MEASUREMENTS AND DATA NEEDED TO ESTABLISH THE GEOLOGIC AND HYDROLOGIC PROPERTIES OF REPOSITORY SITES IN BASALT, SALT, AND TUFF

An Informal Report Submitted in response to a request by E. Conti of the NRC as a supplement to FIN A0367 on Geotechnical, Environmental, and Radiation Field Measurement System Evaluation: HLW

July 1984

E. P. Binnall, H. A. Wollenberg, S. M. Benson, L. Tsao, O. Weres
Lawrence Berkeley Laboratory

E. M. Didwall, A. L. Ramirez, G. A. Armantrout
Lawrence Livermore National Laboratory

Lawrence Livermore National Laboratory
7000 East Avenue
Livermore, CA 94550

8409200390 840911
PDR WASTE
WM-16 PDR

INTRODUCTION

This letter report is submitted to aid the licensing staff of the NRC in preparing to review Environmental Assessments from the DOE on HLW repository sites in basalt, salt, and tuff. We have been asked to comment on "measurements and data needed to establish the geologic and hydrologic properties of repository sites in basalt, salt, and tuff"; and, under this topic area, to comment on "the important issues, what the staff should look for in conducting their reviews, and what are the major uncertainties".

In recent months we have submitted an extensive topical report to the NRC entitled "Critical Parameters for a High-Level Waste Repository in Basalt" (Binnall et al., 1984, UCID 20092). In that report, now being reviewed by the NRC, we have attempted to prioritize critical parameters specific to a repository in basalt, using the Columbia River Basalt Group as the principal example. Prioritized lists of these critical parameters were developed that can be used by NRC staff as guides to what they should look for in conducting their reviews. "Important issues" and "major uncertainties" were strongly considered in generating these lists. Prioritized critical parameter tables (1 through 4) for a basalt repository site have been generated for the four major repository phases: 1) site characterization, 2) construction, 3) operations, and 4) closure and decommissioning. The same parameters have also been separated by discipline (i.e., geomechanical, geological, hydrological, and geochemical) in Tables 5 through 8 for each of the repository phases. For purposes of this present report, we consider "geologic properties" to include the geomechanical and geological disciplines of UCID 20092. We are presently preparing a report covering the techniques to measure and/or monitor the critical parameters identified in UCID 20092.

Comments on measurements and data needed to establish the geologic and hydrologic properties of a repository site in basalt are centered on the critical parameter tables for basalt. Comments pertinent to repository sites in salt and tuff concentrate only on critical parameters that differ significantly from those discussed here for basalt.

A parameter is considered to be "critical" if a mistake in its measurement, or the inability to measure it, could lead to the wrong conclusions of the repository adequacy for safe, long-term disposal of nuclear waste. Moreover, a parameter is considered critical only during those repository phases when it must be measured or otherwise determined, or monitored. Though knowledge of a parameter's values may be critical during repository phases following its determination, once the parameter has been determined and can also be considered as nonvarying, it is no longer considered critical for measurement or monitoring purposes.

BASALT

The prioritized critical parameters, given in Tables 1 through 4 have been chiefly addressed using the geologic setting of the Columbia River Basalt flows as they occur on the Hanford Reservation in Washington. We have assumed that the prospective repository site will be located in a basalt horizon in the saturated zone well below the water table. For example, hydrostatic pressures have been measured at 9.3 MPa (1350 psi) in the Middle Sentinel Bluffs (Cohassett) flow and 11.1 MPa (1600 psi) in the Umtanum flow. This is an important factor in ultimately determining the measurement needs and selecting the techniques to be used to make these measurements and perform in situ monitoring of the critical parameters.

In developing the critical parameter tables, strongest considerations were given to measurements that focused ultimately on the contamination by radionuclides of an aquifer that could be accessible to the biosphere. In this respect, direct assumptions were not made concerning probable radionuclide pathways. Rather, measurements were considered that would be used to evaluate essentially all potential pathways between the repository, aquifers, and ultimately the surface. However, it must be recognized that the basalt flows may be limited in thickness, with high permeability strata above and below the repository horizon, and that the fractured nature of basalt flows can lead to increased vertical connectivity between horizontal aquifers as a result of repository emplacement and operation.

The relative importance of critical parameters for basalt are listed in Tables 1 through 4 for each phase of repository activity: site characterization, construction, operations, and closure and decommissioning. These phases need not be considered as distinct time periods, but can overlap each other. For example, operations may start in one underground location well before construction is completed in another sector of the repository. The relative ranking of parameters within any single numerically designated priority level in these tables is not necessarily listed in any subpriority order. Within numerically designated levels, parameters are considered to have equal priorities.

It should be noted that the relative ranking of closely spaced (in importance) parameters is only approximate and could change significantly, depending on site-specific considerations. In addition, a different group of experts may develop a slightly different relative ranking. However, parameters near the

Table 1. Prioritized critical parameters for site characterization.

PRIORITY LEVEL	CRITICAL PARAMETERS
1.	Hydrostratigraphic unit depth, thickness, orientation, and continuity
	Water inflow rate
	Permeability
	Hydraulic head
	Fluid velocity
	Effective porosity
	Geologic variables, lateral and vertical variations in - lithology - mineralogy - stratigraphy - bedding - sorptive capacity
2.	Fracture properties (including hydrologic properties of fractures) - spacing - orientation - aperture - continuity - connectivity
3.	Temperature
4.	Initial *in situ* stress
	In situ stress changes
	Displacement and deformation
	Rock modulus and Poisson's ratio
	Expansivity
	Rock strength
	Induced fractures (and excavation damage)
5.	Groundwater chemistry - Composition - pH - Eh
	Solubility of radionuclide species of interest
	Sorptive capacity of fracture lining material
	Age of water
6.	Tectonic factors - faulting - folding - seismicity
7.	Thermal conductivity
	Heat capacity
	Thermal diffusivity
8.	Canister corrosion rate (tests) - moisture and temperature at canister surface
	Seal and backfill permeability (tests)
	Seal and backfill leakage (tests)
	Decrepitation and spalling (tests)
9.	Crustal deformation including uplift
	Erosion rate
10.	Existing underground workings
	Water, mineral, and petroleum resources
11.	Potential igneous activity
12.	Naturally occurring radionuclides

Table 2. Prioritized critical parameters for site construction.

PRIORITY LEVEL	CRITICAL PARAMETERS
1.	Fracture properties (including hydrologic properties of fractures) - spacing - orientation - aperture - continuity - connectivity
	Displacement and deformation
	In situ stress changes
	Induced fractures (and excavation damage)
	Water inflow rate
	Permeability
	Fluid velocity
	Effective porosity
	Tectonic factors - faulting - folding
	Geologic variables, lateral and vertical variations in - lithology - stratigraphy - bedding
2.	Rock strength
	Rock modulus and Poisson's ratio
	Initial *in situ* stress
3.	Hydraulic head
	Temperature
	Groundwater chemistry - composition - pH - Eh
4.	Crustal deformation including uplift
	Groundwater discharge and recharge locations and rates (changes)
	Erosion rate

Table 3. Prioritized critical parameters for site operation.

PRIORITY LEVEL	CRITICAL PARAMETERS
1.	Induced fractures
2.	Water inflow rate
3.	Temperature
4.	Displacement and deformation
	Fracture properties (including hydrologic properties of fractures) - aperture - continuity - connectivity
5.	Rock modulus and Poisson's ratio
6.	Permeability
	Fluid velocity
7.	Groundwater chemistry - composition - pH - Eh
8.	*In situ* stress changes
9.	Geologic variables (changes in mineralogy due to heating)
10.	Canister corrosion rate - moisture and temperature at canister surface
11.	Canister movement
12.	Seal and backfill permeability
	Seal and backfill leakage
13.	Decrepitation and spalling
14.	Hydraulic head
15.	Radionuclide leakage
16.	Tectonic factors - seismicity
	Crustal deformation including uplift
17.	Groundwater discharge and recharge locations and rates (changes)
18.	Erosion rate

Table 4. Prioritized critical parameters for site closure.

PRIORITY LEVEL	CRITICAL PARAMETERS
1.	Radionuclide leakage
2.	Seal and backfill leakage
3.	Seal and backfill permeability
4.	Canister corrosion rate (simulation in test facility) - moisture and temperature at canister surface
5.	Groundwater discharge and recharge locations and rates (changes)
6.	Tectonic factors - seismicity
7.	Crustal deformation including uplift
8.	Temperature
9.	Erosion rate
10.	Hydraulic head

top of each table will likely continue to have higher relative importance than those near the bottom of each table, irrespective of site-specific considerations or different expert interpretation.

Greatest concern during the site characterization phase is establishment of an understanding of the geologic setting, especially the depth, thickness, orientation, and lateral continuity of hydrostratigraphic units encompassing and bounding the repository. An understanding of the hydrologic characteristics of these hydrostratigraphic units is also a principal concern during the site characterization phase, with monitoring of these parameters continuing into subsequent phases. Measurement of geochemical parameters: groundwater composition, water age, and sorptive capability of fracture-lining minerals, is also of high priority in the site characterization phase. Canister corrosion tests should be started during the site characterization phase and long-term observations conducted throughout the entire repository sequence. Naturally occurring radionuclide concentrations in the repository rock and groundwater are important to measure during site characterization, and characterization of the fracture, thermal, and mechanical properties of the rock mass is also of high priority. It is extremely important that these properties not only be measured in labortory tests, but also that they be measured in situ in test and evaluation facilities located in the repository horizon.

In several cases, parameters requiring long-term monitoring should be measured initially in test facilities that begin operation during the site characterization phase. The most important tests are those that monitor the performance of canisters, backfill, and seals, and the hydro-thermo-mechanical response of the rock mass to the introduction of the waste. These measurements

and long-term monitoring should subsequently be extended to the actual repository locations as canisters are emplaced and as the full-scale sealing systems are established.

Measurement of geomechanical properties is of even greater importance during the site construction phase, emphasizing the deformation experienced during construction of underground openings and the effect of the openings on the hydrological regime in the near field of the repository. Similar measurements should be made as underground openings are mined for test and evaluation facilities during the site characterization phase.

Highest-priority critical parameters during the site operation phase include those concerned with response of the rock mass and hydrologic system to the thermal effects resulting from the introduction of the radioactive waste. Some critical parameters require measurement and long-term monitoring systems to be installed during the operations phase, with measurement and monitoring continuing into (and in some cases beyond) the closure and decommissioning phase. These parameters include, as high priority, radionuclide leakage and the effectiveness of backfill and sealing systems.

Though federal regulations do not presently require measurements after repository closure, it seems prudent to assume that it will be highly likely that certain measurements will continue to be made. These measurements are listed under the "Closure and Decommissioning Phase" in Table 4. However, we assume that no measurements will be made that require physical penetration into the repository after closure. Future instrumentation technology may allow continued <u>in situ</u> repository monitoring using, yet undefined, remote sensing or isolated communications techniques.

Several geologic parameters, such as faulting, folding, and erosion rate, are not directly measurable by instrumentation systems, but may be determined indirectly by surface and/or subsurface geophysical techniques. Similarly, not all hydrological parameters are directly measurable, but rely on interpretation of measurements of specific hydrological properties of the rock mass.

In terms of the analysis of the different measurement techniques and instruments for the listed parameters, it is useful to separate the parameters listed in Tables 1 through 4 into specific disciplines (i.e., geomechanical, geological, hydrological, and geochemical). In addition, Tables 1 through 4 contain both instrumented and noninstrumented parameters. We have included the noninstrumented parameters for completeness because these need to be known to establish repository adequacy.

Tables 5 through 8 list the critical parameters by repository phase and discipline area. In addition, a differentiation is made between the instrumented and noninstrumented parameters. Within a given phase and discipline area, the relative parameter importance is rank ordered. However, this rank ordering is subject to the caveats previously discussed.

The specific role of each of the critical parameters listed in Tables 1 through 8, specific factors affecting the measurement of each parameter, and the interrelationships between the parameters have been considered in detail in the report by Binnall et al, (1984) (UCID-20092) now being reviewed by the NRC. The tables and most of the comments regarding basalt in this present report have been extracted from UCID 20092, and more detailed descriptions can be obtained from that report.

Table 5. Prioritized critical parameters by discipline for site characterization.

GEOMECHANICAL PARAMETERS	GEOLOGICAL PARAMETERS	HYDROLOGICAL PARAMETERS	GEOCHEMICAL PARAMETERS
<u>Instrumented</u> Fracture properties - spacing - orientation - aperture - continuity - connectivity Temperature Initial <u>in situ</u> stress <u>In situ</u> stress changes Displacement and deformation Rock modulus and Poisson's ratio Expansivity Rock strength Induced fractures (and excavation damage) Thermal conductivity Heat capacity Thermal diffusivity Decrepitation and spalling (tests)	<u>Instrumented</u> Tectonic factors - seismicity Crustal deformation including uplift Naturally occurring radionuclides <u>Noninstrumented</u> Geologic variables, lateral and vertical variations in - lithology - mineralogy - stratigraphy - bedding - sorptive capacity Tectonic factors - faulting - folding Erosion rate Existing underground workings Water, mineral, and petroleum resources Potential igneous activity	<u>Instrumented</u> Water inflow rate Groundwater discharge and recharge locations and rates Permeability Hydraulic head Fluid velocity Effective porosity Hydraulic properties of fractures Seal and backfill permeability (tests) <u>Noninstrumented</u> Hydrostratigraphic unit depth, thickness, orientation, and continuity	<u>Instrumented</u> Groundwater chemistry - composition - pH - Eh Solubility of radionuclide species of interest Sorptive capacity of fracture lining material Age of water Canister corrosion rate (tests) - moisture and temperature at canister surface Seal and backfill leakage (tests)

Table 6. Priortized critical parameters by discipline for site construction.

GEOMECHANICAL PARAMETERS	GEOLOGICAL PARAMETERS	HYDROLOGICAL PARAMETERS	GEOCHEMICAL PARAMETERS
Instrumented Fracture properties - spacing - orientation - aperture - continuity - connectivity Displacement and deformation In situ stress changes Induced fractures (and excavation damage) Rock modulus and Poisson's ratio Initial in situ stress Temperature	Instrumented Tectonic factors - seismicity Crustal deformation including uplift Noninstrumented Tectonic factors - faulting - folding Geologic variables, lateral and vertical variations in - lithology - mineralogy - stratigraphy - bedding Erosion rate	Instrumented Hydraulic properties of fractures Water inflow rate Permeability Fluid velocity Effective porosity Hydraulic head Groundwater discharge and recharge locations and rates (changes)	Instrumented Groundwater chemistry - composition - pH - Eh

Table 7. Prioritized critical parameters by discipline for site operation.

GEOMECHANICAL PARAMETERS	GEOLOGICAL PARAMETERS	HYDROLOGICAL PARAMETERS	GEOCHEMICAL PARAMETERS
<u>Instrumented</u> Induced fractures Temperature Displacement and deformation Fracture properties - aperture - continuity - connectivity Rock modulus and Poisson's ratio <u>In situ</u> stress changes Canister movement Decrepitation and spalling	<u>Instrumented</u> Tectonic factors - seismicity Crustal deformation including uplift <u>Noninstrumented</u> Geologic variables (changes in mineralogy due to heating) Erosion rate	<u>Instrumented</u> Water inflow rate Hydraulic properties of fracture Permeability Fluid velocity Seal and backfill permeability Hydraulic head Groundwater discharge and recharge locations and rates (changes)	<u>Instrumented</u> Groundwater chemistry - composition - pH - Eh Canister corrosion rate - moisture and temperature at canister surface Seal and backfill leakage Radionuclide leakage

Table 8. Prioritized critical parameters by discipline for site closure.

GEOMECHANICAL PARAMETERS	GEOLOGICAL PARAMETERS	HYDROLOGICAL PARAMETERS	GEOCHEMICAL PARAMETERS
<u>Instrumented</u> Temperature	<u>Instrumented</u> Tectonic factors - seismicity Crustal deformation including uplift <u>Noninstrumented</u> Erosion rate	<u>Instrumented</u> Seal and backfill permeability Groundwater discharge and recharge locations and rates (changes) Hydraulic head	<u>Instrumented</u> Radionuclide leakage Seal and backfull leakage Canister corrosion rate (Simulate in test facility) - moisture and temperature at canister surface

SALT

Many of the "important issues" and "major uncertainties" regarding measurements and data needed to establish the geologic and hydrologic properties of a repository site in salt differ in detail from those indicated by the critical parameters tables for basalt. However, for the most part the same general types of measurements will be needed with some notable changes and a number of shifts in priority. We have not yet compiled a set of prioritized critical parameter tables for salt that reflects these changes.

During the site characterization phase, the establishment of an understanding of the geologic setting remains an important issue, including definition of hydrostratigraphic units encompassing and bounding the respository site. The relative importance of various components of the geologic setting (e.g., lithology, mineralogy, stratigraphy, bedding, and sorptive capacity) and of components of the hydrostratigraphic units (i.e., depth, thickness, orientation, and continuity) will depend on whether the repository site is in domal or bedded salt, and whether the repository horizon is above or below the regional water table. In any case, measurements to provide an understanding of the hydrologic characteristics of the hydrostratigraphic units remains an important issue. In domal salt, the hydrologic environment of surrounding sedimentary rocks determines the dissolution rate of the dome. Monitoring groundwater chemistry down-gradient from the dome can detect changes in dissolution of the dome. Clay (and other) interbeds, common to bedded salt, should be adequately characterized to ensure that their long-term hydrologic properties will not significantly degrade due to parting as a result of salt creep or due to thermally induced changes from heat generated by the stored high-level waste. Another important issue with major uncertainties is the

determination and/or development of techniques to locate and map inclusions of nonsalt materials which are common in both domal and bedded salt. These inclusions can be solids, liquids (e.g., brine pockets), and/or gases, which can cause major problems during repository construction and after initial waste emplacement.

Creep in rock salt, its effect on repository openings, and its influence on other repository parameters and their measurements are probably the most important issues that differentiate a repository in salt from one in basalt or tuff. At the present time there are still major uncertainties regarding the amount of creep that will take place and its effects on the repository system, especially at the elevated temperatures that will follow waste emplacement. Even disregarding the high temperature question, Nelson and Kelsall (1984) have shown that for salt, "under conditions of equal stress and temperature, the variations in strain rate among the samples tested (all sites) is three to four orders of magnitude" for secondary (steady state) creep. They also have shown that creep rates of some salts are relatively more sensitive than others to changes in stress and to changes in temperature. "Primary (transient) creep is important immmediately following excavation but its contribution to the total creep rate (primary and secondary components) diminishes with time. In the long term, secondary (steady state) creep will be the dominant creep mechanism" (Nelson and Kelsall, 1984). Russell et al (1984) point out that for Avery Island rock salt "the overall behavior to about 100°C can be described as semibrittle, depending on other variables, but above that temperature, homogeneous plastic deformation dominates." At higher temperatures, there is an appreciable increase in creep rate, and the transition from transient to steady state creep takes considerably less time. They also point out

that increased differential stress has much the same effect on creep as increased temperature.

According to Abel and Djahanguiri (1984), "the most basic problem facing investigators attempting to predict radioactive waste repository response in rock salt is the validation of specimen derived rheological models." The ability needs to be developed "to take data from core tests and predict time-dependent deformation of pillars and rooms --- for repository designs." The important issue here is that the ability to predict creep response in mined openings must be developed by the waste storage programs (rather than by commercial mining operations) because of the unique long-term periods involved and the thermal loading anticipated.

Creep properties will influence the relative importance and the measurement techniques that must be considered for a number of the critical parameters listed in Tables 1 through 8 for basalt when these parameters are applied to a repository in salt. The influence of creep on some of these parameters has been discussed in the preceding paragraphs. The influence on other parameters is tabulated and briefly discussed below:

- Fracture properties. Measurement of fracture properties (spacing, orientation, aperture, continuity, and connectivity), including hydrologic properties of fractures, will not be as important in salt as in basalt and tuff because of fracture healing resulting from the plastic characteristics of salt. However, the fracture properties that might influence hydrology in nonsalt bedded material and other inclusions must be understood. The significance of these fracture properties will be somewhat dependent upon whether the repository horizon lies above or below the water table, and, if below the water table, what the potential hydraulic pressures are.

- Induced fractures. To some extent, the need to monitor for induced fracturing (and excavation damage) will be replaced by the need to monitor salt creep, especially at elevated temperatures. Monitoring for induced fracturing should remain a relatively high priority where there is a chance that clay parting (or parting of other bedded material) may weaken the roof structure over repository openings, or where there is the potential for gas outbursts from pressure pockets.
- In situ stress changes. Direct measurement of long-term in situ stress changes has always been difficult in hard rock where elastic properties dominate. Conceptually, monitoring stress changes in salt may be easier because of the plastic deformation that can take place at the gauge contact surfaces, provided that the gauge characteristics (e.g., modulus, shape, etc.) are properly matched to the salt characteristics. The parameter, in situ stress changes, should have a very high priority in the repository near field because of its influence on creep rate and its need as a parameter for rheologic modeling of the repository.
- Displacement and deformation. Displacement and deformation are significantly greater in salt then in basalt or tuff because of the plasticity of the salt. Therefore, displacement and deformation is one of the most important parameters that must be monitored in a salt repository.
- Rock properties (modulus, Poisson's ratio, and strength). Standardized measurement techniques should be used that will allow separation of elastic and failure parameters from creep parameters over a wide temperature range. For example, in measuring salt rock-strength, progressively more rapid yielding of specimens as failure approaches makes it difficult to pick the peak load at failure.

- Seal and backfill permeability. The ability to predict creep closure rates and sealing mechanisms will help to assess the degree to which salt will converge on repository borehole seals, bulkheads, and backfill. Long-term closure rates are particularly important to the use of crushed salt for backfill material because of the ultimate consolidation of the salt backfill into an essentially impermeable salt monolith (Kelsall et al, 1984).
- Permeability. Less concern over hydrology in the rock salt because of its low permeability should be offset to some extent by the need to determine moisture migration rates and mechanisms characteristic of the salt.

Other important parameters for a repository site in salt include thermal properties (conductivity, heat capacity, diffusivity) and thermomechanical response of the salt, interbedding material, and the bounding media. The thermal properties of the salt are particularly important because of their interaction with temperature effects on other parameters, especially creep rate. Among the important issues influenced by these parameters are the problems that will be encountered if it becomes necessary to retrieve waste in a high temperature hostile environment after openings have been closed as a result of plastic deformation of the rock salt. This concern also applies to any other reasons, besides retrieval, that may make it necessary to reexcavate openings. It is even conceivable that canister (or liner) movement may occur as a result of plastic flow in the salt.

TUFF

The important issues and major uncertainties associated with geologic and hydrologic property measurements of a repository site in tuff are generally similar to those indicated by the critical parameter tables for basalt. The major considerations that will influence the relative importance of these parameters for tuff include whether the repository will be in welded or unwelded tuff, the degree of welding, and whether the repository horizon will be above or below the water table. With present information, we assume that the repository site will be in welded tuff, above the water table, and with a moisture saturation level as high as 95 percent.

Some of the major uncertainties with a repository in the unsaturated region of a relatively porous rock are concerned with the hydrologic measurement techniques and interpretive methods necessary to understand the hydrologic effects that contribute to radionuclide escape from the repository. Most hydrologic measurement and interpretive techniques have been developed for work in saturated regions, and are not directly applicable to unsaturated regions. Tracer tests, which are applicable to unsaturated zones, may be too slow to give any reasonable short-term data on repository-scale hydrology patterns and rates.

A summary by Russell et al. (1984) on laboratory testing of tuff, points out that "this general rock type poses especially difficult problems for repository predictive capability because of enormous variations in rock mineralogy, structure, fabric and porosity." However, there is a correlation between variations in elastic properties and compressive strength with variations in effective porosity. Young's modulus increases exponentially with

decreased porosity, and unconfined tensile strength increases with decreased porosity. Shear strength parameters (internal friction and cohesion) are also inversely proportional to porosity. In general, the strength of tuff varies with the degree of welding, which is reflected in the porosity of the rock. Russell et al. (1984) also report that some water-saturated tuff samples are weaker than room-dry and oven-dry samples, and that the water weakening is ascribed to chemical rather than mechanical effects. Similarly, the strengths of relatively high-porosity tuffs are lower at 200°C than at 23°C but the lower-porosity tuffs appear to be little affected by this temperature variation.

Thermal parameters (conductivity, heat capacity, diffusivity) and thermal expansion are other important properties that have considerable influence on the response of the respository rock to thermal loading. Thermal properties of tuff are dependent on porosity, water content, density, and mineralogical composition. Thermal expansion of tuff is markedly dependent on porosity and rock type. In fact a welded tuff rock mass may be susceptible to contraction when heated over a long term if the discontinuities contain significant amounts of expandable clays or zelolites.

REFERENCES

Abel, J.F., and F. Djahanguiri (1984), Mining Inputs to Salt Repository Design, paper presented and distributed at the 25th U.S. Symposium on Rock Mechanics, June 25-27, 1984, by John F. Abel, Colorado School of Mines, Golden, Colorado.

Binnall, E.P., H.A. Wollenberg, S.M. Benson, L. Tsao, O. Weres, A.L. Ramirez, G.A. Armantrout (1984), Critical Parameters for a High-Level Waste Repository in Basalt, prepared for the U.S. Nuclear Regulatory Commission (presently being reviewed), Lawrence Livermore National Laboratory Report NO. UCID-20092.

Kelsall, P.C., J.B. Case, J.W. Nelson, and J.G. Franzone (1984), "Assessment of Crushed Salt Consolidation and Fracture Healing Processes in a Nuclear Waste Repository in Salt," Proc. Waste Management '84, Tucson.

Nelson, J.W., and P.C. Kelsall (1984), "Prediction of Long-Term Creep Closure in Salt", Proceedings 25th U.S. Symposium on Rock Mechanics, Evanston, Illinois, pp. 1115-1125.

Russell, J.E., N.L. Carter, and J. Handin (1984), "Laboratory Testing for Repository Characterization", Proceedings 25th U.S. Symposium on Rock Mechanics, Evanston, Illinois, pp. 1188-1213.