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ENGINEERS INTERNATIONAL, INC.

25 August 1986
Ref. No. 1148-007-04

Waste Management Engineering Branch
Division of Waste Management
U. S. Nuclear Regulatory Commission
7915 Eastern Avenue
Silver Spring, MD 20910

Attention: Mr. John Buckley, Mail Stop 623-SS

Subject: Contract No. NRC-02-84-002, Task Order 007 Document Reviews

Dear Mr. Buckley:

Enclosed please find the reviews of the following documents:

Baker, S. M., 1985. A Preliminary Assessment of Water Inflow into Proposed Excavations in the Cohassett Flow Interior, SD-BWI-TI-274.

Cross, R. W., and K. R. Fairchild, 1985. Geologic Thickness Data--Candidate Repository Horizons, SD-BWI-DP-011 Rev. 2.

Fredenburg, E. A., and J. C. Sonnichsen, 1985. Performance Assessment in Support of Task V Engineering Studies 5, 6 7, and 9, SD-BWI-ER-006.

Gregory, E. C., and K. Kim, 1981. Preliminary Results of Full Scale Heater Tests at NSTF, RHO-BWI-SA-123.

Mitchell, S. J., 1986. "Evaluation of Damaged Rock Zone Around Repository Openings", Computational brief.

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1148B

Sublette, W. R., 1983B. Rock Mechanics Data Package, SD-BWI-DP-041, Rockwell Hanford Operations, Richland, Washington (CRD C.5)

Vasey, J., 1983. "Design and Support of Excavations Subjected to High Horizontal Stress," Proceedings of the First International Conference on Stability in Underground Mining, C. O. Browner (ed.), American Institute of Mining, Metallurgical, and Petroleum Engineers, Inc., Vancouver, British Columbia, Canada, August 1982, pp. 429-449.

SD-BWI-TI-299, "Geoengineering Design Parameters Workshop, Proceedings of a Workshop Held in Rapid City, South Dakota". Rockwell Hanford Operations, Richland, Washington, December 1985.

If you have any questions, please call.

Sincerely,

ENGINEERS INTERNATIONAL, INC.

Amitabha Mukherjee
Senior Mining Engineer

AM/ja

Enclosure

LTR/DR
1148B

EI DOCUMENT REVIEW SHEET

FILE NO: 1148-07-04

DOCUMENT: SD-BWI-TI-274 Rev. 0, "A Preliminary Assessment of Water Inflow into Proposed Excavations in the Cohassett Flow Interior, "Rockwell Hanford Operations. Richland, Washington, June 1985.

REVIEWED BY: Engineers International, Inc.

DATE REVIEW COMPLETED:

APPROVED BY:

SIGNIFICANCE TO NRC WASTE MANAGEMENT PROGRAM

An assessment of water inflow potential in the repository workings at Hanford is necessary to support safety and feasibility evaluations of the proposed repository construction and operation.

BRIEF SUMMARY OF DOCUMENT

Scoping calculations for groundwater inflow into repository workings are presented in this document, primarily to provide supplemental information with respect to constructability siting guidelines, help guide future testing and analysis, and provide input to design and engineering of the repository excavations.

This analysis uses an assumed value of vertical conductivity for dense interiors, derived from an assessment of available hydraulic data and also assumes that all vertical conduits have been sealed. The analysis is slanted toward assessing steady date operational flow as opposed to instantaneous inflows. Two other inflow scenarios are also considered, namely encountering a fault, and intersecting a flowtop. A further simplification that has been used is that the groundwater is considered to be flowing through a porous medium and not through discrete features (fractures).

The steady state inflow calculations assume no drawdown and that the flow tops are infinite aquifers (constant head boundaries). This calculation indicates a inflow of the order of 100 gpm to a total repository area of 8 x $10m^2$. Calculations in the case where an advance borehole, or a full size drift, intersect a flow top were done. The maximum flow rate for a drift intersection was in the order of 3400 gpm which decreased to 2000 gpm within one hour of flow top penetration.

It is stated that these calculations are conservative and a properly designed sump, and pumping system will be able to handle the water inflow problem adequately.

PROBLEMS, DEFICIENCIES, LIMITATIONS OF REPORT

1. The analyses are very simplistic and does not provide any information other than some water will be encountered. It is acknowledged that information on the site conditions are limited.

2. The accident scenario analyses assumes a homogenous porous medium. However, basalt rock is not. A better approximation may have been to include the damaged rock zone in the diameter of the opening. This might have been a better approximation.

3. The validity of the equations cannot be checked for appropriateness. Moreover the function $w(\lambda)$ on Page 19, is not defined.

4. Considering a porous medium for inflow calculations is inappropriate because flow through discrete structures (fractures and joints) will yield completely different results. Therefore the results of these calculations cannot be concluded as conservative.

EI DOCUMENT REVIEW SHEET

FILE NO: 1148-07-04

DOCUMENT: SD-BWI-DP-011 Rev. 2 "Geologic Thickness Data-Candidate Repository Horizons" Rockwell Hanford Operations, Richland, Washington, March, 1985

REVIEWED BY: Engineers International, Inc.

DATE REVIEW COMPLETED:

APPROVED BY:

SIGNIFICANCE TO NRC WASTE MANAGEMENT PROGRAM

This document provides the current data on basalt flow thickness that are being used by DOE in locating a suitable repository horizon. The document will aid NRC in evaluating DOE's decisions regarding repository location.

BRIEF SUMMARY OF DOCUMENT

This data package contains information on thicknesses, intraflow structure characterizations, and descriptive comments on the Umtanum, McCoy Canyon, Cohassett, and Rocky Coulee flows. The data were obtained from study of drill core, outcrops, and polished thin sections. Geophysical logs were used to interpret intraflow structure thicknesses in rotary boreholes. The total number of sampling points is 22, namely, 20 boreholes and 2 surface sections. It is acknowledged that thicknesses at specific locations may vary considerably from predicted thicknesses because of anomalous or locally varying intraflow conditions. However, the DOE considers the data to be generally representative. The thickness summaries of the four flows are presented in Table 1.

COMMENTS ON THE REPORT

1. Present DOE plans locate the repository in the Cohassett flow, and therefore the thickness data on this flow only need be studied in detail. A study of thickness data in and around the RRL indicates a total flow thickness ranging from about 72m to about 82m (RRL only). The thickness increases from the south-west to the north east. The 200 west area is about 80m thick.

2. Since the vesicular zone will be included in finding a suitable repository horizon within the Cohassett, the total thickness of the flow below the flow top must be considered in the analysis. A study of the thickness data in and around the RRL indicates that this thickness varies from about 60m to 75m (RRL only).

Table 1: Flow Thickness Summary

Flow	Depth to Top of Flow	Total Flow Thickness	Intraflow Structures	Flow Description
Umtanum Flow	Cold Creek Syncline 2958-3723 ft (901.6-1134.9m) RRL: 3474-3723 ft (1058-1134.9m)	Cold Creek Syncline 129-285 ft (39.3-86.9m) RRL: 198.5-232 ft (60.5-70.7m)	Flow Top Thickness: 56-148 ft (17.1-45.1m) Entablature Thickness: 72-144 ft (22-48.9m) Basal Colonnade Thickness: 11-21 ft (3.4-6.4m) locally.	Dense interior is essentially a thick entablature. Flowtop breccia thickens locally at the expense of entablature thickness. Basal pillow breccia, spiracles intraflow shears/fractures, and anomalously jointed zones are present locally.
McCoy Canyon Flow	2646-3576 ft (806.5-1090m)	85-147 ft (25.9-44.8m)	Flow Top Thickness: 20-60 ft (6.1-18.3m) Entablature Thickness: 5.5-83 ft (1.7-25.3m) Basal Colonnade Thickness: 20-88 ft (6.1-26.8m)	Multiple colonnade-entablature tiers. May have internal zones of vesicular rock. Basal pillow breccia, spiracles, intraflow shears/fractures and anomalously jointed zones maybe present locally.
Cohassett Flow	2201-3092.5 ft (670.9 - 942.6m)	154 - 277 ft (46.9 - 84m)	Vesicular Zone Depth Below Flowtop: 87-118 ft (26.5-36m) Vesicular Zone thickness: 0-48 ft (0-14.6m) Basal colonnade thickness: 13-92 ft (4-28m) Dense interior thickness below vesicular zone: 65-156 ft (19.8-47.6m)	Multiple colonnade-entablature tiers. Vesicular zone continuous through RRL. Basal pillow breccia, spiracles, intraflow shears/fractures and anomalously jointed zones may be expected, although not found yet.
Rocky Coulee Flow	1966 - 2924 ft (599.2 - 891.2m)	132 - 203 ft (40.2 - 61.9m)	Flow Top Thickness: 17-81 ft (5.2 -24.7m) Interior thickness above basal colonnade: 38-137.5 ft (11.6 - 41.9m) Basal Colonnade: 15.5-46 ft (4.7-14m)	Multiple colonnade-entablature tiers. Flowtop is variable

The thickness is about 75m in the 200 west area. It is about 60m toward the southwest corner of the RRL and about 74m toward the northeast corner of the RRL.

3. The thickness of the vesicular zone within the RRL varies from about 7.3m to 8.5m. It is generally about 8m within the 200 west area.

4. The depth of the breakout horizon (ES-1) is 958m (at RRL-2). This puts the horizon about 11m below the vesicular zone.

5. A study of the corelogs for borehole RRL-2 indicates that the breakout horizon lies at the intersection of a colonnade tier and an entablature tier. The colonnade is a dark gray, coarse grained basalt with sparse vesicles. The entablature (underlying the colonnade) is a dark gray to black, medium grained basalt.

6. Barton's report on the support requirements for the repository openings (SD-BWI-ER-012) considers cases where the openings are entirely in the colonnade or entablature. A composite condition, as indicated in the previous comment, may cause stability problems not considered in the report.

7. It appears that the repository workings will remain entirely in the colonnade (considering the grade of the workings for water flow) only in the upper dense interior above the vesicular zone. However, it must be noted that the entire upper colonnade is disked indicating the highly biaxial in situ stress field may cause stability problems if repository workings were located here.

8. The lower part of the lower dense interior (depths of 970m to 980m in RRL-2) is also disked. This area consists of columnar entablature and well developed colonnade.

9. Barton's report (SD-BWI-ER-012) indicates a mild rock burst condition in the colonnade. This conclusion may be supported by the disking noticed in the colonnade portions of the Cohassett dense interior, which indicates high stress concentrations.

EI DOCUMENT REVIEW SHEET

FILE NO: 1148-07-04

DOCUMENT: SD-BWI-ER-066, "Performance Assessment in Support of Task V Engineering Studies 5, 6, 7, and 9". Rockwell Hanford Operations, Richland, Washington May 3, 1985

REVIEWED BY: Engineers International, Inc.

DATE REVIEW COMPLETED:

DATE APPROVED:

SIGNIFICANCE TO NRC WASTE MANAGEMENT PROGRAM:

This report provides DOE's assessment of the radionuclide isolation capability of the repository considering all the design alternatives that are being studied by DOE. It will provide NRC with an insight into DOE's choice of a certain combination of repository layout, shaft and tunnel sizes and configurations, and waste emplacement configurations.

BRIEF SUMMARY OF DOCUMENT

The five studies for which performance assessments are provided in this document are as follows:

- Engineering Study Number 5: Shaft Optimization
- Engineering Study Number 6: Tunneling Optimization
- Engineering Study Number 7: Waste Emplacement Optimization
- Engineering Study Number 9: Repository Underground Layout.

The assessments provided in these above documents were only preliminary and useful move for comparative assessments rather than absolute predictions.

This report compares the performance assessment of in-borehole emplacement versus in large diameter drifts using the computer codes MAGNUM-2D and CHAINT. The analyses calculated the temperature distributions, the groundwater flow patterns, concentration distribution of two radionuclides (^{129}I, ^{79}Se), and the fractional release rate and integrated mass transport at the edge of the packing or waste package boundary for the two geometries. MAGNUM-2D is a two-dimensional groundwater fluid flow and heat transport model, and CHAINT is a radionuclide transport model. The conclusions of this study are as follows:

- the calculated maximum fractional release rate for both radionuclides is greater for the in-drift emplacement configuration
- for borehole emplacement, the transport through the packing is controlled by diffusion, whereas in the in-drift configuration the controlling factor is advective transport
- the presence of the heat source creates a convective cell within the packing and the damaged rock zone in both emplacement configurations.

Performance assessment related to the tunneling optimization study evaluated the effect of the following radionuclide travel paths on the tunnel design and construction alternatives:

- all radionuclides travel radially outward through the packing, vertically through the basalt to the first flow top, and then horizontally through the flow top a distance of 10 km to the accessible environment (path through site subsystem)
- all radionuclides travel radially outward through the packing; horizontally through the damaged rock zone parallel to the boreholes placement rooms, and entry and service tunnels to the vertical shafts; vertically through the DRZ around the shafts to the first flow top; and they horizontally through the flow top a distance of 10 km to the accessible environment (path through seals subsystem).

The program REPSTAT was used to provide a quantitative basis for comparison of the alternatives in design, construction techniques and travel paths. The results of the study are as follows:

- the nonsorbed radionuclides ^{14}C and ^{129}I form the significant portion of release at the accessible environment at 10,000 years
- the release is smaller for borehole emplacement than the in-drift configuration.

The releases at 90% confidence level for the radionuclides are given in Table 1.

The differences in the number of shafts and lining compositions is not considered important with respect to performance because the principal travel path to the accessible environment is through the entablature overlying the emplacement waste, and not through the shafts (90% release through the site and 7.7% through the seals).

The performance assessment related to the repository layout evaluated the release at 10,000 years for the different layout alternatives. The fractional release rates from the waste packages were determined using MAGNUM-2D and CHAINT: the hydraulic gradient is determined at 300 years and the flow split between the seal and site subsystems are determined using the codes MAGNUM-3D and PATH-3D; the cumulative probability of release at the accessible environment for both subsystems are determined using the code REPSTAT: finally the cumulative releases are weighted using the flow split percentages determined, to obtain a measure of performance.

PROBLEMS, DEFICIENCIES, AND LIMITATIONS OF REPORT

An analysis such as this is very sensitive to the input assumptions, especially in terms of:

- temperature increases
- changes in hydraulic conductivities both due to buoyancy effects and opening of fractures
- determination of flow paths
- extent of the damaged rock zone
- changes in fracture conditions in the host rock including the vesicular zone

All these parameters appear to have been assumed in the present study.

Table 1. Releases at 90% Confidence Level

Emplacement configuration[a]	Release (EPA limits)		
	Site	Seals	Site + seals
Long hole asymmetric			
Drill and blast, partial face borer	0.442	0.015	0.457
Tunnel boring machine	0.442	0.013	0.455
Long hole symmetric			
Drill and blast, partial face borer	0.442	0.014	0.456
Tunnel boring machine	0.442	0.013	0.455
Tunnel boring machine without alcoves	0.442	0.010	0.452
Short hole	0.442	0.017	0.459
In drift, in pipe			
Drill and blast, partial face borer	1.35	0.107	1.46
Tunnel boring machine	1.35	0.101	1.45
In drift, in trench	2.16	0.062	2.22
In drift, self-shielded	1.60	0.043	1.64

NOTE: EPA = U.S. Environmental Protection Agency.
[a]See RKE/PB 1984.

EI DOCUMENT REVIEW SHEET

FILE NO: 1148-07-04

DOCUMENT: RHO-BWI-SA-123m "Preliminary Results from Full-Scale Heater Tests at the Near-Surface Test Facility," Rockwell Hanford Operations, Richland Washington, 1981

REVIEWED BY: Engineers International, Inc.

DATE REVIEW COMPLETED:

APPROVED BY:

SIGNIFICANCE TO NRC WASTE MANAGEMENT PROGRAM

The document provides an insight into DOE's experimental techniques to determine the response of the basalt rock to elevated temperatures. This property of the basalt rock is important in determining the performance of the repository both during the operational and retrieval periods, and over the long term.

BRIEF SUMMARY OF DOCUMENT

The report describes the two Full-Scale Heater Tests (FS # 1 and FS # 2) conducted at the NSTF and gives some preliminary results. Full-Size, canister scale, electric heaters are used to simulate the operating conditions around an actual canister. FS # 1 has one canister-size heater surrounded by eight peripheral heaters which simulate the effects of neighboring canisters. FS # 2 has a single canister-size heater.

Four types of instrumentation are used to monitor the changes in temperature, displacement and stress field in the surrounding rock mass. They are:

- thermocouples
- USBM borehole deformation gages (BDG)
- IRAD vibrating wire stressmeters (VWS)
- multiple position borehole extensometers (MPBX)

The expected behavior of the rock mass was precalculated using a finite-element code. The analysis assumed a transversely isotropic rockmass which behaves bilinearly elastically. Data from the tests are collected using a Data General N-600 mini computer and independent data logger systems for FS # 1 and FS # 2.

The temperature distributions are given in Figure 1. Measured temperatures are generally 20 to 25% lower than predicted. Temperature changes are influenced by water infiltration. Water infiltration generally lowers the temperature, and temperature increases correspond to increases in heater power levels and dewatering.

Displacements on MPBXs were noticed due to expansion of the rock mass. Relative displacements in vertical MPBXs are negative, indicating an increase in distance between the borehole collars and anchors. Heater power level increases correspond to increases in displacement. In general predicted displacements exceed the measured values by approximately 10%.

Borehole deformation gages and stress meters used for measuring stress changes yielded questionable data due to gage failure.

Examination of heater boreholes showed no evidence of decrepitation for temperatures at the heater liner upto 280°C. The boroscope used for this examination is inoperable above 280°C.

PROBLEMS, DEFICIENCIES, AND LIMITATIONS OF REPORT

1. The test environment is not what is to be expected at the repository horizon due to great depths, higher stress environment, changed water conditions, and greater confinement.

2. The water flow patterns in FS # 1 and FS # 2 are that mainly of surface water (above the water table) as opposed to groundwater below the water table that is expected in the repository horizon.

3. The emplacement configuration in the test is vertical, whereas the present repository design calls for horizontally emplaced canisters. Therefore the heat distribution may be significantly different.

4. The computer code used for predictions is not available for review.

5. Heater tests are necessary in the at depth test facility.

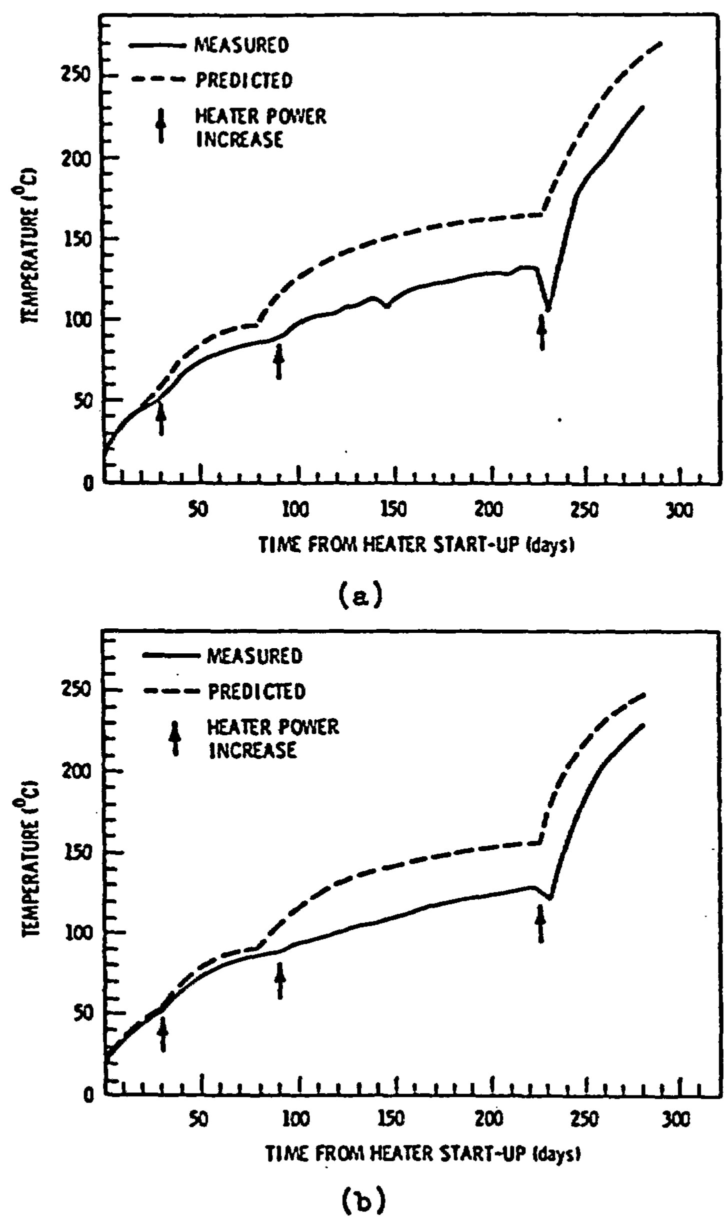

Figure 1. Comparisons of predicted and measured response after 9 months. Thermocouples are attached to vertical extensometers (a) 1E01 and (b) 1E03 located on opposite sides of the FS#1 main heater.

EI DOCUMENT REVIEW SHEET

FILE NO: 1148-07-04

DOCUMENT: Computational Brief "Evaluation of Damaged Rock Zone Around Repository Openings" S. J. Mitchell

REVIEWED BY: Engineers International, Inc.

DATE REVIEW COMPLETED:

APPROVED BY:

SIGNIFICANCE TO THE NRC WASTE MANAGEMENT PROGRAM

The document attempts to define the depth of the zone of yielded rock around underground openings. This presumably will be of greatest interest in ground support and stability considerations. It does not appear to be of interest in defining the DRZ in terms of enhanced permeability, which depends upon different mechanisms.

An appendix treats the possibility of hydraulic fracturing of cavities within the vesicular zone caused by the thermal pulse.

BRIEF SUMMARY OF DOCUMENT

The document develops rock mass failure envelopes for the dense interior and vesicular zone, and estimates stresses at depth. These are input to three forms of ground reaction curve analyses and a FEM model.

Analysis	Failure Law
Hoek & Brown (1980)	Empirical with volume dilations from associated flow rule
Daemen (1975)	Mohr - Coulomb, elastic-plastic
St. John, Van Dillen and Detournay (1983)	Mohr-Coulomb, elastic-plastic
Viscot FEM	Viscoelastic

The openings modeled are a two meter radius and a six by three meter placement room. Two of the analyses incorporate anisotropic stress fields. Thermal effects are incorporated by arbitrarily increasing the far field stresses.

The conclusion section states that the depth of the yield zone for a placement room will be 21 cm in the dense interior and three times that in the vesicular zone. Emplacement holes will yield to a depth of 1.3 and 6.3 cm in the two rock types. The results are said to be within a factor of two, and it is concluded that excavations will be stable with only minor support.

The appendix dealing with possible rupture of fluid filled cavities in the vesicular zone finds no problems.

PROBLEMS, DEFICIENCIES AND LIMITATIONS

The analyses are based on what appears to be optimistic input data. Possible problems appear in the text but are not brought out in the conclusions. When referenced in other documents, such as the Final Environmental Assessment, the document is said to be a conclusive analysis indicating that no possible problems exist.

Specific Comments

- failure envelopes for the dense interior rock mass are said to be current best estimates. They appear optimistic, and are not supported (in this document) by actual test data. As an example, page II.6 shows tensile strengths of 3.8 and 5.3 MPa in RRL-2, but uses an average strength of 11.25 MPa ± 4.8 MPa for analysis (note that the actual standard deviation is not 4.8 but 5.3 due to use of an incorrect formula)

- the technique used to estimate mass strength in the vesicular zone is not well defined. Failure curves for both dense interior and vesicular zone should be supported by presentation of triaxial data

- incorporating thermal loads by increasing far field stresses seems arbitrary and unlikely to produce realistic stress gradients

- in situ stresses in the vesicular zone have not been measured

- a four meter diameter circle is not a reasonable representation for a 3 x 6 meter room, and the FEM analysis which modeled the 3 x 6 room did not incorporate a reduced post-yield rock strength

- two analyses used reduced post-yield strength. The document states that this results in a factor of two increase in depth of yielded zone. this should be "a factor as high as 4.3", the average factor is 2.05 ± 0.75 which indicates a reasonable expectation that the underestimation of yield zone depth is perhaps a factor of three

- the FEM analysis predicts yielded depths of 21 cm (roof) 33 cm (wall) and 59 cm (floor). If these are multiplied by a factor of two or three to represent post-yield strength reduction, the numbers begin to look less insignificant. These are for the dense interior

- the FEM model of the 3 x 6 meter room was not run for the vesicular zone. The document states that the depth of yielding in the VZ would be three times that in the dense interior. Presumably, the depth of yielding in the VZ would be predicted at 63 cm (roof), 99 cm (wall) and 177 cm (floor) for a rock that does not exhibit post-yield softening

- presumably, had the FEM analysis incorporated post-yield strength reduction, it would have predicted the following depth of yielding (in cm):

	roof	wall	floor
dense interior	40-60	60-100	120-180
vesicular zone	120-180	180-300	360-540

The reviewer does believe that the analyses discussed in the document, and the stated 21 cm of yielding are reasonable. A logical interpretation would seem to indicate yielded depths on the order of meters. The analyses do not support the conclusion that underground openings will be stable with minor support. Rather, they would appear to support the observed fact that borehole spalling has enlarged originally circular boreholes to ellipses having a 2:1 diameter ratio.

RECOMMENDATIONS

The assumed failure criteria should be supported by triaxial test data. Perhaps it exists already. If so, the document should include at least some actual data.

Stresses should be measured in the vesicular zone. At the present time, one can only assume that the VZ rock is not sufficiently competent to support borehole instrumentation or packers. This is not encouraging.

FEM analyses combining thermal loading and post-yield strength reduction should be conducted. The analyses presented in the document are not considered to be realistic.

EI DOCUMENT REVIEW SHEET

FILE NO: 1148-07-04

DOCUMENT: SD-BWI-DP-041, "Rock Mechanics Data Package". Rockwell Hanford Operations, Richland, Washington, April 28, 1986.

REVIEWED BY: Engineers International, Inc.

DATE REVIEW COMPLETED:

DATE APPROVED:

APPROVED BY:

SIGNIFICANCE TO NRC WASTE MANAGEMENT PROGRAM:

The report provides rock mechanics information on the McCoy Canyon, Cohassett, Rocky Coulee, and Umtanum flows. This information is being used by DOE in the design of repository openings. This document will be useful to NRC during review of DOE repository design.

BRIEF SUMMARY OF DOCUMENT

This data package is a summary of available laboratory and field test results describing the physical, mechanical, and thermal properties of basalts at the Hanford Site. It is intended to be used for the advanced conceptual design of a repository n basalt. Data for the RRL are separated from other Hanford site data. A statistical summary of all laboratory and field test results for the RRL are also presented. The statistical summary is based on 80% confidence limits, the data distribution is normal, and the confidence intervals are based on the t distribution. The following data are presented:

- physical properties (laboratory)
- thermal properties (laboratory) (intact rock)
- strength characteristics (laboratory) (intact rock)
- elastic characteristics (laboratory) intact rock)
- in situ state of stress (field)
- intraflow structures summary (field)

In situ stress determinations were made in the Umtanum, Cohassett, McCoy Canyon, and Grande Ronde 7 flows using the hydraulic fracturing method. The range of stress in the Cohassett flow in the RRL are as follows:

- maximum horizontal stress (σ_H):52.6 - 76.7 MPa
- minimum horizontal stress (σ_H):30.3 - 35.7 MPa
- vertical stress (σ_V):23.0 - 25.4 MPa
- stress ratios (σ_H/σ_V):2.28 - 3.09
- orientation of σ_H:N28°E - N19°W
- depth of measurement:921-1,018 m

The physical and mechanical properties of intact RRL basalt were obtained from boreholes located within the RRL and are classified as flow top/breccia, vesicular, entablature, and colonade. The range of properties for Cohassett flow are given in Table 1.

Failure envelopes were developed by analyzing the uniaxial and triaxial compression tests results using the least squares linear regression method. The envelopes are presented only for the entablature and colonnade portions of the flows. The Hoek and Brown, and Mohr-Conlomb failure criteria were used. The Hoek and Brown criterion was deemed appropriate for characterizing basalt strength.

Physical and mechanical property data for Hanford site basalts outside the RRL have also been presented. Coefficient of friction of joints were determined by triaxial joint tests on samples located in the Umtanum flow and outside the RRL. The values were of the order of 45° at both ambient and elevated temperature conditions.

Thermal property testing of intact samples from Cohassett, Umtanum, and Pomona flows between temperatures of 20 to 173.4°C indicated a significant dependence of heat capacity on temperature. No significant temperature dependence was found for thermal conductivity or the coefficient of thermal expansion. The data are for samples located outside the RRL.

PROBLEMS, DEFICIENCIES, AND LIMITATIONS OF REPORT

1. The physical and mechanical property data presented in this report are for intact rock only. The data presented should include all discontinuity information such that rock mass strength can be estimated for engineering purposes.

Table 1. Physical and Mechanical Properties of Intact Cohassett Flow in the Reference Repository Location

Intraflow structure	Uniaxial compressive strength (MPa)	Bulk density (g/cm³)	Young's modulus (static) (GPa)	Poisson's ratio (static)	Brazilian tensile strength (MPa)	Modulus of rupture (MPa)
Flowtop/breccia						
Number of samples	10	26	2	2	15	--
Mean	62 08	2.27	31.78	0.195	6.47	--
Standard deviation	21.12	0.125	4.87	0.0778	2.23	--
Range	18 70 - 97 60	1 92 - 2.47	28 34 - 35.23	0.14 - 0.25	2.65 - 11.94	--
80% confidence interval	52 84 - 71.31	2 24 - 2.30	21.18 - 42.39	0.026 - 0.364	5.70 - 7.24	--
Vesicular						
Number of samples	9	21	4	4	8	--
Mean	163 64	2 62	51.43	0.287	10.05	--
Standard deviation	55.21	0.106	5.56	0.0567	3.10	--
Range	70.13 - 244 38	2 45 - 2.77	45.02 - 56.13	0.21 - 0.33	6.25 - 14 24	--
80% confidence interval	137 93 - 189.35	2.58 - 2.65	46.88 - 55.99	0.24 - 0.33	8.50 - 11.60	--
Entablature						
Number of samples	25	84	49	49	23	1
Mean	320 93	2.84	76.37	0.256	14.99	42.11
Standard deviation	67.53	0.031	5.59	0.0173	3.76	--
Range	214.74 - 416.66	2.72 - 2.89	62.88 - 85.74	0.22 - 0.30	8.37 - 23.24	--
80% confidence interval	303.13 - 338 70	2 84 - 2.85	75.34 - 77.39	0.253 - 0.259	13.95 - 16 03	--
Colonnade						
Number of samples	20	90	45	45	30	2
Mean	317 52	2.82	72.36	0.249	16.85	39.31
Standard deviation	47.35	0 061	7.04	0.0172	3.71	4.89
Range	214 06 - 375 40	2 64 - 2 89	51.78 - 86.67	0.20 - 0.28	8.24 - 25.21	35.85 - 42.77
80% confidence interval	303 49 - 331.55	2.81 - 2.83	71.02 - 73.71	0.246 - 0.253	15.95 - 17.73	28.67 - 49.95

Table 1. Physical and Mechanical Properties of Intact Cohassett Flow in the Reference Repository Location (continued)

Intraflow structure	Young's modulus (dynamic) (GPa)	Shear modulus (dynamic) (GPa)	Bulk modulus (dynamic) (GPa)	Poisson's ratio (dynamic)	Grain density (g/cm³)	Apparent porosity (%)	Total porosity (%)
Flowtop/breccia							
Number of samples	2	2	2	2	7	26	7
Mean	53.85	21.75	34.3	0.235	2.91	13.16	23.3
Standard deviation	4.454	1.909	1.838	0.0071	0.0521	3.364	5.19
Range	50.7 - 57.0	20.4 - 23.1	33.0 - 35.6	0.23 - 0.24	2.86 - 3.01	5.0 - 18.8	16.8 - 29.5
80% confidence interval	44.15 - 63.54	17.59 - 25.90	30.30 - 38.3	0.219 - 0.250	2.88 - 2.94	12.28 - 14.02	20.46 - 26.11
Vesicular							
Number of samples	8	8	8	8	6	21	6
Mean	52.05	21.19	32.86	0.222	2.92	5.19	12.21
Standard deviation	10.08	3.516	11.50	0.0430	0.0150	2.44	2.75
Range	39.8 - 65.9	17.16 - 26.20	19.2 - 53.1	0.16 - 0.30	2.90 - 2.94	1.6 - 10.1	7.2 - 14.8
80% confidence interval	47.01 - 57.1	19.43 - 22.95	27.10 - 38.61	0.200 - 0.244	2.91 - 2.93	4.48 - 5.90	10.55 - 13.87
Entablature							
Number of samples	73	73	73	73	21	84	21
Mean	77.24	31.16	49.81	0.240	2.92	1.54	2.80
Standard deviation	5.818	2.247	5.864	0.0207	0.0212	0.838	1.047
Range	60.8 - 86.0	24.0 - 35.0	33.6 - 60.3	0.17 - 0.31	2.87 - 2.97	0.4 - 5.2	1.37 - 5.10
80% confidence interval	76.37 - 78.11	30.82 - 31.49	48.93 - 50.69	0.236 - 0.243	2.91 - 2.93	1.44 - 1.68	2.5 - 3.10
Colonnade							
Number of samples	77	77	77	77	29	90	28
Mean	75.01	30.25	48.53	0.240	2.94	2.48	4.38
Standard deviation	6.288	2.546	6.20	0.0239	0.0333	1.71	1.902
Range	55.10 - 84.20	22.6 - 35.5	30.4 - 63.8	0.15 - 0.30	2.88 - 3.01	0.3 - 8.9	1.7 - 10.1
80% confidence interval	74.09 - 75.93	29.88 - 30.62	47.63 - 49.43	0.236 - 0.243	2.93 - 2.95	2.24 - 2.71	3.91 - 4.85

Note: Data taken from Hulstrom and Hanson (1985a, pp. 10-14; 1985b, pp. 10-13, 19; 1985c, pp. 11-15, 18-19).

2. From a purely theoretical point of view, the number of samples used to determine the statistical summaries is inadequate. Such values must be used with care in repository design.

3. Thermal properties presented are from tests conducted on samples outside the RRL and located in the Umtanum flow. These properties may be similar to the Cohassett flow materials although no tests have been conducted. Also the behavior of the vesicular zone under heated conditions is not known.

4. The failure envelopes have been developed for ambient temperature conditions only.

EI DOCUMENT REVIEW SHEET

FILE NO: 1148-07-04

DOCUMENT: Vasey, J., 1983. "Design and Support of Excavations Subjected to High Horizontal Stress, "Proceedings of the First International Conference on Stability in Underground Mining," C. O. Browner (ed.), American Institute of Mining, Metallurgical, and Petroleum Engineers, Inc., Vancouver, British Columbia, Canada, August 1982, pp. 429-449.

REVIEWED BY: Engineers International, Inc.

DATE REVIEW COMPLETED:

DATE APPROVED:

SIGNIFICANCE TO NRC WASTE MANAGEMENT PROGRAM

This report is a case study of mining in a highly biaxial in situ stress environment similar to BWIP conditions. This report may therefore be of significance in determining the level of design necessary for BWIP excavations.

BRIEF SUMMARY OF DOCUMENT:

This report is a case study involving the excavation of a crusher chamber in a copper mine in South Africa at a depth of 1613m below surface under biaxial in situ stress conditions.

The rock mass properties are as follows:

Rock Type: gneissose, quartz-feldspar-biotite granite, foliation striking N 45°E and dipping 30° to 45° SE; rock is isotropic, homogeneous, and elastic.

Uniaxial Compressive Strength: 237 MPa

spacing is 10 m (average); subsets are spaced a few centimeters apart; joints are tight and coated with a calcite veneer several millimeters thick.

Joints: Parallel sets striking N20° W and dipping 72° W;

In Situ Stress Field: The major principal stress is horizontal, is oriented at N 38° W, has a value of 90 MPa, and is twice the vertical stress (45 MPa); the intermediate principal stress (horizontal) has a magnitude of 45 MPa.

The presence of the stressfield was exemplified by spitting and bursting during shaft sinking, particularly at the shaft bottom.

Also, during mine development, it was found that the drives deteriorated as their orientation changed from parallel to normal to the maximum horizontal stress component. The roof of the drivage became unstable and fractures developed parallel to the sidewalls from the upper corners of the drive, causing large wedges to loosen. Exploratory core drilling through the crusher chamber location indicated a rockmass rating of Class II (Geomechanics system).

The layout of the crusher chamber was designed such that the majority of the openings are oriented parallel or subparallel to the maximum stress direction. Also, the rule of thumb that states that the separation of adjacent excavations should be twice the diameter of the first plus twice the diameter of the second, was used as far as possible. All drives were excavated with smooth corners. Drives which are normal to the maximum principal stress direction, were excavated to the failure profile. The joints sets are subparallel to the longer axis of the excavations; therefore the sidewall slabbing was prevented by bolting.

A two-dimensional boundary element computer program was used to predict the state of stress due to the excavation. The computer simulations indicated that an arched roof, based on an ellipse with a 2 to 1 axis ratio (longer axis parallel to maximum principal stress), will ameliorate the effects of the primitive stress. However, the side walls parallel to the direction of the major principal stress, were shown to be prone to buckling especially due to the presence of the the joint planes. It was estimated that the side walls could be affected to a depth of at least two meters.

The crusher chamber excavation (Figure 1) commenced with the excavation and support of a top slice, by slashing from an access drive to the final wall positions. The remainder of the chamber was excavated by blasting a central slot from the top slice to a heading at the floor elevation of the chamber, and benching the walls back to their final locations. Details of the top slice support system are given in Figure 2 and Table 1. The sidewalls were initially supported with a 1.5 by 1.5m pattern of 3 m long, 20 mm diameter, resin grouted steel reinforcing bars with plates. Finally, the support density was doubled and mesh and shotcrete were installed. Inspection of the Crusher Chamber walls revealed that there was a failed layer of rock, varying in thickness from 0.5 m to 1.0 m. It was decided not to remove this layer but to stabilize it with rockbolts, because it was thought that if the confining effect of the failed rock was lost, by removing this layer, the newly exposed walls would commence scaling under the influence of the stress.

Difficulty was experienced installing the 3 m reinforcing bars through the failed rock layer. When a drill hole was completed and the drill steel withdrawn, a slab or rock, at some point along the hole, would move down cutting off the back of the hole. This problem was solved by first drilling a short hole into which a split set was

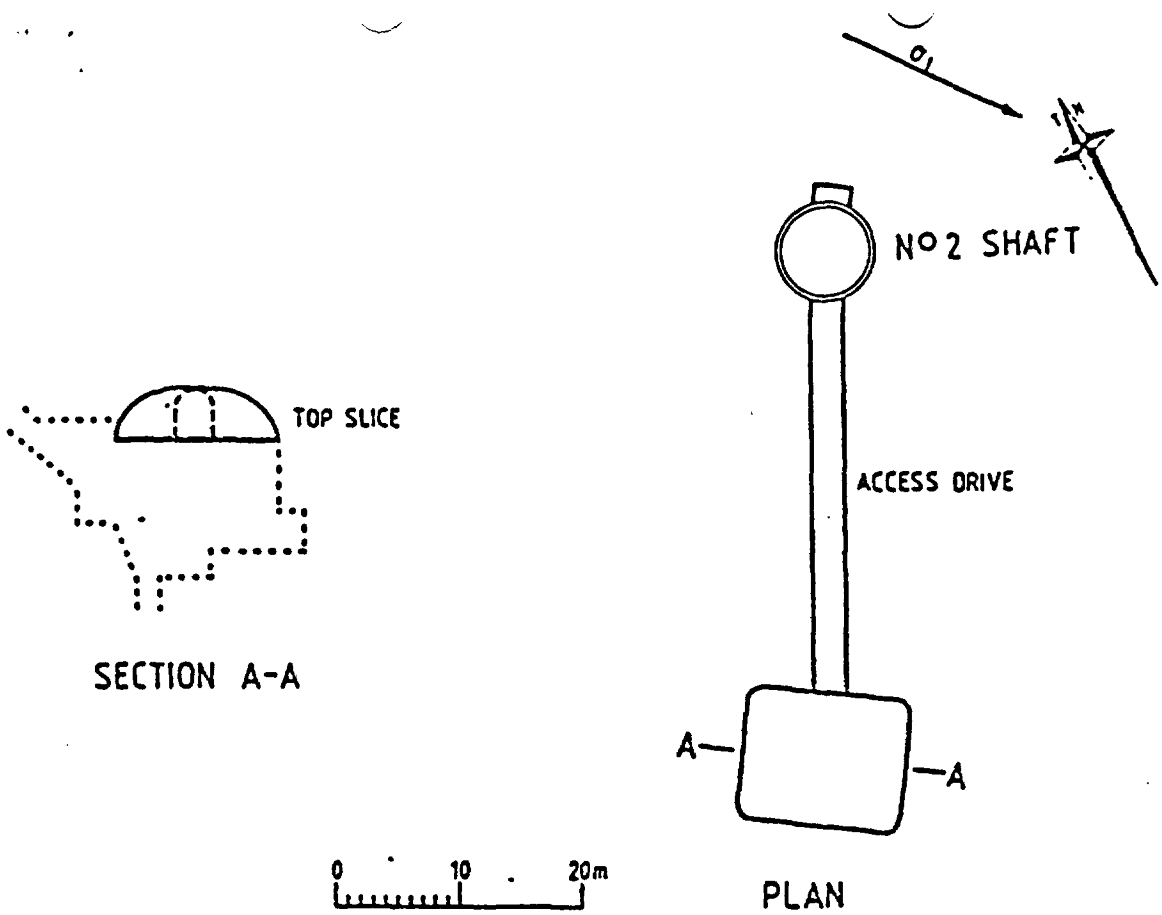

Figure 1. Crusher Chamber Top Slice (1605m Level).

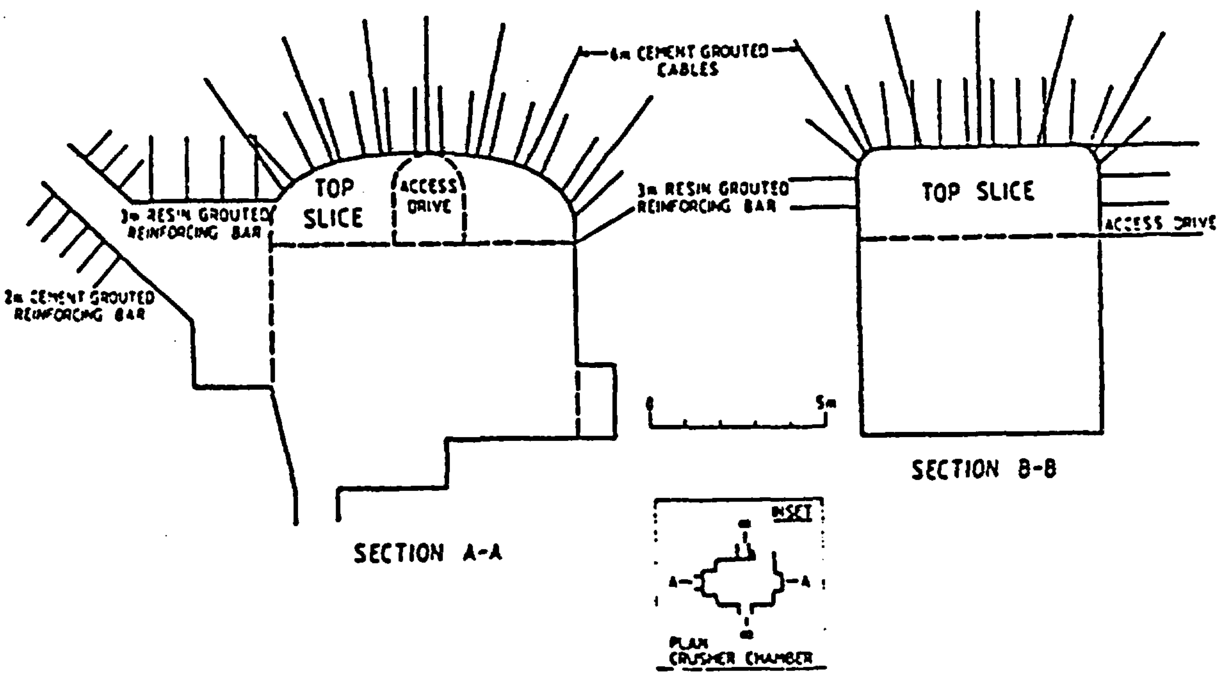

Figure 2. Crusher Chamber Top Slice Support.

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TABLE 1. Details of [illegible] pport

Support Type	Grout	Specifications	Length m	Spacing m x m
Untensioned Grouted Cable	Cement	1:0.37 cement/water ratio 24mm dia. 6 x 7/1 x 7WMC ungalvanised, grease free. 406KN breaking force.	6	2 x 2.5
Steel Re-inforcing Bar and Plate	Resin Capsules	20mm dia. 450 MPa breaking strength	3	1.1 x 1.1
Weldmesh		50 x 50 mm, 2.5mm dia. wire galvanised		
Shotcrete		25mm minimum thickness		

installed, and then drilling a parallel hole close by into which the 3 m reinforcing bar could be installed successfully. The permanent support work was completed by meshing and shotcreting all the walls.

PROBLEMS, DEFICIENCIES, LIMITATIONS, OF REPORT:

1. This document is partially applicable to BWIP due to the biaxial stress condition, however the size of the excavation is much larger than those planned at BWIP.

2. BWIP is going to experience severe problems in excavating drifts perpendicular to the maximum horizontal stress. A special problem may arise in keeping the storage holes open until canisters are emplaced.

3. The effect of heat may cause additional slabbing from the walls of the storage rooms causing problems during the retrievability period.

4. BWIP has been designed using median in situ stress values. In view of he above problems, the design should use extreme values so that the remedial measures that may be necessary are minimized.

5. Barton's analyses indicate a rock burst condition in the dense interior. This is due to the interlocking nature of the columnar jointing. However, failures are to be expected in the vesicular zone due to the lower rock strength.

EI DOCUMENT REVIEW SHEET

FILE NO: 1148-07-04

DOCUMENT: SD-BWI-TI-299, "Geoengineering Design Parameters Workshop, Proceedings of a Workshop Held in Rapid City, South Dakota." Rockwell Hanford Operations, Richland, Washington, December 1985.

REVIEWED BY: Engineers International, Inc.

DATE REVIEW COMPLETED:

APPROVED BY:

SIGNIFICANCE TO NRC WASTE MANAGEMENT PROGRAM:

This report provides NRC an insight into DOE's present thinking and recommendations for further research for the determination of the in situ stress and strength of the basalt rock mass at the Hanford site. Comments on the present status of these determinations and recommendations for further studies have been provided by leading rock mechanics experts.

BRIEF SUMMARY OF DOCUMENT:

This document presents a discussion on the state of in situ stress and the strength of the basalt rock mass at the Hanford site, undertaken in a workshop held in Rapid City, South Dakota.

Specific questions that were discussed are as follows:

- whether the present understanding of the stress and strength parameters are adequate for preliminary repository design
- what values of the parameters should be used in current design studies
- what additional information is necessary and how can they be obtained.

The final comments of the panelists are listed below. The consensus position on the state of in situ stress are as follows:

- hydraulic fracturing is the only method for determining in situ stress condition prior to ES construction and provides reasonably reliable values of in situ stress

- hydraulic fracturing methods indicate the presence of high horizontal stresses and this result is consistent with other observations as core disking, borehole spalling, and seismic activity

- all data from all tests must be included

- alternative methods of interpreting hydraulic fracturing data should be used and submitted for independent peer review, albeit the ultimate result may not change significantly

- extreme values of the in situ horizontal stress should be used in design studies to maintain conservatism

- the values for in situ stress may change due to the work recommended above. However, final design should be based on results of tests conducted in the proposed repository horizon.

The consensus position on the strength of the basalt rock mass are as follows:

- specific recommendations regarding the rock mass strength relationships and values to be used for preliminary design of underground excavations must be included with currently reported rock mass strength values

- the Hoek and Brown criterion is not appropriate for design of excavations because of intense jointing and tight interlocking. Development of alternative approaches is necessary. Based on field measurements, coefficients in existing relationships may be revised

- the use of the Rosengren and Jaeger analog for fractured rock is a reasonable approach to adopt, however the results should be substantiated by an improved discussion of the characteristics of the fractured rock mass

- It is essential to obtain joint data for the rock mass, so that representative structural models of the jointing can be developed.

- strength determination methods must be consistent with currently observed behavior of the rock mass, such as borehole spalling and seismic activity

- simple elastic analyses provide conservative results when applied to repository design. More complex methods cannot be applied without in situ observations. Detailed analyses of excavation shapes should be performed to try to achieve optimum shapes around which the rock mass strength is nowhere exceeded

- mechanistic approaches to the design of a repository that specifically include non-linear rock mass response should also be investigated

- any relevant case histories of excavations in basalt, particularly where there are high stresses, borehole spalling, and core disking, should be documented and estimates of strength obtained from the above recommendations should be shown to be consistent with the above case histories.

PROBLEMS, DEFICIENCIES, AND LIMITATIONS OF REPORT:

1. Based on the current position taken by DOE regarding the inclusion of the vesicular zone within the proposed candidate repository horizon (Cohassett flow), in situ strength and stress determinations are necessary within this zone.

2. Evaluation of suitable excavation shapes within the vesicular zone is necessary.

3. Recommendations regarding strength determinations in the report mention reporting data on case histories of basalt excavations in the high strength environment. This recommendation may be difficult to meet. Cases of high biaxial stress field excavations are however present.

4. The recommendations in the report do not mention the inclusion of heat effects specifically.