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July 23, 1986
Contract No. NRC-02-85-008
Fin No. D-1020
Communication No. 70

Mr. Jeff Pohle
Division of Waste Management
Mail Stop 623-SS
U.S. Nuclear Regulatory Commission
Washington, D.C. 20555

RE: NTS

Dear Jeff:

A copy of the review of each of the following documents is enclosed.

1. Daniels, J.J., Scott, J.H., and Hagstrum, J.T., 1981, Interpretation of Geophysical Well-Log Measurements in Drill Holes UE25a-1, -5, -6, and -7, Yucca Mountain, Nevada Test Site: USGS Open-file Report 81-615, 29 p.

2. Hagstrum, J.T., Daniels, J.J., and Scott, J.H., 1980, Interpretation of Geophysical Well-Log Measurements in Drill Hole UE25a-1, Nevada Test Site, Radioactive Waste Program: USGS Open-File Report 80-941, 32 p.

3. Healey, D.L., Clutsom, F.G., and Glover, D.A., 1984, Borehole Gravity Meter Surveys in Drill Holes USW G-3, UE-25p#1, UE-25c#1, Yucca Mountain Area, Nevada: USGS Open File Report 84-672, Denver, 16 p.

4. Klavetter, E.A., and Peters, R. R., 1985, Fluid Flow in a Fractured Rock Mass. Nevada Nuclear Waste Storage Investigations Project Department, Sandia National Laboratories, Albuquerque, NM.

5. Ortiz, T.S., and others, 1985, A Three-Dimensional Model of Reference Thermal/Mechanical and Hydrological Stratigraphy at Yucca Mountain, Southern Nevada. Sandia National Laboratories, Albuquerque, NM, and Livermore, CA, SAND84-1076, 72 p.

WM-RES
WM Record File
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WEA

WM Project 10, 11, 16
Docket No.
PDR ✓
LPDR ✓ (B, N, S)

Distribution:
J Pohle

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6. Thompson, F.L., Dove, F.H., and Krupka, K.M., 1984, Preliminary Upper-Bound Consequence Analysis for a Waste Repository at Yucca Mountain, Nevada. Sandia National Laboratories, Albuquerque, NM, and Livermore, CA.

7. Walter, G.R., October 1982, Theoretical and Experimental Determination of Matrix Diffusion and Related Solute Transport Properties of Fractured Tuffs from the Nevada Test Site. Department of Hydrology and Water Resources, University of Arizona, Tucson, AZ, for Los Alamos National Laboratory, Los Alamos, NM, LA-9471-MS.

Please contact me if you have any questions concerning these reviews.

Sincerely,

James Osiensky

James Osiensky

JO:sl

enclosures

WMGT DOCUMENT REVIEW SHEET

FILE #:

DOCUMENT #: USGS-OF-81-615

DOCUMENT: Daniels, J.J., Scott, J.H., and Hagstrum, J.T., 1981, Interpretation of Geophysical Well-Log Measurements in Drill Holes UE25a-1, -5, -6, and -7, Yucca Mountain, Nevada Test Site: USGS Open-file Report 81-615, 29 p.

REVIEWER: Williams & Associates, Inc.

DATE REVIEW COMPLETED: July 15, 1986

ABSTRACT OF REVIEW: **APPROVED BY:** Roy E Williams

The report under review presents interpretations of geophysical wells logs recorded for test wells UE25a-4, UE25a-5, UE25a-6, and UE25a-7. Resistivity, density, neutron, gamma-ray, induced polarization, and magnetic-susceptibility well logs were recorded for these test wells. The geophysical logs for the four test holes are interpreted primarily with respect to identifying the major lithologic features penetrated by the boreholes.

BRIEF SUMMARY OF DOCUMENT:

The purpose of the report under review is to present interpretations of borehole geophysical logs recorded in test wells UE25a-4, UE25a-5, UE25a-6, and UE25a-7. Resistivity, density, neutron, gamma-ray, induced-polarization, and magnetic-susceptibility logs were recorded for these test wells. According to the report, interpretation of the well log measurements was facilitated by use of a computer program designed to interpret well logs. Details are not given.

Test wells UE25a-4, UE25a-5, UE25a-6, and UE25a-7 were cored to depths of 138 m, 133 m, 127 m, and 143 m, respectively, on the northeastern flank of Yucca Mountain. Test well UE25a-7 is the only hole that is not vertical. This test well was drilled at an angle of 26 degrees from the vertical.

According to the report, each geophysical log is affected by the physical properties of the rock, the interstitial fluid of the formation, the conditions in the borehole (fluidity and rugosity), the volume of rock investigated by the probe, the vertical resolution of the probe, and the design characteristics of each probe. The report notes that interpretation of the lithologies was complicated by the unsaturated condition of the rocks. According to the report, the fluid level could not be maintained at the land surface in any of the test wells. Resistivity and neutron logs are presented only for that portion of the test wells below which a "standing" water level could be maintained.

According to the report, the resistivity of ash flow tuffs should be a function of welding, devitrification, and void space in the rocks; resistivity in saturated welded tuffs should increase with the degree of welding and decrease with the degree of devitrification and the amount of void space (including fractures). Figures 3, 4, 5, and 6 of the report, respectively, present the resistivity logs for test wells UE25a-4, UE25a-5, UE25a-6, and UE25a-7. According to the report, high resistivity values that occur in the Topopah Spring Member represent welded tuffs; however, a high resistivity zone at the top of the Topopah Spring Member and a low resistivity zone at the base of the Topopah Spring Member cannot be explained by variations in the degree of welding. The report suggests that a possible cause for the high resistivity zone at the top of the Topopah Spring Member may be a vitrophyre. Low resistivity values at the bottom of drill holes UE25a-5 and UE25a-6 may be caused by a lithophysal zone. The report suggests also that variations in the degree of welding that cannot be detected in the drill core may affect the resistivity.

Density logs indicate that non-welded and highly altered units have low bulk densities. Densely welded units have high bulk densities. Figures 7, 8, 9, and 10, respectively, present the density logs for drill holes UE25a-4, UE25a-5, UE25a-6, and UE25a-7. The report suggests that the high density values in the Topopah Spring Member can be interpreted consistently as being caused by the presence of welded tuffs. The report suggests also that an increase in the density near the top of the Topopah Springs Member probably is caused by the vitrophyre indicated on the lithologic log. The density logs for the Topopah Spring Member indicate that the highest and lowest bulk densities occur in test well UE25a-5 and UE25a-4, respectively.

The neutron logs for test wells UE25a-4, UE25a-5, UE25a-6, and UE25a-7 are shown in figures 12, 13, 14, and 15, respectively. It is noteworthy that these neutron logs show and inverse relationship between the degree of welding and the neutron count rate. According to the report, when the neutron well log interpretations are based on this inverse relationship they correspond closely to the lithology as interpreted from core. However, the report notes that a constant value for degree of fluid saturation in each of the formations must be assumed in order for this interpretation to be valid. According to the report, potassium bearing minerals are common in both primary and secondary crystalization regimes in welded tuffs. Therefore, the gamma-ray logs indicate the relative abundance of potassium. Figure 16 of the report presents the gamma-ray logs for the four test wells. According to the report, the gamma-ray signatures for the Topopah Spring Member are correlatable between each of the four drill holes. The lowest intensity gamma-ray measurements occur in test well UE25a-5. The report suggests that if the amount of potassium is related to post-emplacement chemical alteration, then the logs suggest that the degree of alteration between the drill holes may be significant.

The induced polarization (IP) logs for the test wells are shown in Figure 17 of the report. According to the report, a high IP response in volcanic rocks may be caused by cation enriched clays, zeolites or sulfides. The report suggests also that in some cases iron oxide minerals may influence the IP response. According to the report, the IP values are unreasonably high and the usefulness of the logs themselves is questionable. The report suggests that the IP logs apparently were influenced by the invasion of drilling fluid into the unsaturated volcanic rocks.

Magnetic susceptibility logs for the four test wells are shown in Figure 18 of the report. According to the report, these logs are discussed in another paper by Hagstrum and others (1980).

The report under review presents the following conclusions:

1. Interpretation of the borehole geophysical well logs for the four test holes was complicated by the absence of 100 percent fluid saturation. Most geophysical logs are not designed for use in the unsaturated zone.

2. Partial fluid saturation levels caused direct correlation between neutron response and porosity, rather than the usual inverse relationship.

3. The partially saturated rocks caused abnormally high IP values.

4. The density and resistivity logs indicate that near surface fracture zones are least likely to be present near drill hole UE25a-5.

6. Additional mineralogic and petrologic work is needed to interpret the geophysical logs in more detail.

7. Laboratory physical-properties measurements are needed to link the mineralogic and petrologic work to the geophysical well log measurements.

<u>SIGNIFICANCE TO NRC WASTE MANAGEMENT PROGRAM:</u>

The report under review presents interpretations of geophysical logs recorded for test wells UE25a-4, UE25a-5, UE25a-6, and UE25a-7. The report is significant primarily with respect to understanding the lithology and possibly the hydrostratigraphy penetrated by the test wells. The interpretations presented in the report appear to be valid. Therefore, the information presented in the report may become important with respect to understanding the hydrogeologic characteristics in the vicinity of the test wells.

PROBLEMS, DEFICIENCIES OR LIMITATIONS OF REPORT:

The report under review presents reduced (in scale) copies of lithologic logs and geophysical logs recorded for the four subject test holes. The report primarily is an interpretation report and is not intended to present field data. The logs presented in the report do not allow evaluation of "minor features" that may be of hydrogeological significance. However, presentation of the actual well logs is not the intended purpose of this report. The interpretations presented in the report more or less must be accepted to be accurate and valid.

SUGGESTED FOLLOW-UP ACTIVITIES

The interpretations presented in the report under review may become significant as the hydrogeology of the Yucca Mountain area is evaluated in greater detail. However, if this information becomes significant, it would be necessary for the NRC to obtain copies of the original well logs for independent evaluation.

REFERENCES CITED:

Hagstrum, J.T., Daniels, J.J., and Scott, J.H., 1980, Analysis of the Magnetic Susceptibility Well Log from Drill Hole UE25a-5, Yucca Mountain, Nevada Test Site: USGS Open File Report 80-1263, 33 p.

WMGT DOCUMENT REVIEW SHEET

FILE #:

DOCUMENT #: USGS-OF-80-941

DOCUMENT: Hagstrum, J.T., Daniels, J.J., and Scott, J.H., 1980, Interpretation of Geophysical Well-Log Measurements in Drill Hole UE25a-1, Nevada Test Site, Radioactive Waste Program: USGS Open-File Report 80-941, 32 p.

REVIEWER: Williams & Associates, Inc.

DATE REVIEW COMPLETED: July 15, 1986

ABSTRACT OF REVIEW: **APPROVED BY:** Roy E Williams

The report under review presents a preliminary interpretation of the geophysical logs recorded in test hole UE25a-1. Geophysical logs recorded in the test hole include resistivity, density, neutron, gamma-ray, induced polarization, and magnetic susceptibility. Interpretation of the well logs by the authors was facilitated by a computer program designed to interpret well logs individually or simultaneously. No details of the program are given. The primary emphasis of the report is the interpretation of lithologic variations within the tuff units penetrated by test hole UE25a-1.

BRIEF SUMMARY OF DOCUMENT:

The purpose of the report under review is to present an interpretation of the lithologic character of the tuff units penetrated by test hole UE25a-1 from geophysical log measurements. The geophysical logs recorded for the test hole include resistivity, density, neutron, gamma-ray, induced polarization, and magnetic-susceptibility. According to the report, because of the subjective nature of geophysical log interpretation, consistent interpretations of the well logs were facilitated by a computer program designed to interpret well logs either individually or simultaneously. No details of the program are presented.

Test well UE25a-1 was drilled and cored to a depth of 762 m. The purpose of the test hole was to investigate the stratigraphy, structure, mineralogy, petrology, and physical properties of the Paintbrush tuff, the tuffaceous beds of Calico Hills, and a portion of the lower member of the Crater Flat tuff.

Zones of zeolitization, silicification, and calcitization occur within the tuffs penetrated by the test well due to alteration by groundwater. The groundwater level presently is at 469 m in test hole UE25a-1; however, the report notes that alteration related to groundwater saturation occurs up to 80 m above this level.

The geophysical well logs for drill hole UE25a-1 are presented in Appendix A of the report. According to the report, initial interpretation of the geophysical logs is based on geologic observations by Spengler (1979) and Sykes and others (1979). According to the report, a computer program was written to synthesize a consistent interpretation of well log data. The program "assigns particular lithologies for those depth intervals that contain one or more geophysical well log measurements within specified value ranges."

According to the report, degree of welding is correlative with density obtained from neutron logs in the lower portion of the test hole. Because of this fact, "value ranges for the degree of welding (Table 1 of the report) were selected subjectively for these logs to best match the welded zones described by Spengler (1979)." According to the report, the low density values for the densely welded rock in the top portion of the hole are due to borehole wall instability caused in part by the extensive fracturing of these units. In addition, the neutron response values are consistently high due to the absence of groundwater in the upper part of the test hole. The report notes that inconsistencies occur in the response values for gamma-ray, resistivity, and magnetic-susceptibility logs. Because of these inconsistencies, the value ranges were selected subjectively by the authors based on the largest groups of units within a log that gives similar values.

According to the report, densely welded sections of the Tiva Canyon and Topopah Spring Members give gamma-ray measurements of 128.2 to 152.7 cps and 103.8 to 140.5 cps, respectively. The densely welded sections of the Crater Flat tuff give gamma-ray measurements of 79.4 to 103.8 cps. The report attributes these variations in response values to the fact that the fine-grain devitrification products of the Paintbrush tuff units are 40 percent richer in potassium feldspar than the Crater Flat tuff units. The report suggests also that the spherulitic textures are more prevalent in the Paintbrush tuff.

Magnetic susceptibility values are moderate to high for the densely welded Paintbrush tuff sections. However, magnetic susceptibility values are low for the Crater Flat tuff. The report suggests that the differences may be related to the variation of magnetite in the initial composition of magma or that the lower values may be an indication of the degree of oxidation of magnetite to hematite.

According to the report, it was necessary to interpret several well logs simultaneously to best characterize the rock encountered by the geophysical probes. The computer program uses several digitized well logs in the corresponding value ranges subjectively assigned to a particular lithology. The report notes that due to the problems encountered in logging the upper portion of test hole UE25a-1, only the logs for the lower part of the hole are considered in the multiple log analysis.

Figure 8 of the report shows the initial results of multiple log interpretation combining density and neutron logs. Figure 9 of the report presents the results of the computer analysis which assigned depth ranges to the value ranges of those existing possibilities in an individual well log. According to the report, Figure 9 is a preliminary interpretation and should be augmented by a geologist's field log, drillers records, and the detail of the original geophysical well log measurements.

According to the report, notable differences between the resistivity and IP response values exist between densely welded zones of the Prow Pass Member and the Bullfrog Member of the Crater Flat tuff. The density, neutron, gamma-ray, and magnetic susceptibility response values are consistent between these units. The report suggests that the Bullfrog Member probably contains a higher concentration of a low-resistivity polarizable mineral than the Prow Pass Member. In addition, the report suggests that hematite could cause some of the IP responses seen in the Bullfrog Member.

Lower density, neutron, and magnetic susceptibility response values occur in the non welded units than in the welded units. According to the report, the tuffaceous beds of the Calico Hills appear to be the least indurated interval and show the lowest density in neutron values. Resistivity, gamma-ray, and magnetic susceptibility response values also are low for the non welded units; these low values suggest a relatively high porosity and low concentrations of potassium rich minerals and magnetite.

The report presents the following conclusions:

1. Interpretation of geophysical well logs from test hole UE25a-1 was hampered by incomplete log coverage and the complex response of some well logs.

2. The IP measurements did not correspond consistently to any single mineral expected to give a high response.

3. More mineralogic and petrologic work is needed to clarify the causal elements of well-log response in welded tuffs.

4. Future studies must include laboratory physical properties measurements to link the mineralogic and petrologic work to the geophysical well log measurements.

SIGNIFICANCE TO NRC WASTE MANAGEMENT PROGRAM:

The report under review presents interpretations of the geophysical logs recorded for test well UE25a-1. The geophysical logs are interpreted primarily with respect to the major lithologic variations. The interpretations presented in the report may be of value in the detailed evaluation of the hydrogeologic characteristics of the tuff units in the vicinity of test hole UE25a-1.

PROBLEMS, DEFICIENCIES OR LIMITATIONS OF REPORT:

The report under review is limited with respect to characterizing the hydrogeology in the vicinity of test hole UE25a-1 because of the uncertainties involved in the interpretation of the geophysical logs. The report is useful with respect to the identification of major lithologic units. However, additional data are needed to improve the reliability of the interpretations presented in the report. In addition it should be noted that most borehole geophysical logs are not designed for use above the water table.

SUGGESTED FOLLOW-UP ACTIVITIES

Information presented in the report under review may become important with respect to detailed characterization of the hydrogeology in the vicinity of test hole UE25a-1. No follow-up activity is suggested unless additional data become available to improve the reliability of interpretations of the geophysical logs.

REFERENCES CITED:

Spengler, R.W., Muller, D.C., and Livermore, R.B., 1979, Preliminary Report on the Geology and Geophysics of Drill Hole UE25a-1, Yucca Mountain, Nevada Test Site: USGS Open-file Report 79-1244, 43 p.

Sykes, M.L., Heiken, G.H., and Smyth, J.R., 1979, Mineralogy and Petrology of Tuff Units from the UE25a-1 Drill Site, Yucca Mountain, Nevada: Los Alamos Scientific Laboratory Informal Report LA-8139-NS, 76 p.

WMGT DOCUMENT REVIEW SHEET

FILE #:

DOCUMENT #: USGS-OF-84-672

DOCUMENT: Healey, D.L., Clutsom, F.G., and Glover, D.A., 1984, Borehole Gravity Meter Surveys in Drill Holes USW G-3, UE-25p#1, UE-25c#1, Yucca Mountain Area, Nevada: USGS Open File Report 84-672, Denver, 16 p.

REVIEWER: Williams & Associates, Inc.

DATE REVIEW COMPLETED: July 16, 1986

ABSTRACT OF REVIEW: APPROVED BY: Roy E Williams

The report under review presents data collected during borehole gravity meter surveys in drill holes USW G-3, UE-25p#1, and UE-25c#1. The report is a basic data report which presents measurements obtained during the surveys and a description of the methodology used to collect the data. The information contained in the report should be of primary interest to mining engineers involved in the evaluation of shaft and repository construction.

BRIEF SUMMARY OF DOCUMENT:

The purpose of the investigation described in the report under review was to measure the in-situ bulk densities of the stratigraphic units penetrated by drill holes USW G-3, UE-25p#1, and UE-25c#1. A "LaCoste and Romberg Slim hole borehole gravity meter (BHGM) BH-6 was used to log each of the holes logged to date at Yucca Mountain." According to the report, drill hole USW H-1 also was logged with the borehole gravity meter as part of this investigation but at an earlier date (Robbins, Schmoker, and Hester, 1982).

According to the report, the borehole gravity meter is primarily a density logging tool with a larger radius of investigation than conventional logging tools. According to the report, the borehole gravity meter survey provides an independent measure of the in-situ bulk density of the rocks surrounding the drill hole.

Gravity observations obtained by the borehole gravity meter are corrected for the effects of earth tides, instrument drift, and terrain. Gravity data are corrected for the effects of earth tides and instrument drift by the computer program BHGRAV.77. The data reduction program makes terrain corrections from digitized topography determined by hand from topographic maps and from sketches of the drill site.

In order to determine the true bulk density, the free air gradient must be measured. The free air gradient is determined from the following relationship:

$$F = \frac{\Delta g + TC}{\Delta H}$$

where F is equal to the free air gradient, Δg is the difference in gravity (mGal) measured on the ground and at some point above the ground, TC is the difference in the terrain correction between the two points, and ΔH is the vertical distance separating the two points.

Tables 2, 3, and 4 of the report show the stratigraphic units penetrated by drill holes USW G-3, UE-25p#1, and UE-25c#1. Tables 5, 6, and 7 of the report present the in-situ integral bulk densities calculated from the borehole gravity meter data.

Forty-eight gravity observations were made between the depths of 15.24 and 665.99 meters in drill hole USW G-3. According to the report, windy conditions prevented measurement of the free air gradient. Therefore, the data for USW G-3 were reduced using the "normal" value of 0.3086 mGal/m for the free air gradient.

Ninety-one gravity observations were made between the depths of 27.43 m and 1972.22 m in drill hole UE-25p#1. The measured free air gradient at drill hole UE-25p#1 was 0.3146 mGal/m. This free air gradient is 1.8% higher than the assumed "normal" value. According to the report, a fault was penetrated at a depth between 1,191.77 meters and 1,244.19 meters. Gravity and gamma ray logs represent the only reliable data that were obtained in this interval. According to the report, the results of an investigation of this fault will be presented in a "planned interpretation report of the borehole gravity meter data."

Forty-eight gravity meter observations were made between the depths of 19.81 and 900.68 meters in drill hole UE-25c#1. The measured value of the free air gradient was 0.3116. This value is 0.97% higher than the "normal" value. According to the report, this difference is significant and if the incorrect value was used in tonnage calculations for mining purposes an error of about 2% could result.

The report presents the following conclusions and recommendations:

1) Borehole gravity meter surveys at Yucca Mountain provide excellent density data. However, the free air gradient must be measured at or near each logged hole.

2) Additional holes at Yucca Mountain should be logged with the borehole gravity meter, especially those holes close to the proposed shaft and repository.

3) A pilot hole at the shaft site should be considered. Borehole gravity meter and gamma gamma logs should be recorded for this pilot hole.

4) Geologic structure adjacent to a drill hole may be evaluated by comparing borehole gravity meter logs and gamma gamma density logs.

5) The borehole gravity meter is a useful tool and should be utilized fully to help resolve the problems that remain regarding the structural setting at Yucca Mountain.

SIGNIFICANCE TO NRC WASTE MANAGEMENT PROGRAM:

The report under review presents valuable data with respect to density measurements of stratigraphic units penetrated by test holes USW G-3, UE-25p#1, and UE-25c#1. Data presented in the report should be of primary interest to mining engineers in the evaluation of shaft and repository construction. In addition, the borehole gravity meter may prove to be a valuable tool for use in measuring porosity and in delineating faults in the subsurface.

PROBLEMS, DEFICIENCIES OR LIMITATIONS OF REPORT:

The report under review is a basic data report. According to the report an interpretation report of the borehole gravity meter data is planned. The report under review describes the methods used to collect the density data. The report has no significant problems, deficiencies or limitations.

SUGGESTED FOLLOW-UP ACTIVITIES

We suggest that the planned companion report that will present interpretations of the borehole gravity meter data be reviewed by the NRC staff involved with the evaluation of shaft and repository construction. Information presented in this planned report also may be of value with respect to evaluation of porosity values.

REFERENCES:

Robbins, S.L., Schmoker, J.W., and Hester, T.C., 1982, Principal Facts and Density Estimates for Borehole Gravity Stations in Exploratory Wells UE 4ah, UE 7j, UE1h, UE1q, UE2co, USW-H1 at the Nevada Test Site, Nye County, Nevada: USGS Open File Report 82-277, 33 p.

WMGT DOCUMENT REVIEW SHEET

FILE #:

DOCUMENT #: SAND85-0855

DOCUMENT: Fluid Flow in a Fractured Rock Mass. E.A. Klavetter and R.R. Peters, Nevada Nuclear Waste Storage Investigations Project Department, Sandia National Laboratories, Albuquerque, NM.

REVIEWER: Williams & Associates, Inc.

DATE REVIEW COMPLETED: July 15, 1986

ABSTRACT OF REVIEW: **APPROVED BY:** Roy E Williams

A conceptual model for flow in the matrix and fractures of Yucca Mountain is developed. The authors use the concept of Wang and Narasimhan (1985) that at low moisture contents in the fractures water will flow across the fractures from one matrix block to another. At high moisture content in the fractures flow will occur parallel to the fractures. Using both macroscopic and microscopic analyses, two relationships are developed: 1) for the composite conductivity as a function of pressure and 2) for the storage of water in the matrix and in the fractures as a function of pressure. The two developments are in agreement. This work appears to be the most comprehensive model for downward flow in the unsaturated zone in Yucca Mountain that has been developed at this time.

BRIEF SUMMARY OF DOCUMENT:

In this report a conceptual model is developed for the combined matrix and fracture flow systems in the various units of Yucca Mountain. The authors note that it is possible that some portion of the total flux may be diverted at interfaces between the hydrogeologic units due to the contrast in conductivities, but that calculations and field testing will be required to determine whether water actually is diverted in a situation where a perched water table does not form. The concept of flow in fractures contained within a matrix is based on the work of Wang and Narasimhan (1985). This concept presupposes that at low water contents in the fractures the water will flow across the fractures from one block to the other. If the fractures are filled with water the flow will occur parallel to the fractures. The major points of the conceptual model proposed in the paper may be summarized as follows:

"1. The fracture conductivity for water movement across the fracture is probably much larger than the adjacent matrix conductivity. Thus flow across the fractures is controlled by the adjacent matrix conductivity and the fracture conductivity across the fracture may be replaced by the matrix conductivity in flow calculations.

2. The average fracture conductivity for water movement in the plane of the fractures is a highly nonlinear function of fracture saturation or pressure head. If the flux is less than the saturated conductivity of the matrix the water will tend to flow only in the matrix as it moves downward. If the flux is greater than saturated conductivity in the matrix the matrix will saturate and the fractures will carry water also."

<u>Hydrologic Model</u>

The authors review several of the many mathematical models which are available for partially saturated flow in porous media. They then identify two alternatives for modeling situations where water movement occurs in both fractures and the matrix.

"1. Model the fractures explicitly by zoning them into the calculational mesh as a second region that has much different properties from the properties of the matrix portion.

2. Rederive the flow equation for an equivalent porous media, taking into account the fact that there are two porosity systems: the matrix porosity system and the fracture porosity system."

Either approach requires a great deal of knowledge about the size and geometry of the fractures. The second option is used in the report under review because of the large size scale problems inherent with a high fracture density in the region being simulated. The equations that describe flow in the equivalent porous media may be developed either from 1) a macroscopic model assuming that the fracture and matrix hydrogeologic properties used are statistically representative of the large volume of rock mass, or 2) a microscopic model using the actual physical structure of the system of interest combined with the fundamental theoretical considerations for fluid flow in pores of a specified geometry. The goal of either of these procedures is to determine relative hydraulic conductivity and degree of saturation values as functions of pressure head. Both of the above approaches are used in the paper under review and both arrive at essentially the same relationships. Both derivations use capillary tube theory in their evaluation of the hydrogeologic variables and therefore are not applicable for systems containing fractures with apertures of the order of many millimeters or larger.

Macroscopic Derivation of Equation for Water Flow:

The equations of flow for the matrix and the fractures are written separately. They may be combined if the pressure distribution in the fractures is the same as in the matrix. This procedure is justified if the flow is nearly steady which is thought to be the case in Yucca Mountain.

The formulation above leads to an analysis of the depth in the formation to which flow would occur in fractures during an episodic pulse of water from the surface. The water injected into the fracture will move quickly into the matrix because of the following two factors:

1) At the front end of the pulse a large pressure head difference exists between the saturated fracture and the partially saturated matrix. This difference may be on the order of 100 m.

2) Because the fracture conductivity is very low (the fracture may be nearly dry), flow in the fracture is retarded and the pulse is diverted into the matrix. Wang and Narasimhan (1985) indicate that the fracture conductivity for flow within the plane of the fracture may be zero until the nearby matrix material is nearly saturated.

The authors later note that episodic pulses of water could penetrate to great depth in regions near large structural features such as fault zones or where the fracture apertures are large enough that capillary tube theory is not applicable. However, we note that such features would have to be in contact with water at near atmospheric pressure.

In summary the authors indicate that water injected into the surface above the main body of the repository is not likely to penetrate the fractures to appreciable depth. The result is nearly steady flow at depth.

The next section of the report discusses the functional relationships between saturation level and pressure head; the same relationship between conductivity and pressure is discussed also. The equation used for saturation level vs. pressure head is from van Genuchten (1978). All matrix property data and most of the fracture data were taken from Peters et al. (1984). The equation that relates conductivity and pressure head is from Mualem (1976). The authors develop a "capacitance" coefficient which combines the effect of all water storage phenomena such as fracture compressibility, matrix saturation, rock bulk compressibility, fracture saturation level, and water compressibility. The water storage due to each of these factors then is computed separately and the sum is termed the capacitance coefficient. The capacitance coefficient is a highly nonlinear function of pressure head.

Curves are presented for hydraulic conductivity as a function of pressure head for the matrix, the fractures and their sum (composite conductivity).

The authors point out that the various terms in the equations are volume averaged values of these parameters.

Microscopic Derivation of Flow Equation

In the microscopic approach the contributions of the matrix pores and the fractures are combined to determine the hydrogeologic parameters. Consequently, the fractures are being treated as large pores. The pore size distribution data for samples of the tuff matrix were obtained from mercury injection tests; they are presented as a graph of pore diameter vs. incremental intrusion volume (the volume of mercury that has moved into the pores). Burdine's (1953) equation was used to calculate the relative hydraulic conductivity from the saturation level vs. pressure data. Relative conductivity-pressure curves calculated with the composite porosity model (macroscopic model) are compared with the relative conductivity curves that are calculated from the pore size distribution data and from the assumed log-normal aperture distribution for the fractures (microscopic model). In most cases the agreement is excellent. The difference between the two developments is that the macroscopic development considered the compressibilities of water, the matrix and the fractures, whereas the microscopic development did not consider these factors. From the comparison of the results, however, it appears that in most cases the differences are insignificant.

SIGNIFICANCE TO NRC WASTE MANAGEMENT PROGRAM:

This report includes the most comprehensive development to date for the theory of partially saturated flow through the matrix and fractures in Yucca Mountain. The relationships developed between pressure and relative conductivity should facilitate the use of several different mathematical models for describing the magnitude of flux and the pressure and moisture content distributions in the unsaturated zone in Yucca Mountain.

PROBLEMS, DEFICIENCIES OR LIMITATIONS OF REPORT:

The limitation of this report is that the work must be continued and the resulting mathematical models must be applied to Yucca Mountain. A portion of this has been done in the report by Peters, Gauthier and Dudley (1985) which we have reviewed recently (Communication Number 60).

SUGGESTED FOLLOW-UP ACTIVITIES

This work must be continued in order to apply the model to Yucca Mountain and to determine the flux rate and the travel time to the accessible environment.

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Mualem, Y., 1976, A New Model for Predicting the Hydraulic Conductivity of Unsaturated Porous Materials. Water Resources Research 12(3), p. 513-522.

Peters, R.R., Gauthier, J.H., and Dudley, A.L., 1985, The Effect of Percolation Rate on Water Travel Time in Deep, Partially Saturated Zones. Sandia National Laboratory, Albuquerque, NM, SAND85-0854C.

Peters, R.R., Klavetter, E.A., Hall, I.J., Blair, S.C., Heller, P.R., and Gee, G.W., 1984, Fracture and Matrix Hydrologic Characteristics of Tuffaceous Materials from Yucca Mountain, Nye County, Nevada. Sandia National Laboratories, Albuquerque, NM, SAND84-1471.

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Wang, J.S.Y., and Narasimhan, T.N., 1985, Hydrologic Mechanisms Governing Fluid Flow in Partially Saturated, Fractured, Porous Tuff at Yucca Mountain. Sandia National Laboratories, Albuquerque, NM, SAND84-7202.

WMGT DOCUMENT REVIEW SHEET

FILE #:

DOCUMENT #: SAND84-1076

DOCUMENT: Ortiz, T.S., and others, 1985, A Three-Dimensional Model of Reference Thermal/Mechanical and Hydrological Stratigraphy at Yucca Mountain, Southern Nevada. Sandia National Laboratories, Albuquerque, NM, and Livermore, CA, SAND84-1076, 72 p.

REVIEWER: Williams & Associates, Inc.

DATE REVIEW COMPLETED: July 16, 1986

ABSTRACT OF REVIEW: APPROVED BY: Roy E. Williams

The report under review presents a discussion of a three-dimensional model of the thermal/mechanical and hydrogeological reference stratigraphy at Yucca Mountain. The reference stratigraphy is based on porosity and grain density. The model consists of a set of surface representations. Sixteen reference units and one mineralogical surface have been defined. The primary purpose of the model is to assist in the interpolation of the stratigraphy among data points (drill holes). The model is shown to be a powerful tool; however, the limited data base constrains the usefulness of the model at the present time.

BRIEF SUMMARY OF DOCUMENT:

The purpose of the report under review is to present a geometric representation of the rocks at Yucca Mountain. The intent of the report is to use the geometric representation along with associated material properties in the performance assessment and repository design calculations. The stratigraphy used in the model presented in the report is based on porosity and grain density. According to the report, the stratigraphy can be correlated to thermal, mechanical, and hydrogeological properties.

The geometric model presented in the report consists of a collection of three-dimensional surface representations. A separate surface is used to define the base of each thermal/mechanical and hydrological reference unit. The model incorporates a method of analytically interpolating among sparse and irregularly spaced data. According to the report, the method generates a single, continuous analytical surface equation from a collection of three-dimensional coordinates.

An example of the development of a three-dimensional model is shown schematically in figure 3 of the report. The example shown in figure 3 illustrates the results of combining the method of generating an analytical surface equation with information on the location of faults. In this example pre-faulted coordinates of units were used as input data to obtain pre-faulted surfaces. The set of equations used to represent the pre-faulted surfaces is then combined interactively with the fault information.

The report notes that the actual surfaces were assumed to be smooth and continuous when originally formed; deviations from the smoothed surfaces, such as erosion features, or igneous structures cannot be assessed in the model. The report notes also that contrary to the earlier three-dimensional model by Nimick and Williams (1984), locations of pinch-outs are predicted by the model.

For the purpose of the model sixteen reference stratigraphic units have been defined. A description of these units is presented in table 1 of the report. According to the report, in addition to the reference stratigraphic units, the upper level of prevalent zeolites has been modeled as a surface.

Data sources for the model consisted of drill hole locations, lithologic logs, geophysical logs, physical properties, X-ray analyses, gyroscopic surveys. The x, y, and z coordinates input into the model are based on surface positions of drill holes. According to the report, at Yucca Mountain the x and y coordinates are defined in Nevada state plane coordinates; the z coordinates are the absolute elevations above mean sea level for the prefaulted units. All coordinates are presented in feet.

According to the report, a structural block containing drill holes USW G-1, USW G-3, USW GU-3, USW H-3, and USW H-4 was selected as a reference region. This region was assumed to be unfaulted and all fault offsets were determined relative to this block. According to the report,

> three assumptions were made about the faulting at Yucca Mountain: 1) the assumed offset along known faults does not change with depth along the fault; 2) the dip of the fault does not change at least to the maximum depth of interest; and 3) no faults exist at Yucca Mountain other than those mapped.

Tables B-1 through B-12 in Appendix B of the report summarize the input data obtained from drill holes. Table B-13 lists the dates on which surveys for each drill hole were made. Table B-14 lists the faults used to adjust the input data, along with the vertical offset and apparent dip estimated for each fault. Figure 4 of the report shows the location of faults, drill holes, and cross sections discussed in the report.

Evaluation of the reliability of the reference stratigraphy model consisted of the comparison of four cross sections from the model to a geologic map, cross sections, and interpretations presented by Scott and Bonk (1984). According to the report, locations of surface outcrops agree within 40 feet (vertical) and thicknesses were consistent.

Figure 9 of the report is an isopach map of the Topopah Spring welded unit. The model predicts a zone of thickening in the west central portion of the area. This prediction is due to the rapid change in observed thickness between test well UE-25a#1 and test well USW G-4. Figure 10 is an isopach map of the vitrophyre near the base of the Topopah Spring Member. Figure 10 shows that the vitrophyre thins gradually from west to east. The model predicts regions in the eastern portion of the study area where the vitrophyre is absent; the thickness is predicted to be 80 feet at the western edge of the study area. According to the report, the thickness of the vitrophyre probably is less variable than indicated.

SIGNIFICANCE TO NRC WASTE MANAGEMENT PROGRAM:

The report under review presents a geometric representation of the rocks at Yucca Mountain. The model is an attempt to simulate the stratigraphy in the vicinity of Yucca Mountain based on limited data. The primary use for the model appears to be the interpolation of geological characteristics among data points (drill holes). Thus, the model may prove useful by assisting investigators in interpolating among data points.

PROBLEMS, DEFICIENCIES OR LIMITATIONS OF REPORT:

The model presented in the report under review may prove to be valuable in the interpretation of the geology in the vicinity of Yucca Mountain. The model is a powerful tool; however, the absence of geological data in three dimensions limits the usefulness of the model significantly. The report notes that the current fault descriptions lack the detail sufficient to automate the removal of fault movement from input data or its reinsertion into calculated surfaces. For this reason the effects of faulting are handled interactively in the model.

SUGGESTED FOLLOW-UP ACTIVITIES

Future additions of the model presented in the report under review may prove to be valuable in the simulation of the geology and hydrogeology in the vicinity of Yucca Mountain. We recommend that all new models be evaluated to determine their significance to the NRC Waste Management Program.

REFERENCES CITED:

Nimick, F.B., and Williams, R.L., 1984, A Three-Dimensional Geologic Model of Yucca Mountain, Southern Nevada. Sandia National Laboratories, Albuquerque, NM and Livermore, CA, SAND83-2593.

Scott, R.B., and Bonk, J., 1984, Preliminary Geologic Map of Yucca Mountain, Nye County, Nevada with Geologic Sections. USGS Open-File Report 84-494.

WMGT DOCUMENT REVIEW SHEET

FILE #:

DOCUMENT #: SAND83-7475

DOCUMENT: Thompson, F.L., Dove, F.H., and Krupka, K.M., 1984, Preliminary Upper-Bound Consequence Analysis for a Waste Repository at Yucca Mountain, Nevada. Sandia National Laboratories, Albuquerque, NM, and Livermore, CA.

REVIEWER: Williams & Associates, Inc.

DATE REVIEW COMPLETED: July 15, 1986

ABSTRACT OF REVIEW: **APPROVED BY:** Roy E Williams

The report under review presents the results of a preliminary analysis designed to estimate the long-term, cumulative release of radionuclides from a proposed nuclear waste repository at Yucca Mountain. The analysis attempts to delineate upper bounds on the cumulative release of radioactivity to the accessible environment 10 km from the repository boundary. The results of the analysis show that for the highest credible flux of 17 mm/yr, releases of radioactivity to the accessible environment in 10,000 years after closure of the repository are lower than the limits imposed by 40CFR191. However, several limiting assumptions are incorporated into the analysis because of the lack of available field data.

BRIEF SUMMARY OF DOCUMENT:

According to the report under review, the purpose of the study is to estimate upper bounds to the long-term consequences of a release of radionuclides from a potential waste repository considered for location at Yucca Mountain in Nevada. The consequences are presented in terms of cumulative release to the accessible environment and in terms of radiological dose to man. Radionuclides are assumed to be leached by water that infiltrates through the unsaturated zone to the water table. Once the radionuclides reach the water table they are assumed to travel horizontally through the saturated zone to the accessible environment. For the purpose of this study, the accessible environment was considered to be 10 km from the perimeter of the repository. The authors of the report investigated two time periods: 1) 10,000 years after leaching begins, and 2) 250,000 years after leaching begins.

The one-dimensional multi-component mass transport (MMT1D) model prepared by Washburn and others (1980) was used to simulate the movement of radionuclides that might be leached from buried nuclear waste in a repository at Yucca Mountain. According to the authors, the one-dimensional model is designed to represent three-dimensional flow by associating a width and a height with the paths of travel. The MMT1D model is designed to account for convection, dispersion, retardation, and radionuclide decay. The MMT1D model uses a random walk form of the method of characteristics to solve the advection-dispersion equation numerically for solute transport in porous media.

The analysis performed by the authors considers two different locations in the unsaturated zone for the repository horizon. These locations are: 1) the "upper zone," which is composed of welded fractured tuff, and 2) the "lower zone," which is composed of non-welded zeolitized tuff. The upper zone location and the lower zone location are referred to in the report as Case 1 and Case 2, respectively. For the analysis of both cases, the authors assumed that the waste first contacts water 1,000 years after the repository is closed. The spent fuel is considered to be predominantly uranium dioxide (UO_2). The assumed dissolution rate of UO_2 was based on the maximum possible concentration of dissolved uranium. This rate was estimated from the solubility equilibria, pH, and redox potential data for groundwater from well J13. The MINTEQ geochemical model was used to calculate a maximum possible concentration of dissolved uranium. Appendix A presents the details of the geochemical modeling effort.

The analysis of dissolution rates presented in the report is based on pore water velocities ranging from 0.5 mm/yr to 50 mm/yr for Cases 1 and 2. Case 1 consists of a welded fractured tuff similar to the Topopah Spring with a porosity of 5% and a matrix saturation level of 65%. Case 2 consists of a non-welded tuff similar to the Calico Hills with a porosity of 35% and a saturation level of 95%. According to the report, to make the analysis more conservative, the water infiltrating over the entire repository area was assumed to contact the waste. This approach produces the maximum possible dissolution rate (solubility x flow rate).

The report notes that equilibrium solubilities of uranium minerals in water vary with pH, redox potential (Eh), temperature, and the concentration of complexing ligands. According to the authors, the composition and pH of the groundwater from well J13 were used in the analysis. The MINTEQ geochemical model was used to investigate how changes in redox potential and temperature ($T<100^{o}C$) affect predicted equilibrium solubility. The MINTEQ geochemical model was used to estimate the dissolution rate under the following conditions: oxidizing conditions (Eh>200 millivolts), a pH of 7.5, and temperatures between $25^{o}C$ and $100^{o}C$. Under these conditions, the report suggests that concentrations of dissolved uranium would range from 1.48×10^{-6} moles/liter to 1.69×10^{-6} moles/liter. Based on these calculations, the authors chose a "representative value" of 0.40 mg/L ($0.40x10^{-3}$ kg/m^3) as a solubility value.

According to the report, 28 radionuclides constitute more than 99% of the total injection and inhalation hazard for one million years for spent fuel rods. Table 3 of the report lists the decay constants and initial inventories for these radionuclides. Table 4 of the report lists the radionuclides that were simulated in the consequence analysis and the radionuclide inventories 1,000 years after repository closure.

The authors of the report estimated that the radionuclides would continue to be leached from the repository for a period of $1.14x10^7$ years for Case 1 and $1.1x10^6$ years for Case 2. These estimates are based on the total amount of uranium in the repository 1,000 years after closure divided by the dissolution rate for uranium. Table 5 of the report lists the estimated leachate concentration for each radionuclide released from the repository. According to the report, four radionuclides have release concentrations at the repository that are greater than the maximum permissible concentrations. The report notes that the steady state concentrations which reach the accessible environment will be approximately equal to the repository concentration for radionuclides with long half lives.

Characterization of Flow Tubes

According to the report, a flow tube consists of a collection of streamlines beginning at the repository and ending at the release region. Figure 2 of the report illustrates the assumed travel path for radionuclides from Yucca Mountain to well J12. The analysis for Case 1 consisted of three flow tubes: welded fractured tuff, non-welded zeolitized tuff, and the saturated zone. The analysis for Case 2 consisted of two flow tubes: non-welded zeolitized tuff, and the saturated zone. Table 6 of the report shows the flow tube characteristics.

The Variable Thickness Transient (VTT) code prepared by Reisenauer (1980) was used to model flow in the saturated zone. Appendix B of the report presents details of the VTT modeling. The results of the VTT modeling are presented in Table 7 of the report. The shortest average travel time value from Table 7 was used as input for the MMT1D model. As an additional measure to make the analysis more conservative the authors assumed that the flow volume through the saturated zone flow tube is the same as that through the unsaturated zone. This assumption eliminates the need to consider potential dilution by the greater volume of water in the saturated zone.

According to the report, estimates of flow length and travel time from the VTT modeling were analyzed stochastically to evaluate dispersivity to be used in the MMT1D model. In this analysis, the authors assumed that dispersion within a flow tube is caused by the difference in travel time between streamlines composing the flow tube. The travel time variance for streamlines within a given flow tube was used as the primary measure of macro dispersion. Dispersivity values for the unsaturated zone were considered to be approximately 10% of the flow tube length. According to the report, all streamlines within the unsaturated zone were assumed to have the same length because of the absence of better information.

Radionuclide Retardation Data:

According to the report, estimates for distribution coefficients for radionuclides in porous flow under oxidizing conditions were derived from Serne and Relyea (1982). Table 8 of the report lists the radionuclides, assumed distribution coefficients, and retardation factors considered in the transport analysis for Case 1. Table 8 indicates also that with a Darcian velocity of 2 mm/yr, none of the radionuclides reached the accessible environment in 10,000 years. Table 9 of the report indicates that with the Darcian velocity of 0.2 mm/yr, none of the radionuclides would reach the accessible environment within 250,000 years.

According to the report, if the repository is located in the non-welded horizon (Case 2), the analysis shows that non-retarded radionuclides will reach the accessible environment in about 3,200 years (Table 10 of the report). However, the report notes that radionuclides with a distribution coefficient of one (Kd=1.0) would not reach the accessible environment for about 28,000 years. According to the report, only Case 2 produces results that can be compared with the Environmental Protection Agency (EPA) proposed rule 40CFR191.

SIGNIFICANCE TO NRC WASTE MANAGEMENT PROGRAM:

The analysis presented in the report under review attempts to quantify a "natural" release scenario for a repository at Yucca Mountain within the limits of the data available. The report is a good example of the type of analyses that the NRC probably will have to evaluate in the future as additional data become available.

PROBLEMS, DEFICIENCIES OR LIMITATIONS OF REPORT:

The analysis presented in the report under review constitutes a preliminary attempt to quantify a "natural" release scenario within the limits of the data available. A significant number of limiting assumptions had to be made in order to perform the analysis. These assumptions are necessary because of the absence of real field data. The report notes that while the analysis is based on a flux through the unsaturated zone of 5 mm/yr, data and evaluations that have become available since work on this report was completed suggest strongly that the actual flux is less than 1 mm/yr.

Several limitations of the analysis are listed in the report. These limitations are as follows:

1) The source term is based on the assumption of congruent leaching. Departures from congruent leaching increase significantly the maximum radionuclide concentrations at the accessible environment. The report notes, that the assumption of congruent leaching therefore is non-conservative.

2) If fracture flow is the dominant mechanism for transport, then the convective flow rate may be higher than that assumed in the analysis presented in the report. The report notes, however, that evidence obtained to date suggests that flow probably occurs predominantly through the rock matrix rather than through fractures.

3) Use of the maximum possible cross-sectional area increases the conservatism of the results. However, if a smaller cross-sectional area were used the leach rate would be reduced and the duration of leaching increased.

4) The equilibrium solubilities predicted by MINTEQ were based on groundwater of a specified composition, pH, and redox potential. The report notes that the groundwater with a different set of complexing ligands could change the solubility constraint and increase the maximum concentrations of dissolved uranium. In addition, we suggest that the assumption that the groundwater system is in constant chemical equilibrium may be a significant limitation with respect to the analysis for radionuclide retardation.

5) The fact that the retardation factor depends on β (the ratio of bulk density to porosity or moisture content) indicates that increases in saturation level will decrease β. A decrease in β will result in a decrease in the retardation factor. This reduction would reduce the travel time of retarded radionuclides.

6) Lower values of bulk density would increase the conservatism of the results for the retarded radionuclides by decreasing β and, thus, decreasing the retardation factor.

7) Lower values for distribution coefficients increase the conservatism of the results for the retarded radionuclides by decreasing retardation factors.

8) The distribution coefficient is a lumped parameter for evaluating ion transport through a given medium. Like all deterministic model coefficients, predictions of nuclide travel based on laboratory measurements of K_d are valid only to the degree to which field conditions are duplicated. In addition, the distribution coefficients presented in Table 8 of the report are not valid for fracture flow.

The assumptions used in the consequence analyses are presented in Table 1 of the report.

SUGGESTED FOLLOW-UP ACTIVITIES

The report under review is of primary significance to geochemists. The report should be reviewed by a geochemist who is knowledgeable about the use of K_d.

REFERENCES CITED:

Washburn, J.F., and others, 1980, Multicomponent Mass Transport Model: A Model for Simulating Migration of Radionuclides in Ground Water. Pacific Northwest Laboratory, Richland, WA, PNL-3179.

Reisenauer, A.E., 1980, Variable Thickness Transient Groundwater Hydrology Model. Pacific Northwest Laboratory, Richland, WA, PNL-3160, 3 volumes.

Serne, R.J., and Relyea, J.F., 1982, The Status of Radionuclide Sorption Desorption Studies Performed by the WRIT Program. Pacific Northwest Laboratory, Richland, WA, PNL-3997.

WMGT DOCUMENT REVIEW SHEET

FILE #:

DOCUMENT #: LA-9471-MS

DOCUMENT: Walter, G.R., October 1982, Theoretical and Experimental Determination of Matrix Diffusion and Related Solute Transport Properties of Fractured Tuffs from the Nevada Test Site. Department of Hydrology and Water Resources, University of Arizona, Tucson, AZ, for Los Alamos National Laboratory, Los Alamos, NM.

REVIEWER: Williams & Associates, Inc.

DATE REVIEW COMPLETED: July 15, 1986

ABSTRACT OF REVIEW: **APPROVED BY:** Roy E Williams

Molecular diffusion is investigated in this report as a mechanism for transporting dissolved substances from pores and fractures into a rock matrix. Such a process may be important for retarding the movement of solutes, including radionuclides or a tracer. The authors use irreversible thermodynamics to develop an equation to describe the diffusion into the matrix as liquid flows in a fracture. A solution to this equation shows that the attenuating effect of matrix diffusion is directly proportional to the effective diffusion coefficient and matrix porosity and inversely proportional to flow velocity and fracture aperture.

Laboratory investigations were conducted to evaluate the physical and chemical properties which affect solute transport from fractures into the tuff matrix. Many of the tests were unsuccessful because of failures in the detection system but, in general, the results were reasonable. Some results showed that various chemicals diffuse independently of each other with different diffusion coefficients. The full diffusion coefficient matrix for various tracers in J13 well water suggests coupling of the diffusion fluxes of all ionic species.

BRIEF SUMMARY OF DOCUMENT:

Molecular diffusion is investigated in this report as a mechanism for transporting dissolved substances from pores and fractures into a rock or soil matrix of much lower permeability where convective transport dominates. Some studies show that matrix diffusion from a fracture into blocks of porous rock may be an important process in retarding movement of solutes and attenuating concentrations. The three purposes of the research described in this report are: 1) to identify and measure the most important physical and chemical parameters that control matrix diffusion in fractured tuff, 2) to identify and apply groundwater tracers suitable for use in both field and bench scale tests of matrix diffusion in tuff, and 3) to develop a numerical model of convective diffusion from fractures to a rock matrix.

The authors use irreversible thermodynamics to develop an equation to describe the diffusion into the matrix as liquid flows in the fracture. Although the equations developed are applicable to both saturated and unsaturated rocks, this report considers only fully saturated conditions. The authors show that concentration gradients are approximately three orders of magnitude larger than the hydraulic gradients. For this reason, the assumption of no convective transport through the tuff matrix is justified for the range of hydraulic gradient likely to develop under saturated conditions. An analytical solution for transport through a single fracture shows that the attenuating effect of matrix diffusion is directly proportional to the effective diffusion coefficient and matrix porosity and inversely proportional to flow velocity and fracture aperture. In their discussion of tortuosity, the authors state that L_e/L is squared because it is applied as a correction both to the concentration gradient and to the cross-sectional area perpendicular to the actual diffusion path. Tortuosity usually is considered to be a correction to the actual distance over which flow occurs rather than the cross-sectional area.

Various laboratory investigations were undertaken to evaluate the physical and chemical properties which affect solute transport from fractures to the tuff matrix. Laboratory measurements were made of the porosity and pore size distribution of samples of tuff from both G-tunnel and drill holes in Yucca Mountain. Scanning electron micrographs were also taken of fractures of the tuff samples even though diffusion may occur into the crystal lattice of zeolite minerals. The diffusion is considered as part of the kinetics of ion exchange and only the inter granular porosity is considered. Four basic methods exist for estimating porosity and pore size distributions. These four methods are: 1) nitrogen adsorption techniques, 2) mercury infusion porosimetry, 3) successive granulation and 4) microscopic examination using optical and scanning microscopy. Mercury infusion techniques were used in this study to measure the pore size distribution while grain density measurements were used to estimate the total porosity. The porosimeter was capable of measuring pore size distribution for pores with diameters between .1 cm and 10^{-5} cm. The pore size distribution data were plotted on log probability paper to determine whether they follow a log normal distribution. Some of the curves are approximately log normal but many are not. The diffusion coefficients of various ionic species were measured directly through samples of the tuff using a diaphragm diffusion cell. Diffusion experiments were performed using solutions of a given sodium salt dissolved in J13 well water. Steady state time concentration gradient was established through the disk whereupon the time averaged diffusion coefficient then was calculated. Approximately 50 diffusion experiments were performed on nine different disks of tuff from G tunnel and the test hole at Yucca Mountain. Many of the tests were unsuccessful because of failures in the detection system. In general, the results fall within the range of values that would be expected, but some results showed that various chemicals diffuse independently of each other with different diffusion coefficients. The reason for this behavior is unknown. Osmotic experiments also were conducted; they showed that the tuffs may act as membranes and that osmotic pressures may exist between the fractures and the tuff matrix. However, certain inconsistencies and erratic behavior occurred in these experiments. An electrical resistivity experiment was conducted to obtain independent values of tortuosity. The full diffusion coefficient matrix for various tracers in J13 well water indicates coupling of the diffusion fluxes of all ionic species. These effects are being incorporated into a numerical model of multiple component matrix diffusion.

SIGNIFICANCE TO NRC WASTE MANAGEMENT PROGRAM:

This work may be of significance to the Waste Management Program because of the impact that tracer selection might have on measurements of effective porosity for purposes of calculating groundwater travel time. It also may be useful for evaluating the rate of release of radionuclides to the accessible environment.

PROBLEMS, DEFICIENCIES OR LIMITATIONS OF REPORT:

The analysis is limited to saturated flow. The analysis also alludes to some of the well known problems inherent in evaluating diffusion coefficient.

SUGGESTED FOLLOW-UP ACTIVITIES

No follow-up activities are recommended.