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ITASCA
Consulting Group, Inc.

29 June 1987

David Tiktinsky - SS623
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 David:

Enclosed is our review of ""Site Characterization Plan, Chapter 2.0 — Geoengineering (Controlled Draft 1) by the U. S. Department of Energy (January 26, 1987). Please call me if you have any questions.

Sincerely,

Roger D. Hart

Roger D. Hart
Program Manager

cc: R. Ballard, Engineering Branch
Office of the Director, NMSS
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DWM Document Control Room

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ITASCA DOCUMENT REVIEW

<u>File No.</u>: 802-001-02-30

<u>Document Title</u>: "Site Characterization Plan, Chapter 2.0 — Geo-engineering (Controlled Draft 1) by the U. S. Department of Energy (January 26, 1987)

<u>Reviewer</u>: Itasca Consulting Group, Inc. (M. Board)

<u>Approved</u>: Roger D Hart

<u>Date Approved</u>: 6/23/87

Significance to NRC Waste Disposal Program

This document is a draft of the Site Characterization Plan (SCP) Chapter 2.0. It reviews the current status of knowledge of the geomechanical properties of basalt from the Hanford site as well as the ability to excavate and maintain stable openings within the Cohassett flow at the Reference Repository Location (RRL). The SCP is a major program document required of the site (10CFR60.15-.18) which details the present technical knowledge of the site in addition to the conceptual design and various issues related to it. The significance of Chapter 2.0 is that it defines the adequacy of the present state of the geomechanical knowledge and identifies areas in which further data collection is required. In addition, a presentation of the problem areas expected in repository development for the site is made. The data summarized in Chapter 2.0 has also been used for the conceptual design studies to be provided in Chapter 6 of the SCP. The start of shaft sinking activities at the site is contingent upon an NRC review of the SCP.

Summary

This chapter of the SCP reviews the present state of knowledge of geotechnical properties and related design problems for a repository in the Cohassett flow of the RRL. The document does a complete job of presenting the existing data base for intact material properties and in-situ stress conditions. The expected excavation conditions are also given a fairly detailed treatment. There are no apparent glaring holes in the present data base, with the exception that more data on joint properties as well as large-scale at-depth testing under repository conditions is obviously necessary at this point. The biggest drawback of this chapter is that a coherent picture of the constitutive model for basalt has not developed—nor is a detailed discussion of how it is to be developed given. Some of the points which were not adequately examined in this document are:

(1) There is no clear discussion of the distinctions between empirical and analytical models of basalt behavior and how they will be used in future design and performance assessment.

(2) There is no means of determining conservatism inherent in the present design approach. The simplistic models used for determination of thermal stresses appear to overlook important failure mechanisms.

(3) Although field testing shows that the basalt is anisotropic, isotropic models are used to determine induced stresses.

(4) The empirical strength parameters used in design involve a number of reduction factors to account for size effect as well as opening dimensions. It is not clear what the level of conservatism inherent in these calculations is.

(5) Several significant possible problem areas exist at BWIP, including, (a) high rock stress, (b) heavily jointed, yet high, intact rock strength, (c) high rock temperature, (d) possible high water in flow, and (e) probable small amounts of methane gas.

Further detail on these and other limitations is given later.

The outline used in this review follows the suggested SCP Chapter 2.0 outline closely and covers the following topics.

1. Mechanical Properties of Intact Rock
2. Mechanical Properties of Discontinuities
3. Large-Scale (In-Situ) Mechanical Properties
4. Thermal and Thermomechanical Properties of Intact Rock
5. Large-Scale (In-Situ) Thermal and Thermomechanical Properties
6. In-Situ Stress
7. Special Problems
8. Excavation Characteristics of Basalt

A summary of each of these topics is given here:

Mechanical Properties of Intact Rock

The average mechanical properties of the intact rock are taken from Sublette (1983) and essentially are the same as those given in a recent update of the Hanford rock mechanical data base by Sublette, 1986 (reviewed in Itasca, 1986a.) The data base of intact properties is derived from core samples from the Pomona Flow (Near Surface Test Facility) as well as several flows within the Grande Ronde member, including the Cohassett flow. Sample tests were conducted by several organizations, including the Colorado School of Mines, Foundation Sciences, Inc., Lawrence Berkeley Laboratories and BWIP's own testing laboratory at Hanford.

The results of the testing are reasonably consistent and, in the reviewer's opinion, appear to represent an adequate data base of intact strength and deformational properties for the flow entablature and colonnade to be used in conceptual design scoping studies. The intact uniaxial strength for "dense interior" samples averages 237-337 MPa; the Young's modulus averages 70-82 GPa. For flow tops, the results are highly variable as a result of the vesicularity, but the intact strength averages 52-84 MPa, with a Young's modulus of 14-32 GPa. The limitations of the data is discussed in greater detail later.

One point of note given little attention in the document is a reported decrease in the intact strength of saturated samples to 45% of the dry strength for all intraflow types. This seems difficult to believe but is highly significant if substantiated.

Mechanical Properties of Discontinuities

All tests on discontinuities were conducted on small diameter cores (1" to 2.1") from the Pomona (NSTF) and Grande Ronde flows. Two types of tests were conducted: direct shear and triaxial compression of jointed samples. The testing indicated somewhat variable results. The direct shear tests (the most common, and generally more reliable, form of joint testing) showed friction angles of approximately 29° and a cohesion of 0.8 MPa, although the data scatter is very large and the sample size (14) is small. The triaxial joint testing involves cyclic axial loading at constant confinement, resulting in an accumulated damage to the sample. Tests on the Pomona and Grande Ronde flows showed a friction angle and cohesion of 35° and 1.6 MPa and 45.7° and 4.08 MPa, respectively. Values for normal and shear stiffness are within reasonable bounds for similar rock types. Only a few tests have been conducted which examine the effect of water and temperature on the joints, so results are inconclusive. No testing has been specifically aimed at determining the effects of temperature, water and time on the infilling materials. Although the joints are quite narrow (less that 0.37mm), they are 89% filled with montmorillonite clay, known for its high swell potential and low friction angle. Therefore, the possibility of degradation of the strength of the joints is currently unknown. The strength of the joints will likely be the limiting factor for stability of the mine openings and the extent of the mining and thermally-induced damage zone. The strength characteristics of the fracture are of great importance, however, and it is highly improbable that any confidence in the joint properties or behavior will be obtained from tests on small scale samples. Therefore, the most valuable information will be obtained from in-situ monitoring of excavations in the ESTF.

Large-Scale (In-Situ) Mechanical Properties

The large-scale deformability of basalt is derived primarily from three forms of testing conducted at the NSTF within the colonnade of the Pomona flow:

(1) borehole jacking tests;
(2) jointed block test; and
(3) cross-hole seismic tests.

The jointed block test indicated a transversely anisotropic response oriented along the axis of the columns. The stiffness properties also were temperature dependent—it is conjectured that expansion of the rock blocks resulted in a "tighter" mass. There was also a significant confining pressure dependence on modulus.

The static measurements from the above fall within a range of 10 to 47 GPa, depending upon the orientation of the loading and the tool used. This is in comparison to the laboratory-measured intact value of 70 to 82 GPa. A value of 38 GPa is suggested for design purposes, but the method of its determination is not detailed. It is stated that "engineering judgement", in combination with the aforementioned field tests, laboratory tests and empirical rock mass classifications, were used to arrive at this figure. More discussion regarding this point is given later in this review.

An estimate of rock mass strength is developed by fitting triaxial test data to the Hoek-Brown (1980) empirical yield criterion. The strength was then reduced by using the Rosengren and Jaeger (1968) strength-size reduction factors for fractured marble (see Ames, 1985). The strength values are size dependent, incorporating the size of the opening after work by Hardy and Hocking (1980). The result is that the strength criterion for the emplacement room is 158 MPa and 202 MPa for the placement hole. These values are used by RKE/PB in the design of the canister pitch and initial power level in Chapter 6 of the SCP. There are several problems with this approach, as reviewed in the limitations section of this paper.

Thermal and Thermomechanical Properties of Intact Rock

The thermal and thermomechanical properties of intact samples from the Pomona, Umtanum and Cohassett flows have been determined; the greatest number are from the Pomona flow. Only 21 total samples from the RRL (borehole RRL-2, only) have been tested. The results from the testing show consistent average values of thermal conductivity and expansion for dry samples from all flows.* For the Cohassett flow, the following values are used:

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*Some considerable scatter in the data for the Pomona flow at the NSTF was obtained for thermal conductivity. Two testing laboratories were unable to duplicate results and the testing technique is suspected of widely-scattered results.

mean thermal conductivity = 1.51 W/m°C

mean thermal expansion = 6.02 x 10^{-6}/°C

mean heat capacity = 282 J/kg°C at 20°C to 929 J kg°C at 200°C.

The thermal conductivity and expansion show little or no temperature dependence. It is the opinion of this author that these values are acceptable for conceptual design studies due to the general consistency of Grande Ronde measurements as well as the general body of literature. Additional testing will be required for Cohassett samples from the ES facility as a confirmatory measure.

Large-Scale (In-Situ) Thermal and Thermomechanical Properties

The in-situ thermal and thermomechanical properties have been derived from the NSTF heater and heated jointed block testing. The question to be answered here is whether the jointing, joint infillings and rock mass moisture have a significant effect on the thermal and thermomechanical properties, as is apparently the case for mechanical properties.

The in-situ thermal conductivity was determined through curve-fitting of thermocouple data from the full-scale heater tests. The following values were determined:

thermal conductivity	1.71 ± 0.1 W/m°C
heat capacity	845 ± 85 J/Kg°C

The heated jointed block test results indicate a value for the thermal conductivity of 1.57 W/m°C. These values are quite close to those obtained from the laboratory and confirms observations from the Stripa experiments in granite (Jeffrey et al, 1979) and the heated block tests in granite gneiss (Hardin et al, 1982), and tuff (Zimmerman et al, 1986), which indicate little effects of jointing on thermal conductivity.

The thermal expansion coefficient for basalt is reported only as derived from the NSTF full-scale heater tests. Here, the field data from vertical and horizontal extensometry was compared to numerical model best-fits (AMI, 1986). It was seen that a reasonable fit to the field data could be obtained for an expansion coefficient of 6.4 x 10^{-6}/°C, or nearly identical to the laboratory value. An attempt to match the horizontal strains, however, showed large discrepancies. The argument is made that in the vertical (unconfined) direction, the rock is free to expand, and the presence of a series of reasonably tight discontinuities should have little effect on the total strain. There is no particular reasoning posed, however, to explain the small horizontal displacements. The argument is presented (and rightly so) that the displacement anomalies need to be explained through a mechanical representation of the rock which accounts for the non-linearities introduced by the jointing and not by a non-linear expansion coefficient.

The values for thermal and thermomechanical parameters used in design are the laboratory values presented earlier. This appears to be reasonable; however, the inability to predict displacement around the in-situ heater tests raise questions about the adequacy of the present mechanical model. More discussion on this point is given in the section on limitations.

In-Situ Stresses

The information contained in Section 2.6 is primarily a repeat of the report by Kim et al (1986). Here, the indicators of stress observed at the Hanford site, including borehole spalling, seismicity, and core disking are briefly reviewed. The deep-hole hydraulic fracturing conducted in boreholes RRL-2, RRL-6 and DC-4 within the RRL are only discussed here. Measurements from holes DB-15 and DC-12 are not discussed in the report for unknown reasons.

The measurements indicate a large north-south compression with the following reported average values:

σ_1 = 61.5 ± 5.7 MPa at N06°E ± 17°, horizontal

σ_2 = 32.2 ± 2.2 MPa at N84°W ± 17°, horizontal

σ_3 = 24.2 ± 1.1 MPa at vertical

These values have subsequently been used by RKE/PB in the Conceptual Design, Chapter 6.0. The measurements themselves appear to be reasonably consistent; however, the assumption that pore pressure provides some assistance in the hydraulic fracturing makes the results non-conservative (Itasca, 1986b). If the conservative assumption of zero pore pressure is used (a common procedure when dealing with crystalline rock masses—see Pine, 1983), the calculated maximum horizontal stress is roughly 10 MPa higher, or around 75 MPa ± 6 MPa. The above recommended values (used in design) are even at odds with BWIP's own expert review panel, which suggested that, for conservation, the extreme range of the horizontal stresses be used (St. John and Kim, 1986):

$$50 \le \sigma_1 \le 75 \text{ MPa}$$

$$30 \le \sigma_2 \le 40 \text{ MPa}$$

$$\sigma_1/\sigma_2 = 2.5; \quad \sigma_1/\sigma_3 = 3.1$$

Therefore, even using the suggestions of the expert review panel, the design stresses are some 22% low. The effects of this assumption are discussed further in the limitations section.

Several concluding points can be made regarding these measurements:

1. The major horizontal stress is anomalously large, reflecting the regional north-south compression related to the folding and fault structure seen in the Columbia Plateaus.

2. The directions are consistent with other phenomena such as borehole spalling and core disking and seismicity.

3. The deviations in stress

   $$(\sigma_{Hmax}/\sigma_V \approx 2.5)$$

   are very large and are near the top end of the measured range for this depth.

4. The design stresses are non-conservative.

The measured stresses also conform to the microseismicity monitored across the Pasco Basin. This microseismicity is apparently related to slip on existing fractures. One can determine if the stress state is amenable to induced slip on faults or fractures at depth. Using the design stress values suggested by BWIP for an existing through-going fault oriented east-west at a dip of roughly 60°, slip could occur if the friction angle were about 33° or less. Using the expert review panel suggested extreme range of stresses for the same fault, a friction angle of approximately 40° or less is required for slip. In Section 2.6.2.2.5, it states that results of friction measurements on basalt joints exceed the 33° value. This is not true, however, since, in Section 2.2, the direct shear tests by Mitchell (1984) show a friction angle of 29° and the results by Brechtel (1985) show a friction angle of 35°. Therefore, without the additional mining or thermally-induced stresses, it is probable that favorably oriented existing faults or fractures are near a point of incipient instability. The abundant microseismicity at the site appears to be evidence of this point. It is noted that the seismicity near the RRL is deep (>4km) and that no faults are known to exist within the RRL.

Special Problems

Several special geoengineering problems which may present pre- and post-closure performance problems are addressed here. These are:

(1) rockburst potential;

(2) thermal degradation potential;

(3) swelling and shrinkage of infilling materials; and

(4) coupled thermal-fluid-stress-chemical effects.

The high magnitudes and deviation of the in-situ stresses, combined with the brittle intact nature of the basalt has created concern for possible violent rock instability during construction and pre-closure heating. In mining, the violent instability known as a rockburst can be characterized by ground vibration in the range of 0-3 + M_L (Richter magnitude) and expulsion of 0-1000+ tons of rock into the excavations. A report by Blake (1984) is used as the basis for determination of the potential for rock bursting at Hanford. This report reviews the world-wide incidence of rockbursting and attempts to determine those common elements required for this problem. These are:

(1) great depth;

(2) high in-situ stress;

(3) narrow and tabular geometry;

(4) strong and brittle rock;

(5) massive rock (i.e., low joint frequency);

(6) high extraction ratio and extensive mined spans;

(7) geologic structural discontinuities (such as faults);

(8) complex geologic structure; and

(9) maximum principal stress more or less perpendicular to the tabular dimension

We disagree that (3), (5), (7) (8) and (9) are required for rock bursting [as reviewed in Itasca (1987a)]. The primary difference which we take with BWIP is in the definition of rockbursting. BWIP claims that the mining-induced seismic events in the repository construction will be under 1 M_L. This is probably correct, since the extraction ratio is very low and there are as yet unidentified geologic discontinuities such as faults which can further concentrate the stresses. BWIP terms seismic events of <1 M_L as "spalling" and seismic events of >1 M_L as rockbursting. Obviously, the connotation of spalling is less threatening than rockbursting.

Practical experience shows, however, that rockbursting of 1 M_L in an advancing face (although sometimes considered minor from a deep-mining standpoint) can cause considerable physical damage to the excavation as well as a safety hazard to workers. The panel entry design proposed by RKE/PB (1985) results in three intersecting drifts at acute angles—a typical geometry for rockbursting. The extent to which this bursting may effect the damaged zone around the opening and subsequent performance is unknown but is not expected (by this reviewer) to be significant. The report does not adequately address the possible problems created by thermally-induced stress and any resulting instability. It is only stated that additional spalling is possible. A further discussion of the limitations in this approach are given later.

The potential for thermal degradation of the basalt is based primarily on the results of the NSTF full-scale heater experiments. During FS#2, the rock mass was subjected to elevated temperature for more than 600 days. At the conclusion of more than 500 days of heating at a power level up to 5kw, power was increased to as high as 9kw for an additional 120 days. There was no spalling or slabbing of the hole, although some existing fractures were enlarged (the text states "enhanced", page 2.7-7.) Additional laboratory testing from the vicinity of the heater showed only minor changes in average properties. This testing frame is obviously short but was significantly over-powered and indicated no significant borehole decrepitation.

The infilling materials along joints in the Cohassett flow are primarily montmorrilanite clays 0.37mm in thickness. Very little is currently known of the change in mechanical properties of the clays as they undergo temperature and moisture change. It therefore is not possible to arrive at any conclusions regarding their effects on performance prior to in-situ testing.

The coupled phenomena of possible importance at BWIP include mechanical, hydrological, thermal and chemical effects. This report devotes virtually no discussion to the present state of knowledge of coupling phenomena and is, therefore, considered inadequate.

Excavation Characteristics of Basalt

The report reviews case studies of excavation under purportedly similar conditions to Hanford. The expected conditions for excavations include the following:

- high horizontal stress and stress ratio
- high rock temperature
- high fracture frequency
- high intact rock strengths
- saturated rock

As the report states, "These conditions are not duplicated in any one existing excavation case history"—illustrating the unusual conditions encountered at the Hanford site. The case study examples for comparison often illustrate rather inhospitable conditions of high rock stress and temperatures. The bearing of these case studies on the problems of excavation at Hanford are often not stated explicitly, leaving the reader to question its relevance. The following statement regarding mining in the deep gold veins of the Kolar gold fields is an example (page 2.8-3):

> "The horizontal in situ stresses at Kolar are reported to be higher than the vertical stress, suggesting a stress state comparable to that at the Hanford site. Joint frequencies, although unreported, are probably lower than those expected in the Cohassett flow."

In other words, there are no data for comparison of the two at all. The discussion is also replete with ambiguous statements, such as the following as it concerns the Coeur d'Alene mining district:

> "Fracturing is heavy along the main fault (ore bearing) structures and less heavy away from the faults (Miner, 1982). In situ stress measurements indicate high horizontal stresses ranging up to 100 MPa," (no reference cited.)

or:

> "The in situ stresses were not measured; however because of greater depth, it is likely that in situ stresses were higher than those anticipated in the Cohassett flow."

The above statements are examples of the poor research presented in this section. Only those features in common with existing mines which can be substantiated should be placed in this section of the report.

Several case examples of shaft drilling (the Agnew Mine and Amchitka Island) are used to support the statement that "The exploratory shafts are within the range of proven technology" (p. 2.8-6). However, the repository shafts (15 foot OD) are outside the current range of proven technology (RKE/PB, 1984). The possible problems associated with rockbursting at the shaft bottom are addressed in that special "engineering measures have been developed to remove broken rock from the hole and to recondition the hole prior to resumption of drilling." These measures are not described in detail.

The possibility of high water inflow rates are discussed in terms of water which "may reach or exceed the rock temperature (51°C) and may be high enough to burn workers' unprotected skin." Examples are given of water inflow world-wide from tunneling and mining. Although it is possible to recover from large inflow events in mining, it is certainly not a standard practice. Extensive grouting, shielding and water diversion/pumping is necessary in these instances. The impression that such an event would not be a major disruption to repository development must be dispelled.

The presence of methane gas can be averted if large enough quantities of ventilating air are passed through the workings. This is a problem at Hanford only in the maximum possible water inflow event of 3500 gpm. The ventilation capacity (final) would not be sufficient for the expected methane concentration of the groundwater in this instance. However, the methane gas would be the lest of concerns at that point.

The report states that little problem is expected in spalling of the emplacement holes due to "aligning the axis of the emplacement hole in the direction of maximum horizontal stress." In fact, the present plan calls for the emplacement holes to be drilled perpendicular to the maximum stress—the emplacement drifts are to be aligned with the maximum stress. It is possible that spalling of the holes and the hole/drift intersection could occur (Itasca, 1987c).

The rock support plans for the repository appear to be adequate and certainly is as heavy as that typically used in deep mining. The method used to determine the additional support necessary under thermal loading is highly questionable, however, and is reviewed further, in the section on problems, deficiencies, and limitations

The impact of damage in the rock mass induced by excavation is described. Damage is defined as the mechanical impact of blasting and stress re-distribution, and is characterized by joint slip and block rotation. Two consequences of the damaged zone discussed are: (1) the effect on the rock support; and (2) the influence on hydraulic conductivity. The damage in accounted for implicitly in the determination of rock support requirements. The effect of damage on hydraulic conductivity is stated to occur primarily within 1 radius of the opening. The effect of this increase in permeability on post-closure performance is not discussed. Mechanical and hydrologic characterization of the damaged zone is left as an information need.

Problems, Deficiencies and Limitations

Major Comments:

1. The data base of intact mechanical and thermal properties appears sufficient for the present stage of analysis. Additional future testing will need to center on the properties of the Cohassett flow, their variabilities, and effects of temperature and fluid pressure. These tests will likely have to wait until the ES shaft is sunk due to the lack of boreholes and core in the RRL.

2. The in-situ state stress has been defined by hydraulic fracturing. Again, this base of data appears to be consistent and sufficient for conceptual design and present performance calculations. The design values chosen for the site are non-conservative, however, because

   (a) average values of stress components were chosen—not the most conservative combinations of high and low values of the range; and

   (b) the assumption that pore pressure at depth influences fracing pressure in a hard, tight crystalline rock has reduced the calculated major horizontal principal stress.

   BWIP has not incorporated the comments of its own expert review panel* in increasing the conservatism of the calculated stresses, thereby resulting in a design major or principal horizontal stress roughly 20% too low. The possible impact of this change on repository design needs to be examined.

3) It is not possible to determine the conservatism of the BWIP approach to defining "rock mass" strength from intact measurements. The procedure used is to fit the Hoek-Brown (1980) empirical strength criterion to intact compression test results to obtain an intact rock strength as a non-linear function of confining pressure (the non-linearity seems to be important only in the tensile stress region.) Next, the laboratory work of Rosengren and Jaeger (1968) is used to determine a size-strength correction factor for basalt which is applied to the Hoek-Brown criteria to arrive at a "rock mass" strength function. The size of the opening (and thereby the kinematic ability of the rock mass to fail through joint sliding) is accounted for by another reduction factor developed by Hardy and Hocking (1979)+. Therefore, a design rock mass strength is obtained from the intact strength by reduction through two factors. We are unaware of the wide spread use of the Rosengren and Jaeger and Hardy and Hocking approaches to exca-

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*Apparently, the design stresses have not been changed by RKE/PB; however, Chapter 6.0 of the SCP must be examined.

+Although quoted in the Draft SCP, this document is not available from BWIP document control.

vation design. There are no other supporting calculations using other approaches for defining strength with which to compare the conservatism of these results. For example, fairly simple failure mechanisms are evident at the site now, including spalling of boreholes. The strength obtained from these reduction factors should be checked against such a mechanism. Additionally, the use of such an approach in past underground case histories should be reviewed.

4. More data is necessary on the strength of rock joints. Testing quoted in the document showed peak friction values ranging from about 29° (from direct shear tests) to 45° (from triaxial joint tests). A simple analysis of the sliding potential of preferentially-oriented faults or joints shows that, with the non-conservative in-situ stresses, slip can occur for faults with 33° or less friction angle. This indicates that any preferably-oriented structures are very near the point of instability without the additional mining or thermally-induced stress. The document ignores the implications of the potentially low friction angle on joints.

5. The field testing (heater and jointed block) have shown distinctly anisotropic mechanical response of the rock mass. The models used in design to predict induced stresses on repository openings is isotropic and elastic. There is no discussion as to the conservatism inherent in this approach and the resulting effects on design.

6. The overall strategy for constitutive model development in basalt was not clear. It appears that a simple elastic model will be insufficient for design and performance assessment. It is apparent that BWIP plans to develop a continuum model which somehow incorporates the presence of jointing, but the framework of development of this model was not given. It is quite important how the development of new models will affect the conceptual design. Perhaps this is discussed further in Chapter 8.

7. The role which BWIP plans for empirical and analytical (or numerical) models in design and performance assessment is not clear. At the present time, empirical models and size reduction factors for strength are used in design. However, for pre- and post-closure evaluation of mechanical response to

heating, it appears that an analytical or numerical method of prediction of response will be necessary since there is no data base of full-scale response to heating. There is no discussion of the data base required of these models, how they are to be validated via in-situ data, and when their use will enter in the performance assessment and design process. It is possible that this information is covered in Chapter 8.0 of the SCP, but a detailed accounting seems necessary at this stage of model development.

8. The NSTF tests consisted of two primary sets of testing: the heater tests and the jointed block test. Little detail (proportionate to laboratory tests) is given in the write-up on these tests. For example, the analysis of the heater tests showed an inability to predict displacements in horizontal directions around the full-scale heaters. Only a small discussion (about one paragraph) is devoted to this, yet it points out a fundamental lack of understanding of the thermomechanical response of jointed basalt.

9. The method of determination of the pitch of waste canisters for the conceptual design has several problems. The following procedure was used.

   A. Calculate a maximum average temperature rise for the unit volume of rock mass surrounding one canister (i.e., that volume defined by the midplanes between canisters). This temperature rise is determined analytically from a finite line source program, SUPER7T. This calculation was reviewed by Itasca (1987c).

   B. Determine the corresponding elastic stress induced by this temperature change from $\sigma = E \alpha \Delta T$, assuming horizontal (but no vertical) confinement.

   C. Add the stress determined in (B) to the horizontal components of the field stress. Then use an isotropic elastic boundary element code to calculate stress concentrations around the emplacement drift.

D. Assume a representative volume or sample of rock in the peak of the emplacement drift with dimensions B/3 x B/6 (see Fig. 1). Determine the average stress applied to the cube. Using the rock mass strength as determined from the Hoek and Brown criteria and reduced by the Rosengren and Jaeger and Hardy and Hocking approach, compare the stress to strength. Iterate until canister spacing produces a stress change which is less than the strength.

This simplistic approach has many problems. First, it apparently is used since no coupled thermal-mechanical analytical or numerical approach was available. The greatest limitation of this approach is the calculation of the thermally-induced stresses. The determination of an average temperature rise results in spatially-uniform stresses in the horizontal plane (the vertical plane is assumed unfixed). The result is to smear out stress gradients induced by thermal gradients around the heat source and, subsequently, to reduce the stress ratios. Additionally, the tensile stresses induced around the emplacement room due to thermal expansion are not accounted for. Therefore, the result is not conservative since peak stresses will be lower and tensile stresses will not be examined. Additionally, non-conservative field stresses are used as input.

Also, the stress concentration introduced by the emplacement hole (which is one-third the room height) is not added to the induced room stresses. This will result in significant additional stress concentrations around the room periphery.

Calculations presented in Itasca (1987b) for 1.6kw canisters for the BWIP geometry indicate that the most critical location for potential instability is the drift wall at the intersection of the emplacement borehole. Transient tensile stresses are induced in a vertical and horizontal direction which could result in slabbing or spalling of the walls of the drift. This could potentially impair the retrieval of the canister.

The point of this discussion is (1) that it is possible that the simplistic analysis presented does not examine the potentially worst failure mechanisms, and (2) that the stresses used apparently are non-conservative.

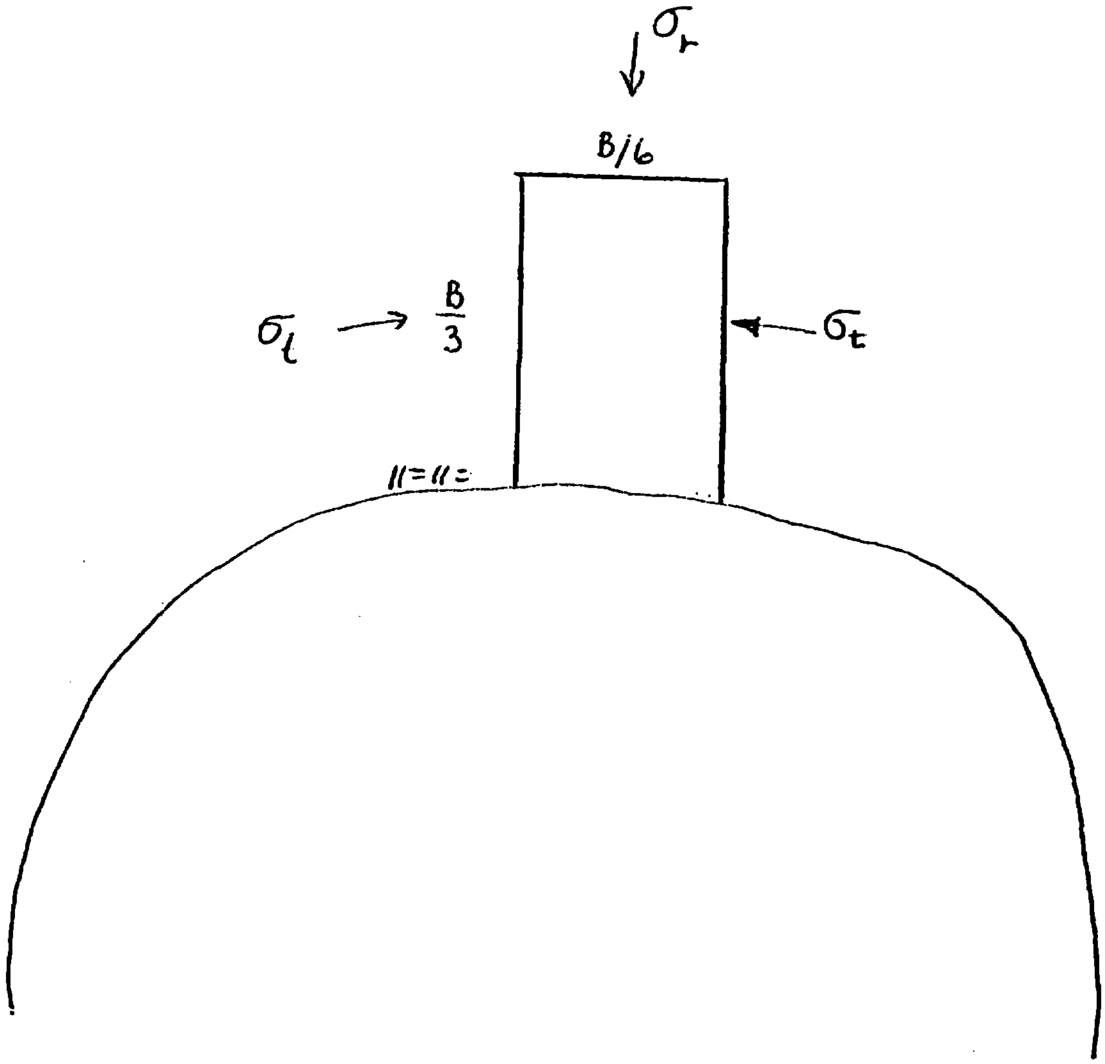

Fig. 1 Representative Volume for Rock Mass Strength Calculation

10. The case studies presented in Section 2.8, although from deep mining, may bear little resemblance to the construction at BWIP. Many irrelevant or unsubstantiated statements are made, as reviewed in the summary.

11. A potential work safety and performance problem exists in rockbursting at the Hanford site. Borehole spalling, core disking and microseismicity indicate that stresses are high enough to produce failure with excavation or fault-induced anisotropy. The document attempts to make a distinction between "rockbursting" and "spalling", where rockbursts are Richter magnitude 1.0 or greater and spalling is Richter magnitude less than 1.0. The events classed as spalling are treated as being of minor damage. There are many examples of significant damage occurring in drifts which essentially are isolated from other mining (Itasca, 1987a). It is probable that some 1.0 magnitude or less bursting will occur at BWIP, potentially at the acute angle drift intersections at panel entries as well as at the shaft bottom during drilling. The performance effects of these events are not discussed in the document. One minor point concerning the BWIP discussions on stability of openings: the negative effects of jointing on stability are downgraded by what is termed the "interlocking" nature of the jointing—however, when the discussion turns to the possible intact failure mechanisms such as rockbursting, slip on the heavily-jointed structure is cited as a means of relieving energy from the system in a non-violent fashion (Blake, 1985).

12. The data uncertainties described in Section 2.9 are reasonable. In our opinion, the uncertainties in the large-scale tests (in situ) thermomechanical response of basalt is great due to the lack of agreement obtained in the full-scale tests and in the anisotropy and non-linearities in mechanical and thermomechanical response of the block test. These uncertainties cast doubt on the use of simple models in design studies to be presented in Chapter 6.0.

13. Information needs are presented in Section 2.9. We agree with the needs identified for intact mechanical and thermal properties as well as joint properties. In general, the basic information needs for in-situ mechanical and thermal response are listed (because nearly all forms of data are listed as needs). We feel that information needs are lacking in the following areas.

1. A geotechnical description of the rock mass needs to be furnished. The results of the NSTF and the geologic mapping of the Cohassett flow from surface and core shows that the rock mass is highly variable in its structure. More emphasis needs to be placed on a basic description of the Cohassett flow and its lateral and vertical variability.

2. Concerning constructability, information needs should include the ability to drill large (14-foot plus) diameter holes in basalt at Hanford. Little emphasis is placed on demonstrating the ability to detect and seal high-pressure, high-volume water inflows.

3. Information needs on excavation stability are lacking. Although the excavation response is to be measured, the need to demonstrate the full-scale response of heated excavations, emplacement, retrieval, and support systems under varying ground conditions needs to be emphasized.

4. The establishment of confidence in the design and performance models should be emphasized in the information requirements for predictability of rock mass response.

Recommended Action

The following documents (all referenced in Chapter 2.0) should be obtained and reviewed prior to final SCP review.

1. Ames, R. R. "Cohassett Strength Criterion/Allowable Stress," RHO Computational Brief No. 00155, 1985.

2. AMI. "Thermomechanical Analysis of Full-Scale Heater Tests 1 and 2 Conducted at the Near Surface Test Facility," SD-BWI-TI-315, 1986.

3. Cramer, M. L., G. T. Berlin, R. E. Heath, and J. J. Keating. "Block Test #1 Final Report: Results from Experimental and Numerical Analyses at Elevated Temperature," SD-BWI-TD-023, 1985.

4. Cramer, M. L., and K. Kim. "Block Test #1 Interim Report: Results from Experimental and Numerical Analyses at Ambient Temperatures," SD-BWI-TD-015, 1985.

5. Hardy, M. P., and G. Hocking. "Rock Mechanics Design Criteria for a Repository in Basalt," BWIP Microfiche # 4322, 1979.

6. KE/PB. "Site Characterization Plan, Conceptual Design Report, Project B-301, Task V, Engineering Study No. 10," BWIP Microfiche # 3247, 1986.

7. Draft Chapter 6 of the SCP

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Jeffrey, J. A., T. Chan, N.G.W. Cook, and P. A. Witherspoon. "Determination of In-Sit Thermal Properties of Stripa Granite from Temperature Measurements in the Full-Scale Heater Experiments, Methodology and Preliminary Results," Swedish-American Cooperative Program on Radioactive Waste Storage in Mined Caverns in Crystalline Rock, Lawrence-Berkeley Laboratory Report LBL-8423, 1979.

Kim, Kunsoo, Steven A. Dischler, James R. Aggson, and Michael P. Hardy. The State of In-Situ Stresses Determined by Hydraulic Fracturing at the Hanford Site. RHO-BW-ST-73 P. February 1986.

Miner, G. "Cut and Fill Stoping at the Star Mine," in Underground Mining Methods Handbook, pp. 549-553. W. Hustrulid (Ed.). New York: SME-AIME, 1982.

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Pine, R. J. "Pressure Transient Analysis for Large Scale Hydraulic Injections in the Carnmenellis Granite, England," Proceedings of the 9th Workshop on Geothermal Reservoir Engineering (Stanford University, December 1983).

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