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Nevada Nuclear Waste Storage Investigations Project

**Technical Correspondence in Support
of the Site Characterization Plan**

Francis B. Nimick

Prepared by
Sandia National Laboratories
Albuquerque, New Mexico 87185 and Livermore, California 94550
for the United States Department of Energy
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Abstract

This document is composed of two technical memorandums containing information that has been referenced in the Site Characterization Plan for the Nevada Nuclear Waste Storage Investigations (NNWSI) Project. The NNWSI Project is characterizing the Yucca Mountain site on the Nevada Test Site (NTS) to study the feasibility of constructing a high-level waste repository in the Topopah Spring Member of the Paintbrush Tuff. The information pertains to the following subject areas: (1) the potential for thermal degradation of the Topopah Spring tuff; and (2) updated data analysis for Goodman Jack tests performed in G-tunnel on the NTS.

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FOREWORD

This document contains two separate technical memorandums supporting information in the Site Characterization Plan (SCP) for the Nevada Nuclear Waste Storage Investigations Project which is studying the feasibility of constructing a high-level nuclear waste repository at Yucca Mountain in Nevada. The memorandums are collected in this report as a convenient means of providing referenceable, previously unpublished information cited in the SCP. The SCP is to be published by the Department of Energy and was not completed at the time this collection of technical correspondence was assembled.

Francis B. Nimick
NNWSI Geotechnical Project Division
Sandia National Laboratories

April 1987

INTRODUCTION

The Nevada Nuclear Waste Storage Investigation (NNWSI) Project currently is investigating the feasibility of disposing of high-level radioactive waste in volcanic tuff. The proposed repository setting is in a densely welded tuff known as the Topopah Spring Member of the Paintbrush Tuff. Design and performance assessment of a repository require data relevant to predicting the thermal and mechanical behavior of the welded tuff and its response to the presence of underground openings and to waste-generated heating. The two memorandums which comprise the body of this report contribute such data.

The first memorandum discusses the potential for thermal degradation of the Topopah Spring Member. Degradation here is taken to mean the creation of new microcracks and/or permanent increases in preexisting microcrack porosity resulting from exposure of the rock to elevated temperatures. The information is important to design because of the relationship between porosity and mechanical properties of the rock. The information is also required for performance assessment because the hydrologic properties of the rock are a function of porosity.

The second memorandum provides an analysis of data collected from tests with a Goodman jack conducted in the Grouse Canyon Member in G-Tunnel on the Nevada Test Site. The analysis uses techniques developed since the results of the tests were published in 1982. The information is important to the design process because of the need to extrapolate laboratory-obtained mechanical properties to in situ conditions. Such an extrapolation for welded tuff has been attempted only for the Grouse Canyon Member, and the usefulness of the extrapolation depends on the accuracy of both the laboratory-measured and the field-measured data.

The major results of the work discussed in the two memorandums are the following:

- rapid heating of saturated samples of the Topopah Spring Member to a temperature of 225°C does not result in any permanent changes in the microstructure of the rock

- changes in the strength and permeability of the Member as a result of heat-induced microcracking are expected to be negligible for temperatures $\leq 225^{\circ}\text{C}$
- the recalculated mean value of the deformation modulus for the Grouse Canyon Member lies in the range of 14.7 to 17.6 GPa, compared to a mean value of 10.64 GPa calculated from the tests in 1982.

**VERY NEAR-FIELD THERMAL DEGRADATION
IN TOPOPAH SPRING TUFF**

S. J. Bauer and B. M. Schwartz

Note: In Table 1 of this memorandum, U.S. Geological Survey Open-File Report 83-723 is cited. Complete information for the citation is not provided in the memorandum, and is as follows:

Maldonado, F., and S. L. Koether, 1983, "Stratigraphy, Structure, and Some Petrographic Features of Tertiary Volcanic Rocks at the USW G-2 Drill Hole, Yucca Mountain, Nye County, Nevada," U.S. Geological Survey Open-File Report 83-732, Denver, CO.

Sandia National Laboratories

Albuquerque, New Mexico 87185

date: May 6, 1985

to: J. R. Tillerson, 6314

from: 
S. J. Bauer, 6314 and B. H. Schwartz, 6313

subject: Near-Field Thermal Degradation in Topopah Spring Tuff

Purpose: The potential was considered for near-field thermal degradation of densely welded Topopah Spring Tuff resulting from emplacement of contained hot nuclear waste in cold, partially to fully saturated ambient temperature rock.

Introduction: Emplacing hot waste in relatively cold (30°C), wet (80 percent saturated) tuff produces a geologically instantaneous thermal load on the rock-water system. Both uniform and non-uniform temperature changes and development of thermal stresses result (Timoshenko and Goodier, 1970). Certain phenomena, including mineral phase changes, dehydration phenomena, and mineral expansion, are the consequence of a uniform temperature change. Their sum total effect has been quantified by numerous thermal expansion measurements (c. f. Lappin [1980]). Each of these phenomenon can promote intergranular thermal stresses resulting from grain-scale mismatches in relative thermal expansion coefficients. Thermal cracking is minimal in the tuff because of its fine grain size. Ceramicists have long recognized this grain-size effect (Kingery et. al., 1976), and since intergranular stresses should be independent of grain size, Kuszyk and Bradt (1973), suggest that microcracks can develop only when sufficient strain energy is released to form new surface area. In a single grain, strain energy is a function of volume (L^3) whereas fracture energy is a function of area (L^2).

A nonuniform temperature change (temperature gradient) will generate a stress field in a solid whenever differential thermal expansion or contraction cannot proceed freely (Timoshenko and Goodier, 1970). (Think of the fracture of certain glasses when its surface is heated rapidly, or the fracture of an ice cube when it is put in a glass of water.)

The thermomechanical loading hypothesized in a repository is the consequence of both uniform and nonuniform heating. It can be shown that they are interdependent phenomena (Johnson and Gangi, 1981).

Our purpose here is to extend our understanding of possible, near-field thermal effects and then speculate on subsequent effects they may have on

the mechanical and transport properties of tuff. For the hand specimen scale, both of these classes of properties are somewhat dependent upon crack and pore characteristics (size, shape, density, interconnectivity, etc.). Our task was to examine relative changes in porosity characteristics before and after thermal treatment which we believe is similar to that for rock in the near-field as a result of waste emplacement. Sample size was chosen by convenience of availability and is less than desirable for observed fracture spacing.

In a preliminary fashion we can idealize the state of stress in the immediate vicinity of a borehole (especially one oriented horizontally) to be similar to that of an infinite plate with a circular hole in uniaxial compression (p). The radial stress component is everywhere 0 MPa at the hole wall. Tangential stress at the hole wall ranges from $-p$ to $3p$ depending on location with respect to the applied stress. If the superposed in situ horizontal stress is not greater than p , a "0 MPa" state of stress is then predicted for somewhere on the borehole wall (0 must be crossed in going from a $(-)$ to a $(+)$ state of stress). It is therefore reasonable to consider an ambient experimental confining pressure (0.1 MPa) as being realistic.

We can consider one extreme of the thermal loading to be a near instantaneous imposition of 225°C upon the rock. The in situ moisture state is estimated to be 80 percent saturated; we choose for convenience, however, to use an initial moisture state near 100 percent saturated, according to the attached procedure for this scoping experiment.

Densely-welded Topopah Spring tuff samples, in the above saturation state, were placed in an oven preheated to 225°C and allowed to heat up and de-water at a rate which depended on at least the heat capacity, thermal conductivity, and permeability. Because of the dynamic nature of the experiment, these three rock properties were probably not constant with time (temperature). The rate of drying (flow out of the sample) also depends on the driving pressure, water viscosity, and surface tension (all temperature dependent). Hypothetically, if the rock-water system heated fast enough, it is conceivable that cracks could initiate and extend from trapped water owing to its thermally-induced volume expansion due to liquid vaporization. An upper limit to the pressure buildup within a pore is the tensile strength of a grain boundary which intersects the pore. Whereas we have no means to measure this strength directly, we are assured that the adhesive strength of the inter-minerallic interfaces is often significantly lower (50 percent) than the cohesive strength of adjacent phases (Savanick and Johnson, 1974). Recent direct measurements of the tensile strength of intact tuff indicate a range of 2 to 7 MPa to be representative (Olsson, personal communication). Consequently, the grain boundary strengths we may encounter could range from about 1 to 3.5 MPa. A temperature of 160° to 180°C could generate an "internal" pressure on the order of this assumed grain boundary strength. If this situation existed and new cracks were generated, it is likely that a measure of them would be obtained in (1) a relative change in total porosity and (2) a relative change in the

"average rate" of saturation, as discussed below. Whereas the above two measures are by no means rigorously quantitative, changes in them would provide impetus to pursue the subject.

Experimental Procedure: The samples were selected from unused test specimens previously machined for mechanical testing. The samples were rejected for mechanical testing due to the presence of fractures, chips and other defects present. Sample information is shown in Table 1.

A flow diagram of the experimental procedure is also shown in Figure 1. The vacuum saturations were performed in a vacuum approximately equal to the vapor pressure of water and the pressure saturations were performed under a pressure of approximately 14 MPa. Dry weights used in the percent moisture content calculations were those obtained during Step 3 (Thermal Shock and dry).

The original data sheets are in a Bulk Properties Notebook maintained by Barry Schwartz. Copies of the data sheets have been sent to the NNWSI CF File, as defined in QAP XI-9, Rev. A.

Summary and Implication of Results: Measurements have been made of the saturated percent moisture content (PMC) of densely welded Topopah Spring tuff before and after thermal treatment. The PMC is an indirect measure of the volume of interconnected pore space in a sample. A change in the PMC after thermal treatment is therefore indicative of a relative change in either the volume and/or interconnectivity of the pore space. A laboratory determination of experimental error in weighing saturated densely welded tuff was performed by Schwartz on July 7, 1983. The data, which was obtained through ten replicate weighings, show that the standard deviation (as a percentage of sample weight) was $\pm 0.023\%$. Within the range of experimental error, no change in the PMC was obtained (Table 2). A few tenths of a percent volume change have been measured for uniform heating of granite (Bauer and Handin, 1983). We therefore conclude that (1) if new void space (cracks) was induced in the rock, it was of insufficient magnitude to be measured, and (2) if new cracks were induced they did not act to enhance interconnectivity to previously isolated void space. From these conclusions we can further speculate that upon heating the saturated densely welded Topopah Spring tuff, anomalously high pore pressures resulting from water trapped in voids (on the order of the tensile strength of grain boundaries as a maximum) were never generated. This could mean that either all pore space was initially well interconnected and/or high temperatures facilitated fluid flow (by decreasing water viscosity and opening preexistent cracks). It is expected that cracks reopened under such conditions would open only enough to release internal pressures, and would subsequently close, in that other portions of the rock retain their integrity (see above: minimal thermal cracking). Also, the "completeness" of crack closure is facilitated by how well the two surfaces are mated. The tensile nature of hypothesized cracking would tend to foster well-mated surfaces. The PMC would therefore remain unaffected. If we consider this experiment representative of short-term thermomechanical loading on the microscale, we can further speculate that no permanent microstructural damage is to be expected in the very near field. Furthermore, changes in matrix strength or permeability (two microcrack sensitive material properties) are not expected due to near-field thermal degradation.

TABLE 1
Sample Information

Hole ID	Depth Interval(Ft)	Sample ID	Diameter (inches)	Length (inches)	Description*
USW G-2	1274.7-A	1	0.991	2.003	Densely welded, devitrified, 30-40% lithophysae.
USW G-2	1274.7-C	2	0.996	2.009	Densely welded, devitrified, 30-40% lithophysae.
USW G-2	949.6-A	3	0.996	2.005	Densely welded, devitrified, 20-30% lithophysae.
USW G-2	1587.-A	4	0.996	2.005	Densely welded, devitrified, 2-5% lithophysae.

*From United States Geological Survey (USGS) open file report 83-732.

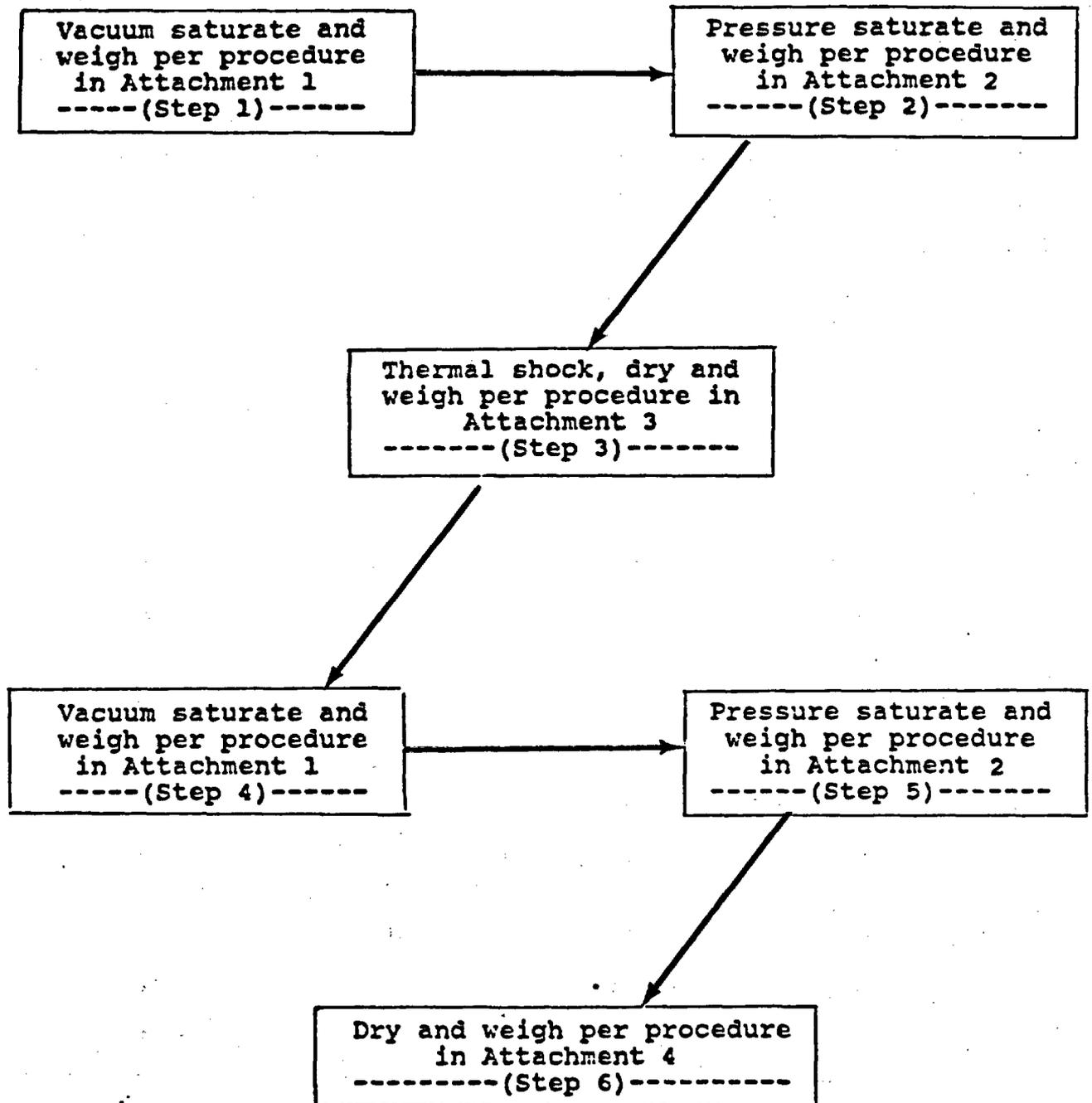


Figure 1. Experimental Procedure Flowchart

Table 2
Moisture Content Determination

<u>Procedure</u>	<u>x Weight¹</u> <u>(gms)</u>	<u>% Weight</u> <u>change</u>	<u>% Moisture²</u> <u>content</u>
Hole ID <u>USW G-2</u> Depth Interval(ft) <u>1274.7-A</u> Dry wt (gm) <u>56.35</u>			
Vacuum Saturation³			
Step 1			
Phase I	59.10 ± 0		4.88
Phase II	59.085 ± .015	-.025	4.85
Phase III	59.08 ± .01	-.008	4.84
Pressure Saturation			
Step 2			
24 Hrs	59.08 ± .01	0	4.84
48 Hrs	59.06 ± .01	-.030	4.81
Vacuum Saturation³			
Step 4			
Phase I	59.985 ± .005		4.68
Phase II	59.02 ± 0	+.058	4.74
Phase III	59.025 ± .005	+.008	4.75
Pressure Saturation			
Step 5			
24 Hrs	59.065 ± .015	+.070	4.82
48 Hrs	59.06 ± 0	-.010	4.81

¹Mean of two weighings ± mean variation

²Percent Moisture Content = $\frac{\text{Saturated wt} - \text{Dry wt}}{\text{Dry wt}} \times 100$

³See Attachment 1 for explanation of vacuum saturation phases

Table 2. (cont'd)

Moisture Content Determination

Procedure	x Weight ¹ (gms)	% Weight change	Hole ID
			USW G-2
			Depth Interval(ft)
			1274.7-C
			Dry wt (gm)
			55.09
Vacuum Saturation³			
Step 1			
Phase I	57.735 ± .005		4.80
		+0.043	
Phase II	57.76 ± 0		4.85
		-0.029	
Phase III	57.745 ± .005		4.82
Pressure Saturation			
Step 2			
		0	
24 Hrs	57.745 ± .005		4.82
		-0.03	
48 Hrs	57.73 ± 0		4.79
Vacuum Saturation³			
Step 4			
Phase I	57.685 ± .005		4.71
		+0.069	
Phase II	57.725 ± .015		4.78
		+0.009	
Phase III	57.73 ± 0		4.79
Pressure Saturation			
Step 5			
		+0.08	
24 Hrs	57.775 ± .005		4.87
		-0.02	
48 Hrs	57.765 ± .005		4.86

¹Mean of two weighing ± mean variation

²Percent Moisture Content = $\frac{\text{Saturated wt} - \text{Dry wt}}{\text{Dry wt}} \times 100$

³See Attachment 1 for explanation of vacuum saturation phases

Table 2. (cont'd)

Moisture Content Determination

Procedure	x Weight ¹ (gms)	% Weight change	Hole ID	USW G-2
			Depth Interval(ft)	949.6-A
			Dry wt (gm)	57.39
Vacuum Saturation³				
Step 1				
Phase I	59.985 ± 0			4.52
Phase II	60.045 ± .005	+ .100		4.63
Phase III	60.055 ± .005	+ .0166		4.64
Pressure Saturation				
Step 2				
24 Hrs	60.265 ± .005	+ .350		5.01
48 Hrs	60.25 ± 0	- .020		4.98
Vacuum Saturation³				
Step 4				
Phase I	59.795 ± .005			4.19
Phase II	59.865 ± .005	+ .117		4.31
Phase III	59.885 ± .015	+ .033		4.34
Pressure Saturation				
Step 5				
24 Hrs	60.245 ± .015	+ .600		4.97
48 Hrs	60.225 ± .015	- .030		4.94

¹Mean of two weighing ± mean variation

²Percent Moisture Content = $\frac{\text{Saturated wt} - \text{Dry wt}}{\text{Dry wt}} \times 100$

³See Attachment 1 for explanation of vacuum saturation phases

Table 2. (cont'd)

Moisture Content Determination

Hole ID USW G-2
 Depth Interval(ft) 1587.8-A
 Dry wt (gm) 58.385

Procedure	x Weight ¹ (gms)	% Weight change	% Moisture ² content
Vacuum Saturation³ Step 1			
Phase I	60.915 ± .005		4.33
Phase II	60.92 ± .010	+ .008	4.34
Phase III	60.905 ± .005	- .024	4.32
Pressure Saturation Step 2			
24 Hrs	60.965 ± .015	+ .100	4.42
48 Hrs	60.94 ± 0	- .040	4.38
Vacuum Saturation³ Step 4			
Phase I	60.825 ± .005		4.18
Phase II	60.865 ± .005	+ .066	4.25
Phase III	60.885 ± .005	+ .030	4.28
Pressure Saturation Step 5			
24 Hrs	60.93 ± 0	+ .070	4.36
48 Hrs	60.935 ± .005	+ .010	4.37

¹Mean of two weighing ± mean variation

²Percent Moisture Content = $\frac{\text{Saturated wt} - \text{Dry wt}}{\text{Dry wt}} \times 100$

³See Attachment 1 for explanation of vacuum saturation phases

Attachment 1

Vacuum Saturation ProcedureIntroduction

For each batch of test specimens which are vacuum saturated together, one test specimen must be analyzed per the vacuum saturation data sheet (attached). The remaining test specimens from the batch will have their post-saturation weights and sample identities included on the same data sheet. If the analyzed test specimen does not exceed the 0.05 percent maximum weight change specification, then that specimen and the remainder of the batch is said to have met the specification. Conversely, if the analyzed test specimen exceeds the 0.05 percent maximum weight change specification, then the sample and the remainder of the batch does not meet the specification and Phase II of the vacuum saturation procedure should be repeated until the 0.05 percent maximum weight change specification is satisfied.

The vacuum saturation procedure descriptions are keyed to the line numbers that appear on the Vacuum Saturation Data Sheet for NX Size and Smaller Test Specimens. Before performing the vacuum saturations, complete the test information data (Section 1) of the vacuum saturation data sheet.

Section II -- Test DataPhase I

- Line 1: Perform an "active" vacuum saturation in water for 30-32 hours on the batch of test specimens in a vacuum approximately equal to the vapor pressure of water.
- Line 2: Allow the pressure and temperature in the vacuum chamber to rise to ambient, maintaining sample submersion, for 8-24 hrs.
- Line 3: Record the weight of the test specimen including the date and time at which the measurement was made.
- Line 4: Make a duplicate weighting to that of line 3 making sure that the test specimen has been resubmerged for 2-5 minutes between the weightings in lines 3 and 4.
- Line 5: Obtain a mean weight of lines 3 and 4.

$$X = \frac{\text{Line 3} + \text{Line 4}}{2}$$

Phase II

- Line 6: Repeat the "active" vacuum saturation in water, which entails 15-17 hrs of vacuum saturation on the entire batch defined in Section I of the data sheet. The vacuum should be approximately equal to the vapor pressure of water.
- Line 7: Allow the pressure and temperature in the vacuum chamber to rise to ambient, maintaining sample submersion, for 8-24 hrs.
- Line 8: Record the weight of the test specimen including the date and time at which the measurement was made.
- Line 9: Make a duplicate weighing to that of line 8 making sure that the test specimen has been resubmerged for 2-5 minutes between the weighings in lines 8 and 9.
- Line 10: Obtain a mean weight of lines 8 and 9.

$$X = \frac{\text{Line 8} + \text{Line 9}}{2}$$

- Line 11: The percent weight gain is calculated by dividing the increase in test specimen weight due to water absorption by the weight of the saturated test specimen from the previous cycle. If the percent weight change is 0.05 percent, the vacuum saturation process has met specification and all specimens in the batch are ready for jacketing and testing (disposition - acceptable). If the percent weight change is 0.05 percent, then the specimens must continue to be saturated by repeating the Phase II procedure (disposition-in progress) until the 0.05 percent weight change specification has been satisfied. In these cases, lines 5-11 should be repeated until the specification has been met.

Example

Disposition of test specimens (check box)

Acceptable

In Progress

VACUUM SATURATION DATA SHEET FOR
NX-SIZE AND SMALLER TEST SPECIMENS

I. TEST INFORMATION

Sample ID of "Test" Specimen _____
Analytical Balance Used _____
Initial "As Received" Weight _____ gm

Employee ID _____
Laboratory ID _____

ID of Remaining Specimens in Batch	Initial "As Received" Weight (gm)	Post Vacuum Saturation Weight (gm)

II. TEST DATA

- 1) Date and time Phase I vacuum saturation begins. Date _____
Time _____
- 2) Date and time vacuum saturation ends and ambient temperature and pressure submersion begins. Date _____
Time _____
- 3) Weight/date/time at end of submersion. _____ gm Date _____
Time _____
- 4) Repeat weight measurement allowing 2-5 minutes of resubmersion in J-13 water prior to measurement. _____ gm
- 5) Calculate average weight from lines 3 and 4. \bar{X} = _____ gm
- 6) Date and time Phase II vacuum saturation begins. Date _____
Time _____
- 7) Date and time vacuum saturation ends and ambient temperature and pressure submersion begins. Date _____ Time _____
- 8) Weight/date/time at end of submersion _____ gm Date _____
Time _____
- 9) Repeat weight measurement allowing 2-5 minutes of resubmersion in J-13 water prior to measurement. _____ gm
- 10) Calculate average weight from lines 8 and 9. \bar{X} = _____ gm
- 11) Calculate percent weight gain: $\frac{\text{Line 10} - \text{Line 5}}{\text{Line 5}} (100) = \text{_____} \%$
Weight from Line 5

If the percent weight gain is $\leq |0.05|$ percent, the vacuum saturation process has met specification and all specimens in the batch are ready for jacketing and testing (disposition - acceptable).

If the percent weight gain is $> |0.05|$ percent, then the specimens must continue to be saturated by repeating the Phase II procedure (disposition - in progress) until the $|0.05|$ percent weight gain specification has been satisfied. In these cases, line 10 should be transferred to line 5 of a new data sheet, and lines 5-11 should be repeated until the specification has been met.

Disposition of test specimens (check box)

Acceptable
In Progress

Attachment 2

Pressure Saturation Procedure (Steps 2 & 5)Introduction

For each batch of test specimens which are pressure saturated together, one test specimen must be analyzed per the vacuum saturation data sheet (attached). The remaining test specimens from the batch will have their post-saturation weights and sample identities included on the same data sheet. If the analyzed test specimen does not exceed the 0.05 percent maximum weight gain specification, then that specimen and the remainder of the batch is said to have met the specification. Conversely, if the analyzed test specimen exceeds the 0.05 percent maximum weight gain specification, then that sample and the remainder of the batch does not meet the specification and Phase II of the pressure saturation procedure should be repeated until the 0.05 percent maximum weight gain specification is satisfied.

The pressure saturation procedure descriptions are keyed to the line numbers that appear on the Pressure Saturation Data Sheet for NX-Size and Smaller Test Specimens. Before performing the pressure saturations, complete the test information data (Section 1) of the vacuum saturation data sheet.

Section II -- Test Data

PHASE I

- Line 1: Record the start time of the pressure saturation.
- Line 2: Record the pressure applied to the sample.
- Line 3: Record the completion time of the pressure saturation.
- Line 4: Record the weight of the test specimen including the date and time at which the measurement was made.
- Line 5: Make a duplicate weighing to that of line 4 making sure that the sample has been resubmerged for 2-5 minutes between the weighings in lines 4 and 5.
- Line 6: Obtain the average weight from lines 4 and 5.

PHASE II

- Line 7: Record the start time of the pressure saturation.
- Line 8: Record the pressure applied to the sample.

- Line 9: Record the completion time of the pressure saturation.
- Line 10: Record the weight of the test specimen including the date and time at which the measurement was made.
- Line 11: Make a duplicate weighing to that of line 10, making sure that the sample has been resubmerged for 2-5 minutes between the weighings in lines 10 and 11.
- Line 12: Obtain the average weight from lines 10 and 11.
- Line 13: The percent weight gain is calculated by dividing the increase in test specimen weight due to water adsorption by the weight of the saturated test specimen from the previous cycle. If the percent weight gain is ≤ 0.05 percent, the pressure saturation process has met specification and all specimens in the batch are ready for jacketing and testing (disposition - acceptable). If the percent weight gain is > 0.05 percent, then the specimens must continue to be saturated by repeating the Phase II procedure (disposition - in progress) until the 0.05 percent weight gain specification has been satisfied. In these cases, lines 6-13 should be repeated until the specification has been met.

Example

Disposition of test specimens (check box)

Acceptable

In Progress

PRESSURE SATURATION DATA SHEET FOR
NK-SIZE AND SMALLER TEST SPECIMENS
I. TEST INFORMATION

Sample ID of "Test" Specimen _____
Analytical Balance Used _____
Initial "As Received" Weight _____ gm

Employee ID _____
Laboratory ID _____

ID of Remaining Specimens in Batch	Initial "As Received" Weight (gm)	Post Vacuum Saturation Weight (gm)

II. TEST DATA

- 1) Date and time Phase I vacuum saturation begins. Date _____ Time _____
- 2) Pressure applied to samples during Phase I. _____ psi
- 3) Date and time Phase I pressure saturation ends. Date _____ Time _____
- 4) Weight/date/time of Phase I weighing. _____ gm Date _____ Time _____
- 5) Repeat weight measurements allowing 2-5 minutes of resubmersion in solvent prior to measurement. _____ gm
- 6) Calculate average weight from lines 4 and 5. \bar{X} = _____ gm
- 7) Date and time Phase II pressure saturation begins. Date _____ Time _____
- 8) Pressure applied to samples during Phase II. _____ psi
- 9) Date and time Phase II pressure saturation ends. Date _____ Time _____
- 10) Weight/date/time of Phase II weighing. _____ gm Date _____ Time _____
- 11) Repeat weight measurements allowing 2-5 minutes of resubmersion in solvent prior to measurement. _____ gm
- 12) Calculate average weight from lines 10 and 11. \bar{X} = _____ gm
- 13) Calculate percent weight gain: $\frac{\text{Line 12} - \text{Line 6}}{\text{Line 6}}(100) =$ _____ %

If the percent weight gain is $\leq |0.05\%|$, the pressure saturation process has met specification and all specimens in the batch are ready for jacketing and testing (disposition - acceptable).

If the percent wt gain is $> |0.05\%|$, then the specimens must continue to be saturated by repeating the Phase II procedure (disposition - in progress) until the $|0.05\%|$ weight gain specification has been satisfied. In these cases, line 12 should be transferred to line 6 of a new data sheet, and lines 6-13 should be repeated until the specification has been met.

Disposition of test specimens (check box)

Acceptable

Prepared by Barry Schwartz
Sandia Labs, Div. 6313
(505) 846-1532, FTS 846-1532

In Progress

Attachment 3

Thermal Shock and Dry Procedure (Step 3)

- 1) Heat the oven to 225°C in an air atmosphere.
- 2) Place the fully saturated, ambient temperature samples into the hot (225°C) oven.
- 3) Dry the samples at 225°C for 24 hours.
- 4) Lower the oven temperature to 105°C and maintain heating for another 48 hours.
- 5) Turn the oven off. Allow the oven to cool to ambient with the oven door closed.
- 6) Weigh the dry samples.
- 7) Make a duplicate weighing.

Attachment 4

SUBJECT: Oven-Drying Procedures

Included in this package are procedures for oven-drying in air and a corresponding data sheet.

The data sheet should be completed each time this procedure is followed.

The procedure has been empirically derived using NX-size samples from densely welded Topopah Spring Member tuff from the Busted Butte outcrop and should be valid for NX and smaller size densely welded samples.

Any questions regarding these procedures should be forwarded to:

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Oven-Drying Procedure

Introduction

For each batch of ten test specimens which are oven-dried together, one test specimen must be analyzed per the oven-drying data sheet (attached). The remaining test specimens from the batch will have their post-drying weights and sample identities included on the same data sheet. If the analyzed test specimen does not exceed the 0.05% maximum weight loss specification, then that specimen and the remainder of the batch is said to have met the specification. Conversely, if the analyzed test specimen exceeds the 0.05% maximum weight loss specification, then that sample and the remainder of the batch does not meet the specification and Phase II of the oven-drying procedure should be repeated until the 0.05% maximum weight loss specification is satisfied.

The oven-drying procedure descriptions are keyed to the line numbers that appear on the Oven-Drying data sheet for NX Test Specimens. Before performing the oven-drying, complete the test information data (Section I) of the oven-drying data sheet.

Samples should always be placed in the oven before the oven is heated above ambient temperature. The oven temperature should be raised no more than 15°C at a time, and at least one hour should elapse between temperature increments. Cooling of samples should occur before weighing, and cooling should be accomplished by turning off the oven and leaving the specimens in the oven with the door closed until the temperature reaches 40°C or less.

Section II--Test Data

Phase I

Line 1: Dry the batch of test specimens at 105°C for 120 hours. Specimens should then be cooled as described above before weighing.

Line 2: Record the weight of the test specimen including the date and time at which the measurement was made.

Line 3: Make a duplicate weighing to that of line 3.

Line 4: Obtain a mean weight of lines 2 and 3.

$$\bar{X} = \frac{\text{Line 2} + \text{Line 3}}{2}$$

May 6, 1985

Phase II

Line 5: Repeat the 105°C portion of drying for 24-36 hrs on the entire batch defined in Section I of the data sheet. The specimen should be cooled before weighing.

Line 6: Record the weight of the test specimen including the date and time at which the measurement was made.

Line 7: Make a duplicate weighing to that of line 6.

Line 8: Obtain a mean weight of lines 6 and 7.

$$\bar{x} = \frac{\text{Line 6} + \text{Line 7}}{2}$$

Line 9: The percent weight loss is calculated by dividing the decrease in test specimen weight due to water loss by the weight of the test specimen from the previous cycle. If the percent weight loss is $\leq 0.05\%$, the oven-drying process has met specification and all specimens in the batch are ready for jacketing and testing (disposition - acceptable). If the percent weight loss is $> 0.05\%$, then the specimens must continue to be dried by repeating the Phase II procedure (disposition - in progress) until the 0.05% weight loss specification has been satisfied. In these cases, lines 4-9 should be repeated until the specification has been met.

Example

Disposition of test specimens (check box)

Acceptable



In Progress



All specimens which have met the weight loss specification (acceptable) should be placed in a desiccator immediately after weighing and should remain in the desiccator until sample testing begins.

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Attachment

**OVEN-DRYING DATA SHEET FOR
BUSTED BUTTE OUTCROP XI-SIZE AND SMALLER TEST SPECIMENS**

I. TEST INFORMATION

Sample ID of "Test" Specimen _____ Employee ID _____
Analytical Balance Used _____ Laboratory ID _____
Initial Weight _____ gm

ID of Remaining Specimens in Batch	Initial Weight (gm)	Post Oven-Drying Weight (gm)

II. TEST DATA

- 1) Date and time Phase I 105°C portion of oven-drying begins. Date ___ Time ___
- 2) Weight/date/time at end of oven-drying. _____ gm Date ___ Time ___
- 3) Repeat weight measurement. _____ gm
- 4) Calculate average weight from lines 2 and 3. \bar{X} = _____ gm
- 5) Date and time Phase II 105°C portion of oven-drying begins. Date ___ Time ___
- 6) Weight/date/time at end of oven-drying _____ gm Date ___ Time ___
- 7) Repeat weight measurement. _____ gm
- 8) Calculate average weight from Lines 7 and 8. \bar{X} = _____ gm
- 9) Calculate %wt loss $\frac{\text{Line 8} - \text{Line 4}}{\text{Weight from Line 4}} (100) =$ _____ %.

If the %wt loss is \leq 0.05%, the oven-drying process has met specification and all specimens in the batch are ready for jacketing and testing or storage in desiccator (disposition - acceptable).

If the %wt loss is $>$ 0.05%, then the specimens must continue to be dried by repeating the Phase II procedure (disposition - in progress) until the 0.05% weight loss specification has been satisfied. In these cases, line 8 should be transferred to line 4 of a new data sheet, and lines 4-9 should be repeated until the specification has been met.

Disposition of test specimens (check box)

Acceptable



In Progress



Prepared by Barry Schwartz Sandia Labs, Div 6313, 3/30/84 (505) 846-1532, FTS 846-1532
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GOODMAN JACK TEST RESULTS

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date: December 11, 1985

to: R. M. Zimmerman, 6313

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from: F. B. Nimick, 6313

subject: Goodman Jack Test Results

The results of 20 Goodman jack tests in the Grouse Canyon Member of the Belted Range Tuff are listed in SAND81-1971 (Zimmerman and Vollendorf, 1982). Unfortunately, at the time the report was written, methods of reducing the test data accurately had not been fully developed. It is the purpose of this memo to summarize such a data reduction.

Methods of Data Correction

Two sources of error must be accounted for during data reduction. The first of these results from longitudinal bending of the platens under the applied loads. Heuze and Salem (1976) performed finite-element analyses of the problem and published a curve of the "true" elastic modulus (E_t) of the test material versus the modulus (E_c) calculated from test data. The latter is derived using the following equation from Heuze and Salem (1976):

$$E_c = (0.86)(0.93)(D) \left(\frac{\Delta Q_h}{\Delta D} \right) (K(v,B)) \quad (1)$$

where D is the borehole diameter, ΔQ_h is the change in applied hydraulic pressure, ΔD is the change in borehole diameter, and $K(v,B)$ is a parameter to account for the incomplete match of the borehole and platen radii, where v is Poisson's ratio of the test material and B is the half-contact angle between the platen and the borehole wall. Similar curves of E_t versus E_c for $v = 0.25$ and $v = 0.33$ were published by Heuze and Amadei (1985), and an equation for the E_t -versus- E_c curve for $v = 0.25$ was calculated by Patrick et al. (1985), as follows:

$$E_t = 0.03032 + 0.979484E_c - 2.042103 \times 10^{-8} E_c^2 + 1.792758 \times 10^{-13} E_c^3 \quad (2)$$

This equation of Patrick et al. (1985) was used as one correction to the data from the Grouse Canyon Member.

The second source of error involves the mismatch in radii between the platen and the borehole wall. The correction for this error is incorporated in the last parameter in Equation (1). Heuze and Amadei (1985) reviewed the development of this correction from the factor $K(\nu, \beta)$ in Equation (1), originally presented by Goodman et al. (1970), through a new version of this factor called T^* by Hustrulid (1976), and finally to slightly revised values of T^* in their own paper. Table 1 summarizes the sequence of modifications or reevaluations of this factor.

In addition, Heuze and Amadei (1985) used the analyses by Shuri (1981) to estimate a value of ΔQ_h at which full contact between the platen and borehole is achieved, henceforth called ΔQ_{hmin} . This variable is a function of ν and of E_t of the test material. Heuze and Amadei (1985) suggest using ΔQ_{hmin} as a discriminator in deciding which test data to analyze, rather than looking at the linear portion of the ΔQ_h -versus- ΔD curve.

The test data from the Grouse Canyon Member have been corrected using the following calculation sequence:

1. ΔQ_{hmin} was calculated using the formula in Heuze and Amadei (1985) for undersized holes; this formula requires data for ν , α (where 2α is the deviation of the borehole diameter from 3.000 inches), and an estimate of E_t .
2. Test data for $\Delta Q_h > \Delta Q_{hmin}$ and associated values of ΔD were fit by linear least-squares to obtain a value of $\Delta Q_h/\Delta D$.
3. Equation (1) was used to calculate E_c , except that $K(\nu, \beta)$ was replaced by T^* , the most recent correction for borehole/platen mismatch (Heuze and Amadei, 1985).
4. The formula of Patrick et al. (1985) was used to calculate E_t from E_c .
5. The value of E_t obtained in step 4 was used to calculate a new value of ΔQ_{hmin} . If this value resulted in a new range of ΔQ_h applicable to the calculations, steps 2-4 were repeated. If the range of $\Delta Q_h > \Delta Q_{hmin}$ was the same as for the preceding calculational sequence, the process was complete.

In order to correct the data, values of ν and estimated E_t were required. Zimmerman et al. (1984) report a range of laboratory-determined ν of 0.16-0.32 for the Grouse Canyon Member. A value of 0.24 was used in the reduction of the data for this study. Use of $\nu = 0.16$ would result in values of E_t less than 7 percent higher than those obtained using $\nu = 0.24$, and $\nu = 0.32$ results in E_t values 5 percent or less lower.

The initial value of E_t was assumed to be 10 GPa. This was based on laboratory values of 22-28 GPa (Zimmerman et al., 1984) and the recommendation by Heuze and Amadei (1985) that this initial estimate be 0.4 of the laboratory value.

Borehole diameters were taken to be 3.000 inches less the average of the readings at $Q_h = 0$ of the two LVDTs on the Goodman jack. Uncertainty in the diameter might be as high as 0.002 inch. Such differences would change the calculated values of E_t on the order of 0.1 percent.

Results

The corrected data for the Grouse Canyon Member are presented in Table 1. In the table, a suffix of "H" indicates a measurement made with the platens in an approximately horizontal orientation, and a "V" indicates approximately vertical positioning.

Some tests are identified in Table 2 as having readings on the two LVDTs more than 0.02" apart. The instruction manual for the Goodman jack (SINCO, undated) states

"When the difference between readings reaches approximately 0.020 inch, excessive wear on the guide pins and LVDT adapter may occur. When tilting greater than this takes place, it is recommended that the test be discontinued and the jack moved up or down to another location where the material may be more homogeneous and uniform." (p. 11)

These tests have been highlighted because of the potential for erroneous results, even though the instruction manual does not state that incorrect results would be obtained.

A value of E_t is not given in Table 2 for four tests. One of these tests did not have readings for the LVDTs at $Q_h = 0$, so the diameter of the borehole was not available (test EV6-13-3H). For the other three, calculated values of E_t were significantly higher than the laboratory-determined moduli, suggesting one or more violations of the assumptions necessary for data correction. No attempt has been made to identify specific problems with these tests.

Discussion

Prior to the calculation of a mean value of E_t from the data in Table 2, the data were examined to determine if test results were a function of either orientation in the borehole or of distance along the hole. Figure 1 is a plot of E_t measured horizontally against E_t measured vertically at the same distance along the borehole. Five of the 7 results plot below the line of isotropic moduli, suggesting a mild anisotropy. However, data are insufficient to reach a definite conclusion. Based on geometric considerations of the orientations of the two boreholes relative to the strike and dip of the Grouse Canyon Member, the results depicted in Figure 1 can be extrapolated to suggest that the Grouse Canyon Member itself is not strongly anisotropic in terms of the field modulus of deformation. This conclusion is consistent with that made by Zimmerman and Vollendorf (1982) based on the uncorrected data.

Figure 2 shows the variation of E_t along the two boreholes. No consistent trend is evident from the actual data points. Linear least-squares fits to the two sets of data (assuming isotropy) suggest that $\Delta E_t / \Delta(\text{depth}) = 0.1-0.2$ GPa/ft, but the correlation coefficients for these fits are so low that no statistical significance of the trend exists. It is interesting, however, that the trend of increasing stiffness with increasing distance from the mined opening is what would be expected intuitively, and is qualitatively consistent with Goodman jack data trends in the Climax stock, described by Patrick et al. (1985).

Given that no significant anisotropy or variation with depth exists, the data in Table 2 can be grouped, and a mean and standard deviation can be calculated. Table 3 provides information on these quantities. Separate means were calculated for the tests with readings ≥ 0.02 " apart in order to examine the possibility that these tests gave different results. In both drill holes, these tests did indeed show mean values of E_t lower than the mean E_t values from other tests. The difference is not statistically significant for either RM-P2 or EV6-13. Results for the tests with readings ≥ 0.02 " apart are statistically the same between the two boreholes, as are those for tests without these readings. Comparison of the "with" and "without" data, grouping the two boreholes together, suggests that no statistically significant difference in E_t has been caused by LVDT readings more than 0.02" apart, so that all E_t entries in Table 2 can be treated as a single sample population. The net result is that E_t of the Grouse Canyon Member as measured by 16 Goodman jack tests is calculated to be 14.74 ± 7.03 GPa.

The corrected mean value of E_t reported above compares to an uncorrected mean value of 12.11 GPa (Zimmerman and Vollendorf, 1982) for 20 tests, and of 10.64 GPa for the 16 samples for which E_t values are given in Table 2. Thus, the corrections to the test data have resulted in an increase in the mean value of E_t of almost 40 percent of the uncorrected data.

Zimmerman and Vollendorf (1982) observed that the relationship between ΔQ_h and ΔD approached linearity only at higher values of Q_h . They chose to use the range of Q_h of 48 to 65.5 MPa (7000 to 9500 psi) to calculate $\Delta Q_h/\Delta D$. If the same pressure range is used to calculate corrected values of E_t , the result is $E_t = 17.56 \pm 8.13$ GPa. This mean value is 65 percent higher than the uncorrected mean from Zimmerman and Vollendorf (1982).

Historically, the test data to be used in calculating E_c have been selected to be those comprising the most linear portion of the ΔQ_h -versus- ΔD curve. Patrick et al. (1985) chose to use the criterion of linearity to define a range of ΔQ_h rather than the ΔQ_{hmin} procedure advocated by Heuze and Amadei (1985) because the latter seemed to accept or reject data on a random basis and was therefore ineffective. The preceding paragraphs indicate that the mean value of E_t for the Grouse Canyon Member varies from 14.7 to 17.6 GPa, depending on which choice of ΔQ_h data is made. For the tests on the Grouse Canyon Member, the data were no more or less linear using the 48-65.5 MPa pressure range than they were using the pressure range determined using the ΔQ_{hmin} procedure. Therefore, because a strong case cannot be made for preferential use of either the criterion of linearity or the ΔQ_{hmin} procedure to select the appropriate range of ΔQ_h , the conclusion is made that the mean value of E_t lies in the range of 14.7 to 17.6 GPa.

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Table 1

Sequence of Modifications to Correction
Factor for Borehole/Platen Mismatch

Factor	Reference
$K(v, \beta) = \frac{1+v}{(\sin\beta)2\tau} \left\{ -2\beta \left[\frac{5-4v}{2} \sin\beta + \frac{3-4v}{6} \sin 3\beta \right] \right.$ $- \sum_{m=1}^{\infty} \frac{1}{2m} \sin 2m\beta \left[\frac{3-4v}{2m+1} \left(\frac{\sin(2m+1)\beta}{2m+1} + \frac{\sin(2m+3)\beta}{2m+3} \right) \right.$ $+ \left(\frac{3-4v}{2m-1} + \frac{1}{2m+1} \right) \left(\frac{\sin(2m-1)\beta}{2m-1} + \frac{\sin(2m+1)\beta}{2m+1} \right)$ $\left. \left. + \frac{1}{2m-1} \left(\frac{\sin(2m-3)\beta}{2m-3} + \frac{\sin(2m-1)\beta}{2m-1} \right) \right] \right\}$	<p>Goodman et al. (1970)</p>

$$K(v, \beta) = \frac{(1+v)}{2\tau \sin\beta} \int_0^{\beta} (\text{RHS}_1 \cos\theta + \text{RHS}_2 \sin\theta) d\theta = T^*$$

Hustrulid (1976)

$$K(v, \beta) = \frac{720}{\tau^2} \frac{1}{\beta} (1-v^2) \sum_{m=1}^{\infty} \frac{1}{m^3} [1-(-1)^m] \sin^2 m\beta$$

Heuze and Amadei
(1985)

$$T^* = \frac{\sin 45}{\tau} \left(\frac{180}{\beta} \right) K(v, \beta)$$

Table 1
(continued)

$$\text{RHS}_1 = -2\beta - \sum_{m=1}^{\infty} \frac{1}{m} \left[\frac{X}{2m-1} + \frac{1}{2m+1} \right] \sin 2m\beta \cos 2m\theta$$

$$- X \sum_{m=1}^{\infty} \left(\frac{1}{2m-1} \right) \left(\frac{1}{m-1} \right) \cos 2m\theta \sin 2(m-1)\beta$$

$$- \sum_{m=0}^{\infty} \left(\frac{1}{2m+1} \right) \left(\frac{1}{m+1} \right) \cos 2m\theta \sin 2(m+1)\beta$$

$$\text{RHS}_2 = \sum_{m=1}^{\infty} \frac{1}{m} \left[\frac{X}{2m-1} - \frac{1}{2m+1} \right] \sin 2m\beta \sin 2m\theta$$

$$+ X \sum_{m=1}^{\infty} \left(\frac{1}{2m-1} \right) \left(\frac{1}{m-1} \right) \sin 2m\theta \sin 2(m-1)\beta$$

$$- \sum_{m=1}^{\infty} \left(\frac{1}{2m+1} \right) \left(\frac{1}{m+1} \right) \sin 2m\theta \sin 2(m+1)\beta$$

$$X = \begin{cases} 3-4\nu & \text{for plane strain} \\ (3-\nu)/(1+\nu) & \text{for plane stress} \end{cases}$$

θ = Angle measured counterclockwise from center of platen ($\beta = 0^\circ$)

TABLE 2

Test Data and Resulting Values
of Deformation Modulus (E_t)

<u>Test Id</u>	<u>Hole Diameter (in.)</u>	<u>Depth (ft)</u>	<u>E_t (GPa)</u>
<u>Hole RM-P2</u>			
1H	2.9845	5.25	16.35
1V	2.9805	5.25	NA
2H	2.9740	10.5	9.16
2V	2.9885	10.5	17.18
3H*	2.9755	13.5	12.12
3V*	2.9715	13.5	4.66
4H	2.9815	19.5	25.67
4V*	2.9810	19.5	23.13
5H*	2.9735	30.0	13.14
5V*	2.9745	30.0	10.05
6H*	2.9765	20.5	29.53
6V*	2.9825	20.5	NA
<u>Hole EV6-13</u>			
1H*	2.9870	9.5	10.51
1V*	2.9840	9.5	6.07
2H	2.9785	16.0	21.43
2V	2.9850	16.0	11.03
3H	Unknown	22.5	NA
3V	2.9815	22.5	NA
4H	2.9780	26.0	12.18
4V	2.9730	26.0	13.65

*Some or all of the LVDT readings more than 0.02" apart. See text for discussion.

TABLE 3

Mean Values and Standard Deviations
For Various Sample Groupings of E_t Data

<u>Sample Group</u>	<u>Mean (GPa)</u>	<u>Standard Deviation (GPa)</u>	<u>Number of Samples</u>
RM-P2, *tests	15.44	9.16	6
RM-P2, other tests	17.09	6.76	4
EV6-13, *tests	8.29	3.14	2
EV6-13, other tests	14.57	4.70	4
all *tests	13.65	8.50	8
all other tests	15.83	5.55	8
all tests	14.74	7.03	16

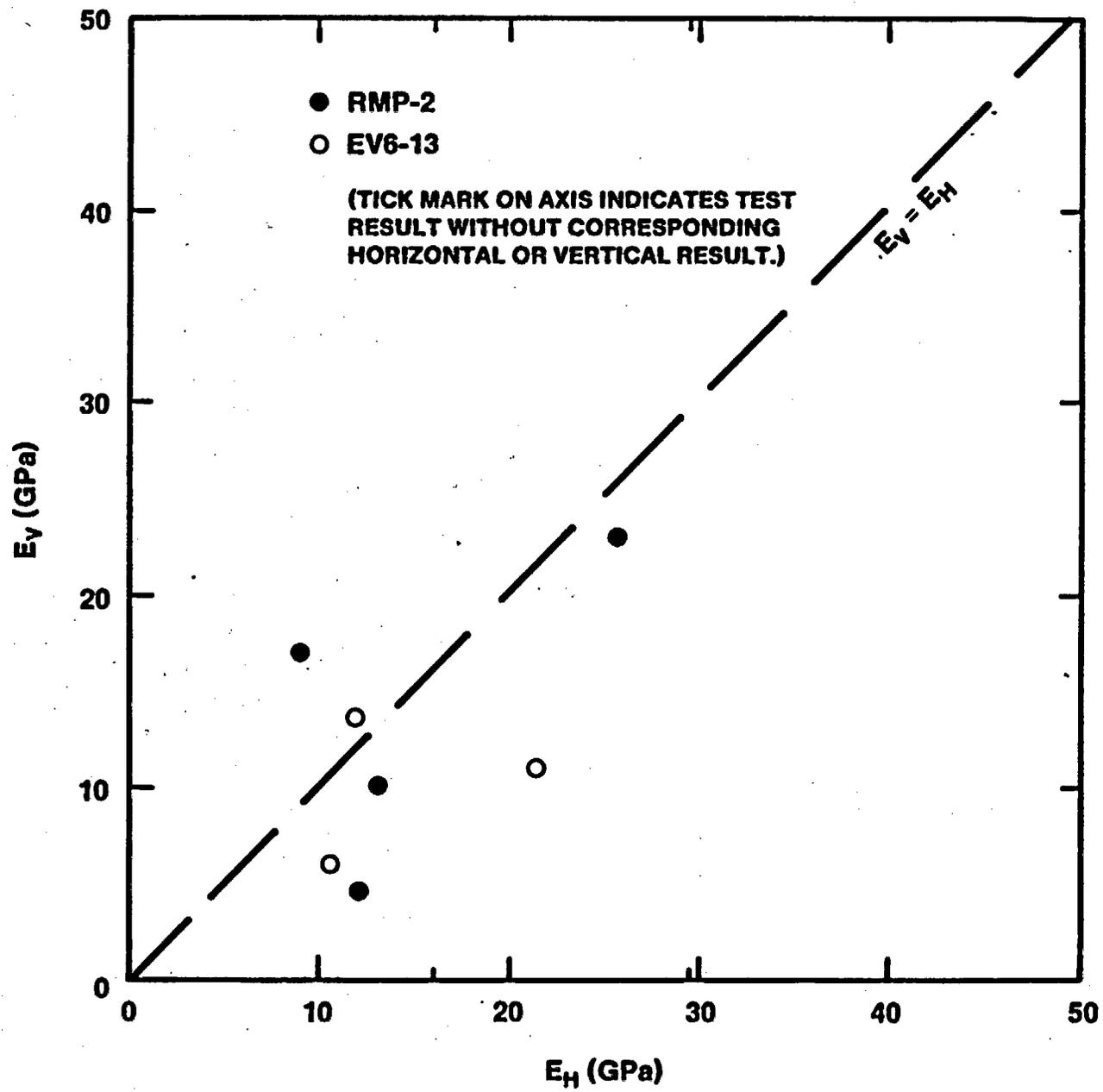
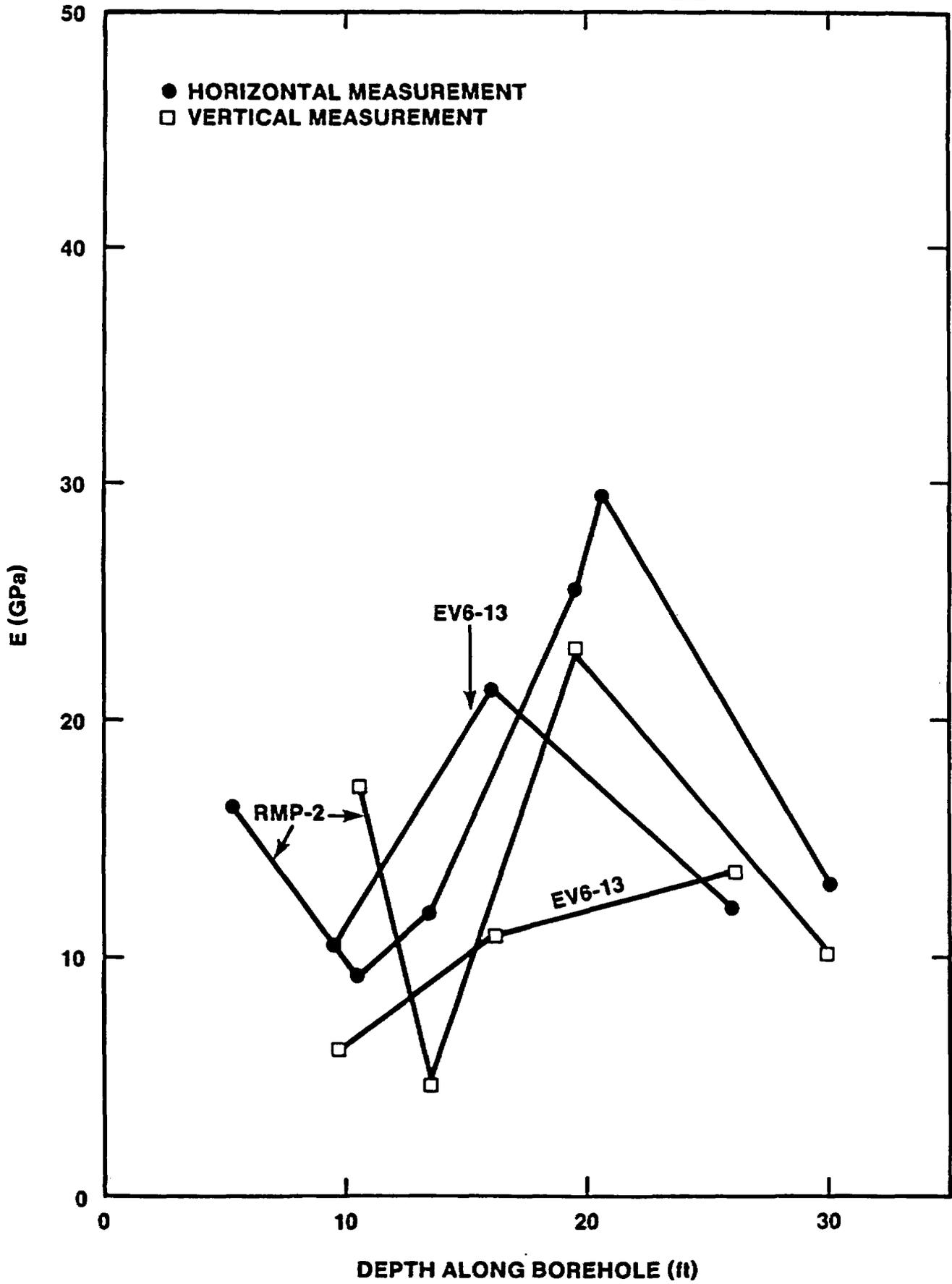


FIGURE 1

FIGURE 2



APPENDIX

This report contains no data from, or for inclusion in, the RIB and/or SEPDB.

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51/L14A.A-4/1/84 and 55/F01.A-2/1/81)
6314 S.J. Bauer (2)
6315 S. Sinnock
6332 WMT Library (20)
6430 N.R. Ortiz
3141 S.A. Landenberger (5)
3151 W.L. Garner (3)
8024 P.W. Dean
3154-3 C.H. Dalin (28)
for DOE/OSTI

Case No.	Case Name	Case Description
1	Case 1	Description of Case 1
2	Case 2	Description of Case 2
3	Case 3	Description of Case 3
4	Case 4	Description of Case 4
5	Case 5	Description of Case 5
6	Case 6	Description of Case 6
7	Case 7	Description of Case 7
8	Case 8	Description of Case 8
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49	Case 49	Description of Case 49
50	Case 50	Description of Case 50



