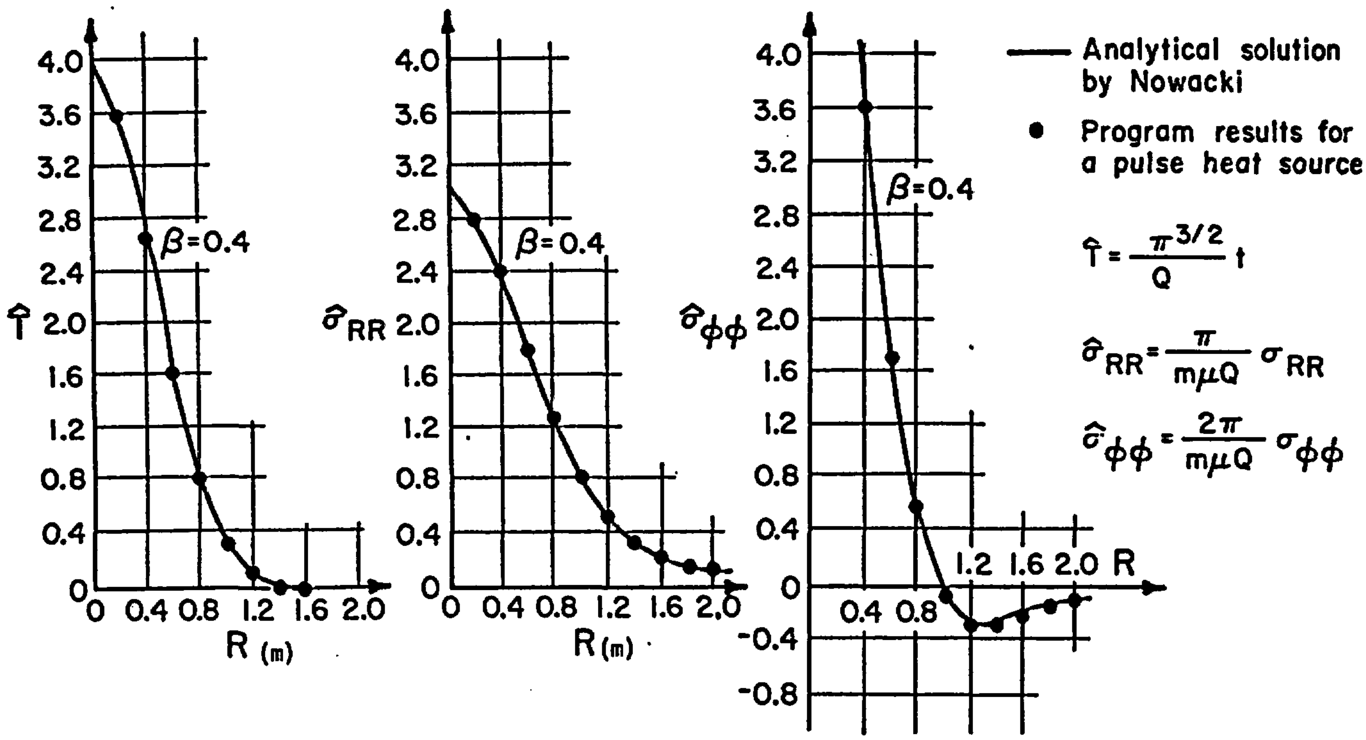


Fig.1 Temperature and Stresses Resulting From an Instantaneous Heat Source (comparison between Nowacki's published solution and that obtained using STRES3D) [St. John and Christianson, 1980]

End Effects — End effects are significant for three major reasons: (1) two-dimensional analysis of test results is appropriate only if ends are sufficiently distant, so that stresses and displacements vary only in the plane of analysis; (2) confirmation of stability of excavations requires that the beneficial effects, from a stability standpoint, not be present; and (3) measurements of convergence, among others, requires recognition that some displacement may occur before it is feasible to install instrumentation.

An estimation of the longitudinal extent of the zone around the heading of a circular excavation (for a hydrostatic stress initial stress state) within which the ground mass stress and radial displacement magnitudes are functions of the longitudinal position relative to the tunnel face has been made by Ranken et al (1978). These authors concede that it is difficult to delineate precise boundaries that separate the transition zone from the undisturbed ground ahead of the excavation and the final equilibrium state behind the face, because the boundaries are not indicated by abrupt change in medium behavior. Nevertheless, the authors suggest that the picture obtained from available data is that of a transition zone of 3-D response extending over a total distance of approximately six times the maximum radius of the plastic zone, R, that forms around the unlined tunnel. If no plastic yielding occurs, this distance is approximately 6a, where a is the tunnel radius. Figure 2 illustrates the longitudinal extent of the zone and its relation to the position of the advancing tunnel face.

Ranken et al (1978) make similar observations for excavations lined near the face which indicate that the liner significantly influences the longitudinal extend of the transition zone. They estimate that this zone extends out ahead of the excavation to a distance of about 3 radii of the plastic zone which forms around the lined tunnel and to a distance of one tunnel radius behind the leading edge of the liner.

As a practical application of this concept, consider the proposed layout at the 1200 ft ES Main Test Level (DOE, 1985), as shown in Fig. 3. This figure indicates that the longitudinal extent of cross-sections B and C is insufficient to reach the desired final equilibrium state.

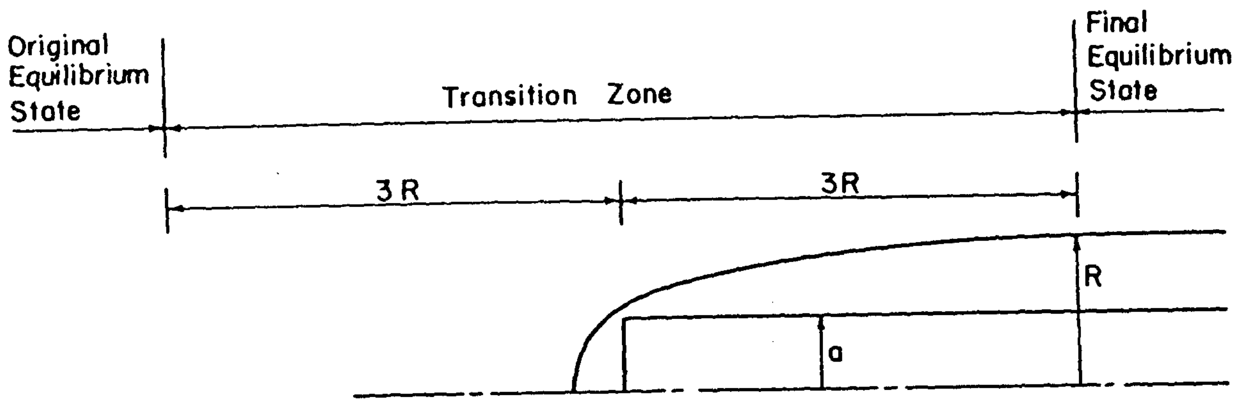


Fig. 2 Transition Zone of Three-Dimensional Variation of Stress and Displacement — Tunnel Lined Far Behind the Face [Ranken et al, 1978]

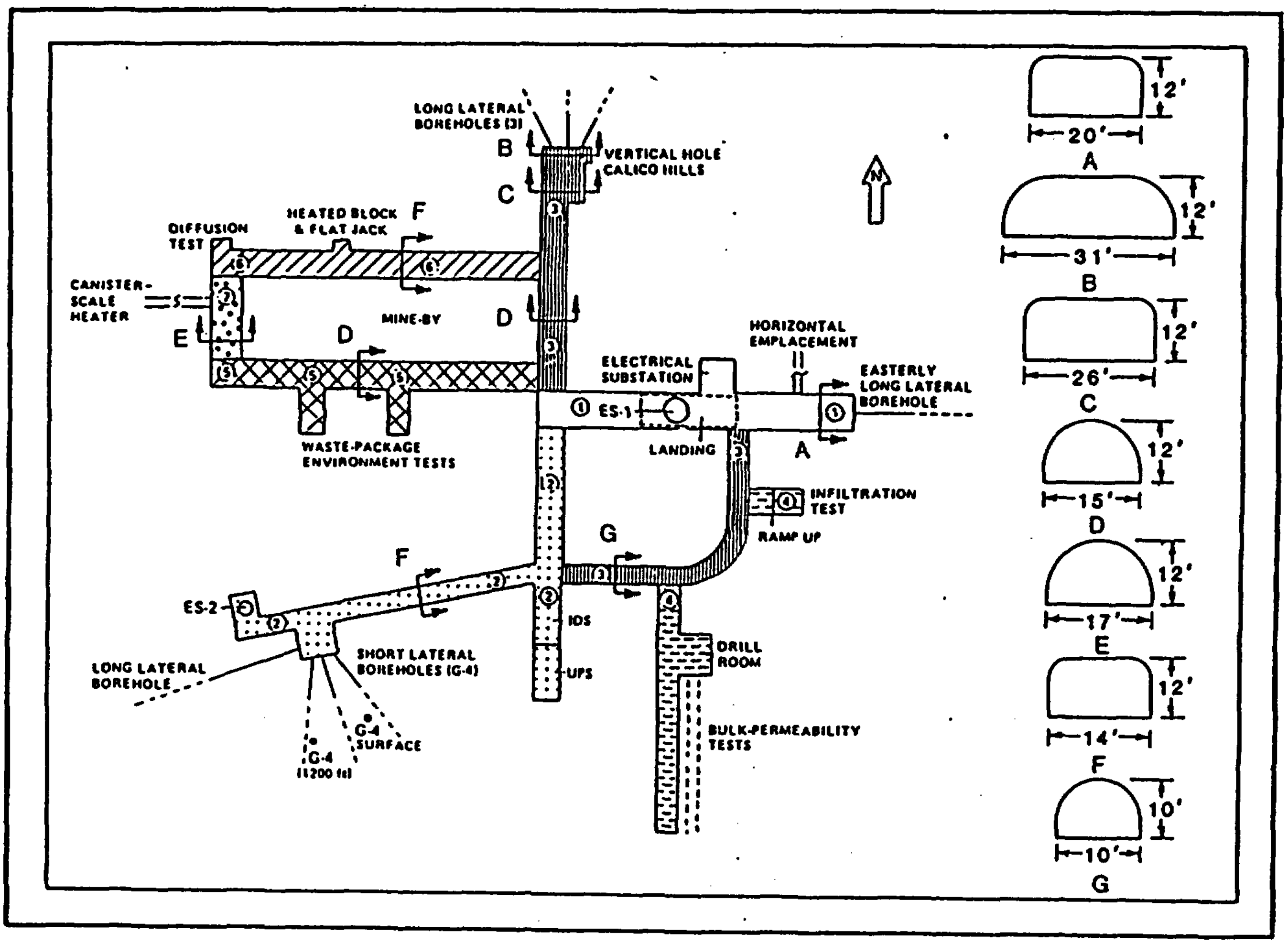


Fig. 3 Proposed Layout at the 1200 ft. ES Main Test Level [DOE, 1985]

Test Sequencing — The acceptance criteria for in-situ planning and scheduling of testing is given by the Generic Technical Position on In-Situ Testing During Site Characterization for High Level Nuclear Waste Repositories, Section 5.6 (pp. 12-13). This section prescribes general criteria in the following areas:

§5.6.1, Amount and Variety of Testing;

§5.6.2, Scale of Tests; and

§5.6.3, Duration of Tests.

For the NNWSI, testing sequence and duration are of critical importance, especially with regard to time-dependent properties. The following quote from Blacic et al (1986) provides the rationale for determining time-dependent properties.

> A quantitative determination of these time-dependent phenomena will require careful measurements on target-horizon tuff samples held at simulated repository conditions for long time periods. For example, it is not known what effects might be anticipated during heating and cooling cycles in unsaturated devitrified tuff such as the Topopah Spring Member, which is the potential host rock at Yucca Mountain. Detailed examination of tested samples should identify the physical-chemical mechanisms involved. In addition, the difficult task of determining the rates of the processes leading to changes in mechanical properties will be required. Once these rates (or at least reasonable estimates) are determined, they can be incorporated in design and performance models to predict or bound the mechanical response of the host rock mass over both the operational time of the repository and after closure.

The logical result of this, and the concern expressed in the GTP is that tests which are intended to assess time-dependent properties, such as strength, be initiated as early as possible in the testing program and be allowed to continue through the performance confirmation period.

Scoping Calculations — A set of scoping calculations should be presented for each field test planned. These calculations should bound the likely temperatures, displacements, and stress fields.

The purposes of such calculations include:

(1) provision of instrumentation which is capable of making measurements in the predicted range of response in the instrument environment;

(2) provision of a framework for planning, executing, and interpreting the instrumentation program; and

(3) provision of preliminary estimates of response for comparisons with observed measurements required for validation by section 8.3.2.5, Repository Modeling.

Flexibility in Testing — Because of the experimental nature of the in-situ site characterization program, it will be necessary for the testing to be flexible with regard to many aspects, including

(a) number of tests;

(b) test duration; and

(c) exact individual test site(s).

8.3.2.2 Verification or Measurement of Host Rock Environment

This section of the SCP will identify and describe the SCP tests and analyses which will define the geomechanical environment of the host rock necessary to model the repository design. The specific design information needs are given in Section 6.3, Assessment of Design Information Needs.

In-Situ Stress Measurement

In-situ stress measurement methods developed to date exploit two separate and distinct principles in measurement methodology. The most common procedure is based on determination of strains in the wall of a borehole, or other deformations of a borehole, induced by overcoring. Suitable gauges for such borehole measurements include USBM gauges, CSIRO gauges, or door-stopper gauges. If sufficient strain or deformation measurements are made during the stress-relief operation, the six components of the field stress tensor can be obtained directly from experimental observations using solution procedures developed from elastic theory. A direct consequence of this is that, at a minimum, Young's modulus and Poisson's ratio for the rock must be known or assumed. In using a triaxial strain cell, six independent observations must be made of the state of strain in six positions/orientations on the hole wall. From this, six independent simultaneous equations of the following form may be established:

$$[A]\ \{p\} = \{b\}$$

where {p} represents a column vector of the six stress components. The position/orientations of the strain observations must be selected to ensure a well-conditions coefficient matrix [A] (Brady and Brown, 1985). Redundant observations should be made to determine a logically averaged solution for the field stress tensor. These should be used to determine a locally averaged solution for the ambient state of stress in the zone of influence of the stress determination.

Determination of the state of stress in a jointed and fractured medium, such as found at Yucca Mountain, will likely be complicated by the spatial heterogeneity of the stress distribution. Results of a comprehensive program of measurement of in-situ stress state reported by Brady et al (1986) suggest that stresses may be locally "locked in" and that, if field measurements are made at spacings less than the mean spacing of joints, the results may not be representative of the average in the medium.

Errors in absolute stress measurement with borehole deformation gauges are believed to be 20 to 100% in magnitude and 10 to 25% in direction (Hall and Haskings, 1972). The primary source of error is in the assumptions required to convert deformations to stress rather than in the functional operation of the gauge (Pratt and Voegele, 1984).

The second type of procedure is represented by flatjack measurements and hydraulic fracturing. The flatjack method requires:

(1) a relatively undisturbed surface of the opening constituting the test site; and

(2) a rock mass which behaves elastically in that displacements are recoverable when the stress increments inducing them are reversed.

These requirements eliminate this method as a method at NNWSI if excavations are developed by drill and blast.

Hydraulic fracturing, on the other hand, is, in some sense, more simple than the overcoring method in that the elastic properties of the rock do not need to be measured or assumed. However, uncertainty as to interpretation of the fluid pressure-flow behavior during crack initiation and propagation (e.g., the effects of changing fracture path, and changing permeability and fluid penetration into the rock as the hole is pressurized) result in an associated uncertainty in the calculation of maximum and minimum stresses. The fundamental assumptions in analysis of hydraulic fracturing results are that a principal stress is parallel to the borehole axis, the tensile strength of the rock can be determined, and the rock is isotropic and elastic..

Pratt and Voegele (1984) reviewed laboratory tests of hydraulic fracturing by others and concluded that the tests predicted the maximum horizontal stress to within ± 25%, vertical and minimum horizontal stress to within ±10%, and the stress orientation to within ±10%. They also suggest that the percentage error in the minimum horizontal stress may be dependent on the ratio of horizontal stresses and the magnitude of the minimum stress.

In reviewing the significance of in-situ stress measurement in rock mechanics, Fairhurst (1980) concludes by stating that "Difficulties of interpreting the in-situ measurements, especially in the practically important situations where discontinuities and inhomogeneities in the rock mass have a significant but uncertain influence, make the focus on stress-determination unrewarding."

He argues that a more effective design strategy is to give greater emphasis to the overall effects of interaction between stress state, rock mass properties, and excavation geometry. Convergence measurement, described in the next section, is the primary example of such an integrated effect.

Convergence Monitoring (Shaft and Exploratory Drifting)

The effects of spatial variability of the rock mass can often be determined by exploratory drifting and measurement. At NNWSI, the primary sources of spatial variability will likely result from differences in discontinuities, faults, and lithophysal content. It therefore is desirable that the exploratory drifting experience as wide a range of conditions as possible within the obvious limitations on drifting length. Ideally, the amount of actual drifting should be governed by the repeatability of ground conditions and/or the ability to confidently predict rock mass response.

DOE should discuss the adequacy of exploratory drifting to establish representative design parameters for the entire repository block. Other considerations affecting the amount of exploratory drifting are discussed in NUREG/CR-2959 (pp. 12-13).

At a minimum, the convergence monitoring should consist of the following.

1. Measurements at regular intervals (or closer, as ground conditions vary) of closure points from roof to floor and wall to wall should be made to provide a time history of opening displacements.

2. Rod extensometers with 5 or 6 anchors drilled radially in the roof and walls should be installed at larger intervals. The furthest anchor should be installed outside the zone of influence of the excavation. The extensometers should be installed at the face— preferably, from a previous excavation.

Convergence points and extensometers should be protected to avoid blast damage.

A valuable discussion of the advantages and disadvantages of 13 displacement measuring instruments is provided by Pratt and Voegele (1984). These authors also provide similar discussions of stressmeters used to measure increases in compressive stress. Measurements of increases in compressive stress surrounding excavations should be made to confirm results predicted by numerical analysis.

The analysis of recorded data is discussed extensively by Cording et al (1975). Single-heading excavations provide a very simple initial geometry for model comparison. As excavations proceed, it should be possible to narrow in on the required rock mass properties and in-situ stresses for bounding the measured response. Because the excavations will be small (approximately 3mx3m), it is likely that significant inelastic response will not be observed. Significant inelastic response will require excavation of larger cross-section or introduction of thermal stresses.

Whereas most of the exploratory drifting will be done with relatively small excavations, it will be necessary, at some point, to excavate larger cross-sections to confirm the stability of the prototype-sized excavations. These confirmations may be done as single heading excavations, or mine-by excavations, as discussed later.

Another use of the experimental drifts is in characterizing discontinuities through back analysis of block fall-out in unsupported areas. This approach has been used previously (e.g., Yow, 1985). It may also be possible to characterize joint properties by studying blocks which do not fall.

Heading Directions for Exploratory Drifts

Choices for heading direction of exploratory drifts may be governed by the following considerations.

1. If the directions of the proposed repository excavations are determined by criteria such as available space, ventilation requirements, etc., the exploratory drifts should parallel the proposed directions.

2. If certain underground features such as suspected faults or high lithophysal zones are to be explored, the exploratory drifting may be governed by such requirements.

3. In the absence of (1) and (2), some excavations should be oriented parallel and perpendicular to measured principal stresses. Analysis of excavations not directed parallel to principal stress components must take into account the antiplane stresses. The significance of the antiplane problem is described by Brady and St. John (1982).

4. In order to bound the range of likely stability conditions, a three-dimensional stability analysis should be made using the orientations of discontinuities mapped in the exploratory shaft. Such an analysis will predict heading directions which will likely encounter the greatest and least stability problems from a limit equilibrium point of view. Each of these directions should be investigated by exploratory drifting.

Mine-By (Sequential Drift-Mining) Evaluations

From the geomechanics point of view, mine-by tests can be seen as an extension of the exploratory drifting program. The objectives (purposes) cited by Vieth et al (1985) for conducting sequential drift-mining evaluations are:

(1) to validate a geomechanical model based on measurements taken during drift mining for use in establishing predictive capabilities for repository design activities;

(2) to define limits for the relaxed zone around a drift using exploratory borehole and mechanical measurements in order to enhance repository designs;

(3) to continue and improve mining evaluations started during the Demonstration Breakout Room (DBR) Testings; and

(4) to relate air and water permeability measurements to each other for reference in hydrological calculations.

The first three of these objectives concern geomechanics issues. These three objectives are also addressed by careful convergence monitoring of shaft and exploratory drifts. The question to be asked, then, is what can be learned from a mine-by test that can not be learned (from the geomechanics point of view) from other methods. The obvious advantage of a mine-by is that instrumentation may be installed in the rock mass region that forms the second excavation.

In order for meaningful and useful results to be obtained, an assessment must be made of how important displacements ahead of the face differ from what would be predicted by elastic analysis. Such an analysis of radial displacements around a shallow tunnel in a weak frictional-cohesive material indicated that radial displacements at the face (Fig. 4) were not significantly different than the elastic displacements (Ranken and Ghaboussi, 1975). The fundamental assumption in such an analysis is that the rock behaves as a continuum. If continuum analysis is not appropriate, then both the results and analysis is likely to be very site specific.

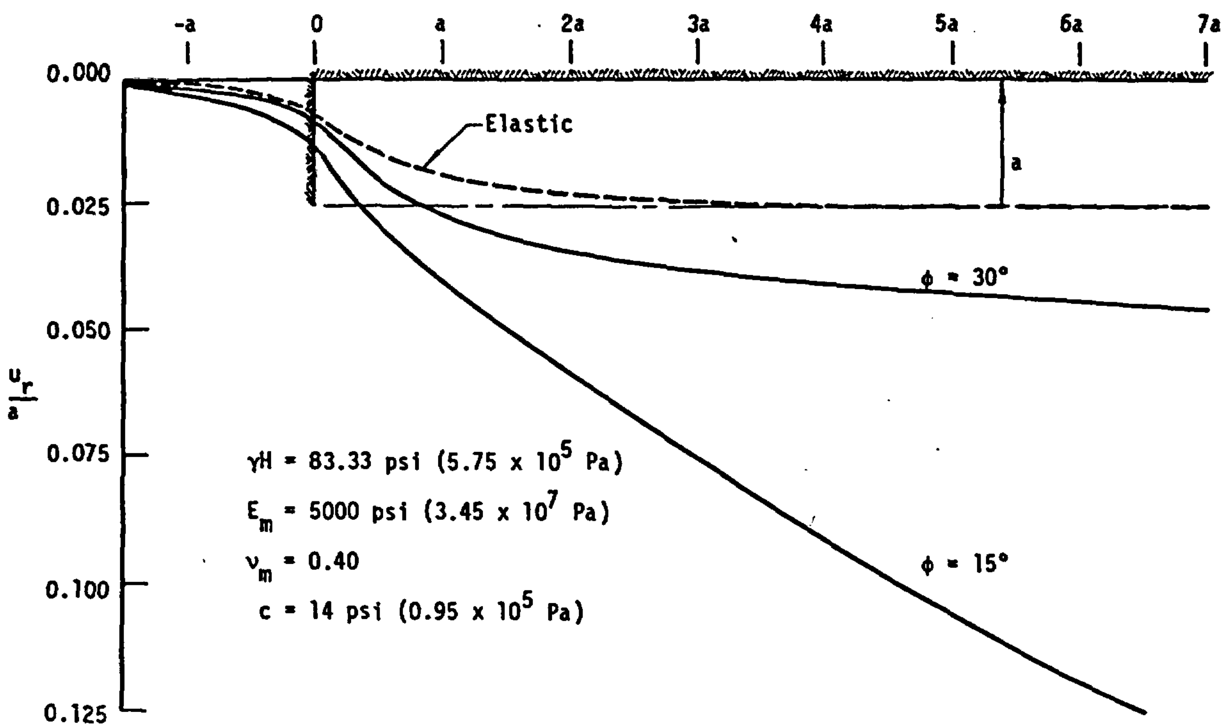


Fig. 4 Radial Displacements for an Unlined Tunnel in an Unlined Tunnel in an Elasto-plastic Medium — ϕ not equal to 0 [Ranken and Ghaboussi, 1975)

The prospect for obtaining meaningful geomechanical results from a mine-by test at NNWSI, therefore, relates to three major considerations:

(1) how important is characterizing behavior ahead of the face of an excavation;

(2) how representative the selected site(s) is(are) compared to the rest of the sites; and

(3) how important is providing a significantly different loading condition (i.e., pillar-type loading). If excavations are located close enough to each other to interact, a pillar-type loading results. This is important in model qualification because it is possible that some models may simulate single excavations well but might not represent multiple excavations well.

If a mine-by test is selected, it is advisable for several holes to be drilled completely through the pillar to measure absolute drift to drift convergence. This should eliminate questions related to horizontal displacement orientation as experienced in the Climax Spent Fuel Mine-by.

Construction-Related Observations

The near-field behavior of rock masses around excavations are affected not only by the physical properties of the rock mass and in-situ stresses but also by the construction activities related to generation of the excavation. Cording et al (1975) give the following list of items which should be recorded at a minimum for construction-related observations:

(1) opening dimensions;

(2) amount of advance/round;

(3) overbreak (shape of perimeter, size of overbroken zone);

(4) orientation and pattern of blastholes, total amount of powder, amount of powder in each delay, amount of powder in each hole, spacing and loading of perimeter holes, sequence of delays, length of holes;

stemming, changes in procedures (Note: This information is usually available in a standard blasting report, but modifications often occur. See, for example, Climax Mine-By Test);

(5) support (weight, spacing, time of installation in the round, method of installation); and

(6) water conditions.

Block Test

Previously discussed tests (i.e., the mine-by tests and exploratory drifting) are limited in their usefulness by the fact that the far-field boundary conditions are not known and the geometry of discontinuities is not well known. The block tests seeks to simplify the analysis procedure by studying the behavior of a small volume of rock with prescribed conditions. A primary focus of such tests is the evaluation of the rock mass constitutive model. Equivalent continuum constitutive models usually do not perform well in areas of high stress gradients and, therefore, any block test should, during the course of testing, seek to impose a high stress gradient on the block for evaluation with the constitutive model. Other block test requirements (suggestions) are presented by Zimmerman et al (1986) and are based on results of the G-Tunnel Heated Block Test.

One question that must be asked is what new information can be obtained by performing a block test at Yucca Mountain beyond what was learned at G-Tunnel. Certainly, if the test were conducted in a rock mass containing a high lithophysal content, then supplemented information beyond the G-Tunnel data could be obtained.

Plate-Loading Tests

The ISRM suggested method for performing a plate load test is given by Brown et al (1981). The authors suggest using a loaded area of about 1m in diameter but do not recommend an ultimate load capacity for obvious reasons. The relative merits of plate load tests are given by Stagg and Zienkiewicz (1974).

The fundamental purpose of in-situ testing is to influence such a large volume of rock that the results obtained will be representative of that region of the rock mass. Ideally, this requires that the linear dimension of the loaded areas be large compared to the discontinuity interval. With the ISRM suggested loaded area, the rock which will be effectively influenced is of the order of 1 to 2 meters, which may not be appreciably greater than the depth to which the rock has been disturbed during excavation operation. Results from tests on areas much smaller than this are liable not be to representative and will probably be closer to those obtained from laboratory tests on samples.

The magnitude of applied load is largely dependent on the size of the loaded areas—the load must be great enough to give reasonably measured deformations [Experimental errors greater than 0.01mm can invalidate test results when the rock mass modules exceed $3.5x10^4$ MPa (Benson et al, 1969)]. Typical reported loads used are 300 tons over an area of $1m^2$ and 720 tons over $1.2m^2$ (Stagg and Zienkiewicz, 1974).

An alternative to a plate load test is to use a cable-jacking test. The advantage of this test is that higher loads applied over larger loaded areas may be used, thus allowing a large loaded area to be influenced. Loads of up to 1000 tons can be applied by using a single cable. A typical model is shown in Fig. 5.

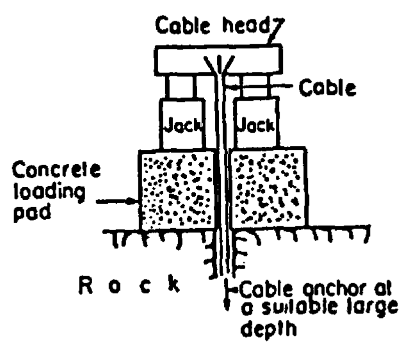


Fig. 5 Cable-Jacking Test [Stagg and Ziekiewicz, 1974]

With two adjacent cables (Fig. 6), loads tangential to the surface can be applied and information obtained about the variation of deformation moduli with direction of lead.

Even if the rock mass is not highly anisotropic, a larger rock mass will be loaded using a double-cable system.

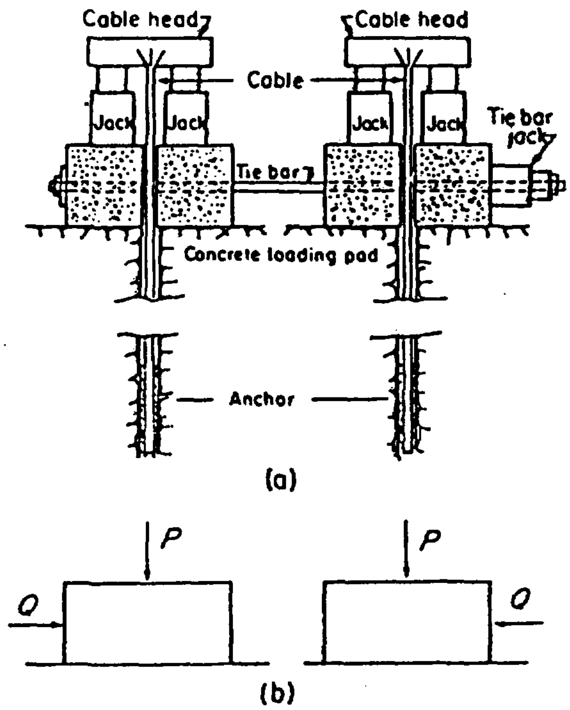
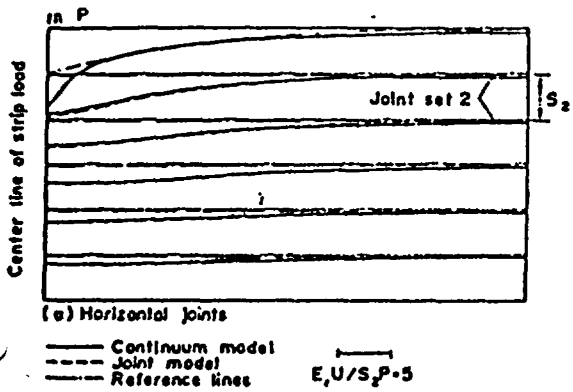


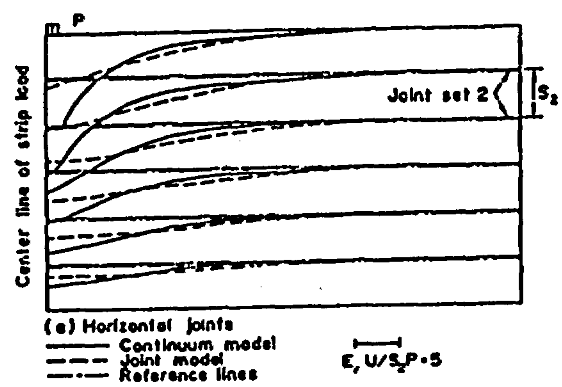
Fig. 6 The "Double-Cable" Test: (a) test arrangement; (b) diagrammatic loading [Stagg and Zienkiewicz, [1975]

Again, one reason which may be cited for conducting such tests is that they provide a basis for comparing equivalent continuum with discontinuum concepts. Differences in elastic behavior for plate-loading type situations are given by Singh (1973)—see Fig. 7.

Similar comparisons can be made for inelastic response as shown by Cundall and Fairhurst (1985) in Figs. 8 and 9.



$K_N = K_S$



$\frac{K_N}{10} = K_S$

Fig. 7 Comparison of Continuum and Discontinuum [Singh, 1973]

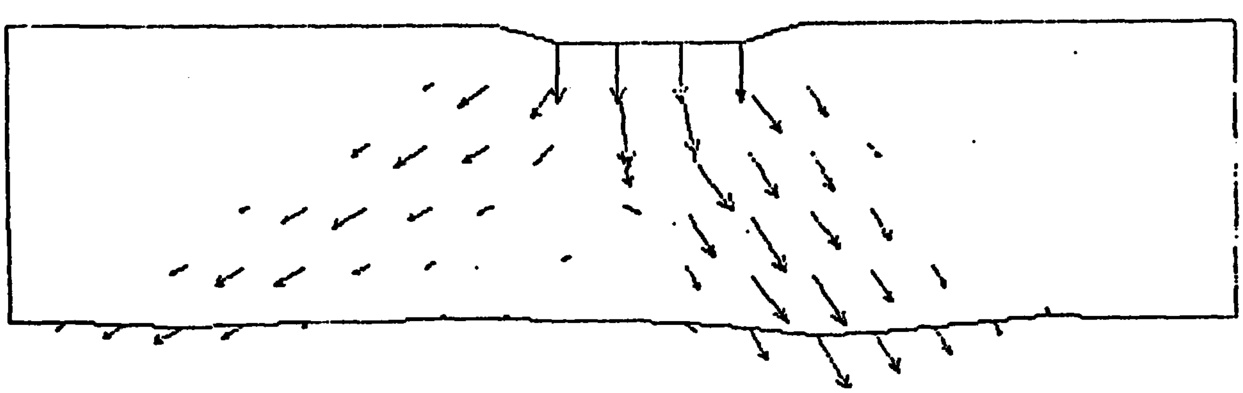


Fig. 8 Displacement Vectors and Boundary Deformation Resulting From Rigid Die Penetration Into a Ubiquitously-Jointed Continuum [Cundall and Fairhurst, 1985]

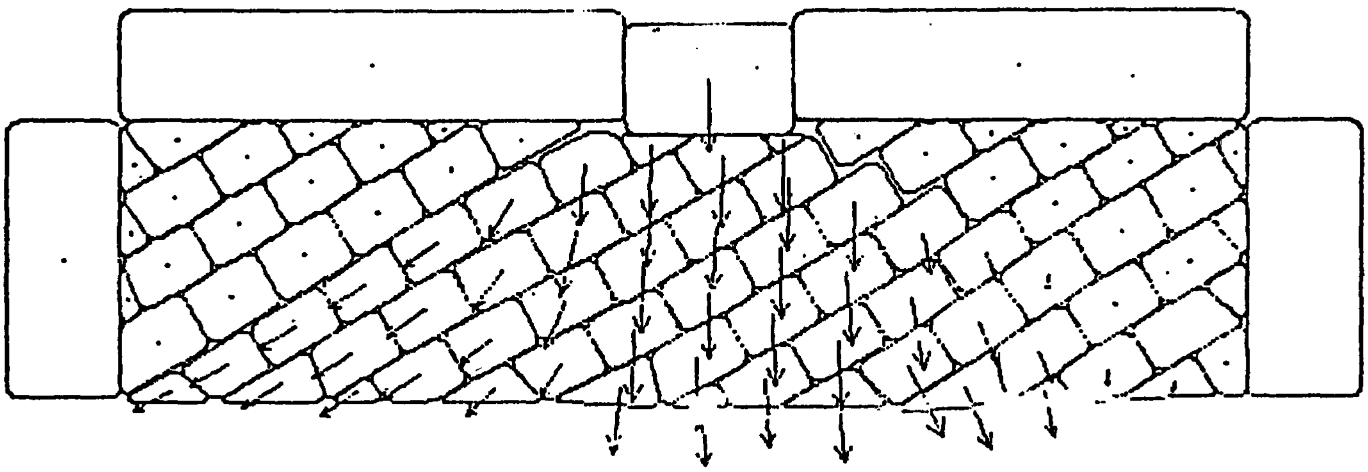


Fig. 9 Velocity Vectors and Displaced Block System Resulting From Rigid Die Penetration Into a Discontinuum (Compare to Fig. 8) [Cundall and Fairhurst, 1985]

Slot-Strength Testing

The slot strength tests (Vieth et al, 1985) represent a new concept in strength testing. In theory, the slot strength test can supply significantly higher stress loads than the plate-loading test. A relatively undisturbed surface of the opening constituting the test site is required for successful application of the method. If such a site is found, interpretation of results is complicated by:

(1) complex 3-D problem geometry requiring 3-D analysis; and

(2) unknown or assumed state of stress around the excavation in which the test is to be conducted.

In view of the foregoing, slot strength testing must be considered a supplemental test for experimental purposes.

Rock Mass Mechanical Strength

Before addressing discussion of rock mass mechanical strength, it will be very important to determine what exactly needs to be known concerning rock strength in order that only those components of rock strength which are in question be addressed. Recall that the "determination of the global mechanical properties of a large mass of discontinuous in-situ rock remains one of the most difficult problems in the field of rock mechanics" (Brady and Brown, 1985).

Because the stated objective of testing in this sections is "measurement of the geologic/geotechnical properties necessary to model the repository design" (DOE, 1985b?, p. 59), it will be important to know which types of models are being considered and, more particularly, how the discontinuities in the rock mass are to be considered.

Classically, rock mass strength is viewed as consisting of two components: (a) strength of intact rock; and (2) strength of discontinuities.

Three fundamental approaches may be considered.

(1) Empirical Approach

The most completely developed of the empirical approach is that introduced by Hoek and Brown (1980). These authors gave a strength criterion which would predict failure stresses for the rock mass. Unfortunately, their criterion did not include tuff nor did it describe the behavior of the material after failure. Application of this criterion to Yucca Mountain would require introducing numerous rock mass failures to develop an empirical data base.

It should be noted that values given in Table 12 of Hoek and Brown (1980) may be extremely pessimistic (conservative)—i.e., the lower strength values are far too low and unrealistic (see, for example, St. John and Kim, 1986).

(2) Equivalent Continuum

In this approach, behavior of the intact rock and discontinuities are combined based on the theory of composite materials. Therefore, the joints are considered as a different material from the rock.

(3) Discontinuum Models

This approach considers the behavior of the intact rock and boundary interactions (joints) between intact rock separately.

Both of the latter two approaches require characterization of the intact rock material and the discontinuities. Note that it may be possible to use (3) to develop formulations for either (1) or (2).

Again, the type of model to be used will, to some extent, determine the requirements for testing. The most common strength criteria used for intact rock is the linear Mohr-Coulomb criterion, which requires determination of cohesion and internal friction angle from a series of triaxial test results. In order to model dilatant behavior, the dilatency angle must also be defined.

Brady and Brown (1985) suggest that, although widely used, Coulomb's shear strength criterion is not always a satisfactory criterion for rock material. They cite the following three reasons for this.

1. It implies that a major shear fracture exists at peak strength. Observations such as those made by Wawersik and Fairhurst (1970) show that this is not always the case.

2. It implies a direction of shear failure which does not always agree with experimental observations.

3. Experimental peak strength envelopes are generally non-linear. They can be considered linear only over limited ranges of σ_n or σ_3.

Part of the site characterization process should include a justification for the strength criterion used in the numerical model.

Discontinuity properties to be defined at a minimum include the normal stiffness, shear stiffness, cohesion, friction, and dilatency angle. An important consideration here is that any laboratory discontinuity testing should include constant normal stiffness shear tests as well as constant normal stress shear tests. The reason for this is that, whereas constant normal stress tests may reproduce discontinuity behavior adequately in the case of sliding on an unconstrained block of rock from a slope, it may not be suited to the determination of stress-displacement behavior of discontinuities isolating a block in the periphery of an excavation.

A quantitative description of the structure of the rock mass (which contributes to the strength of the rock mass) is accomplished through measurement or observation of the following discontinuity parameters (Brown, 1981):

(1) orientation;

(2) spacing;

(3) continuity;

(4) surface roughness;

(5) equivalent compressive strength of adjacent walls;

(6) aperture;

(7) infilling material; and

(8) water conditions.

In addition, the number of joint sets and characteristic features should be reported.

Finally, some attempts have been made to measure rock mass strength in situ. Heuze (1980) presents a summary of in-situ rock strength testing. The reported tests are both bearing capacity and compression tests. The author was not able to reach a general conclusion concerning minimum test size for bearing capacity tests. With regard to compression tests, Heuze's 1980 data does not contradict previous observations by Bieniawski (1978), who observed that no further strength decrease occurs in tests with cube edges exceeding 0.5m.

8.3.2.3 <u>Coupled Interactive Tests</u>

The issue to be addressed here is the extent to which the coupled processes need to be characterized. From the waste isolation point of view, characterization of the effect of coupled processes on radionuclide flux may not be possible or significant enough to warrant detailed definition through field testing. However, with regard to waste containment (e.g., canister loading) and retrievability (i.e., emplacement hole/liner and room stability), characterization of the thermal/mechanical/hydro/chemical environment through testing is desirable and technically more feasible.

The coupled processes are of greatest significance when in close proximity to the excavations and heat sources. The majority of non-linear effects occur in these areas of high temperature and stress gradient. The ability to describe these coupling processes on a large scale through the use of small-scale field testing is open to question. The reliability of tests without independent control of the various coupling parameters and without the ability to characterize the rock mass in detail is probably poor. An important consideration here is the concept of a "disturbed zone", which was introduced in 10CFR60 because it was recognized that adequate characterization of the behavior of that portion of the rock mass subject to high temperature and stress gradients may not be possible. Regarding in-situ testing, NRC gives the following conditions concerning the acceptability of underground testing (NRC, 1985).

- In evaluating overall repository performance, no credit is taken for that portion of the rock that cannot be evaluated adequately without direct testing of coupled thermal effects.

- The components of the natural system, for which performance credit is taken, are characterized adequately for evaluation of overall repository performance.

- Components of the engineered system, such as the waste package, are designed with adequate conservatism to compensate for, or reduce, uncertainties with respect to the coupled thermal, mechanical, hydrologic, and geochemical conditions that will be encountered.

- As with all site characterization tests, the tests that support the design of the engineered system are carried out under conditions that bound repository conditions. This means that the design of the tests takes into account the full range of uncertainty about hydrothermal conditions that are expected to be encountered.

From the waste isolation point of view, it may be reasonable for the site not to take credit for the performance of the disturbed zone where the uncertainties in measurement and evaluation exist. Coupled interactive in-situ testing should, instead, focus on accurately understanding the performance of those components of the natural and engineered systems which affect waste containment and retrievability. These tests should be carried out under conservative ranges of temperature and stress conditions to bound the possible range of rock mass response.

The proposed coupled interactive tests related to the area of design/rock mechanics include:

- small-scale heater experiment
- canister(full)-scale heater experiment
- heated block test.

Previous tests at G-Tunnel have shown that the laboratory measured values for thermal expansion values for thermal expansion coefficient and thermal conductivity compared closely to those determined for the heated block test (Zimmerman et al, 1986). If it can be shown that a similar relation exists at Yucca Mountain, then the task of extrapolation results throughout the repository requires only the laboratory testing of the range of materials expected to be encountered. It should be noted that none of the testing will likely be of sufficient duration to address the issue of temperature effects on compressive strength. This effects will need to be studied beyond the end of the site characterization period.

For the first two test types, a detailed description of the parameters to be evaluated, test methodology, limitations, reliability, recommended test program, and potential advancements in the state-of-the-art are given by Roberds et al (1982). Significant considerations for these tests in tuff are presented in the following paragraphs.

<u>Small-Scale Heater Test</u>

A small-scale heater test is planned for the high lithophysal-rich tuff to determine whether laboratory properties are sufficient for input to a thermal model of such rock (Vieth et al, 1985).

The limitations of the small-scale heater test include the following:

(1) effects of stress dependence on thermal or thermomechanical properties not evaluated;

(2) the rock volume affected may not be representative of the rock mass at the repository scale; and

(3) properties may be evaluated only over a relatively short time interval.

Reliability of the small-scale heater test is generally ensured by using redundant monitoring instruments and equipment.

The design criteria and recommendations for the small-scale heater test are given below (from Roberds et al, 1982).

> The recommended small-scale heater test array consists of a small heater (15.0cm or smaller) surrounded by a thermocouple array. The actual configuration and number of thermocouples used to measure the temperature field will be dependent on modeling.
>
> The design criteria and recommendations for the small-scale heaters should be such that:
>
> - heater output (Q) is measurable and thermocouples are utilized on the heater body to ensure that the heater temperature is uniform
> - heater is capable of operating over a range of heat outputs; in addition, the heater is capable of maintaining a constant heat output for the duration of each heating cycle
> - provision for two heating elements/power controllers, so that in the event of failure of one of the elements/power controllers the test can still be performed
> - heater can withstand the maximum predicted borehole temperatures
> - heater is provided with centering mechanism such as fins for borehole installation

- provision for a dewatering system if water inflow appears to be a problem at the site (i.e., to cause heater failure or convective heat transfer)

- heater is calibrated in the laboratory prior to installation

The small-scale heater installation consists of inserting the liner in the borehole. The annular space between the liner and the rock should be backfilled (e.g., sand) to minimize convective heat transfer.

The small-scale heater is centered in the liner and installed such that the horizontal midplane of the heater is at the specified test depth. Thermal insulation should be used above the heater to minimize heat loss along the borehole. A thermal insulation pad should be placed on the surface of the drift floor (or shaft wall) in the vicinity of the test to minimize heat losses due to ventilation.

The small-scale heater test will consist of heating the rock with a constant power output and monitoring temperatures over time until steady-state (or quasi-steady state) conditions are attained. The heat output can then either be increased, decreased or turned off, depending on the desired results.

Temperature measurements intervals should be more frequent during the transient state (perhaps every few minutes), while the intervals should be much less frequent during steady state conditions.

Canister(Full)-Scale Heater Experiment

The canister-scale heater test is concerned with examination of the detailed thermal, mechanical, and chemical processes which occur within a few radii of the emplacement boreholes. Here, the structure of the waste canister, the overpack and backfill design, and the borehole geometry are important factors. The details of heat transfer from the waste form to the rock mass are examined, as well as the effects of high thermal gradients on borehole stability. These processes are of greatest concern on a "short" timeframe, when the peak temperatures are greatest. This occurs at timeframes less than 100 years and encompasses the retrievability period. However, the eventual re-saturation of the hole and the subsequent hydrochemical processes occur on a long-term time scale.

A single horizontal canister-scale heater experiment is planned at the repository horizon (Vieth et al, 1985). The objective of this test is to document the near-field rock behavior around the opening that envelops the waste package system. The limitations and reliability considerations for this test are the same as those for the small-scale heater test. The design and execution of the test are as follows, from Roberds et al (1982).

> The full-scale heater test array will consist of a central full-scale heater surrounded by an array of instruments at various radial and vertical distances. The instruments utilized in the recommended full-scale heater test include
>
> - thermocouples
> - multiple-position borehole extensometers (MPBX)
> - borehole deformation gauges
> - water migration monitors (incorporated into flow measuring-dewatering system)
> - ventilation monitors

The design criteria and recommendations for the full-scale heater are:

- the heater should duplicate the geometry of a waste package

- heater output (Q) is measurable and thermocouples should be utilized on the heater body to ensure that the heater temperature is uniform

- heater is capable of operating over a range of outputs; in addition, the heater is capable of maintaining a constant heat output for the duration of each heating cycle

- provision for four heating elements/power controllers such that maximum heat output is possible in the event three heating elements/power controllers fail

- canister retrievability can be evaluated

- provide equipment to remove water and steam in the borehole and measure flowrates (Johnstone, 1980; Ewing, 1981)

- heater is calibrated in the laboratory prior to installation

The installation of the full-scale heater should be the same as that proposed for the prototype waste package, with the possible exception that water migration equipment will be utilized in the recommended full-scale heater test and that such a system may not be utilized in the prototype waste package. In addition, the dewatering system serves to prevent anomalous temperature distributions to the rock resulting from convection and minimizes heater problems. The heater should be centered in the borehole such that the horizontal midplane of the heater corresponds to the desired test depth.

The thermocouple design considerations and installation procedure is similar to the small-scale heater test, with the exception that the thermocouples should be installed in the MPBX boreholes and borehole deformation gauge boreholes, thus eliminating the need for thermocouple only boreholes. With the test configuration proposed, adequate measurement of the temperature field should be possible.

The full-scale heater test is also designed to measure thermally induced displacements and strains. Multiple-position borehole extensometers (MPBX's) are used to measure the axial displacements in a borehole.

The recommended full-scale heater test consists of heating the rock in constant power output stages and measuring the rock mass response. The heating cycles should consist of several increases in heater output, followed by a cooling phase. The heater output should remain constant until after steady state (or quasi-steady state) conditions have occurred in the rock mass, before it is increased (or decreased).

Data collection intervals should be more frequent in the initial stages of the heater test, e.g., as often as every five minutes. The channel may be monitored every 15 to 20 minutes during the transition from heatup to steady-state operation, and every hour during steady-state operation (Johnstone, 1980). Actual data collection times will depend on the site response. In addition, water migration should be monitored in tuff.

Following the cool-down period, the rock should be heated until borehole failure occurs (or until maximum heater output is attained). This will permit an evaluation of canister retrievability. In addition, post-test borehole conditions should be further characterized by the borehole techniques discussed earlier, namely, geophysical well logs, borehole TV logs, crosshole sonic velocities, and permeability tests and compared with initial survey findings.

An additional post-test characterization should include rock samples cored in the vicinity of the heater hole(s). The core should be examined in the laboratory to determine if any geochemical or alteration changes occurred as a result of the heater test. A supplementary small-scale heater test should be performed near the full-scale heater test to evaluate the scale effects of the two tests.

Heated Block Test

A heated block test similar to the G-Tunnel Heated Block Test is proposed at the repository horizon at Yucca Mountain (Vieth et al, 1986). The proposed test will likely follow closely the G-Tunnel Heated Block Test. If such a test is deemed appropriate, the recommendations listed by Zimmerman et al (1985, pp. 12-9 and 12-10) should be considered.

Thermomechanical Room-Scale Test

A room-scale test previously had not been proposed at NNWSI, yet perhaps the least understood question concerning repository design is the long-term thermomechanical response of underground openings.

The testing plans written to date (Vieth et al, 1985) attempt to resolve this issue by conducting single-heater and block-type experiments. In these, an attempt is made to validate a thermomechanical code(s) using the data generated. The validated code(s) is(are) then used for room-scale design. Confident application of room-scale design models whose validation is based on tests which thermally load only small blocks of ground that are highly confined (kinematically) is questionable.

Alternatively, it is suggested that a practical engineering demonstration approach be considered to this problem by subjecting a large volume of ground to elevated temperature conditions prototypical of the repository. The rooms and pillar from the multiple excavation test provide an excellent geometry for conducting a room-scale thermomechanical test. Electrical heaters can be used in the conceptual arrangement to provide the thermal load. The instrumentation (with supplemental temperature sensing and compensation) can be used to monitor the test.

One drawback of the test is the large amount of time required to heat the rock mass. The test should be in continuous operation from ES testing through license application, construction authorization, and construction. Thus, it will provide initial thermomechanical response for license application and a basis for long-term data. In short, such a test provides a defensible demonstration of the repository concept and the design's ability to satisfy design requirements of 10CFR60.

8.3.2.4 Design Optimization

This section describes the design optimization studies and activities which require site characterization. Potential topics include

- refinement of design data needed to resolve design alternatives
- design performance verification for activities such as rock excavation and mining technique, waste package emplacement, and retrieval issues.

The specific areas likely to be discussed are:

(a) demonstration of feasibility of drilling long horizontal holes, replacing and retrieving waste;

(b) evaluation of alternative support systems; and

(c) precise measurements of in-situ stress state

The specific acceptance criteria applicable to potential licensing issues of this section are given in 10CFR60.122(c)(20) - Complex Engineering Measures.

8.3.2.5 Repository Modeling

This section of the SCP will identify and describe planned repository design model and code development and utilization, verification and validation activities which require site characterization data. Potential subjects include repository component and subsystem models and their use in conducting performance, safety, and design optimization analyses.

Because there is no empirical data base from which performance can be assessed and because the timeframes of the analyses are so long, models (numerical, analytical) must be used to a great extent to predict performance of the repository. In order that the design and performance assessment process be made tractable, the repository must be divided into a number of physical scales: canister, room, repository, and regional.

Different models may be used for different scales, with each scale model providing appropriate but uncoupled boundary conditions for the physically neighboring scale models. A more rigorous approach couples two or more scale models into a single hybrid model. For example, the room scale near-field behavior may be modeled with distinct elements, taking into account the location and nature of discontinuities, whereas far-field behavior may be adequately represented using a boundary element scheme (see, for example, Lorig et al, 1986). A similar hybrid approach has been documented for finite element and boundary element methods (Brady and Wassyng, 1981). In any case, each scale model must be properly validated for use in the design and performance assessment process.

The discussion of numerical modeling methodology which follows is based on a recent report on the status of thermomechanical modeling (Itasca, 1986).

Basic Aspects of a Logical Methodology

A logical methodology for performing thermomechanical analysis must be followed in order to evaluate the reliability of the numerical models and to establish credibility in the analysis results. A general approach is presented by Brady and St. John (1982) for applications related to engineering rock mechanics. A diagram illustrating the basic aspects of this approach is reproduced in Fig. _. The approach is an extension of the observational approach to geotechnical design and incorporates the reliance on advanced computational methods.

One aspect of the methodology is the formulation of a site geotechnical model based on site exploration and characterization. This includes information from laboratory and field testing supplemented with generic information on rock types when site-specific information is not available. Specific problems associated with formulation of the geotechnical model include scale effects, representativeness of testing, and definition of initial in-situ conditions.

A second aspect is the selection (or development) of an appropriate computer code for performing design calculations and the verification of this code (i.e., the process of ensuring that the code is computationally correct for all conditions under which it will be applied).

The site geotechnical model must then be incorporated into the computer code and the resulting numerical model must be validated (or qualified, as defined in Fig. 10) for the analysis of site-specific problems.

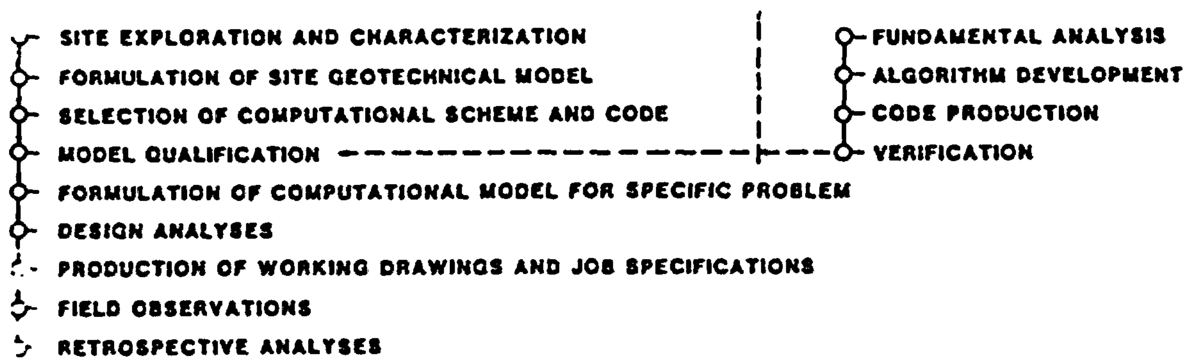


Fig. 10 A Logical Methodology for Semi-Quantitative Application of Advanced Computational Schemes in Rock Mechanics [Brady and St. John, 1982]

According to this approach, code verification can be performed in the absence of site-specific data. Brady and St. John (1982) contend that field tests "represent an extra level of complexity, compared with laboratory experiments, due to poor definition of experimental parameters" and, therefore, are not to be used in code verification.

Model Validation

The aspect of model validation is concerned with the demonstration that the numerical model of a specific site and geologic setting is an acceptable representation of both the thermal and mechanical processes affecting the site and the geologic character of the rock medium. Validation is necessarily an evolving process as more information becomes known, but a difficulty arises in defining the conditions to be achieved for model validation. Brady and St. John (1982) provide a rational criterion for the validation of a computation scheme. The decisive requirement, as stated by Brady and St. John, is "that for a given set of properly determined site parameters, the model can predict the response of the rock medium to some controlled perturbations, to some prescribed tolerance." For example, a validation exercise for a thermomechanical model could be the computational and experimental determination of mechanically- and thermally-induced stresses and displacements around a heated excavation test panel in the rock mass. The model would be considered validated by achieving a correspondence between the observations and predictions within a tolerance prescribed by the uncertainty in the input data.

Figure 11 illustrates the criterion for validation. Each rock mass parameter should be prescribed a specified level of confidence. Bounding predictions are then made using the model and the parameters within the confidence limits. If these bounds bracket the response measured in the field experiment, the model can be considered validated for application for processes and geologic settings similar to those of the experiment.

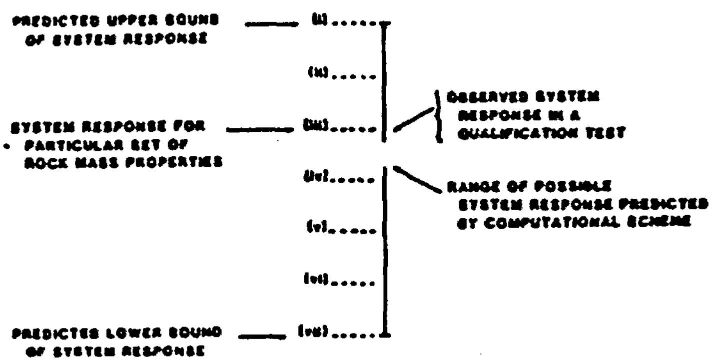


Fig. 11 Criterion for Validation of a Computational Methodology for a Specific Site by Predictions Bounding the Observed Response of a Test Site [Brady and St. John, 1982]

Model validation is particularly difficult for analyses related to retrievability and post-closure conditions, where the time scale of concern precludes a realistic experimental program. In such instances, Brady and St. John (1982) suggest that model validation may require demonstration that the model results are consistent with historical experience of analogous conditions.

Equivalent Connt with historical experience of analogous conditions.

Equivalent Continuum Models

As discussed earlier, the ability to perform even room scale analysis may require the use of an equivalent continuum model. The site characterization process provides a good opportunity for evaluating the performance of the equivalent continuum models. In addressing this issue, the effects of traditional limitations of, and objections to, such models should be evaluated.

The fundamental objections that can be raised on the validity of these equivalent models are given by Detournay and St. John, 1985.

- There is no interaction between joints (either within a set, or between sets). The stress state within the joints and matrix is homogeneous (the macroscopic

- The derivation of these equivalent continuum does not follow the self-consistent method described by Hill (1967) for the characterization of composite materials. (This requires estimating the behavior of a joint in the discontinuous rock medium as that of a single discontinuity in the equivalent homogeneous body).

- The question of scale effect can not be addressed with the ubiquitous models because of lack of a characteristic length.

Strict adherence to assumptions underlying the equivalent continuum approach requires the following (Gerrard, 1983):

(1) discontinuities occur in sets, each of which can be recognized by its regular spatial pattern;

(2) the typical spacing between joints in a set is much smaller than the critical dimension of the problem under consideration (e.g., span of an underground opening); and

(3) either the relative movements on a particular joint set are limited or the spacings between the joints in the set are extremely small.

It should be noted that there appears to be very little quantitative information on the limits of applicability of equivalent continuum models. This issue deserves serious attention.

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