WMGT DOCUMENT REVIEW SHEET

FILE #:

DOCUMENT: Kilbury, R.K., 1984, Water Intake at the Atmosphere-Earth Interface in a Fractured Rock System: Department of Hydrology and Water Resources, University of Arizona, Tucson, AR 85721. Principal investigator Daniel B. Evans for the U.S. Nuclear Regulatory Commission, Department of Radiation Programs and Earth Sciences.

REVIEWER: Williams and Associates, Inc.

DATE REVIEW COMPLETED: November 1985

BRIEF SUMMARY OF DOCUMENT: DATE APPROVED:

This study involves the development of a conceptual model, and experimental work in the field concerning the flow of water into a fractured rock system. A field site consisted of a densely welded tuff outcrop near Patagonia, Arizona. A Fractured Rock Infiltrometer (FRI) was developed and used to measure air and water intake rates in individual fractures in the study area. Analytical methods were developed to calculate fracture apertures from flow of either air or water. The aperture widths calculated from the various experiments ranged from 1 micrometer to approximately 35 micrometers; the widths appear to be normally distributed. A model was developed to simulate flow across the atmosphere-earth boundary. The model input included historical climatic conditions at the study area in terms of rainfall intensity, duration and seasonal variation. The average surface water intake into the fractured rock system was estimated at 2.1 millimeters of water for the period simulated, which is less than one percent of annual precipitation. The intake appears to be more dependent on storm duration than on intensity. The methods developed provide a means of characterizing water intake rates into a fractured rock surface based on rainfall characteristics.

GENERAL TECHNICAL DISCUSSION:

Page 2. The author notes correctly that most studies to date have been limited to characterization and modeling techniques applied within the rock mass, not at interfaces. The purpose of this study was to develop a reliable method for prediction of flow through the fractured rock interface. The principal objectives included: 1) determination of water intake rates at the earth boundary, 2) development and improvement of field and analytical techniques used to determine fracture intake and apertures, 3) classification of average fracture apertures with regard to a statistical distribution, 4) comparison of results from air and water methods of aperture calculation, and 5) development of a model capable of simulating water intake across the atmosphere earth boundary.

Section 3.1.1 Fractured Rock and Infiltrometer Design. The fractured rock infiltrometer is similar to the old double ring infiltrometer in that it has two rings through which infiltration occurs. The assumption is that the flow through the outer ring will maintain the flow through the inner ring in a vertical direction. In the FRI, the device was bolted to the rock and sealed such that there was no flow across the surface of the rock. In this section the author states "The water set-up incorporates a dual chambered system designed to minimize lateral flow at depth, allowing the assumption of vertical flow when measuring water intake from the interior." It is questionable whether vertical flow actually occurs to any great depth in this situation. The author also questions the assumption later in the report.

Figure 3.1 and 4.1 are interchanged but the titles are in the correct places.

Table 3.2, page 23. This table presents data with time for the flow into a particular fracture. The fracture aperture has been calculated from the equations; but the values given change with time. This indicates that the equations may not be valid at small values of time. The fracture aperture eventually reaches a more or less steady value.

On page 25 there are a number of items in the various equations that should be defined. The units are not presented for h_r in equation 3.5 e_w. is not defined and equation 3.7 should read $R_e = e_w \rho v/\mu$.

Section 3.3.2 Analytical Results. The author states that water intake fracture aperture, depth to wetting front, and fluid velocity were calculated for the various experiments. Considerable work with these equations is necessary to see how this was done. The explanation could be improved. It also became apparent here that the analysis assumes that there is no flow into the porous matrix. The author states this later in the report but it probably should be pointed out at the start of the development.

Page 31, Section 3.3.4. A question raised previously in the discussion of the experimental device relative to horizontal flow is discussed in this section.

Page 32, "Sources of experimental error include", there probably should be a seventh item here relative to possible flow into the matrix itself.

Section 4.4 Analytical Results and Comparison. In Figure 4.2 the aperture width as measured by air is plotted versus the aperture width as measured by water. The author states that the results indicate relative agreement between the methods of aperture calculation. However, it appears that the data show that usually the aperture width measured by air is greater than that measured by water. As an example, two points show a smaller width for air, one is the same and seven points show a greater width for air. All the widths were calculated using the cubic law for fluid flow between two plates. In the case of air flow from the FRI, it seems that air very likely flows into the crack and horizontally out from under the test device. Since there is no reason for air to flow downward due to its small specific weight, it would simply flow outward into the atmosphere by the easiest route possible. This is also indicated by the fact that the inflow with air does not change with time. It simply gives a constant value.

With water, on the other hand, the tendency is to move downward into the rock due to gravity and due to the capillary forces in the fracture. Thus with water the flow field is constantly expanding and the rate of flow decreases with respect to time. Use of the cubic law in each case would give some measure of aperture width. It is possible that the nearly consistent difference between the two methods is due to the water flowing into the porous matrix whereas there is no tendency for air to flow into the porous matrix. It appears that the author fails to realize that water is a wetting fluid and air is a non wetting fluid. The physics of flow into a porous material is therefore different due to the different wetting properties.

Section 4.5 Effect of a Wetted Fracture on Fracture Air Intake. In this section the author discusses the use of air after water has been placed in the fracture. As one would expect the air flow is initially low and then increases. This would be due to the fracture being partially wet with water, reducing the cross-sectional area flow to air. After some time, however, the water will evaporate and cause the fracture area to increase to the dry value.

Section 5.1.2 Assumptions and Theoretical Basis. In equation 5.1 q_w is defined as water intake per unit length of fracture. W on the other side of the equation is defined as fracture length. This is inconsistent. Either q_w should be defined as water intake or W should be defined as unit length of fracture.

SIGNIFICANCE TO THE NRC WASTE MANAGEMENT PROGRAM:

The report under review is a topical report of the research being conducted at the University of Arizona. The final results of this research undoubtedly will be important to the NRC Waste Management Program.

PROBLEMS, DEFICIENCIES OR LIMITATIONS OF REPORT:

The report makes an important contribution to understanding flow into fractures from rock surfaces. It shows that the cubic law is probably valid and may be used for estimating the aperture width. Factors that should be recognized when relating this to natural infiltration into fractures are 1) many times there is a thin soil mantle over the fractures which would completely change the phenomenon of flow into the fractures; in volcanic tuff the porous matrix itself has permeability and will attract water. It appears that it may be necessary to use some sort of a sprinkling infiltrometer to evaluate the effect of a soil mantle and flow into the porous matrix, on water movement into volcanic tuff.

SUGGESTED FOLLOW-UP ACTIVITY:

The final report and any progress reports should be reviewed when they are released.

WMGT DOCUMENT REVIEW SHEET

FILE #:

DOCUMENT #:

DOCUMENT: Trimmer, D., 1982, Laboratory Measurements of Ultralow Permeability of Geologic Materials. American Institute of Physics, REV. SCI. INSTRUM. 53 (6), p. 1246-1254.

REVIEWER: Williams & Associates, Inc.

DATE REVIEW COMPLETED: Draft, October 9, 1986

ABSTRACT OF REVIEW: APPROVED BY: Roy Williams/al

The report under review describes an apparatus for measuring permeability of geologic materials as a function of confining pressure, pore pressure, and deviatoric stress. Permeabilities (intrinsic permeability) on the order of 10^{-11} to 10^{-24} m^2 may be measured along with electrical conductivity, acoustic velocity and amplitude. The testing method described in the report should be of interest to people involved directly with the measurement of permeability of core samples.

BRIEF SUMMARY OF DOCUMENT:

The report under review presents a description of a new apparatus for measuring permeability of geologic materials as a function of confining pressure [to 200 megapascals (MPa)], pore pressure (to 25 MPa) and deviatoric stress (500 to 800 MPa). The apparatus described in the report is capable of measuring permeabilities two to three orders of magnitude lower than those that have been reported in the literature.

Permeability measurements are made on large samples (0.15 meters in diameter by 0.28 meters in length). The permeability of the sample is measured by inducing a pore water pressure gradient between the ends of the sample while water transport through the sample is monitored. According to the report, permeabilities as low as 10^{-17} m^2 (hydraulic conductivity equal to 9.8×10^{-9} cm/sec) are measured with a conventional steady-state flow technique. A transient pulse technique is used for rock samples having permeabilities between 10^{-17} and 10^{-24} m^2. The transient pulse technique is necessary because the water flow rates through samples with permeabilities less than 10^{-17} m^2 are too small for convenient direct measurement. According to the report, a modified transient pulse technique is used for samples with permeabilities in the range of 10^{-22} to 10^{-24} m^2. For these very low permeabilities, the time constant of the system is very long. Under these conditions, establishment of equilibrium requires two weeks to six months. Therefore, in order to simplify the testing procedure, the author makes the assumption that the system reaches equilibrium when the pressure in the upstream reservoir has changed less than 0.1 MPa in 10^6 seconds (approximately one week). According to the report, measurement is terminated when either the pressure in the upstream reservoir has decayed by 1.0 MPa (50% of the pressure step) or the time has exceeded 10^6 seconds.

Equation 2 of the report describes the pressure-time history for water flow through a compressible sample-reservoir system. This equation is as follows:

$$\frac{\partial^2 P}{\partial x^2} = \frac{\mu \beta \phi_e}{k} \frac{\partial P}{\partial t} ,$$

$$\phi_e = \phi_c + \frac{\beta_r - (1+\phi_c)\, \beta_s}{\beta} ,$$

for t>0, 0<x<L, and with boundary conditions

$$\frac{\partial P}{\partial x} = \frac{\mu V_1 \beta}{Ak} \frac{\partial P}{\partial t} \qquad x = 0, t>0,$$

$$\frac{\partial P}{\partial x} = \frac{\mu V_2 \beta}{Ak} \frac{\partial P}{\partial t} \qquad x = L, t>0,$$

and initial conditions

$$P(x,0) = P_0 \qquad 0<x\leq L,$$

$$P(0,0) = P_0 + \Delta P,$$

where:

P = pressure,
X = distance from the upstream end of the sample,
ϕ_e = the effective sample porosity,
ϕ_c = the interconnected porosity of the sample,

β = the compressibility of water,
β_r and β_m = the compressibilities of the sample (bulk and mineral matrix, respectively,
V_1 and V_2 = the volumes of the upstream and downstream reservoirs, respectively),
ΔP = the step increase in pressure, and
t = the time since ΔP was applied.

Because of the large size of the samples, the pore volumes of the samples are large relative to the reservoir volume. Because the water storage in the rock is significant, Equation 2 cannot be simplified. Therefore, the author of the report modeled the experiment using a finite element computer code.

According to the report, a parameter study indicated that for a given sample geometry, pore fluid, and reservoir volume, the pressure-time history is a function of permeability and effective porosity. The report suggests that the permeability of a sample can be inferred by visually comparing experimental pressure-time histories with numerically generated histories if the effective porosity is known.

According to the report, Equation 4 can be used to determine effective porosity for samples with time constants that are small enough to allow sample equilibrium. Equation 4 is as follows:

$$(P_o+\Delta P)\ V_1 + P_o\ (V_2+AL\phi_e) = P_f\ (V_1+V_2+AL\phi_e)$$

or

$$\phi_e = \frac{(P_o+\Delta P-P_f)\ V_1 + (P_o-P_f)\ V_2}{(P_f-P_o)\ AL}$$

The report notes that for samples that display time constants too long to allow effective porosity to be determined from Equation 4, effective porosity must be determined by comparing the experimental data with numerically generated curves.

According to the report, the next step is to generate a family of curves with the appropriate effective porosity and various permeabilities. The permeability of the sample then is inferred by visually matching the experimental data to numerically generated pressure-time histories. Figures 3A and 3B of the report present examples of numerically generated pressure vs log time histories. According to the report (p. 1248), the shaded portions of the curves are given the most weight in determining permeabilities for the following reasons:

1. The thermal transient induced by the initial pressure pulse has disappeared by this time.

2. The slope is greatest allowing maximum (curve matching) resolution.

3. This portion of the curve is relatively insensitive to the water-storage term.

Test samples are prepared from diamond drill core that is approximately 0.17 meters in diameter. The samples are ground and cut to form right circular cylinders that are 0.15 meters in diameter and 0.28 meters long. Pages 1249 through 1252 describe the sample preparation and the testing apparatus.

Figure 13 of the report presents permeability data as well as normalized conductance, acoustic velocity, and amplitude data for the Westerly granite. Figure 14 of the report presents the same type of data for fractured Westerly granite. The report notes that as in the case of intact rock, the acoustic and conductance data show a good correspondence with the permeability data.

SIGNIFICANCE TO NRC WASTE MANAGEMENT PROGRAM:

The report under review presents a description of a testing method for measuring permeability in geologic materials as a function of confining pressure (to 200 MPa), pore pressure (to 25 MPa), and deviatoric stress (500 to 800 MPa). The testing procedure described in the report under review is not significant with respect to the NRC Waste Management Program at the present time. The report should be of primary interest to people involved directly with laboratory measurements of very low permeability geologic materials.

PROBLEMS, DEFICIENCIES OR LIMITATIONS OF REPORT:

The report under review presents a description of testing techniques and data analysis, sample preparation, a description of the apparatus used in the experiments, and a discussion of typical results. The primary limitation of the testing method is that the effective porosity and permeability of the core sample is determined by comparing experimental data to numerically generated curves. The portions of the curves that are given the most weight in determining permeabilities are very similar. Because of this similarity it is difficult to decide which curves yield the best match with the experimental data. The curve matching procedure is very subjective.

SUGGESTED FOLLOW-UP ACTIVITIES:

No follow-up activities are necessary.

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WATER RESOURCES RESEARCH, VOL. 21, NO. 6, PAGES 889–891, JUNE 1985

Comment on "Double-Porosity Models for a Fissured Groundwater Reservoir With Fracture Skin" by Allen F. Moench

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This paper constitutes a commendable effort to summarize and expand the theoretical basis for the analysis of drawdown data for fractured terrane that can be characterized by matrix blocks. The method applies porous media theory to fractured rocks by defining saturated hydraulic conductivity of the fracture system as the product of the hydraulic conductivity by the ratio of the total volume of the openings to the bulk volume of the rock (block or fracture) according to the method described by *Gringarten* [1982]. *Moench* [1984] incorporated the effect of a mineralized film (skin) on the wall of the fractures where the skin has its own separate hydraulic conductivity and its own thickness. The geometries of the block are considered in the controlling equation for the fissured network via the control of the geometry on permeability distribution and on boundary conditions. In several respects this approach is similar to the standard approach for leaky aquifers when leakage is derived from storage in the confining layer, except for the addition of the hydraulic properties and thickness of the mineralized layer on the walls of the fractures. By varying the values of the hydraulic properties of the fracture system and the mineralized layer on the walls of the fractures, virtually any drawdown curve can be simulated by the theory. Not surprisingly the drawdown curves produced by the method (type curves) are similar in shape to standard leaky aquifer curves within the influence of boundaries or with the influence of partial penetration. The method could in fact produce curves identical to those of Hantush [1960] [see *Lohman*, 1979] given appropriate geometry and the absence of a skin on the fractures.

This observation brings me to the major purpose of this critique. That purpose is to attempt to elucidate the plight (or perhaps the responsibility) of the field hydrogeologist under the current state of the art status of aquifer testing technology. I refer to the condition of the field hydrogeologist as a plight because he must conceptualize the hydrogeologic environment in some manner prior to deciding which theoretical analysis is appropriate to the particular hydrogeologic conditions with which he must deal at a specific site. I have alluded to this problem above by noting the similarity between the curves produced by this method and leaky drawdown curves affected by partial penetration and/or barrier boundaries. Moench has applied a solution to the aforementioned controlling equations to drawdown data from two wells at the Nevada Test Site. Well UE-25b#1 is the pumping well and well UE-25a#1 is the observation well. The wells are only 107 m apart. Moench points out correctly that five major zones of water entry over a depth interval of about 400 m occur in the pumping well. These data were obtained from a borehole flow survey log of the pumping well. The borehole flow survey log was obtained using the trace ejector method while the pumping well was being pumped. Moench used the results of the third of three pumping tests as field drawdown data for matching purposes. Because the pumping test was conducted over the entire producing interval, he necessarily treated all the producing zones in the pumping well as one homogeneous aquifer even though the discrete producing zones cover a vertical section 400 m thick. This observation is pertinent for two reasons. Reason one is that partial penetration effects may have been operative because the distance between the two wells is only about one fourth the thickness of the total assumed aquifer and because it is impossible to ascertain that all the producing zones in the pumping well were intercepted by the observation well. It is almost certain that the producing zones at this site are not horizontal. The second reason is that the borehole flow survey log shows that the third and fourth producing zones in the pumping well are separated by about 200 m of very tight rock. The other producing zones are separated by between 10 and 50 m of very tight rock. Consequently, in terms of standard aquifer terminology, the borehole flow survey data show that the producing zones (whatever geologic feature they may be caused by) could be interpreted as a multiple aquifer system wherein the producing zones are separated by rock with very low saturated hydraulic conductivity. Data are not yet available on the hydraulic properties of the individual producing zones (aquifers?). The importance of this second reason is that the collective behavior of the individual producing zones would produce a drawdown curve that reflects both boundaries and leakage, depending on the characteristics of the individual producing zones penetrated by each well. It is important to note also that the available reports do not show that a borehole flow survey has been run on the observation well. Consequently, in the absence of knowledge about the producing zones in the observation well, Moench was forced to assume that the aquifer(s) in the observation well is homogeneous and identical to the aquifer(s) in the pumping well. He had no choice but to make that assumption. In this regard it is important to note that the drawdown at the end of test 3 in the pumping well was about 10.41 m, whereas the drawdown in the observation well was only 0.64 m. The pumping test lasted approximately 3 days at a pumping rate of 35.8 L/s (567.5 gal/min). Because the wells are only 107 m apart, this small drawdown in the observation well may suggest that only a portion of the producing zones (aquifers?) identified in the borehole flow survey of the pumping well responded in the observation well. Admittedly, other interpretations of these data are defensible also. Furthermore, according to the data file for the two wells and *Lobmeyer et al.* [1983], the observation well did not respond at all to pumping test 1. No discussion is presented in the data base about why this was the case. This test was conducted for 4 days at a pumping rate of 14 L/s (222 gal/min). These observations illustrate that the effects of partial penetration may have been operative at the observation well because the observation well did not penetrate all the producing zones penetrated by the

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pumping well, all of which are separated by tight rock according to the borehole flow survey. A similar situation at an NRC licensed site has been interpreted to mean that the observation well is simply on the margin of the fault controlled aquifer in which the pumping well is located [see *White and Gainer*, 1984].

Moench decided to analyze the drawdown data by assuming slab-shaped blocks because of "the scale of the problem and the observation that the distances between the two wells and the average distance between the zones of water entry shown in Figure 9 are of the same magnitude (about 100 meters)." Moench points out that he believes more closely spaced water entries would be needed to justify the use of sphere shaped blocks. I suggest that other choices are defensible as well. Moench's choice necessarily forces the assumption that the blocks, in fact, exist, that the mineralized coating on the walls of the fractures is actually reflected in the pump test data, that leakage in the usual sense of the word is not occurring, and that all the water producing zones in the pumping well are penetrated by and reflected in the drawdown in the observation well, in spite of the high pumping rate and the low drawdown in the observation well. In this particular case, vertical and horizontal hydraulic continuity and hydraulic gradient between all the producing zones in the pumping well and in the observation well are questionable and very important. Gradient is important because it appears that flow at this location is predominantly horizontal (no change in head with depth). One could erroneously interpret this to mean that vertical hydraulic continuity exists at the site (discussed below). It might be possible to demonstrate such continuity by packing off individual producing zones in the pumping well and in the observation well and investigating responses to pumping them separately.

Moench brings up the problem of the effects of partial penetration in his paper. However, he states that it probably is not important in this well test because the major zone of production appears to have been fully penetrated by the pumping well. He states also that there is evidence that there is good hydraulic connection between producing zones (in the pumping well). As I suggested above, he probably is correct that the pumping well fully penetrates all the producing zones, but it is not at all clear that the observation well penetrates all the same producing zones because the geometry of the poducing zones cannot be interpreted. I point out above that the only field evidence for good vertical hydraulic connection between the producing zones in the pumping well consists of the fact that heads measured in each of the producing zones in the pumping well after isolation by packers are nearly identical. I repeat that this observation does not mean necessarily that there is good vertical hydraulic connection between the zones. Individual aquifers can have identical hydraulic heads with virtually no hydraulic connection between them. The only requirement is that equipotential lines in the producing zones be vertical. Core permeability data from the pumping well and slug tests in the pumping well suggest that the nonproducing zones are much less permeable than the producing zones. In addition, under steady state conditions, which Yucca Mountain presumably has reached since the Pleistocene, the boundaries on a flow system determine to a large extent the hydraulic head distribution within that flow system. Moench also points out that the effects of anisotropy probably are significant. He points out correctly that a well test with data from a pumped well and a single observation well is insufficient to evaluate the anisotropy.

Lastly, he points out that it is possible also that hydraulic boundaries due to major faults or intrusive dikes and sills are present within the flow regime. He points out correctly that the change in slope that occurs at 1000 min on the drawdown curve might be interpreted by taking these factors into account. He states, however, that the change in slope is on the order of 10 to 1 rather than 2 to 1, the latter of which is characteristic of a single hydraulic boundary. This slope could easily be affected by the multiple aquifer system in combination with one or more boundaries.

The last sentence in Moench's article (prior to conclusion) merits thought. He states, "Also, as the data appear to be consistent with the assumptions of the double porosity model it is not necessary to call upon added complications." This statement merits thought because it reflects to a large extent the plight of the field hydrogeologist. If these "complications" actually exist and are not recognized in the field, then the hydraulic property values derived for the fracture system, the blocks, and the mineral coatings on the walls of the fractures will apply to some other conceptual model. They may reflect vertical saturated hydraulic conductivity values of confining layers, they may reflect multiple layered leaky aquifers, they may reflect barrier boundaries or recharge boundaries, or they may simply reflect the effect of partially penetrating wells. These questions should be resolved by some type of independent field evidence about the hydrogeologic framework for the system. Unfortunately, available technology in our profession restricts to a considerable extent the feasibility of this approach. Research is needed badly in this area.

One method of approaching the problem of obtaining reliable field data to characterize fractured aquifer systems is to study the distribution of permeability from inside the aquifer. We have attempted to accomplish this objective by gaining access to fractured aquifer systems via hard rock mines [see *Williams*, 1982, and *Riley et al.*, 1984]. Preliminary interpretations of water production characteristics in drifts and drill holes in the vicinity of the hard rock mines that we have evaluated suggest that the major producing zones are fault controlled rather than controlled by discrete fractures. Major faults in particular drain over a long period of time, whereas fractures generally drain quickly as a drift proceeds. Inclined or horizontal drill holes that intersect faults soon tend to discharge at a relatively steady state, whereas drill holes that do not intersect faults tend to approach zero flow soon after completion. Perhaps eventually research conducted inside fractured aquifer systems will reduce the number of alternative interpretations of drawdown data observed during pumping tests and ultimately improve the "plight" of the field hydrogeologist who must fit the hydrogeologic regime to a conceptual model so that it can be tested properly.

Finally, I reemphasize the fact that my purpose here is not to discount the importance of Moench's paper and his work. I have little doubt about the fact that his interpretation and analysis of the drawdown data from wells UE-25a#1 and UE-25b#1 can be defended, except possibly for the effects of the observation well not penetrating all of the same producing zones as the pumping well. My purpose is to emphasize that on the basis of the existing data base the solution is not unique. Other conceptual models certainly can be defended also. Subsequent analyses such as travel time calculations must depend heavily on selecting the correct conceptual model. Therein lies the problem.

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WATER RESOURCES RESEARCH, VOL. 21, NO. 6, PAGES 893–894, JUNE 1985

Reply

Allen F. Moench

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I thank *Williams* [this issue] for taking the time to comment on my paper [*Moench*, 1984] and providing me with the opportunity to respond to his thoughts regarding my paper and the "plight" of the field hydrogeologist. The primary purpose of my paper was to provide a physical mechanism, backed by a mathematical model, for resolving a conflict between two theories for flow to a well in a double-porosity formation. One theory, proposed by *Warren and Root* [1963], makes the assumption that fluid flow from blocks to fissures occurs under conditions referred to as "pseudo-steady state." The other theory, proposed by *Kazemi* [1969], assumes fully transient block-to-fissure flow. The two theories each appear to be supported by well-test data in the disciplines of groundwater hydrology and petroleum engineering. In my paper I show that the two theories can be unified by incorporating fracture skin in the mathematical model. I surmise that Williams has no disagreement with the theoretical part of my paper.

The major problem Williams has with my paper appears to stem from his concern for the field hydrogeologist, who being confronted with a multitude of type curves, must choose one that is suited to the hydrogeological conditions at a specific field site. Williams points out the "similarity between the curves produced by [the proposed] method and leaky drawdown curves affected by partial penetration and/or barrier boundaries" and says that with the introduction of fracture skin "virtually any drawndown curve can be simulated by the method." Although I agree that the method is flexible and permits the hydrogeologist to generate a large number of type curves, it is hardly capable of explaining all drawdown data for flow to a pumped well. With regard to the problem of dealing with numerous type curves, I submit that it is the responsibility of the hydrogeologist to do exactly as Williams suggests; namely, "conceptualize the hydrogeologic environment in some manner prior to deciding which theoretical analysis is appropriate ... at a specific site." All available geologic, geophysical, and hydrologic data must be considered in order to narrow down the number of alternative interpretations. Properly designed well tests then allow the hydrogeologist to confirm or reject a given conceptualization. It is risky to attempt such a conceptualization on the basis of well-test data alone.

Williams takes issue with my interpretation of the well-test data (test 3) from wells UE-25b#1 and UE-25a#1 at the Nevada Test Site. He implies that the data do not necessarily support the dual-porosity model for a fissured aquifer with fracture skin and can be explained equally well, or perhaps preferably, by classical methods involving leaky aquifers, partial penetration, and barrier boundaries. I agree that alternative explanations for these data can be found. I have provided one interpretation that I believe explains the observed hydrologic and geologic data. It is a simple model of a rather complex system.

Williams objects to my treatment of the 400-m-thick production zone, as evidenced by the borehole flow survey, as a singel aquifer. He says that because the borehole flow survey shows several zones of water entry separated by tight rock of varying thicknesses (ranging from 10 to 200 m) the entire production zone could be interpreted as a multiple-aquifer system. He states that this is important because "the collective behavior of the individual producing zones would produce a drawdown curve that reflects both boundaries and leakage, depending on the characteristics of the individual producing zones." Williams also states that because of the proximity (110 m) of the observation well to the pumped well, effects of partial penetration may have been operative. He notes that no borehole flow survey was obtained for the observation well and that I was therefore forced to assume that the aquifer in the vicinity of the observation well is identical to the aquifer in the vicinity of the pumped well. Also he notes the "small" drawdown in the observation well at the end of test 3 and the fact that "according to the data file for the two wells and *Lobmeyer et al.* (1983), the observation well did not respond at all to pumping test 1."

The suggestion that effects of partial penetration are operative addresses the question of whether or not the system under study is homogeneous in its hydraulic properties. If an aquifer can be assumed to be homogeneous (as required by double-porosity models) and the pumped well is fully penetrating, there will clearly be no partial penetration effects observed in a partially penetrating observation well regardless of its proximity to the pumped well. If it can be convincingly demonstrated that the assumption of aquifer homogeneity is invalid for the test in question then Williams is correct that effects of partial penetration will be important. Under these circumstances the proposed double-porosity model will not apply. For the scale of this test, however, it appears that treating the 400-m-thick zone of production as a single aquifer and assuming that the aquifer in the vicinity of the observation well is the same as the aquifer around the pumped well are good approximations to reality. This conclusion is partially supported by the fact that the observation well, which is located only 110 m from the pumped well, penetrates the same formations at about the same depths as the pumped well. At a depth of 762 m the observation well penetrates about two thirds the thickness of the production zone. It is not necessary, however, that the same producing zones in the pumped well be intersected by the observation well. It is necessary only that they be interconnected, a fact that appears to be clearly demonstrated, as is explained below.

As Williams points out, it is important to establish whether or not there is vertical hydraulic continuity between all the producing zones. The evidence in support of hydraulic continuity is as follows. (1) The head in each of the producing zones after isolation by packers is nearly identical. This condition would be highly fortuitous if there were poor or no hydraulic connection between producing zones. This is especially true in

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light of the real possibility that water from occasional intense precipitation events on Yucca Mountain may reach the saturated zone in spite of its great depth. (2) Examination of acoustic televiewer logs in the pumped well and cores from both the pumped well and observation well reveals the existence of numerous steeply dipping fractures and faults. Staining on the fracture surfaces suggests that many are water bearing. The absence of major zones of water entry in the middle section of the aquifer may be due, in part, to the tendency of the drill holes to deviate from the vertical in a direction parallel to the dip of the fault planes. Also, the probability of the well intersecting near-vertical fractures is small. (3) With regard to the charge that the observation well is not responding as though it were fully penetrating, the "small" drawdown in the observation well at the end of the test is what it should be based upon a simple distance-drawdown calculation for a homogeneous aquifer. This calculation makes use of the independent determination of the product of hydraulic conductivity and reservoir thickness (*KH*) from the late time data for the pumped well [*Moench*, 1984, Figure 14*b*]. Also, the absence of measured drawdown in the observation well for test 1 reported by *Lobmeyer et al.* [1983] is due to the fact that no pressure measurements were made in the observation well during test 1 (D. H. Lobmeyer, oral communication, 1984). It is probable that drawdown did in fact occur in the observation well during test 1. (4) The most convincing evidence for horizontal and vertical continuity of the fluid in the fracture network around wells UE-25b#1 and UE-25a#1 comes from the analysis of a tracer test [*Waddell*, 1984]. Waddell packed off the lowermost producing horizon in well UE-25b#1 (located between 866 and 872 m below land surface) and placed dissolved sodium bromide in well UE-25a#1. Breakthrough of sodium bromide occurred 2 days after the onset of pumping from the packed-off zone.

There are several reasons for my rejection of Williams' suggestion that the entire production zone could be interpreted as a multiple-aquifer system. I agree that in the absence of fracture skin, dual-porosity models may produce type curves that are similar, if not identical, too type curves for multiple-aquifer systems. That this is true has been pointed out by numerous investigators [e.g., *Gringarten*, 1982; *Streltsova*, 1982]. However, even if the drawdown data for wells UE-25b#1 and UE-25a#1 were to fit such type curves, which they do not, it would not be correct to describe a clearly fractured network as a multiple-aquifer system because of the contrary geological information. Also, the 10-to-1 change in slope indicated at 1000 min in Figure 4*b* [*Moench*, 1984] would, if due to barrier boundaries, require a rather complicated configuration of boundaries all located at about the same distance from the pumped well. Such a system would very likely have caused a similar change in slope in the observation-well data. No break in slope was observed [*Moench*, 1984, Figure 4*a*]. Another compelling reason for my rejection of the multiple-aquifer interpretation lies in the evidence, described above, that there is vertical hydraulic continuity between producing zones.

I think it may be possible to devise a multiple-aquifer flow system with barrier boundaries, leakage, and partial penetration that will give a response in the pumped well and observation well that matches the observed data. One could accomplish such a feat by trial and error using a digital simulation model. However, such a model would contradict the geologic and hydrologic information discussed above. Also, such a model would have little usefulness as it would have no transfer value to other field sites.

The fact, pointed out by Williams, that I treated all the producing zones in the pumped well as one aquifer is an important point. The proposed double-porosity model is probably valid only at the scale of this particular test. By packing off and testing individual production zones, as Williams suggests, the scale of the problem will be changed and effects of aquifer heterogeneity will be magnified. Analysis of pump test data from individual packed-off zones may require that different models be used and may therefore yield different aquifer parameters.

At the present time, based upon the above considerations, I remain convinced that the dual-porosity model for a fissured groundwater reservoir with fracture skin provides the preferred explanation for the well-test data from wells UE-25b#1 and UE-25a#1. The model has the advantage over alternative interpretations of being internally consistent. Two type curves each with identical aquifer parameters (γ, σ, S_F, and W_D) match the well-test data. That is, the observation-well response and the pumped-well response are those predicted by theory. This simple model explains satisfactorily not only the drawdown data but also is in agreement with all the available geological, geophysical, and hydrological data.

Most hydrogeologists will agree that further research on fractured rock is needed. This is especially true as it applies to heterogeneous systems. The work of Williams and his coworkers on the hydrology of hard rock mines is particularly appropriate to this endeavor. The view from within the aquifer may provide a source of much improved understanding of the hydrological behavior of fractured-rock systems.

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COVER LETTER 1/10/85

REVIEW OF A PH.D. THESIS TITLED "PERMEABILITY OF UNSATURATED FRACTURED METAMORPHIC ROCKS NEAR AN UNDERGROUND OPENING", COLORADO SCHOOL OF MINES, BY PARVES MONTAZER

by

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This thesis was presented at the Colorado School of Mines in partial fulfillment of the requirements for the degree of Doctor of Philosophy in Geological Engineering, dated November 22, 1982. The sections of the thesis that were reviewed in detail pertain directly to the subject of unsaturated flow in rock. Other sections on other subjects were not reviewed in detail.

Summary of Abstract

This study was undertaken to investigate the problems of permeability measurements and analyses in unsaturated fractured hard rock masses. A field study was conducted in the Idaho Springs Formation of the Colorado Front Range of the Rocky Mountains. Multichamber packer injection test equipment was developed to characterize the in situ permeability of the fractured rock surrounding an excavated chamber. The equipment reportedly is capable of measuring permeabilities as low as 10^{-17} cm^2 and capable of detecting leakage around the packers. Fracture continuity was delineated also. Detailed fracture mapping of the walls, logging of the cores, and visual examination of the borehole walls with a TV camera revealed two persistent, nearly vertical fracture sets.

An analytical method was developed to prepare a data base for all the various sampling methods used. Hydrogen was used as the injection fluid most often because it was found to be more suitable for testing unsaturated fractured rock with very low wetting fluid potential. Carbon dioxide and water also were used as injection fluids to determine the response of the rock to the injection fluid. Analysis of the data revealed that absolute values of permeability could not be determined from single tests. A nonlinear relationship was observed in many cases for the reciprocal pressure versus permeability relationships. It is hypothesized that positive slopes for these curves are due to unsaturated state of the rock and negative slopes are due a combination of Klinkenberg effect, lubrication, complexity of the fracture network and boundary conditions.

Analysis of the existing theory suggests that an approach combining Darcy's law and the Klinkenberg effect may prove useful in solving the difficulties in analyzing permeabilities of unsaturated fractures. It was concluded that in unsaturated fractured rocks testing with nitrogen exaggerates permeability of the high conductivity fractures and facilitates their detection. Skin damage caused by stress redistribution and blasting is favorable for underground disposal of radioactive water in other engineering projects where low radial permeability is an important design factor.

Section 1. Introduction

The thesis begins with a statement of the problem of determining permeability around openings and emphasizes the fact that unsaturated flow through fractures is significant in estimating water inflow during the active life of a repository and during resaturation. The experimental work in this project was concerned with the situation where desaturation occurs due to a tunnel or hole and not where the material was previously unsaturated. The test site consisted of an excavated room approximately 100 m below the ground surface in which detailed fracture mapping had been completed. The research included design, assembly and testing of appropriate equipment to measure the low permeabilities encountered in crystalline rocks at depth. Specific objectives of the project were

1. To prepare a descriptive conceptual model for the test site with emphasis on hydrologic and geologic characteristics that may affect the interpretation of the permeability test results.

2. To employ some current techniques and develop new methods for fracture characterization.

3. To improve current instrumentation for injection testing of very low permeability unsaturated fractured crystalline rock.

4. To evaluate the validity of the steady state packer injection test results under controlled conditions.

5. To study the spatial distribution of permeability.

6. To use the equipment to evaluate the nature and extent of damage to the rocks surrounding an underground excavation by employing packer injection techniques.

7. To understand the physical laws controlling the behavior observed during these experiments.

Section 2. Survey of Previous Work

The literature review is very extensive with over 700 references including many on the work of the past 20 years characterizing fracture flow as well as many references from the petroleum industry on field measurements of material properties.

The parallel plate model is concluded to be the most commonly used model for fracture flow analysis. The discrepancies between the model and the actual conditions in the fracture include aperture variation and fracture roughness. The aperture width of a fracture is affected by effective stress and pore pressures. The velocity of flow in the fracture is dependent on the square of the aperture width while the flow rate is dependent on the cube of the aperture width. The flow rate is therefore very sensitive to aquifer deformation resulting from the higher stress near the fracture than in the matrix of the material. No universal relationship between fracture stress and strain has been discovered.

The author points out that packer tests give only information that applies to the rock that is relatively close to the borehole; as a result details of fracture behavior cannot be determined readily. Analysis of flow through unsaturated fractures has begun only recently; a great deal of research is required before this problem can be solved even partially.

Section 3. Theoretical Considerations

The equation for one dimensional, single phase flow between parallel plates is developed followed by development of the equations for two phase flow.

The capillary rise between two parallel plates is used correctly for two phase flow. The author states, "in a vertical unsaturated fracture, water would continue flow downwards until encountering a saturated zone or another fracture with larger aperture." This is misleading because water under tension (unsaturated flow) would move into smaller fractures in preference to larger fractures. In the case of granular (non crystalline) materials such as volcanic tuff water would move horizontally into the fine grained matrix in preference to flowing down a large fracture. The author is correct in stating that in fractures where there are points of contact there would be water in pendular rings around the points of contact. In such a medium water may be moving through the matrix while the fractures are still unsaturated.

There is considerable discussion on the problems of the use of gas flow to measure permeability. The author summarizes these problems as follows: "Theoretically when an ideal gas is injected into an unsaturated fracture, the increase in pressure and effective conductivity may a) increase due to increase in gas saturation, b) become equal to the saturated conductivity, c) exceed the saturated conductivity due to lubrication and Klinkenberg effects, and d) decrease to saturated conductivity. Some of these steps may be absent depending on the nature of the fracture." Another factor which the author did not discuss was that when gas is passed through a partially saturated material the permeability will increase with time due to water evaporation unless the injected gas is initially saturated with water vapor. In summary it appears that the use of gas injection for measuring permeability in a partially saturated material gives very questionable results.

Section 4.4. Hydrogeologic Characteristics of the Mine

This section presents a description of the hydrogeologic characteristics of the mine. The region surrounding the mine was divided into a zone of topographic gradient, a zone of vertical gradient and a zone of regional gradient. The amount of flow in the zone of vertical gradient was so small that the rock surface in the mine was kept completely dry by normal evaporation aided by natural and mechanical ventilation of the mine. In dead end drifts of the mine the rock surface was slightly wet, but seepage could be seen only along major shear zones.

Section 6. Design, Fabrication and Calibration of the Permeability Testing Equipment

The design criteria used for the testing equipment was based on the following characteristics: a) very low matrix permeability of 10^{-15} cm^2, b) the unsaturated nature of the rock, and c) heterogeneous fracture distribution. The author notes that equipment designed to measure high permeabilities is generally insensitive to small changes of permeability. In addition to increasing the resolution of pressure sensitive devices, he wanted to provide a means to detect leakage and develop reliable methods of calibration. The unsaturated nature of the rock necessitated the applicability of both gas and water which required a dual flow metering system that could accurately measure flow rates of both water and gases.

Section 6.2. Instrumentation

In the description of the packer system, figures 6-1, 2, 3 are left out of the text. The main probe had three chambers. Pressure transducers were connected to each chamber. The center chamber only was pressurized; an increase of pressure in either of the neighboring chambers would indicate either a) leakage around the packers or b) fractures located near to and parallel to the borehole. Each monitoring probe consisted of one chamber isolated by two packers. The figures also are omitted in the description of the flow metering system. Due to the wide range of flow rates, four rotameters of different sizes were used for measuring flow of either gas or liquid. The main probe was calibrated inside a pipe the same size as a borehole. Pressures as low as 7 Pa (.001 psi) could be detected in the boreholes. In general, the author's instrumentation appears to use current technology.

Section 7. Testing of Packer Equipment in a Concrete Column Model

The purpose of this part of the investigation was to determine the validity of the assumptions made in packer test analysis and to provide an additional method for calibration. A concrete column, 3.7 m long and .61 m in diameter, was prepared from silica sand and portland cement. The cylinder was cast with a hole to simulate a borehole down the center. The cylinder was then cured inside the mine for six months prior to testing at which time there were no visible cracks or imperfections. The main probe was placed inside the hole and tested. A test with nitrogen then was conducted. Later the cylinder was tested with water but complete saturation of the concrete could not be attained. Two 15 cm cores were then obtained from the concrete column for laboratory testing. One sample was tested with nitrogen and the other with water. The gas flow rate was measured both at downstream (piston displacement) and upstream sides (flow meter) of the sample. Since the permeability of the sample was calculated on the basis of data collected by a completely different set of instruments than from the packer tests of the large concrete column the data should be comparable without bias. The sample which was tested with water could not be saturated even after three weeks of maintaining an upstream pressure of 1.4 megapascals and a downstream pressure of .5 atmospheres, vacuum. This procedure for attempting to saturate a porous medium is somewhat questionable. A better procedure is to saturate under vacuum. In other words, air is removed from the sample and water then is allowed to flow into the material.

Section 7.4.1.2. Analysis of Decay and Pulse Test

The author uses transient one dimensional flow of an ideal gas, referenced to Collins (1961). For the analysis of the pulse tests used in the experiment, a series of curves of pressure versus time were developed in dimensionless form. The curves were obtained by numerical simulation. A figure is also presented which the author says shows the experimental results, which are reproduced by the numerical model. The two figures are not directly comparable because the data of the experimental curve are plotted as pressure (psi) versus time (hrs), whereas the other curve has dimensionless axes. It is not readily apparent whether the experimental curve fits the numerical curve or not. The experimental figure includes a line but no data points.

Section 7.5. Results

The results section includes plots of permeability versus pressure for flow of nitrogen, carbon dioxide and water through the two samples as well as the concrete column. One of these plots evidently shows the Klinkenberg effect with the permeability decreasing with increased pressure. The extrapolated permeabilities for liquid compare favorably with the other results at a value of about 1.3×10^{-13} cm^2. The author also concludes that the permeability of the 5 cm cores corresponds to that of the 3.9 m column so there is no apparent size effect. The permeabilities determined from packer testing apparently are reliable even though simplified equations are used for permeability calculations. The instrument apparently is reliable at very low levels of permeability.

Measurement of permeability of the column with water also is presented. In this case permeability increased with increase in pressure. Evidently the concrete was not saturated, and the entrapped air was compressed at higher pressures which produced an increase in permeability. The permeability measured with water was approximately two orders of magnitude smaller than that measured with the nitrogen gas. As the author states this is likely due to not obtaining complete saturation. There also was considerable scatter in the permeability measured with water which was correctly explained by the effect of compressibility and dissolution of entrapped air. Whether or not vacuum saturation was attempted was not mentioned. The medium next was saturated with a gas more soluble than water (carbon dioxide) before water injection so that the gas would dissolve and the material would become saturated with water more rapidly. This effort was not successful as the permeability to CO_2 was about the same as to water. The author does not state whether he actually injected water after the concrete was saturated with CO_2.

It was concluded that the permeability obtained with nitrogen at infinite pressure is a close estimate of saturated permeability to liquid and that the packer testing equipment can also measure the permeability of porous media with an accuracy comparable to laboratory testing equipment. At the end of the summary the author states: "I believe that the results of nitrogen injection testing of the concrete are more reliable than the results from the other two fluids, provided that correction is made for the Klinkenberg effect".

Although this may be true, we question the data obtained with nitrogen for two reasons:

1. In one dimensional flow the pressure appropriate for use in the plot of reciprocal pressure versus permeability is the average of the pressures at each end of the sample. In radial flow such as that in the concrete column, the average pressure is not the average of the pressures inside and outside the column because the cross-sectional area of flow increases with increases of radius. The author does not state what pressure was used.

2. It is doubtful that the samples were completely dry when nitrogen was being used so there might have been an increase of permeability with time as the nitrogen evaporated the water.

Section 8. Fracture Permeability Characterization

The testing conducted in the field to attempt to characterize the fractures is described. Three types of tests were used: a) quasi steady state, b) decay after quasi steady state equilibrium, and c) a pulse test after natural or steady state equilibrium. In testing the boreholes a relatively long injection zone of 2.13 m was used with the sequentially overlapping interval method in which each interval is overlapped 57% by another test. This method made possible much fewer tests than would have been necessary if a shorter test section had been used.

Section 8.3.4. Results of Systematic Nitrogen Injection

The results of the nitrogen injection are incomplete because figures 8.5 through 8.10 are missing. These figures are for the permeabilities at infinite pressures along each borehole as well as the pressure permeability trends for single fractures encountered within two or three consecutive test intervals. The author states that despite frequent stringent efforts at calibration, recalibration and checking for leakage, straight horizontal lines were not obtained in the pressure permeability plots which contradicts the concept of permeability and Darcy's law. The pressure permeability curves are not the same shape consistently which shows that the effect is not the result of flow meter malfunctioning or flow rate calculation procedures. Therefore it was concluded that the effect is due to the behavior of the fluid in the medium.

It sould be pointed out that the straight horizontal lines would be obtained only if there was flow of a liquid along with complete saturation. If a gas were flowing in one dimension the Klinkenberg effect would result, but since this is radial flow it is difficult to say whether the classic Klinkenberg curve would occur. Because of the unusual data, three sets of tests were repeated with the same results. The author's examination of the pressure permeability curves indicate that with an increase in test pressure, a systematic decrease in permeability occurred. The decrease of measured permeability with pressure increase is explained by the Klinkenberg effect but the characteristic curves of most of the higher conductivity fractures were nonlinear.

It appears that there are several things in this part of the thesis that are not explained fully.

Section 8.3.4.2. Radial Boreholes

Permeabilities measured during testing of the radial boreholes were very low; but the fracture permeabilities were several orders of magnitude larger than those calculated for fractures in the longitudinal boreholes. The author states that the possible discrepancies are 1) that blasting affected the conductivity of the fractures at less than 1 m depth in the rock, 2) the fractures near the beginning of the boreholes usually connect with the room resulting in a shorter flow path to the large open space of the room and thus larger apparent permeability of the fractures, or 3) roughness of the boreholes in their beginning sections may provide leakage around the packers. The packers were tested for leakage inside a 3-inch pipe. It appears that it would be possible for the packer to work correctly in a 3-inch pipe but leak when it was in a rough borehole. Some of these discrepancies are discussed and some are not.

Section 8.4.1. Scale Effects

Data for the pressure permeability plots for intervals selected for testing are presented. In all cases the Klinkenberg effect appears to be insignificant. The author states that the effect increases as the length of the test interval increases. It appears that, except in one case, the data indicate a constant permeability. Permeabilities extrapolated to the infinite pressure also are presented; they show that intervals longer than about 10 m have values of permeabilities that are about 5×10^{-11} cm^2. As the length of the interval is increased the probability increases that more fractures belonging to the same sets parallel to the axis of the borehole are included in the flow path of the fluid. Therefore, the flow through the fractured medium approaches that of a porous medium. There appears to be reasonably good agreement between prediction of the permeabilities from nitrogen injection testing as compared to the actual test results. Data are presented showing that the agreement is within an order of magnitude.

Section 8.5.1. Testing Procedures

Considerable care was taken to reduce leakage in the flow system to an undetectable level; an attempt was made to reduce the leakage around the packers to less than .01 cubic cm of water per minute. Long-term injections were done in one borehole with monitoring in the adjacent boreholes. Air injection was conducted first but only after the boreholes were allowed sufficient time to reach natural equilibrium (twelve months after the last water test and 60 days after the last nitrogen test). During the water injection phase the walls of the room were checked frequently for signs of seepage.

Section 8.5.3.1. Pressure Profile Along the Shear Zone

This experiment showed the continuity of a shear zone between the three boreholes. Data are presented concerning the pressure variation with time and the response in one borehole to pressurization in another borehole. The author states "any change in pressure in one borehole is clearly reflected in the others". However, in part of the figure it is not reflected as the water was injected into PA3 and there was no pressure response in PA1 or PA2. The author further states "all of the observations noted in this set of tests point to the fact that the conductivity to water of the shear zone reduces toward the room as was concluded from systematic nitrogen injection testing. This proves that the effect cannot be due to the unsaturated nature of the rock. If such was the case, the trend of the effective conductivity of the fracture to water would have been opposite to that to nitrogen."

Section 8.5.3.2. Cross Hole Testing of Boreholes REH-1 and REH-2

A large fracture with relatively high conductivity was encountered in connecting boreholes REH-1 and REH-2. The noise of gas leakage was apparent in the adjacent borehole during injection testing. Several tests with nitrogen, carbon dioxide and water were conducted to understand the nature of the unsaturated flow through a single fracture. During the nitrogen injection tests the pressure and flow reached steady state condition after only a few minutes. Although there may have been residual saturation of water in the fracture it did not affect the flow of the nonwetting phase (nitrogen).

Similar pressure and flow trends were observed for carbon dioxide displacing nitrogen. Two tests were conducted to insure saturation of the fracture with carbon dioxide prior to water testing. When this fracture was tested with water the smooth and steady behavior during testing with the nonwetting fluids was not observed. Both flow and pressure were erratic and a steady state condition was not established. The author attributed this to a piston displacement by water which showed a decrease of flow rate with time because of the overall decrease of mobility ratio (permeability/viscosity) since the fluid with a high mobility ratio (carbon dioxide) is being replaced by a fluid with a low mobility ratio (water). After the initial water injection both boreholes were pressurized with water to attain maximum saturation. Although smoother trends were produced by this test, a general decline of the flow rate and decrease of the pressure was observed. Sudden jumps in pressure which were observed were probably due to the escape of entrapped gas either from the cavity or in the fracture.

In the final test, the water in the fracture was displaced with nitrogen. The pressure decline is consistent throughout the entire injection period and is accompanied by an upward trend in the flow rate. This is exactly opposite to that observed during the water test. In this case the overall mobility ratio in the system is increasing with time. The permeabilities calculated from these tests are plotted versus the inverse of the pressure. The data for the gases, nitrogen and carbon dioxide, show a decrease of permeability with increased pressure as predicted by the Klinkenberg effect while the two points for water are at a relatively high pressure and would be about the same as measured with the gas.

Section 8.6.2. Data Analysis

The flow from a horizontal borehole into a vertical fracture is discussed. It is pointed out that when water is injected it does not flow radially because of gravity. For this reason air injection testing was selected over water injection testing for the comprehensive investigation of permeability.

Section 8.6.3. Results

In this section the effect on permeability of a blast at one face of the room is considered. Water injection was used for these tests and a significant decrease in permeability occurred after the blast. The slope of the pressure-permeability curve was increased and the curve shifted toward a lower permeability. The slope of the pressure-permeability curve is explained as due to more fractures containing water but the decrease of permeability after the blast is not explained. This work may be of use in NTS because ultimately blasting will occur which could have a significant effect on the fracturing and the resulting permeability.

Section 8.7. Summary of Results

"Systematic injection testing of the longitudinal boreholes with nitrogen revealed that the pressure-permeability relationship is non-linear; therefore effects other than Klinkenberg's control the flow. Two types of pressure-permeability trends are delineated:

1) Permeability decreases with increase in the equilibrium pressure, and

2) Permeability increases with increase in the equilibrium pressure.

The first trend is seen mostly for high permeability zones and the second for low permeability zones. In both cases, extrapolation to infinite pressure was assumed reliable for comparison." The author has not explained the permeability increase with increase of equilibrium pressure. One possibility is that the material has some significant water saturation at the time that gas injection is begun. The water then evaporates as gas moves through, decreasing the saturation, and allowing an increase of gas permeability with time. This effect could be prevented by presaturating the gas with water vapor. No statement that this was done is included. The Klinkenberg effect can only be evaluated if the material is completely saturated with gas so that there is no liquid saturation. There is no way that the material could be dried out and all the water removed before the gas injection was begun. The nonlinearity referred to in this thesis could be due to the radial flow rather than one-dimensional flow.

Section 9.1. Analysis of the Pressure Permeability Trends from Systematic Nitrogen Injection Tests

The two types of pressure-permeability trends are listed again: "1) a non-linear decrease in permeability with increase in pressure and 2) a increase in permeability with increase in pressure which has somewhat an S-shaped inverted curve". The reviewers do not agree with the second statement as only one curve out of 92 has any type of S curve, although several show an increase of permeability with pressure. The author considers the causes for the inverse pressure permeability relationship and mentions the gas slip phenomenon (Klinkenberg effect), the lubricating effect described by Rose, and interference due to subsequent steady state tests. He goes on to say that the Klinkenberg theory predicts a linear variation between inverse pressure and the permeability whereas in this work he found the relationship to be highly nonlinear.

As discussed previously, a possible explanation for this relationship is that the pressure which is plotted is an average pressure according to the paper by Klinkenberg. The average pressure which he used was the average through a cored sample where the flow was one dimensional and over a fixed length. In the present work the flow is radial from the borehole outward and the pressure used is not stated. If the average pressure between the pressure in the borehole and the atmospheric pressure at some radius was used, it would not be the same as the average pressure in the case of radial flow in the concrete column.

A possible explanation which the author describes is that as pressures increase a step-gradient is imposed on the system. The result is that during the later stages of the test the permeabilities are underestimated. This explanation contradicts what is known about flow of viscous fluids. Another possible cause which is given is that gas will move into fractures which intersect the main flow path, taking up some of the mass but which then does not move on down the pressure gradient. In the summation the author states: "no single method could be justified for determination of the absolute permeability of the tested zones. Nevertheless, it can be seen that all trends of the first kind can be extended to infinite pressure to obtain a single value of permeability. This is considered to be the absolute permeability."

Section 9.1.2. Causes for the Trends of the Second Kind. Increase in Permeability with Time

The stated reason for an increase of permeability with time is that the fractures are partially filled with water as the air is injected and this water is gradually forced into the smaller pores thereby allowing a permeability increase. Another factor which he did not mention is that the gas could be evaporating the water and reducing the water saturation so that the permeability increased. This phenomena apparently does not occur when the fractures are large, as would be expected.

Section 9.1.2.2. Increase in Permeability with Pressure A Conceptual Model

A possible model is developed for the occurrence of water at points of contact in the fractures and how these would change with the injection of a gas. The conceptual model supports the idea of the liquid recovering back to its initial position when pressure is released, which appears to occur in the physical state.

Section 9.2. Variation of Permeability Along Fractures

The permeability of the fractures closest to the room were lower than those further away and, in fact, there is an order of magnitude decline. This decrease of permeability towards the room is due to a decrease in fracture width, but it is not indicated why the fractures are smaller near the room. The smaller fractures near the room may be due to the additional stress on the rock, near the room which tends to close the fractures. There is considerable discussion of the effect of saturation on the fractures. The author feels that this reasoning is also supported by the conceptual model that the higher conductivity fractures are drained by gravity.

Section 9.4.2. Effects of Stress Modification

An explanation of the lower permeabilities observed in the boreholes near the room due to the stress changes around the room is presented. Some theoretical analysis is given which shows that the permeability changes in the three boreholes along the same fracture may be explained by the stress modification caused by the excavation of the room. This is a preliminary conclusion. More rigorous investigation of stress/deformation relationship of fractures is required for definition resolution.

Section 9.6. Summary

"The pressure permeability trends are comparable, at least in a relative sense. They indicate the unsaturated state of the fractures, which in turn is indicative of the fracture characteristics. High permeability fractures show a decrease in permeability and low permeability fractures show an increase in permeability with increase in test pressure". The author's discussion of the increase of permeability with increased pressure is not easily understood nor completely convincing and could be due to a time effect of the gas evaporating liquid from the rock.

Bibliography

An extensive list of references (about 760) is presented. It appears that an excellent job of reviewing the literature associated with flow in fractured materials was conducted, particularly the foreign literature. It is perhaps a little short of articles on unsaturated flow. Several additional articles could have been included which contain applicable information but extensive list from soil physics and petroleum literature was presented. Overall it is an excellent literature review.

Conclusions about this thesis by the reviewers are as follows:

1. Many of the discrepancies between data in this report and other data or theory have possible explanations that are not mentioned in the thesis.

2. The advisability of attempting to determine saturated conductivities or permeabilities with either gas or water when the material is not saturated with either fluid is questionable.

3. Even though the data from this study are questionable, there probably are no in-situ methods of determining permeability that would be any better.

4. A shortcoming of the experimental work reported on in this thesis is that no attempt was made to measure the water content of the rock nor to determine the pressure in the fluid phase which was not flowing. This sort of information would be necessary to adequately define what was actually occurring during injection.

5. It is unknown whether field methods for determining permeability in fractured crystalline material would work in fractured material such as volcanic tuff.

APPENDIX

Dr. Montazer's conclusions and recommendations are presented below.

CONCLUSIONS

The migmatite-biotite gneiss hosting the CSM/ONWI room is a heterogeneous, moderately fractured rock. In the vicinity of the Edgar Mine, within which the room is located, the rock consists of three distinct hydrogeologic zones:

a) zone of topographic gradient, a shallow-surficial zone of highly fractured rock in which most of the interflow occurs and is underlain by;

b) the zone of vertical gradient, which is unsaturated and the flow of moisture is mostly vertical; and

c) the zone of regional gradient, which is saturated and is overlain by the zone of vertical gradient.

The following conclusions have been reached from the results of this study:

1. The fracture characterization technique used for this study is believed to be applicable to radioactive waste repository site characterization.

2. Detailed fracture mapping used here seems to be unnecessary. Statistical sampling of small fractures combined with deterministic mapping of the

more prominent features is more practical.

3. Apertures measured in boreholes are not the same as the equivalent parallel plate apertures and are much exaggerated.
4. Estimation of the equivalent aperture by injection testing may be used, along with borehole surveys, to better understand the distribution of the aperture for specific fracture sets.
5. Permeability testing methods used here are applicable to characterization of unsaturated fractured hard rocks.
6. Although in situ permeabilities smaller than 10^{-14} cm^2 were not encountered in this investigation, the instrument is capable of detecting permeabilities of 10^{-17} cm^2 by the steady state injection. More resolution but less accuracy is gained employing transient testing and/or by increasing the pressure and distance between the packers.
7. The instrument produces results comparable in accuracy to laboratory permeability testing results.
8. For porous material, the steady radial flow equations can be used reliably to estimate the permeabilities in the order of 10^{-13} cm^2. When such materials are dry or have low water content, nitrogen seems to

be a suitable testing fluid.

9. Water and carbon dioxide underestimate the permeability.

10. Tests with nitrogen would require wide ranges of pressures to delineate the Klinkenberg effect.

11. The sequentially overlapping interval method of borehole injection testing significantly increases spatial resolution and reduces testing efforts. However, analysis of the data to obtain permeabilities of the overlapped intervals requires numerical techniques.

12. Pressure-permeability relationships from systematic injection testing of the longitudinal boreholes are non-linear and are due to a combination of effects of unsaturated nature of the rock and gas slip phenomenon.

13. These relationships are valuable in comparison between permeabilities of various zones and estimation of the saturated permeability. Employing these relationships and comparison with the result of cross-hole testing with water and nitrogen along a few fractures indicate that permeabilities along some of the high conductivity fractures is smaller near the room.

14. The overall permeability of PA-3 (nearest the room)

is about 1.0E-12 and is one order of magnitude smaller than the overall permeability along the other two longitudinal boreholes.

15. The permeability of the shear zone is almost two orders of magnitudes smaller in PA-3 than the other two boreholes.

16. Conclusions 13 to 15 are suspected to be due to an increase in the normal stress in the plane of the fractures perpendicular to the room axis.

17. Large permeability values are recorded for the first 0.5 meter of 50 percent of the radial boreholes.

18. Conclusion 17 is probably due to a combination effect of blasting and an increase in the component of the stress in the plane of fractures parallel to the room axis.

19. If Conclusions 16 to 18 are true, a significant change in the orientation and magnitude of the permeability tensor in the 1.5m envelope must have occurred. The increase in ratio of longitudinal to radial permeability may have been as much as 100.

20. If Conclusion 19 is proven to be the case for the CSM/ONWI room, it can be used advantageously to design underground storage rooms so that the radial

permeability after the excavation would be almost as low as the matrix permeability. This would significantly reduce the rate of leakage of the stored substances, the rate of escape of radio nuclides, and the drainage problem.

RECOMMENDATIONS

For future work on this specific site the following tasks are suggested:

1. Intact-fracture samples of some of the identified fractures should be taken from the room. These samples can then be tested to study stress-permeability relationships as well as unsaturated flow investigations.

2. A three-dimensional finite element stress-flow model should be set up for the ONWI Room.

3. The present packer system is capable of measuring large-scale anisotropic permeabilities of the rock; this capability should be used to calibrate the finite element computer modeling.

4. A large-scale permeability test is suggested for the entire room. This may be accomplished by injecting air into the room blocked at the entrance. Analysis of the transients observed in the instrumented boreholes would provide the skin factor

which is indicative of either blast damage and/or stress effects. This method would clearly estimate the zone of influence.

5. An instrument should be developed to measure _in situ_ stiffness properties of the fractures in the exploratory boreholes. This is a necessity in predicting the behavior of the fractures prior to excavation of an actual repository.

Investigation on this subject can be duplicated at a different site in this mine or another underground location to simulate other repository conditions. The difference would be that the new site should be completely instrumented, tested for permeabilities, and mapped for fractures _prior_ to _excavation_. Then the post-excavation modification of the stress and permeability could be predicted by the methods and theories presented here, and the predictions could then be compared with the actual post-excavation conditions.

GEOTRANS COVER LETTER OF 84/9/5

ATTACHMENT B: SUMMARY OF PLUVIAL CLIMATE STUDY

Mifflin, M.D. and M.M. Wheat, 1979, "Pluvial lakes and estimated pluvial climates of Nevada," Nevada Bureau of Mines and Geology Bulletin 94, 57 pp.

The prime objective of this study was to evaluate past pluvial paleoclimates of the Nevada portion of the Great Basin. The search for shoreline evidence in more than 81 basins of Nevada yielded recognition of 53 pluvial lakes of Lahontan (Wisconsinan) age. The frequency and size of the lakes decreased toward southern Nevada. The nearest lakes to Yucca Mountain were north and northeast in Gold Flat, Kawich, and Emigrant Basins. In both the Ash Meadows and Las Vegas areas, it was concluded that lakes did not exist. Using modern aspects of Great Basin climates and associated hydrology, the observed pluvial lake paleohydrology could have been maintained by: (1) mean annual temperatures approximately 5°F lower than those of today, (2) corresponding pluvial mean annual precipitation averaging 68% over modern precipitation, and (3) mean annual pluvial lake evaporation averaging 10% less than mean annual modern lake evaporation.

GEOTRANS COVER LETTER OF 84/09/05

ATTACHMENT C: SUMMARY OF DOUBLE-POROSITY RESEARCH PAPER

Moench, A.F., 1984, "Double-porosity models for fissured groundwater reservoir with fracture skin," Water Resources Research, Vol. 20, No. 7, pp. 831-846.

Studies of fluid flow in a fractured rock mass where fissure flow dominates and is augmented by contributions from adjacent porous blocks is generally termed double-porosity flow. This paper extends existing double-porosity flow theory by incorporating the effects of a thin layer of low-permeability material or fracture skin that may be present at the fracture-block interfaces as a result of mineral deposition or alteration. The effect on flow of a fracture skin in double-porosity systems is to delay flow contributions from the porous block to the fissure, and give rise to pressure responses that are similar to those predicted under the assumption of pseudo steady-state flow.

The first part of this paper is dedicated to the theoretical development. Although this aspect is of interest, it is not reviewed here. The latter part of the paper deals with an application of the model using well test data from a pumped well and from an observation well located at Yucca Mountain, Nevada. It is this part of the paper that is reviewed here.

The pumped well is UE-25b#1 and the observation well is UE-25a#1. Both wells have a ground elevation of 1,198.7 m and the approximate depth to static water level in both wells is 470 m. Well b#1 was drilled to a total depth of 1,219.2 m with casing set at a depth of 518 m. It is perforated through the depth interval of 477 through 501 m. The well diameter below static water level is 0.22 m. This well was drilled with air, detergent, and water. Well a#1, on the other hand, is drilled to a total depth of 762.2 meters, has no casing, was drilled with bentonite mud, and has a well diameter below static water level of 0.075 m. Cores are presented from both wells showing typical mineral-filled fractures. A borehole flow survey is presented for b#1 which shows five major zones of entry over a depth interval of about 400 m ranging from the bottom of the casing to a depth of approximately 875 m. For the purpose of this analysis this zone was assumed to be the reservoir with a thickness of 400 m.

A pump test termed Test 3 was analyzed. This test consisted of pumping b#1 at a rate of 35.8 l/s for nearly 3 days. Well a#1 is separated from b#1 by approximately 110 meters. Drawdown data at both a#1 and b#1 are provided in tabular form as well as graphical form.

In analyzing the data, the author made several assumptions including well bore skin was assumed to be negligible and the porous blocks have an average thickness of 80 meters. Based on his analysis the following parameters were obtained:

(1) A fissure system hydraulic conductivity of 1×10^{-5} m/s.

(2) A porous block system hydraulic conductivity of 2×10^{-6} m/s.

(3) Specific storage of the fissure system of 1.5×10^{-6} /m.

(4) Specific storage of the block of 3×10^{-4} /m.

(5) A ratio of the hydraulic conductivity of the skin to the thickness of the skin was 5×10^{-8} /s.

The author concludes that the interference test data from Yucca Mountain support the hypothesis that fracture skin may be important in some double-porosity systems. If it is true that fracture skin is important at Yucca Mountain, then the following implications can be made:

(1) The data are more complex and more difficult to analyze than previously thought.

(2) Previously analyzed tests, without assuming a fracture skin, may have given rise to inappropriate determination of system parameters.

(3) A fracture skin implies that there will be less matrix diffusion occurring during the transport of radionuclides.

This final implication could be very significant in calculating travel times of radionuclides, as they will migrate faster, and needs to be studied further. The author points out that the minerals deposited on the fractures from these wells are probably MnO_2 and Silica. The effect of these minerals on sorption of radionuclides also needs to be studied further.

Distribution:
WMHL file: TRC
WMHL r/f MRKnapp
WM r/f PMOrnstein & r/f
NMSS r/f HJMiller
JBMartin JOBunting
REBrowning
MJBell

3100/PO/1/12/82/0

INFORMATION TO APPEAR ON DOCUMENT REVIEW SUMMARY SHEET*

DOCUMENT: Geohydrology of Bandelier Tuff LA-8962-MS

DATE REVIEW COMPLETED: January 11, 1982

REVIEWER: Peter Ornstein

SIGNIFICANCE OF INFORMATION TO NRC PROGRAM:
Document is an indepth study of the hydrogeologic properties of the Bandelier Tuff in New Mexico which may be analogeous to the bedded tuffs at the Nevada Test Site. Special emphasis is placed on unsaturated flow.

ACTION RECOMMENDED:
Route to the NRC's NTS information library to serve as a future reference on geohydrologic properties of tuff.

ACTION TAKEN:
Document is being reviewed more closely and will be routed to the NTS information library shortly.

REFERRED TO (FOR INFO):

Name Pages

SUMMARY OF DOCUMENT: The Bandelier Tuff at the Los Alamos National Laboratory has served as a radioactive waste disposal site since 1944. Data concerning the local hydrogeology has been gathered and analyzed in an attempt to study the extent of radionuclide transport. Migrating groundwater and vapor phase diffusion were the two methods of transport studied. Because subsurface transport of radionuclides is influenced by the hydraulic conductivity, which is in turn regulated by the moisture content of a given material, a study was also undertaken involving precipitation and surface runoff.

Although the climatalogical and the hydrogeologic studies have been vigorously dealt with, a coupling of the two studies is not clear.

Results of the study, although site specific for the Bandelier Tuff, show very small and often undectable radionuclide migration.

WMGT DOCUMENT REVIEW SHEET

FILE #:

DOCUMENT #: LA-9328-MS

DOCUMENT: Daniels, W.R., and others, 1982, Summary Report on the Geochemistry of Yucca Mountain and Environs. Los Alamos National Laboratory, Los Alamos, NM, LA-9328-MS, 364 p.

REVIEWER: Williams & Associates, Inc.

DATE REVIEW COMPLETED: September 15, 1986

ABSTRACT OF REVIEW: APPROVED BY: Roy E Williams

The report under review is a lengthy (364 pages) description of work conducted at Los Alamos National Laboratory pertaining to the geochemistry of tuff with particular emphasis on retardation processes. The report discusses the various aspects of sorption by tuff, the physical and chemical make-up of tuff, diffusion processes, tuff/groundwater chemistry, waste element chemistry under expected repository conditions, transport processes involving porous and fracture flow, and geochemical and transport modeling. The report contains valuable information with respect to the potential retardation processes affecting radionuclide migration in tuffs. Much of the report is devoted to descriptions of laboratory procedures followed during the experiments. Because of this fact, the report is of most value to geochemists involved directly with the analysis of retardation processes in tuff.

BRIEF SUMMARY OF DOCUMENT:

The purpose of the report under review is to describe the technical contributions of the Los Alamos National Laboratory to NNWSI from 1977 until March 1982. The report describes the results of a series of sorption experiments in which groundwater from well J-13 was used as the reference groundwater.

One of the most significant aspects of the sorption experiments conducted in tuffs from Yucca Mountain is the fact that filtration of the water through 0.45-um Millipore filters was found to be inadequate. According to the report, filtration through a 0.45 um filter yields erroneously high results for iron content. This result is significant because this is a standard practice for the filtration of groundwater samples. According to the authors of the report, water for this study was filtered through a 0.05 um Nuclepore membrane rather than a 0.45 um Millipore filter. Accurate iron concentration in solution is important because it influences the Eh of the solution.

The composition of the groundwater as a function of location in the vicinity of Yucca Mountain was measured to evaluate the effect of groundwater composition on the waste package, on the waste itself, and on retardation mechanisms. The results of the groundwater samples indicate that deep water may be oxygen deficient compared to water at the waste level. A series of short-term experiments was conducted to evaluate possible reactions between groundwater and tuff samples. Samples from different lithologies (Topopah Spring, tuffaceous beds of Calico Hills, and Bullfrog 2) were tested. Basic reactions that occurred between the groundwater and tuff included rounding of surfaces and precipitation of clays, precipitation of other fine-grained silicates, and the dissolution of clinoptilolite crystals. According to the report, the main changes in the composition of the contacting water were large increases in sodium, potassium, and silicon concentrations and large decreases in the magnesium and calcium concentrations.

Various studies have been conducted to understand actinide solubility and speciation. This section of the report describes the chemistry of actinide, and methods used for preparing feed solutions for use in the experiment. The laboratory techniques used in the experiments, including filtration, and centrifuging are described in the report. The report also describes studies and experiments that were being planned at the time this report was written.

A number of hydrothermal experiments were in the preliminary phase at the time this report was written. These experiments were conducted to evaluate potential phase changes in tuffs at known values of pressure and temperature. Preliminary data (at the time this report was written) indicate that the upper stability of morgenite is probably between 300 and 400°C; the upper stability for clinoptilolite appears to be below 300°C. These stability values are for 400 bars of water pressure.

A series of experiments was conducted to evaluate the sorptive behavior of tuff. Experiments were conducted using both the batch method and a column method to evaluate potential differences in the results. According to the report,

> Preliminary results from hole-core column studies indicate that there is better agreement with the results of batch experiments when batch work is performed with samples from which the very fine particles have been removed. However, greater variation should be expected in hole-core samples because of the heterogeneity of tuff; as more hole-core experiments are completed, the samples having R_d (sorption ratios) values greater than those from the batch experiments may be found.

In addition to the batch and column methods, sorption ratios were measured by a circulating-system method which incorporates features of both batch and column methods. Pertinent data from the batch and circulating-system sorption and desorption measurements are presented in tables XXXIII and XXXIV of the report. The report presents the following conclusion with respect to the various methods used to evaluate sorption ratios:

> When material of the same particle-size distribution is used, the results from batch, column, and circulating-column methods are in reasonable agreement. The column method gives information on dispersion that cannot be obtained in batch systems. Batch methods, however, allow for processing a large number of samples with ease under a variety of conditions.

According to the report, strontium, cesium and barium are thought to sorb mainly by ion-exchange reactions. The lowest sorption ratios for these elements are associated with devitrified tuffs. The maximum sorption ratios correspond to non welded tuffs that contain the zeolite clinoptilolite. The report notes that for the elements in samples studied, samples containing no clinoptilolite have significantly lower sorption ratios than those containing more than a few percent of the zeolite. The report notes also that sorption ratios for technetium, cerium, europium, and americium show no obvious correlations or trends with the abundance of clinoptilolite. Sorption ratios for neptunium, uranium, and plutonium are higher for the zeolitized tuffs than for the non zeolitized tuffs. The report notes also that sorption ratios for the desorption experiments generally are slightly higher than those from sorption experiments. The report notes that the presence of very fine particles (less than 38 um) in rock fractions of larger particle size apparently can change the observed sorption ratio of an element by a factor of 2 to 5, especially for devitrified tuffs. In order to avoid this potential problem the report recommends that larger size fractions be wet-sieved thereby avoiding the presence of fine particles.

Sorption isotherms were studied to evaluate the following:

1. Determine the influence of groundwater/tuff interactions on sorptive properties of tuff.

2. Accurately model the retardation of waste elements under various source-term and groundwater conditions.

3. Detect irreversible sorption processes that could constitute very positive properties if discovered in tuff.

4. Interpret and model diffusion into the tuff matrix as it would occur in fracture controlled flow.

5. Explain the observed dependence of the distribution coefficient on the solution-to-solid ratio and predict real conditions from laboratory measurements.

The Langmuir and Freundlich isotherms and the relationship from mass action equilibrium were used for these applications. According to the report, experimental fits to the Freundlich isotherms for strontium, cesium, barium, cerium, and europium generally indicate non linear behavior for non zeolitized welded tuff and linear behavior for zeolitized tuff. The effect of non linear isotherms on sorption phenomena were studied, and equations and computer programs to solve the diffusion equations with non linear isotherms were developed.

According to the report, permeability and storage capacity was measured in the laboratory by means of a transient pressure pulse method. Porosity was evaluated by measuring the grain density and the wet and dry weights of samples, and by mercury porosimetry. Results of the studies indicate the absence of a correlation between permeability and porosity in tuffs. However, mercury porosimetry indicates that permeability is related more closely to pore size than to total porosity.

According to the report, results of experiments that were designed to examine transport in a single fracture were compared with transport model predictions to validate or demonstrate deficiencies in the models. According to the report, the lack of agreement between the experimental and theoretical elution curves suggest a more complex selection mechanism than simple linear sorption. In addition, the report suggests that sorption and matrix diffusion in tuff (especially welded tuff) appear to be more complex than expected. The report presents the following conclusions from laboratory fracture flow studies:

1. Matrix diffusion is an important mechanism contributing to the retardation of radionuclides in fracture controlled flow; however, simple analytical models do not appear to be adequate to predict accurately the transport of waste elements in tuff fractures.

2. The high porosity of tuff makes matrix diffusion much more effective in retarding movement of soluble species than does the low porosity of crystalline rock such as granite.

3. Undisplaced, induced Bullfrog- and Tram-Member tuff fractures subjected to a simulated lithostatic stress of 3,000 psi sealed to cause a fracture permeability comparable to that of the undisturbed matrix.

A series of experiments using chromatographic columns packed with crushed rock were performed to examine the transport of radionuclides through porous media. Experiments also were performed using solid-tuff columns. The following radionuclides were used in the experiments: I-131, Sr-85, Cs-137, Ba-133, Ce-141, Eu-152, Tc-95, and H-3. The report presents the following conclusions with respect to these experiments:

1. The sorption ratio determined by using column methods agree with those determined by the batch techniques within a factor of 10.

2. At water velocities comparable to regional flow velocities (approximately 10^{-5} cm/sec), the shapes of peak elution for some simple ions are comparable to what would be expected from diffusional broadening alone.

3. The anion exclusion effect may have been observed in a highly zeolitized tuff.

4. Plutonium particulate matter was filtered out by flow through a solid core column.

Experiments to evaluate kinetic sorption (sorption as a function of time) were conducted on thin tablets of tuff. The tablets (or wafers) of tuff were 0.75 inch in diameter (2 to 3 mm thick) and 1.1 to 1.4 grams in weight. The average sorption ratios calculated from these experiments are presented in tables XLVIII and XLIX in the report. According to the report, the sorption ratios from the wafer experiments and the column results are in fairly good agreement. A discussion is presented in the report of fracture flow studies conducted by other investigators. The discussion includes the flow equations for transport through fractures as well as results of some tracer experiments using granite cores. Experiments that were conducted to evaluate the transport of radionuclides through porous media are discussed also.

According to the report, at the time this report was written Los Alamos National Laboratory was in the process of developing and testing geochemical and transport models in support of their nuclear waste management programs. The report notes that efforts in geochemical modeling have been concentrated on testing available codes and improving the thermodynamic data base.

SIGNIFICANCE TO NRC WASTE MANAGEMENT PROGRAM:

The report under review presents a description of geochemical investigations conducted at Los Alamos National Laboratory as of 1982. The report discusses the various aspects of sorption by tuff, physical and chemical make-up of tuff, diffusion processes, tuff/groundwater chemistry, waste element chemistry under expected repository conditions, transport processes involved in porous and fracture flow, and geochemical and transport modeling. While the report is very lengthy (364 pages), much of the text is devoted to descriptions of procedures followed in laboratory experiments. This information would be of value to the laboratory chemist; however, much of the detailed information regarding procedure is of relatively little value to the NRC Waste Management Program. Even though many of the data presented in the report are fairly old (1982), they should be of considerable value to geochemists involved in the analysis of the retardation potential of tuff.

PROBLEMS, DEFICIENCIES OR LIMITATIONS OF REPORT:

The report under review presents a detailed description of work conducted at Los Alamos National Laboratory as of 1982. While the report contains much useful information, a significant portion of the text is devoted to descriptions of procedures followed in the laboratory during experiments. Because of this fact the report is of greatest value to laboratory chemists or geochemists involved directly in the analysis of the sorption capability of tuff. A fairly significant portion of the report also is devoted to the discussion of future experiments that the authors believed should be performed. The primary limitation of the report is its relatively old age. The report contains the results of experiments performed through March of 1982. Therefore some of the data presented in the report may be outdated.

SUGGESTED FOLLOW-UP ACTIVITIES

The report should be reviewed by geochemists involved in the analysis of sorption of radionuclides by tuffs.

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 acti..ties are recommended.

LA-09667-MS

WMGT DOCUMENT REVIEW SHEET

FILE #:

DOCUMENT: TRACR3D: A Model of Flow and Transport in Porous/Fractured Media by B.J. Travis, Los Alamos National Laboratory, Los Alamos, New Mexico 87545.

REVIEWER: Williams and Associates, Inc.

DATE REVIEW COMPLETED: January 21, 1986

BRIEF SUMMARY OF DOCUMENT: **DATE APPROVED:**

This report describes the TRACR3D computer code which solves the equations of transient two-phase flow and multi-component transport in deformable, heterogeneous, reactive, porous/fractured media. The application of this program is in areas of transport of fluids (water, air and a variety of reactive chemical species) through porous/fractured materials such as soils and rock.

An implicit finite-difference scheme is used for flow: a semi implicit scheme is used for transport. The equations used in the model are introduced, the numerical solution procedure is described, some partial verification and validation is presented. A users guide also is given. The program will consider the air-water system as well as hydrocarbon reservoir problems as examples of two phase flow systems.

COMMENTS:

The Model:

On page 3 the author states that the program was written with flexibility in mind. This is partly true because it will handle a great variety of problems. However, units used in the model must be in the CGS system. It would have been preferable to formulate the code such that any consistent system of units could be used. In this section there are also several equations introduced that have undefined symbols. The author does not define symbols immediately after the equation is presented and some of the symbols are not even defined in the table at the beginning of the report. For this reason, it is somewhat difficult to follow his derivations. In this same section on page 6 the Forchheimer equation is introduced in an unfamiliar form and the source is not given. The actual formulation of the flow process involves satisfying the continuity equation in an element of the finite difference mesh and satisfying the Darcy equation for flow across all faces. This is basically the process used in the integrated finite difference formulation.

On page 25 the author discusses the formulation for fracture flow. The program will allow flow into the matrix from fractures but it does not appear to allow flow across a fracture when the fracture is only partially saturated.

Boundary Conditions:

The program allows several boundary conditions: 1) constant flux, 2) constant potential or concentration, 3) continutive outflow, 4) band release of radionuclides, and 5) time dependent. It does not appear to handle such conditions as atmospherically controlled evaporation or infiltration.

Time Step Control:

The time step limit is calculated from an equation relating the time increment to the square of the spatial increment. It is necessary to input a value of maximum time step which appears to be a very arbitrary value. The program uses a different time step for tracer transport than for flow transport. The steps involved in the numerical procedure are given below:

1) Set initial values of dependent variables, set time and material properties.

2) Sweep through the mesh at each cell, solve the non-linear algebraic set of finite difference equations. After each sweep, test pressure in the gas and pressure in the liquid for convergence; if not converged make another sweep through the mesh. In each cell, latest values are used for neighboring cell dependent variables.

3) After cell centered variables have been up-dated in Step 2, cell air and liquid interface velocities are calculated.

4) Up-dating of tracer movement is accomplished next. If tracers have been specified, they can move with one phase or the other but not both simultaneously.

5) Boundary conditions and time are up-dated.

6) Printouts and plotting dumps are checked.

7) Problem and time is checked. If the calculation has not reached the end time, return to Step 2 for the next time level.

Verification of Flow:

The report lists three tests of the flow model:

1) Comparison with the solution for water infiltration into partly saturated soil.

2) Comparison with the solution for two-dimensional steady potential flow with a sink and a source.

3) Steady flow with pressure dependent permeability.

These are all compared with analytical solutions and appear to give good verification.

Verification of Transport:

Five comparisons of the computer code with analytical solutions are given. These comparisons all appear to be very good.

Validation:

Three experiments are used for validation of the code. These are: 1) water pulse in a partially saturated column of crushed tuff, 2) diffusion of adsorbing tracer into a thin wafer of tuff from a thoroughly stirred solution, and 3) migration of radioactive tracers from an underground nuclear test to a nearby well as a result of pumping in the well. The validation in the first two of these is very good. In the last it does not appear to be very good except that the author states that the difference between calculated and observed breakthrough curves is approximately equal to the margin of error in the observations. The users guide in Appendix A appears to be satisfactory although if one was to attempt to run the program from the information given here, there undoubtedly would be many questions. The author does give several sample problems which include the data input as well as the output. As in all large programs, the data input appears to involve a large amount of work and the output from even a small program consists of many, many pages of data. In the case of the example problem run here there are over 100 pages of output.

SIGNIFICANCE TO NRC WASTE MANAGEMENT PROGRAM:

The report under review is one of many computer models that are being developed to simulate multiphase flow in porous media.

PROBLEMS, DEFICIENCIES OR LIMITATIONS OF REPORT:

There are no major problems or deficiencies in the report. However, the program is large and it is questionable whether field, data collection methodologies are sophisticated enough to provide the data necessary for optimal use of the program.

SUGGESTED FOLLOW-UP ACTIVITY:

No follow-up activity is suggested.

WMGT DOCUMENT REVIEW SHEET

FILE #:

DOCUMENT: Kerrisk, J.F., 1983, Reaction-Path Calculations of Ground Water Chemistry and Mineral Formation at Rainer Mesa, Nevada: LA-9912-MS, Los Alamos National Laboratory, Los Alamos, New Mexico, 41 p.

REVIEWER: Williams and Associates, Inc.

DATE REVIEW COMPLETED: January 21, 1986

BRIEF SUMMARY OF DOCUMENT: DATE APPROVED:

The purpose of the paper under review is to describe reaction-path calculations of ground water chemistry and mineral formation based on the model proposed by Claassen and White (1978). The reaction-path calculations were performed to test whether equilibrium processes could be used to explain ground water chemistry and minerals found at Rainer Mesa, Yucca Mountain, and other NTS locations. The reaction-path calculations presented in the report under review represent a very simplified model of the complex geologic system. According to the report, only the major chemical components are included in the model, and only equilibrium processes are considered at each step in the reaction path. The reaction-path calculations were performed in an attempt to calculate and therefore predict ground water composition (major components) and mineral formation (major minerals) at Rainer Mesa. The physical model by Claassen and White (1978) was used to simulate the change in ground water quality along a flow path from recharge area to discharge area. Recharge water was modeled as being saturated with CO_2. The pH was assumed to be 4.5 as a consequence of aerobic biological activity in the soil zone. Reaction-path calculations were performed to identify the products formed as this water reacts with volcanic glass. According to the report, as dissolution of the volcanic glass proceeds, the aqueous phase becomes saturated with respect to various minerals. These minerals are allowed to precipitate, but it is assumed that they remain in contact with the aqueous phase. Thus, a mineral that precipitates early in the reaction path may redissolve later as conditions such as pH or cation concentrations change.

According to the report, the dissolution process consists of an ion exchange reaction in which H^+ from the aqueous phase is exchanged for cations from the volcanic glass to maintain electrical neutrality. The dissolution process was modeled by assuming that OH^- is one of the dissolution products. The OH^- dissolution rate was controlled by the requirement of maintaining electrical neutrality.

A major limitation of this technique is that the detailed mechanism of dissolution is ignored. However, the report notes that a better calculational model undoubtedly could be developed if mechanisms of glass hydration and dissolution were understood more quantitatively. Another limitation of the model is that if the aqueous phase becomes supersaturated with respect to a particular mineral during the reaction-path calculation, the mineral precipitates. The report under review notes, however, that in reality, many ground waters are supersaturated with respect to a number of minerals. Perhaps most importantly the assumed initial pH controls the supply of H^+ ions. In this model we think the assumed supply of H^+ ions is anomalously high (pH assumed to be anomalously low).

The reaction-path calculations were performed by the EQ3/6 chemical equilibrium computer program. The EQ3/6 program was modified to allow the dissolution rates of the various species from the volcanic glass to vary with the pH of the aqueous phase. Because of a lack of data, most of the solute solutions were treated as ideal solutions. Thermodynamic data were available for 223 minerals, 293 aqueous complexes, and 14 solute solutions.

The results of the reaction-path calculations consist of an aqueous-phase composition and a list of minerals that are in equilibrium with the aqueous phase. According to the report, the general trend of the results is the same for all of the cases modeled. The aqueous-phase composition is controlled by the dissolution process during the early stages of the reaction path; mineral precipitation is essentially non-existent in the early stages. During intermediate stages, various minerals begin to precipitate and the precipitation of the minerals begins to control the aqueous-phase composition. Later in the reaction path the aqueous-phase composition is controlled by a stable mineral assemblage. The results of the reaction-path calculations for various temperatures are presented in figures 4 through 20 of the report.

SIGNIFICANCE TO NRC WASTE MANAGEMENT PROGRAM:

The report under review presents reaction-path calculations of ground water chemistry and mineral formation at Rainer Mesa based on a model proposed by Claassen and White (1978). The report under review is significant with respect to understanding the precipitation of certain minerals along the reaction path. The information presented in the report is significant with respect to the geochemistry and mineralogy of the volcanic tuffs in the vicinity of the Nevada Test Site. The report also may be useful with respect to understanding the mechanisms that control radionuclide retardation along potential flow paths to the accessible environment. However, this would require a very detailed analysis of the ground water chemistry data that are available for the Nevada Test Site.

PROBLEMS, DEFICIENCIES, OR LIMITATIONS OF REPORT:

The reaction-path calculations presented in the report under review represent a very simplified model of the complex geologic system. Only major chemical components were included in the model. Limitations such as adding aqueous species to the aqueous phase to simulate glass dissolution, requiring precipitation as soon as the aqueous phase becomes supersaturated with respect to a particular mineral, and suppressing the precipitation of particular minerals to slow precipitation kinetics were necessary because of the limited data base and the limited capability of the model. These limitations appear to be inherent in the modeling technique used. However, we are not familiar with the degree of sophistication of the EQ3/6 chemical equilibrium program. In addition the assumed pH of the recharge water appears to us to be anomalously low. This assumption introduces an anomalously large supply of H^+ ions to the model.

SUGGESTED FOLLOW-UP ACTIVITY:

While ground water chemistry data are important with respect to supporting or disproving potential conceptual models of ground water flow, no specific follow-up activity is suggested for the report under review. The report under review deals primarily with mineral precipitation; therefore, any follow-up activity probably should be recommended by a geochemist.

REFERENCES CITED:

Claassen, H.C., and White, A.F., 1978, Application of Geochemical Kinetic Data to Ground Water Systems, A Tuffaceous-Rock System in Southern Nevada in Chemical Modeling in Aqueous Systems: E.A. Jenne, Ed., American Chemical Society Symposium Series 93, 771-793.

WMGT DOCUMENT REVIEW SHEET

FILE #:

DOCUMENT: Ogard, A.E., and Kerrisk, J.F., 1984, Ground Water Chemistry Along Flow Paths between a Proposed Repository Site in the Accessible Environment: LA-10188-MS, Los Alamos National Laboratory, Los Alamos, New Mexico, 48 p.

REVIEWER: Williams and Associates, Inc.

DATE REVIEW COMPLETED: January 21, 1986

BRIEF SUMMARY OF DOCUMENT: DATE APPROVED:

The report under review discusses the chemical analyses of ground water from the saturated zone from several deep wells in the vicinity of Yucca Mountain. The report notes that pore water from the unsaturated zone has not been sampled as yet, but samples will be taken during construction of the exploratory shaft. The report notes that knowledge of the vertical and lateral variation of ground water composition at Yucca Mountain can aid in modeling local hydrology; however, no interpretation of the chemical data pertaining to ground water flow paths is presented in the report. The report is divided into four sections: 1) the experimental procedures for sampling and analyzing the water, 2) the water compositions determined, 3) the implications of the data for spatial and temporal variations in water chemistry, speciation and solubility, pH buffering capacity, and redox buffering capacity, and 4) conclusions and proposals for future work.

Three different methods were used to collect ground water samples. These methods are as follows:

1) Samples were taken aerobically and sometimes anaerobically during USGS pumping tests. These samples consisted of composite samples of ground water from all producing zones that contributed to the well during pumping.

2) Samples were collected from permeable zones that were isolated by inflatable packers. This sampling method was used to collect samples from well UE-25b#1 and well USW H-3. Values

of Eh were measured from the two wells to provide estimates of water Eh at depth.

3) These samples were collected from selected depths in static holes. The sampler consisted of an evacuated stainless steel bottle with an electronically activated valve. The report under review notes that it has not been established whether or not the results are representative of water that is in equilibrium with the particular zone sampled.

The ground water samples were analyzed for dissolved cations and anions, Eh, pH, sulfide, dissolved oxygen, alkalinity, and for detergent. According to the report under review, detergent was considered to be a good indicator or tracer of drilling fluids in the well.

The ground water chemistry data presented in the report indicate that sodium is the principal cation and that carbonate is the principal anion. According to the report under review, the molar distribution of anions in the water is relatively uniform for all wells: about 80% bicarbonate; the remainder is sulfate, chloride, and fluoride. The molar distribution of cations is more variable; sodium ranges from a high of over 95% to a low of about 65%. Calcium, potassium, and magnesium are the other cations present in significant concentrations. According to the report, the similarity of the relative cation and anion compositions of water from the tuffaceous aquifers at Yucca Mountain, Pahute Mesa and Rainer Mesa indicates a hydrologic connection or a similarity in reaction mechanism during recharge. While the relative cation and anion compositions of the water are similar, significant differences in the oxidation-reduction potential (Eh) were detected. For example, water from well USW H-3 and from the packed off Bullfrog zone of well UE-25b#1 are reducing. The report notes that the solubilities of many waste elements such as uranium, plutonium, neptunium, and technetium are greatly affected by the oxidation-reduction potential of the water. The report notes that there are no models describing water Eh at Yucca Mountain.

The report suggests that three specific water compositions can be used to estimate the concentrations of waste elements along the flow paths from Yucca Mountain to the accessible environment. These water compositions are as follows:

1) The composition of ground water from well USW H-3 is indicative of water below the proposed repository site.

2) Ground water from well UE-25b#1 represents the carbonate aquifer underlying much of the area and is the most concentrated ground water possible along the flow path.

3) Ground water from well J-13 is typical of wells surrounding Yucca Mountain; the composition of such waters may be influenced greatly by juvenile recharge water.

Results of experiments on ground water from well J-13 indicate that the water alone or with minerals commonly found in Yucca Mountain has a relatively good pH buffering capacity. According to the report under review, this is particularly true for the water/mineral system that is subject to H^{+} addition. Ground water from wells UE-25b#1, USW H-1, H-4, H-5, H-6, and G-4 are expected to have buffering capacities similar to those of well J-13. Ground water from well USW H-3 has a higher pH and higher carbonate content than ground water from well J-13; therefore, it would have a higher buffering capacity for H+ addition. According to the report, insufficient data are available to determine the Eh buffering capacity of the system.

The report presents the following conclusions:

1) The water below the repository site at Yucca Mountain has the same relative chemical composition as the recharge water from Pahute Mesa; it is predominantly $NaHCO_3$ water.

2) There is a progressive increase in calcium and magnesium concentrations at the expense of sodium from Yucca Mountain to the Amargosa Desert.

3) The water below the repository site displays reducing conditions.

4) The natural organic content is very low in the ground water.

5) The chemical composition of the ground water can be modeled on the basis of the reaction of CO_2-saturated infiltration water with glassy and devitrified tuffs.

6) Sufficient data are available for the ground water compositions in the area between Yucca Mountain and discharge locations in the Amargosa Desert to adequately model the ground water composition along the flow path, once the flow path is totally defined. The only data that may need reinforcement are the negative oxidation-reduction potentials below the repository site.

7) The pH buffering capacity of the regional hydrology is determined by the CO_2 dissolved in the recharge water, the biota at the ground surface and zeolites in the saturated zone.

8) Four extremes or bounds of water composition for the area have been recognized from this work and the works of Claassen (1983) and White and others (1980).

SIGNIFICANCE TO NRC WASTE MANAGEMENT PROGRAM:

The report under review presents ground water chemistry data and interpretations of the data in the vicinity of Yucca Mountain. These data are important with respect to understanding the chemical factors that will control migration of wastes from the repository to the accessible environment. These data also are important with respect to the development of conceptual models of the ground water flow systems that exist in the vicinity of Yucca Mountain. The ground water chemistry data alone cannot be used to develop conceptual models of the ground water flow systems in the vicinity of Yucca Mountain; however, ground water chemistry data must support any conceptual models of the ground water flow systems that are developed.

PROBLEMS, DEFICIENCIES, OR LIMITATIONS OF REPORT:

The primary limitations of the report under review consist of unanswered questions concerning ground water composition along possible flow paths to the accessible environment. These limitations are listed in the report under review beginning on page 43. The report under review questions whether "thief" samples of ground water are representative of waters in equilibrium with the tuff strata from which the sample was taken. This is an important limitation of some of the water chemistry data because thief samplers yield mixed samples of the water contained in the borehole. Another significant limitation of the report is whether calculations and laboratory experiments on solubility, sorption, fracture transport, and filtration of particulates represent actual processes and conditions of the Yucca Mountain repository site. Despite these limitations, the report under review presents very valuable ground water chemistry data and interpretations.

SUGGESTED FOLLOW-UP ACTIVITIES:

The existing conceptual models should be evaluated to determine whether they are consistent with the ground water chemistry data presented in various reports.

REFERENCES CITED:

White, A.F., Claassen, H.C., and Benson, L.B., 1980, The Effect of Dissolution of Volcanic Glass on the Water Chemistry in a Tuffaceous Aquifer, Rainer Mesa, Nevada: USGS Water Supply Paper 1535-Q.

Claassen, H.C., 1983, Sources and Mechanisms of Recharge for Ground Water in the West Central Amargosa Desert, Nevada--A Geochemical Investigation: USGS-OFR-83-542.

WMGT DOCUMENT REVIEW SHEET

FILE #:

DOCUMENT #: LA-10263-MS

DOCUMENT: Perkins, B., Travis, B., and DePoorter, G., 1985, Validation of the TRACR3D Code for Soil Water Flow Under Saturated/Unsaturated Conditions in Three Experiments. Los Alamos National Laboratory, Los Alamos, NM, LA-10263-MS, 33 p.

REVIEWER: Williams & Associates, Inc., George L. Bloomsburg

DATE REVIEW COMPLETED: January 20, 1987

ABSTRACT OF REVIEW: APPROVED BY: Roy E. Williams

The report discusses experimental verification of the saturated/unsaturated flow portion of the computer code TRACR3D. Six, large (12 ft diameter by 16 ft high) caissons were placed in the ground and filled with compacted volcanic tuff. Moisture content and tensiometer readings could be taken at seven different elevations in the caissons. The experiments consisted of 1) a pulse of water entering the soil, 2) steady unsaturated flow, and 3) two slugs of water entering the soil under field conditions. The simulation of moisture(s) contents and pressures agreed very well with those measured experimentally. The transport and air movement options of the code were not verified.

BRIEF SUMMARY OF DOCUMENT:

The TRACR3D computer code was developed to simulate transport of solutes through unsaturated or saturated soils. The model considers water and/or air flow under moisture conditions ranging from fully saturated to completely dry. Transport mechanisms include advection, diffusion and dispersion. The present report concerns the validation of TRACR3D in three different experiments.

The experimental equipment consisted of caissons 12 feet in diameter and 16 feet deep filled with compacted volcanic tuff.

Six of these surrounded a caisson of the same size used for access. Access holes were installed from the access caisson to each experimental caisson for use of experimental equipment. Water could be added at the surface and the drainwater at the bottom of the caisson could be measured. Both neutron moisture measurements and tensiometers were used for moisture measurements at a total of seven different levels in the caisson. Preparation of the tuff for placement in the caissons consisted of excavating tuff, crushing and screening the material through a 12.7 mm screen and mixing in a cement truck with enough water to produce a uniform moisture content of 10 to 13 percent by volume. The damp tuff was placed in layers in the caisson and each layer was compacted. Actual density measurements showed that the maximum density for packed tuff was achieved.

The three experiments consisted of 1) a pulse of water entering the soil and initially moving under conditions of saturated flow rapidly changing to unsaturated flow; 2) steady state unsaturated flow; 3) two slugs of water entering the soil under field conditions. During each experiment the moisture content was measured with neutron probes and the moisture tension was measured with tensiometers.

Two relatively minor errors are present in the discussion of the results on page 9 of the report. "When this ponded water had infiltrated the top boundary condition reverted to atmospheric conditions of no pressure and zero saturation." The 'zero saturation' is incorrect because the water content would revert to residual saturation. On the same page, "According to the Brooks-Corey model relative water permeabilities given by the equation $K_{rw} = S^{3+2/\lambda}$ where S is saturation and λ is the pore size index." This equation should be stated in terms of effective saturation rather than saturation.

The data are presented as plots of degree of saturation versus distance from the ground surface. The computer simulation consists of a smooth curve while the experimental results consist of the mean value with error bars showing the variation. The agreement is excellent in all cases. In most cases the median experimental value is on the simulation curve, and in all cases the error band crosses the simulation curve. In the second experiment (steady unsaturated flow), the simulated line of degree of saturation versus distance should be a straight vertical line. However, the experimental data deviates from a straight line suggesting that packing of the tuff is nonhomogeneous. The third experiment was run under field conditions. In this case the simulated results do not fit well with the experimental data because the properties of the material are not as well known as those in the caisson. In most cases, however, very good agreement exists between simulation and field measurements. The authors note that for computer simulation to be possible, experimental data for both boundary conditions and initial moisture levels must be available. Errors in these inputs will affect the simulated results.

The sensitivity of the simulation to a variation in porosity as well as to variation in the saturated permeability is investigated. Lower saturated permeability results in a pulse that moves slightly slower than in the simulation while a change in porosity results in a change in the rate of the pulse movement. In general, the report shows verification of the model for the particular options which were investigated. It should be noted that transport of solutes and movement of air have not been verified; however, the work was satisfactory as far as it went.

SIGNIFICANCE TO NRC WASTE MANAGEMENT PROGRAM:

The report has some importance to the NRC Waste Management Program because it is a start at verification of the TRACR3D code. However, it is unknown whether this code will be significant in the NTS program because it does not consider flow in fractured media. The authors state that perhaps its most useful aspect would be in simulating the movement of contaminants from landfills or similar disposal sites; they do not discuss use of the model in fractured media. They also do not state whether the model could be modified for use in fractured media.

PROBLEMS, DEFICIENCIES OR LIMITATIONS OF REPORT:

Verification of several options of the program such as transport of solutes and air movement was not investigated. It is unknown whether the code could be modified for use in fractured media.

WMGT DOCUMENT REVIEW SHEET

FILE #:

DOCUMENT #: LA-10415-MS

DOCUMENT: Carlos, B.A., 1985, Minerals in Fractures of the Unsaturated Zone from Drill Core USW G-4, Yucca Mountain, Nye County, Nevada. Los Alamos National Laboratory, Los Alamos, NM, 55 p.

REVIEWER: Williams & Associates, Inc.

DATE REVIEW COMPLETED: August 7, 1986

ABSTRACT OF REVIEW: APPROVED BY: Roy E Williams

The report under review describes the minerals present in fractures in drill core from test hole USW G-4, between the depths of 800 ft and 1,770 ft. The report describes the sequence of deposition and the identity of minerals that might be natural barriers to radionuclide migration through the unsaturated zone. The report does not describe the ion exchange capacity of individual minerals present within the fractures.

BRIEF SUMMARY OF DOCUMENT:

The purpose of the report under review is to describe the mineralogy of the fractures in drill core from test hole USW G-4. The mineralogy of fractures between the depths of 800 ft and the static water level at 1,770 ft was examined to identify the minerals within the fractures. The purpose of the investigation was to identify minerals that might be natural barriers to radionuclide migration from a nuclear waste repository at Yucca Mountain.

According to the report, test hole USW G-4 was selected for detailed study of fracture-filling materials because it is located closest to the proposed exploratory shaft in Yucca Mountain. The fracture materials within the core for test hole USW G-4 are believed to be representative of the minerals that can be expected to exist along flow paths within the northeastern part of the repository.

Test hole USW G-4 was drilled to a total depth of 3,001 ft in 1982. The hole was cored continuously from 22 ft to the total depth. According to the report, the drilling history, lithology of the core, and geophysical logs of the test hole are given in Spengler and others (1984).

The method of study used in the investigation consisted of selecting representative core samples for each interval and each fracture type within an interval. According to the report, samples with the most extensive coatings for each type of fracture were chosen to provide sufficient material for x-ray diffraction analysis. Representative samples also were chosen for scanning electron microscope analyses. According to the report, samples for x-ray diffraction analysis were scraped from fracture surfaces with a steel scraper; a binocular microscope was used to examine the scraped materials. Hand-picked samples from the scraped materials were crushed to a powder in a ceramic mortar and exposed to x-rays either as pressed powder or as smear samples.

According to the report, identifications of the minerals were made by comparing observed patterns with the standard patterns produced by the same x-ray diffraction analysis equipment and by comparing patterns with the standards from the Joint Committee on Powder Diffraction Standards. Thin sections of samples that had sealed fractures were made for microprobe analysis. Imaging and qualitative composition studies were made on a scanning electron microscope.

Pages 12 through 52 of the report present descriptions of the minerals which line the fractures in each stratigraphic unit. The report states that the fracture mineralogy varies greatly between the devitrified, glassy, or zeolitized zones within the host rock. Minerals that are present as fracture fillings include clinoptilolite, quartz, feldspar, mordenite, manganese oxides/hydroxides, heulandite, and calcite. Polymorphs of quartz are present also in some fractures.

SIGNIFICANCE TO NRC WASTE MANAGEMENT PROGRAM:

The report under review presents a description of the minerals present within fractures in core from test hole USW G-4. This document is significant with respect to evaluating the potential for retardation of radionuclide movement through the unsaturated zone beneath the proposed repository in Yucca Mountain. It should be of primary interest to geochemists involved in the evaluation of radionuclide migration through the unsaturated zone at Yucca Mountain.

PROBLEMS, DEFICIENCIES OR LIMITATIONS OF REPORT:

The report under review describes the minerals present in the unsaturated zone in fractures in drill core from test hole USW G-4. The primary emphasis of the report is to describe mineral coatings within the fractures; however, the current conceptual model for flow in the unsaturated zone proposed by USGS considers the movement of water through the unsaturated zone to occur solely through the matrix of the tuffs. An understanding of the mineralogy within fractures in the unsaturated zone is important to geochemists involved in evaluating the potential for retardation of radionuclide migration through fractures if the flux rate exceeds 0.5 mm/yr. The report presents descriptions of the minerals present in fractures only. The ion exchange capacity of individual minerals is not evaluated in the report.

SUGGESTED FOLLOW-UP ACTIVITIES

We suggest that the report under review be reviewed by a geochemist familiar with the ion exchange capacity of various zeolites. We suggest also that it would be advisable to request an explanation for studying the retardation characteristics of minerals in fractures when the prevalent USGS conceptual model envisions flow through the matrix of the tuffs.

REFERENCES CITED

Spengler, I.W., and others, 1984, Stratigraphic and Structural Characteristics of Volcanic Rocks in Core Hole USW G-4, Yucca Mountain, Nye County, Nevada. USGS Open-File Report 84-789.

WMGT DOCUMENT REVIEW SHEET

FILE #:

DOCUMENT #: LA-11070-MS

DOCUMENT: Campbell, Katherine, August 1987, Lateral Continuity of Sorptive Mineral Zones Underlying Yucca Mountain, Nevada. Los Alamos National Laboratory, Los Alamos, NM, LA-11070-MS, 44 p.

REVIEWER: Williams & Associates, Inc., James T. Osiensky

DATE REVIEW COMPLETED: November 19, 1987

ABSTRACT OF REVIEW: APPROVED BY: Roy E. Williams

The report under review describes the results of x-ray diffraction analyses of samples from 14 drill holes in the vicinity of Yucca Mountain. The report describes the compositional data in terms of the existence and location of zeolite minerals. The report concludes that no significant lateral trends in total zeolitization within the units tested are obvious in the vicinity of the exploratory block; however, trends in the abundances of individual zeolite minerals do exist. This report is written strictly from the mineralogist's point of view.

BRIEF SUMMARY OF DOCUMENT:

The report under review describes the mineral composition of samples collected from 14 drill holes in the vicinity of Yucca Mountain. The analyses of the mineral distributions were performed by x-ray diffraction. Figure 1 of the report shows the locations of the drill holes from which samples were collected for analysis.

Ortiz et al. (1985) compiled drilling data from Yucca Mountain and vicinity into a "functional stratigraphy." The report under review investigates the homogeneity of these functional units with respect to mineralogy. The major zeolitized intervals (nonwelded, partially welded, and bedded tuffs) below the Topopah Spring Member are considered in the report.

The tuffs below Yucca Mountain are classified as vitric, zeolitized, and devitrified (Ortiz et al., 1985). The report under review evaluates this classification with respect to the x-ray diffraction data. According to the report, samples from zeolitized units generally are distinguished by the presence of more than 15% zeolitites (clinoptilolite, mordenite, and/or analcine). Glass was found only in vitric units, except for two samples from test wells USW H-5 and USW H-6, and one sample from J-13. The report notes that about 35% of the nominally vitric samples contain no glass.

Figure 7 of the report shows a projection of x-ray diffraction data onto a plane. This figure shows that the major mineralization types are well separated. However, minor anomalies do occur. According to the report, if the data are reclassified the mineralizations can be divided more cleanly (fig. 8). Figure 9 of the report shows the distribution of total zeolitites in the x-ray diffraction samples from three units defined in the functional stratigraphy used by Ortiz et al. (1985). As suggested by the report, the mineralogy of the units shown on figure 10 may be correlated better with the formal geologic stratigraphy than with the referenced (functional) stratigraphy defined by Ortiz et al. (1985). The referenced stratigraphy defined by Ortiz et al. (1985) defines units with distinct thermal, physical, mechanical, and hydrological properties.

Figure 11 of the report suggests that a trend of decreasing mordenite and increasing clinoptilolite occurs from north to south in the vicinity of the exploratory block. According to the report, total zeolitization in drill hole G-2 is comparable to other drill holes. The report notes that contacts between the unit CHn (basically the tuffaceous beds of Calico Hills) and the overlying Topopah Spring Member and the underlying welded Prow Pass Member cannot be estimated accurately from the sparse and randomly selected x-ray diffraction data. This point is important because depth is a significant factor in accounting for total zeolitization and alkali-feldspar abundance in the x-ray diffraction samples (figs. 12 and 13 of the report).

Table 2 of the report lists models for the abundance of minerals in reference unit CHn. Appendix D of the report discusses the construction of the probabilistic models. The report notes that the models are preliminary, univariate models, the primary use of which is to indicate the extent that observed variability in the data is unaccounted for by detectable trends. Table 3 of the report presents models for the clinoptilolite/mordenite distribution in reference unit CHn at a relative depth of D=0.5.

Samples from reference unit CFUn (lower Prow Pass Member) have been collected from nine drill holes. According to the report, well J-13 stands out because the zeolitization in the three J-13 samples consists entirely of analcine; in addition, the J-13 samples contain higher than average concentrations of quartz. The zeolite composition ranges from 100% clinoptilolite in the vicinity of USW G-3 and H-3 to an average of 40% clinoptilolite in the vicinity of USW G-2. According to the report, depth is a factor that explains much of the variability in total zeolitization (fig. 18) and in alkali-feldspar abundance; however, no lateral trends have been observed. Table 4 of the report lists models for the abundance of minerals in reference unit CFUn.

Samples from reference unit CFMn in the middle of the Crater Flat tuff (lower Bullfrog Member and upper Tram Member) were collected from seven drill holes. According to the report, drill holes J-13, UE-25b#1H and USW G-2 located to the north and east of the exploratory block contain little clinoptilolite, display lower overall zeolitization, display the absence of cristobalite, and contain more quartz than drill holes USW G-1, GU-3, and H-3 that are located within the exploratory block. Samples from well USW G-4 exhibit higher overall zeolitization than samples from the north and east of the exploratory block. Table 6 of the report lists models for the abundance of minerals in reference unit CFMn.

In summary, the report suggests that the variability in mineral distribution among drill holes does not appear to be significantly greater than the variability within holes. Two exceptions to this statement are noted. These are:

1. Samples from holes in the lowest CFMn reference unit are split geographically by hole location with high clinoptilolite and low quartz to the southwest, and low clinoptilolite and high quartz to the northeast.

2. The mineralogy in wells J-12, J-13, and USW G-2 (well outside the exploratory block) appears to be different from the mineralogy in the remaining holes.

SIGNIFICANCE TO NRC WASTE MANAGEMENT PROGRAM:

The report under review presents a description of x-ray diffraction data from 14 drill holes in the vicinity of Yucca Mountain. This document is significant with respect to evaluating the potential for retardation of radionuclide movement beneath the proposed repository in Yucca Mountain. It should be of primary interest to mineralogists and geochemists involved in the evaluation of radionuclide migration from the proposed repository.

PROBLEMS, DEFICIENCIES OR LIMITATIONS OF REPORT:

The report under review describes the results of x-ray diffraction analyses of samples from 14 drill holes in the vicinity of Yucca Mountain. The primary emphasis of the report is to describe the continuity of zeolite minerals along potential pathways for radionuclide migration beneath the proposed repository location. An understanding of the mineralogy beneath the proposed repository is important to geochemists involved in evaluating the potential for retardation of radionuclide migration. The discussions presented in the report are limited strictly to the mineralogy of units of interest below the proposed repository. The geochemistry of the individual minerals (zeolites) is not evaluated in the report.

SUGGESTED FOLLOW-UP ACTIVITIES

We suggest that the report under review be reviewed by a geochemist and/or a mineralogist who is a recognized expert on the ion exchange capacity of the various zeolite minerals.

REFERENCES CITED:

Ortiz, T.F., Williams, R.L., Nimick, F.B., Whittet, B.C., and South, D.L., 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.

WMGT DOCUMENT REVIEW SHEET

FILE #:

DOCUMENT #: LA-UR-81-3141

DOCUMENT: Nuclide Migration Field Experiments in Tuff, G Tunnel, Nevada Test Site. B.R. Erdal, K. Wolfsberg, R.S. Rundberg, and W.R. Daniels (Los Alamos National Laboratory, Los Alamos, NM), D.L. Fortney and K.L. Erickson (Sandia National Laboratory, Albuquerque, NM) and A.M. Friedman, S. Fried, and J.J. Heinz (Argonne National Laboratory, Argonne, IL), submitted to International Symposium on the Scientific Basis for Nuclear Waste Management Materials Research Society, Boston, Mass., November 16, 1981.

REVIEWER: Williams & Associates, Inc.

DATE REVIEW COMPLETED: May 28, 1986

ABSTRACT OF REVIEW: APPROVED BY: Roy E Williams

This report considers a proposed insitu experiment in G tunnel on the Nevada Test Site. The purpose of the experiment is to develop techniques for defining radionuclide migration through fractured rock. Fractures in a horizontal plane will be saturated by injection of water. The movement of tracers then will be investigated. The flow of water will be essentially in a horizontal plane at saturated conditions rather than in a vertical plane at unsaturated conditions such as in Yucca Mountain.

BRIEF SUMMARY OF DOCUMENT:

The factors which will go into selecting a repository site are discussed in this report. The authors discuss the necessity for determining concentration and travel times for radionuclides that may leave a repository and the need for predictive models based on the understanding of the dynamic processes that occur at each location in the repository system. The analysis for the flow in the repository is being conducted by Los Alamos National

Laboratory, Sandia National Laboratory and Argonne National Laboratory. The three principal objectives of the work in the report under review are:

"1) to develop the experimental, instrumental and safety techniques necessary to conduct controlled small-scale radionuclide migration field experiments,

2) to use these techniques to define radionuclide migration through rock by performing generic, at depth experiments under closely controlled conditions in a single fracture in a porous rock, and

3) to determine whether available lithologic field, chemical and hydraulic properties together with existing or developed transport models are sufficient and appropriate to describe real field conditions."

The site for one field experiment is in tuff exposed in G Tunnel at the Nevada Test site. A single fracture will be used because the emphasis of the project is on flow and element migration. The authors state that "the bedding/parting plane was selected for use because a horizontal flow system was preferred for these initial experiments. It is felt that the system could be controlled better in a horizontal than in a vertical system." We suggest that it may be easier to control flow in the vertical direction than in horizontål direction if the region is unsaturated such as in Yucca Mountain. The reason is that steady state downward flow can be achieved in the vertical direction whereas it cannot be achieved easily in the horizontal plane. The authors state subsequently that "prior to injection of tracers groundwater will be injected for sometime to fully saturate the rock and establish steady state flow." Actually it is very difficult to saturate a rock completely or attain completely steady state flow. The authors also mention sheet flow but they do not define the meaning of such flow.

The remainder of the paper constitutes a detailed discussion of a particular experiment and the suitability of various tracers for use in a fractured porous medium. In addition various mathematical models which would be needed are considered. In summary, this paper is a review of the factors that enter into the characterization of the site.

SIGNIFICANCE TO NRC WASTE MANAGEMENT PROGRAM:

This paper has no apparent significance for the proposed repository in Yucca Mountain since it is not reporting on research that has been done, but rather it is proposing an insitu experiment.

PROBLEMS, DEFICIENCIES OR LIMITATIONS OF REPORT:

The work proposed herein would be conducted at saturated conditions (water is injected until rock is saturated) whereas Yucca Mountain is unsaturated.

SUGGESTED FOLLOW-UP ACTIVITIES

No follow-up activities are suggested.

WMGT DOCUMENT REVIEW SHEET

FILE #:

DOCUMENT #: LA-UR-81-3141

DOCUMENT: Nuclide Migration Field Experiments in Tuff, G Tunnel, Nevada Test Site. B.R. Erdal, K. Wolfsberg, R.S. Rundberg, and W.R. Daniels (Los Alamos National Laboratory, Los Alamos, NM), D.L. Fortney and K.L. Erickson (Sandia National Laboratory, Albuquerque, NM) and A.M. Friedman, S. Fried, and J.J. Heinz (Argonne National Laboratory, Argonne, IL), submitted to International Symposium on the Scientific Basis for Nuclear Waste Management Materials Research Society, Boston, Mass., November 16, 1981.

REVIEWER: Williams & Associates, Inc.

DATE REVIEW COMPLETED: May 28, 1986

ABSTRACT OF REVIEW: APPROVED BY: Roy E Williams

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Laboratory, Sandia National Laboratory and Argonne National Laboratory. The three principal objectives of the work in the report under review are:

"1) to develop the experimental, instrumental and safety techniques necessary to conduct controlled small-scale radionuclide migration field experiments,

2) to use these techniques to define radionuclide migration through rock by performing generic, at depth experiments under closely controlled conditions in a single fracture in a porous rock, and

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The remainder of the paper constitutes a detailed discussion of a particular experiment and the suitability of various tracers for use in a fractured porous medium. In addition various mathematical models which would be needed are considered. In summary, this paper is a review of the factors that enter into the characterization of the site.

SIGNIFICANCE TO NRC WASTE MANAGEMENT PROGRAM:

This paper has no apparent significance for the proposed repository in Yucca Mountain since it is not reporting on research that has been done, but rather it is proposing an insitu experiment.

PROBLEMS, DEFICIENCIES OR LIMITATIONS OF REPORT:

The work proposed herein would be conducted at saturated conditions (water is injected until rock is saturated) whereas Yucca Mountain is unsaturated.

SUGGESTED FOLLOW-UP ACTIVITIES

No follow-up activities are suggested.

~~LA~~ MS
LA-UR-84-40

WMGT DOCUMENT REVIEW SHEET

FILE #:

DOCUMENT: Travis, B.J., Hodson, S.W., Nuttall, H.E., Cook, T.L., Runberg, R.S., 1984, Preliminary Estimates of Water Flow and Radionuclide Transport in Yucca Mountain: NNWSI Milestone Report, Department of Energy, Nevada Operations Office

REVIEWER: Williams and Associates, Inc.

DATE REVIEW COMPLETED: November 1985

BRIEF SUMMARY OF DOCUMENT: DATE APPROVED:

This report examines the effect of lithology and presence of fractures on water flow and radionuclide transport in Yucca Mountain, Nevada. Both analytical and numerical procedures are used to analyze flow and transport in fractured tuff. The numerical programs used include the TRACR3-D code which computes saturated and unsaturated two-phase flow in fractured porous media with transport of radionuclides. The WAFE code which computes water, air, vapor and energy movement in porous media also was used as were analytical solutions for transport of sorptive species down single fractures with matrix diffusion for steady water flow. A sensitivity analysis is used to analyze the sensitivity of water flow and species transport to several physical processes such as fracture flow, matrix potential, diffusion and chemical adsorption. Three questions are considered in the report.

1) How far down can water flow through fractures in unsaturated tuff?

2) How well can the fractured and nonfractured tuff layers retard radionuclide transport?

3) What is the effect of repository heat load on hydrology?

The sensitivity analysis is used for transport along a one-dimensional pathway that passes vertically downward through the densely welded unit (Topopah Spring Member and the bedded tuff) and the lower clastic unit (Calico Hills) and then horizontally in the saturated region through the Prow Pass Member, Bullfrog Member, or Tram Unit.

GENERAL TECHNICAL DISCUSSION:

Fracture Flow:

The authors initially discuss the ten to twenty thousand years travel time through the volcanic tuffs if the flow consists of matrix flow only. However, if there is a possibility of fracture flow, that time must be reduced considerably. The authors develop a conceptual model for flow in the fractures designed to answer the question: Will the recharge water move vertically through unfractured layers and then enter fractures? They note correctly that to enter a fracture from the porous rock, water would have to overcome capillary tension which would require saturations close to one. Their model is designed to determine how far a finite water slug would move down through a fracture before it would move into the porous material. There is a mistake in their initial analysis in that they assume that the capillary pressure in a fracture is equal to twice the surface tension divided by half the fracture width. They mention that this is for a capillary tube; however, the fracture is a two-dimensional problem and the equation should simply be surface tension divided by half the fracture width. In equation 2 on page 7, they do not define which is in the equation. The first solution for this analysis determines that in order for a water slug from the repository to reach the water table through a fracture, the fracture width would have to be much larger than 200 microns or the matrix would have to be almost saturated. Some formations in the matrix are up to 80 to 90 percent of saturation; however, a numerical solution of the equation shows that penetration to hundreds of meters requires either very wide cracks and/or high matrix saturation and/or small values for flow into the matrix. The numerical solution also shows that the analytical solution underestimates the depth reached. Their model does consider a finite length of slug initially. However, this may not be a valid assumption. It may be possible for water to flow continuously into the fracture during a a long duration rainfall event and the model does not appear to cover this possibility. There is discussion of the fact that there are two relatively unfractured layers, the upper clastic and the lower clastic, which lie below the fractured Tiva and fractured Topopah Spring layers, respectively. Water moving down the fractures will encounter these porous layers which will act a buffers controlling the rate at which water flows into the fractures below. For example, water cannot flow into fractures in the Topopah Spring below the Pah Canyon Member any faster than the hydraulic conductivity of the Pah Canyon Member permits.

The authors use a recharge of 8 mm/year, but do not reference the source. They then note that if there is 8 mm of recharge per year there would necessarily be fracture flow through the low permeability fractured regions and there would be alternating layers of porous flow and fracture flow from the surface down to the water table. They state that their interpretation implies that water in the high saturation region should be older than that in the low saturation regions unless the 8 mm recharge rate is high and the true recharge is almost zero. The logic of their reasoning is not obvious. It appears that water toward the bottom of Yucca Mountain would perhaps be older than water at the top, but there does not appear to be a reason why various layers would have different ages of water if the water is moving steadily downward. Using the assumption that most of the conductivity in the fractured layers is due to the fractures, an estimate of about 80 microns is made for the fracture aperture.

The authors next discuss the radionuclide transport based on their previously obtained water flow equations. Several curves are presented of sorption ratio variation for the various radionuclides and retardation factors are given in tabular form. When they actually determine the radionuclide transport they do not assume any water flow into the matrix. In other words, they are ignoring what they previously determined to be conservative. Concentration break through curves are also presented for all radionuclides. Of the ten nuclides considered, the only one that can reach the water table in less than 10,000 years is Technetium-99. The diffusion end of the matrix chemical sorption, and radioactive decay are concluded to prevent any of the other radionuclides from reaching the accessible environment in less than 10,000 years.

The next topic the authors consider is the effect of the heat formation in the repository which is expected to last for perhaps a few hundred years. This heat source will have a profound effect on the local and saturated hydrology. Near the repository, water will evaporate and move outward due to a concentration gradient. It will condense in colder regions and then tend to move towards the repository in liquid phase due to a saturation gradient. This phenomenon may bring about the possibility of a nearly saturated region above the repository in which case the water could flow down through the repository after cooling begins. The heat source may also thermally alter the porous material. The WAFE computer code was used to compute one- and two-dimensional transient two-phase air, vapor, and water flow with heat transport. Water saturation contours, velocity vectors, vapor and air velocities, and temperature contours are presented for 50 and 100 years after closing the repository. The authors conclusions are as follows:

"1) Significant fracture flow can occur in both water tables but only through high saturation, low permeability tuff.

2) Diffusion into the matrix and adsorption have a profound effect on transport. Migration times to the water table for all but one of the important radionuclides are considerably longer than 10,000 years and none of the radionuclides considered reaches the accessible environment in less than 10,000 years.

3) Heat load in partially saturated tuff can result in a dry, steam filled region extending several meters above and below a repository with recharge during cool down phase.

It is very important that the reader bear in mind the various assumptions and simplifications made in this preliminary analysis. Future analyses which include more detail may indicate considerably longer migration times and considerably different heat affects."

SIGNIFICANCE TO THE NRC WASTE MANAGEMENT PROGRAM:

The report under review presents a preliminary conceptual model of experted conditions in the vicinity of the repository. This report may become significant to the NRC Waste Management Program during further analysis of the conditions that can be expected to occur in the vicinity of a repository.

PROBLEMS, DEFICIENCIES OR LIMITATIONS OF REPORT:

The report under review presents a preliminary analysis of water flow and radionuclide transport in Yucca Mountain. Problems with the report are noted in the summary.

SUGGESTED FOLLOW-UP ACTIVITY:

The report under review is preliminary in nature. Conceptual models of the conditions that will exist in the immediate vicinity of a repository also are preliminary and should be evaluated as they are developed.

GEOTRANS COVER LETTER OF 84/09/05

ATTACHMENT D: PRELIMINARY TRANSPORT CALCULATION STUDY FROM LOS ALAMOS NATIONAL LABORATORY

Travis, B.J., S.W. Hodson, H.E. Nuttall, T.L. Cook, and R.S. Rundberg, 1984, "Preliminary estimates of water flow and radionuclide transport in Yucca Mountain," Los Alamos National Laboratory Report LA-UR-84-40, 75 pp.

Presented in this report are results from analytical models and two numerical models, TRACR3D and WAFE. The documentation for WAFE is in preparation; documentation for TRACR3D has been released, but we have been unable, as yet, to obtain it. This, coupled with the fact that much other supporting material is either in preparation or "written communication" makes it difficult to critically review this report.

The analytical solutions are used to (1) evaluate the rate of flow of a water slug down a vertical fracture and the change in matrix saturation, and (2) calculate transport of radionuclides in a porous medium with steady flow and constant sources as well as transport in a porous medium containing a set of parallel equidistant fractures.

For the first case, ranges of unsupported data are used for a highly idealized flow system. The primary conclusion is that "... for a water slug to reach from the repository to the water table through a fracture, the fracture width would have to be much larger than 200 microns or the matrix would have to be almost saturated."

For the second case, transport was simulated using, in large part, unsupported data. For certain data, the values selected cast considerable doubt on the results and conclusions. For example, porosities of 10%, 8%, 30%, and 30% are used for the densely-welded Topopah Spring, the densely-welded bedded tuff, the Calico Hills (lower clastic unit), and Prow Pass, respectively. These values are too high to be representative of effective porosities in a fractured media, causing travel times to be overestimated. Keeping this in mind, the conclusion was "Diffusion into the matrix, chemical sorption, and radioactive decay prevent any of the radionuclides from reaching the accessible environment in less than 10,000 years, given the assumptions made in this study." Given the results from Moench (1984) on fracture skin, diffusion into the matrix may not be as important a mechanism as this article indicates.

TRACR3D was used to simulate the same one-dimensional, vertical flow problem as the first analytical solution, only with a variable horizontal water velocity at the edge of the crack. Similar conclusions are reached. Surprisingly, this was the only use of this code.

The WAFE code was used to evaluate heat loading. Four cases were considered: (1) the tuff is uniform and heat is loaded into a volume 2 m by 6 m, (2) heat is spread uniformly across a cylinder that is 2 m high and has a radius of 35 m, (3) one-dimensional flow perpendicular to the canister axis and a heat load history provided by M. Revelli (with venting) and, (4) same as (3) but without venting. The primary conclusion is "Heat load in partially saturated tuff can result in a dry, steam-filled region extending several meters above and below a repository with recharge during cool down phase."

None of the results are surprising, especially given the assumptions and data used. As the authors point out, there is a need for substantial, reliable data. In view of the lack of this data, scoping calculations such as those provided are reasonable. Because of the lack of data, however, (1) these scoping calculations should not be taken as fact, and (2) more sensitivity analysis should be performed, especially on critical parameters such as porosity and matrix diffusion.

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December 31, 1987

009/1.3/WWL.011
RS-NMS-85-009
Communication No. 233

U.S. Nuclear Regulatory Commission
Division of Waste Management
Geotechnical Branch
MS 623-SS
Washington, DC 20555

Attention: Mr. Jeff Pohle, Project Officer
Technical Assistance in Hydrogeology - Project B (RS-NMS-85-009)

Re: Subtask 1.3 - Document Review of "Atmospheric Overview of the Nevada Nuclear Waste Storage Investigations, Nevada Test Site, Nye County, Nevada", by Bowen, J.L. and Egami, R.T. (NVO-269 / DE84002818)

Dear Mr. Pohle:

Attached please find the document review of the NNWSI report "Atmospheric Overview of the Nevada Nuclear Waste Storage Investigations, Nevada Test Site, Nye County, Nevada", by Bowen, J.L. and Egami, R.T. (NVO-269 / DE84002818). The document review was prepared by Water, Waste and Land (WWL) under Subtask 1.3 of the current contract, as directed by the Project Officer's letter of September 25, 1987. The review was prepared under WWL's standard quality assurance procedures as controlled by NWC's Quality Assurance Manual. The document review has been reviewed for technical and managerial content and approach by Mark Logsdon of NWC.

The WWL reviewers conclude that the document is of limited use to the NRC's hydrogeologic site reviews because the information is of a general, essentially regional nature. The general data presented are not for points sufficiently close to the Yucca Mountain site to allow quantitative calculations (such as precipitation or recharge trends) of importance to evaluating the long-term performance of a HLW repository.

NWC considers that the focus of the report appears to have been on meteorological impacts on construction and operational phases (see WWL review p. 5). Since such matters as atmospheric dispersion may be of importance to evaluating the likely performance of the repository against the requirements of 10 CFR 60.111(a) and the referenced requierements therein of 10 CFR Part 20, NWC recommends that the report be reviewed by the NRC Staff's design engineers who are responsible for these portions of the NNWSI evaluations.

In addition, NWC concurs with the WWL conclusion that the evaluation of recharge/vertical flux may require substantial information on site-specific weather data; thus, we support the WWL recommendation that the Staff review in some detail the NNWSI SCP plans for obtaining weather information.

If you have any questions about this document review, please contact me or Mr. Davis immediately.

Respectfully submitted,
NUCLEAR WASTE CONSULTANTS, INC.

Mark J. Logsdon

Mark J. Logsdon, Project Manager

Att: Document Review of "Atmospheric Overview of the Nevada Nuclear Waste Storage Investigations, Nevada Test Site, Nye County, Nevada", by Bowen, J.L. and Egami, R.T. (NVO-269 / DE84002818)

cc: US NRC - Director, NMSS (ATTN PSB)
HLWM(ATTN Division Director)
Mary Little, Contract Administrator
HLTR (ATTN Branch Chief)
D. Chery, HLTR

bc: M. Galloway, TTI
L. Davis, WWL
J. Minier, DBS

1.0 INTRODUCTION

WWLNUM:	80
Document No.:	NVO-269 (DE84002818)
Title:	"Atmospheric Overview for the Nevada Nuclear Waste Storage Investigations, Nevada Test Site, Nye County, Nevada"
Authors:	Bowen, J. L. and Egami, R. T.
Publication Date:	November, 1983
Reviewer:	Water, Waste & Land, Inc.
Date Review Completed:	December 23, 1986
Scope:	General overview of climate and weather in southern Nevada and the Nevada Test Site. Reviewed in the context of reports usefulness to the hydrogeologic studies at Yucca Mountain.
Key Words:	Climatology and Meteorology
Date Approved:	

2.0 SUMMARY OF DOCUMENT AND REVIEW CONCLUSIONS

2.1 Summary of Document

The stated task of the report was to summarize available and needed information requirements concerning atmospheric phenomena in conjunction with the construction of a repository for high level nuclear wastes at the Nevada Test Site (NTS). Two aspects of atmospheric phenomena were considered:

1. Effects on the repository, due to weather, during both construction and operation phases.
2. Effects on the air of the surrounding area due to the repository.

A brief description of the topography at NTS was given, along with the air shed boundaries designated by the State of Nevada Division of Environmental Protection. The air sheds correspond to the hydrologic basins of Nevada as determined by the Nevada Division of Water Resources in 1971. A brief description of the paleoclimatology at the NTS was also given. The important information presented was that the Great Basin contained a number of lakes which are not present today. The authors concluded that the climate of southern Nevada was less dry than at present.

The report states that the southwestern part of the NTS is within the extreme southern climatological zone of the State of Nevada, with the mountainous areas tending to modify the local climate. A Class 1 weather station, initially at Yucca Flat and subsequently moved to the Desert Rock Airport, was available for data analysis. The data from this station was compared to five other Class 1 stations from around Nevada to determine where the Yucca Flat data fit in Nevada climatology. The Yucca Flat data was found to lie between Las Vegas and Reno in terms of temperatures and precipitation, with more similarity to Reno in many cases.

Other meterological stations (besides Class 1) were available for analysis at the NTS. However, the lengths of records were not as long and, as concluded by the authors, not as desirable for a good climatological data base. Wind and temperature data were available for about 10 years and precipitation data was available for about 20 years. A previous study by Quiring (1968) was presented. In that study, four NTS stations had been analyzed for wind and temperature data while data from 24 stations were analyzed with regard to precipitation. The authors concluded that Quiring's study was useful for making qualitative conclusions about the climatology. Some of these qualitative conclusions were:

1. All stations showed a tendency for the wind to be either northerly or southerly.
2. Averaged speeds from the four sites show daily maxima in mid-afternoon and annual maxima in the months of April and May.
3. Winter precipitation in southern Nevada was dependent on the location of the storm tracks.
4. Summer precipitation in the form of thunderstorms can vary greatly.
5. Higher terrain will have more precipitation, with elevation accounting for 95 percent of the variance in precipitation probability.

Future climatological expectations are also addressed by the authors on a qualitative basis. Two general factors were considered as having the potential to change the climate of the NTS. The first considered the natural fluctuations in the earth's climate. Considering only this factor, the future changes in the climate for NTS would mean a sequence of wet, possibly cooler years followed by dry, warm years with periods on the order of 25,000 years. The second factor for future climatic changes was the contribution of human activity to the changes. The authors concluded that such long-term climatic effects would be difficult to predict because of the lack of understanding of the interactions between the natural climatic variations and the effects of future human development.

Severe weather was considered because of the hazards presented during construction and operational phases of the repository. The primary cause of severe weather considered was due to thunderstorms and included high winds, heavy precipitation, and lightning. The probability of straight winds and tornado winds at the site are listed. Precipitation extremes for a number of stations around Nevada are listed.

Air quality was discussed from an overview standpoint. The authors state that the air quality in southwest NTS is mostly an unknown quantity. The criteria pollutants were defined as sulfur dioxide, nitrogen dioxide, carbon monoxide, ozone, total suspended particulate matter, and lead. The authors did not consider radioactive species. However, they concluded that the present air quality is probably good in most instances.

Dispersion of any air pollutants was considered to be a function of wind speed, stability, mixing height and terrain. A general discussion on the stability of an air mass and how it relates to mixing characteristics was given. Terrain influences on the dispersion of pollutants was considered. The remainder of the document contained information on noise, general requirements for an environmental statement, and air quality regulatory requirements. These topics are of little or no concern for the hydrogeologic evaluation of the repository.

2.2 SUMMARY OF REVIEW CONCLUSIONS

The report under review was prepared to provide an overview of the atmospheric phenomena associated with the construction and operation of a high level nuclear waste repository. The report provides a qualitative overview of the climate at the NTS. The climate overview considered past changes and current conditions concluded that future climate changes will probably be similar to those of the past. The anthropogenic effects on future climate were not determined.

Severe weather was considered more for the construction and operational phases of the repository, and not for the long-term performance aspects. Likewise, air quality and noise were considered more from the impacts due to construction and operation phases. Long-term performance for air quality was not addressed.

3.0 SIGNIFICANCE TO NRC WASTE MANAGEMENT

The report provides a general overview of the climate at the NTS. However, a significant amount of meteorological information which was collected at the NTS for over 20 years was not analyzed nor presented. The general data that was presented is not sufficiently close to Yucca Mountain to allow any quantitative calculations, such as precipitation or recharge trends, to be performed.

The significance of the report to the hydrogeology of the Yucca Mountain site is minimal. Information contained in the report is only of a general nature. The report does point out the general effects which elevation has on wind, temperature, and precipitation. Dispersion effects are discussed and a recommendation was given that site-specific meteorological data be collected at the proposed repository site.

4.0 DETAILED REVIEW

The report discussed from a qualitative viewpoint, the general trends in precipitation at NTS and southern Nevada. Generally, the report briefly summarized the date and conclusions from other investigators. The report did emphasize the direct relationship between increasing elevation at NTS and increasing precipitation. An example of the large differences between sites at NTS having different elevations was given. A meterological station at 1,055 m MSL had an average yearly rainfall of 4.5 inches while a station at 2,280 MSL averaged 12.2 inches over the same period of time.

The anthropogenic effect on future climatic changes was discussed. The conclusion reached was that it would be difficult to predict the ultimate effect. One likely factor presented was the increase in the earth's temperature in the next 100 years. However, the subsequent climatic changes would be complicated, with some areas becoming wetter and other areas drier because of shifts of temperate zones toward the poles. Specific information for the NTS was not given, therefore, the report provides no data of use for future precipitation trends for use in the hydrogeologic studies.

The information presented in the reviewed report is of a qualitative nature and provides no data specifically for Yucca Mountain. Therefore, the report is of little use in the evaluation of the Yucca Mountain site from the hydrologic perspective.

5.0 RECOMMENDATIONS

As described in the previous section, the report does demonstrate the potential variability in weather conditions in the vicinity of Yucca Mountain. These variations may have an effect on the amount of infiltration which ultimately becomes recharge beneath Yucca Mountain. Since this vertical flux is a very important parameter with respect to both groundwater travel time and compliance with EPA release standards, accurate measurements of weather conditions at the site will be required. It is recommended, therefore, that plans for obtaining weather information be carefully evaluated during review of the Site Characterization Plan.

6.0 REFERENCES

Quiring, R. F., 1968. Climatological Data - Nevada Test Site and Nuclear Rocket Development Station. ESSA Research Laboratories Technical Memorandum - ARL 7, Las Vegas, NV, 171 pp.

WMGT DOCUMENT REVIEW SHEET

FILE #:

DOCUMENT #: SAND80-1464

DOCUMENT: Johnstone, J.K., and Wolfsberg, K., Editors, 1980, Evaluation of Tuff as a Medium for a Nuclear Waste Repository: Interim Status Report on the Properties of Tuff. 134 p.

REVIEWER: Williams & Associates, Inc.

DATE REVIEW COMPLETED: August 26, 1986

ABSTRACT OF REVIEW: APPROVED BY: Roy E. Williams

The report under review presents the interim status of studies of the properties of tuff evaluated from samples obtained from Yucca Mountain and Rainer Mesa (G-Tunnel). The report describes experiments performed as of 1980 on samples of tuff. The report describes also studies proposed at the time this report was written (1980). The report is relatively old and out-dated. Much of the data presented in the report has been up-dated by subsequent reports.

BRIEF SUMMARY OF DOCUMENT:

The report under review is the second in a series of summary briefings to the National Academy of Science Committee on Radioactive Waste Management. The report discusses a series of experiments performed on samples from drill hole UE25a-1 (Yucca Mountain) and test well J-13 (Jackass Flats). Where tuffs have undergone the process of devitrification, the original glass particles have been recrystallized to feldspar plus cristobalite or quartz. The report notes that this alteration process is dominate in densely welded horizons throughout the section. Zeolitization which results from the interaction of glass with groundwater, occurs at the non welded base of the Topopah Spring Member through the non welded bedded tuffs of Calico Hills, and in the non welded portion of the Prow Pass Member. Zeolitization occurs in stratigraphically equivalent horizons in test hole

UE25a-1 and test well J-13. According to the report, stratigraphic units are thinner at test well J-13 than at test hole UE25a-1. The report suggests that the most likely cause of the thinner units is due to greater distance of test well J-13 from source areas rather than paleotopography.

Tuff samples ranging from those containing a significant percentage of zeolites to devitrified tuff containing mainly feldspars and silica minerals were studied to determine the sorptive properties. The results of the study as of 1980 indicate the following:

1) Cesium, strontium and barium sorb better on zeolitized tuff than on devitrified tuff.

2) Plutonium sorbs on both zeolitized and devitrified tuffs.

3) A large range of sorption ratios was noted for americium and lanthanides. The report notes that the sorption ratios do not correlate with mineralogy except that sorption appears highest for tuff containing clay.

4) Sorption of anionic species--iodine, technetium, and uranium was low for all tuffs studied.

5) Sorption ratios generally are lower than desorption ratios for batch determinations. According to the report, strontium, cesium, and barium are thought to sorb and desorb predominantly by an ion exchange mechanism. Lanthanides, actinides, technetium, and uranium show values that differ by more than an order of magnitude.

6) Migration rates evaluated from flow experiments in crushed tuff sometimes are faster than values predicted from batch experiments with the same material.

Experiments were underway (1980) using rock columns containing a single, artificial (saw cut) fracture. Preliminary modeling of nuclide transport through jointed media suggests that intergranular porosity and penetration depth, fracture aperture, fracture length, fluid velocity and sorption distribution coefficient are the primary factors controlling radionuclide transport along fractures.

According to the report, the authors have developed a method for predicting the minimum theoretical matrix thermal conductivity of tuff based on grain density. The authors of the report suggest that by including the porosity, the conductivity of a broad range of tuffs can be predicted routinely to an accuracy of 15% or better. According to the report, thermal expansion measurements based on ambient pressure studies indicate the following:

1) Thermal expansion of devitrified welded tuffs generally is linear with temperature and is independent of both porosity and heating rate. The report notes that the only mineralogic factors that affected expansion behavior were the presence or absence of cristobolite and altered biotite.

2) Non welded tuff generally is characterized by thermal contraction. The report suggests that the contraction appears to be a function of complex dehydration reactions, probably of zeolite, hydrated glass, and/or clay.

Mechanical property studies have been conducted at ambient temperatures. According to the report, emphasis has been placed on the effects of confining pressure, water content, joints, and strain rate. The results of these studies indicate the following:

1) There is a relationship between strain (compressive and tensile) and porosity (degree of welding). The report notes that welded tuff is as much as three times stronger than non welded tuff.

2) The compressive strength of dry welded tuff is about 25% greater than for saturated samples tested under the same conditions.

3) The elastic moduli of tuffs is anisotropic.

4) Preliminary compression tests at 200°C on welded and partially welded tuff show a 30% decrease in strength compared to room temperature data.

5) Both saturated and dry samples of welded tuff show an approximate 6% decrease in compressive strength per decade of decrease in strain rate.

6) The coefficient of friction in artificial fractures is about 9% higher for saturated samples than for dry samples.

According to the report, initial studies of water loss from welded tuff have been performed in order to understand the effect of water loss in canister holes, mine shafts, and pillars when exposed to a drying atmosphere. The model developed for these experiments considers water lost via vapor diffusion through the pores of the rock.

The report describes the in-situ tuff water-migration/heater experiment. According to the report, water was collected continuously during the heating phase (63 days) of the experiment in the heater hole (approximately 60 L) and in two of the three satellite water collection holes (1.5 and 3.6 L). The report suggests that in the immediate vicinity of the heater hole, water movement occurred by vapor diffusion into the hole; water migration into the satellite holes was believed to be by Darcy flow driven by the high partial pressure of water at the vaporization front. Final results of the in-situ tuff water-migration/heater experiment is presented in Johnstone and others (1985).

According to the report, the nuclide-migration experiment in G Tunnel was initiated at the time this report was being written (1980). The later report by Norris and others (1982) describes the geochemistry studies pertaining to the G Tunnel radionuclide migration experiment.

SIGNIFICANCE TO NRC WASTE MANAGEMENT PROGRAM:

The report under review describes the status of studies conducted. up to 1980 pertaining to the evaluation of tuff as a medium for a nuclear waste repository. Some of the basic information presented in the report may be of value to the NRC Waste Management Program. However, because of the old age of the report with respect to studies being conducted at the Yucca Mountain site, much of the material presented in the report is out-dated and has been superseded by other reports. The report is an interim status report on the properties of tuff; the DOE's knowledge of the properties has increased significantly since this report was published.

PROBLEMS, DEFICIENCIES OR LIMITATIONS OF REPORT:

The report under review is an interim status report on the properties of tuff. The report presents the results of experiments conducted up to 1980. Besides the fact that the report is of limited value because of its relative old age, there are no specific problems, deficiencies or limitation of the report.

SUGGESTED FOLLOW-UP ACTIVITIES

No follow-up activities are recommended.

REFERENCES CITED:

Johnstone, J.K., Hadley, G.R., and Waymire, D.R., 1985, In-Situ Tuff Water Migration/Heater Experiment: Final Report, Sandia National Laboratories, Albuquerque, NM, and Livermore, CA, SAND81-1918, 106 p.

Norris, A.E., and others, 1982, Geochemistry Studies Pertaining to the G-Tunnel Radionuclide Migration Field Experiment. Los Alamos National Laboratory, Los Alamos, NM, LA-9332-MS, 42 p.

WMGT DOCUMENT REVIEW SHEET

FILE #:

DOCUMENT #: SAND80-2639

DOCUMENT: Thermal Analysis of Nuclear Waste Emplacement in Welded Tuff. B.S. Langkopf, prepared by Sandia National Laboratories, Albuquerque, NM, for the U.S. Dept. of Energy, August 1982.

REVIEWER: Williams & Associates, Inc.

DATE REVIEW COMPLETED: May 28, 1986

ABSTRACT OF REVIEW: APPROVED BY: Roy E. Williams

Thermal analysis for a repository 300 m below the water table is considered theoretically in this report. Results are presented as graphs of temperature rise vs. distance above and below the repository. Since the present proposed repository is over 300 m above the water table, the information presented in the report is not relevant.

BRIEF SUMMARY OF DOCUMENT:

The objectives of this work are:

"1) to define the anticipated environment for a repository in welded tuff either above or below the water table.

2) to identify both model and data needs for confident design of repository in welded tuff.

3) to develop conceptual test plans for insitu tests to resolve the issues identified above.

4) to integrate results of insitu tests and laboratory modeling studies into an engineering design data package for use in the conceptual design of repository."

This paper examines the thermal analysis of a repository located below the water table. Calculations are carried out for various repository geometries for the very near field. Various waste forms are considered also. The repository was assumed to be 330 m below the water table, and 50 m below the contact between the Bullfrog and Prow Pass Members of the Crater Flat tuff.

Thermal convection was not modeled. Thermal radiation was modeled in the air gap between the canister and the borehole wall by using an "effective" thermal conductivity. Two dimensional models were used for the far field calculations and two and three dimensional models were used for near field and very near field calculations. Results are presented in the form of graphs of temperature rise vs. depth above and below the repository. Isotherms of the temperature distribution and the various configurations are presented also. The highest temperature to be expected at the canister is determined to be 295°C. Room and pillar three-dimensional calculations show that temperatures in the room and pillar configuration should remain below 120°C.

SIGNIFICANCE TO NRC WASTE MANAGEMENT PROGRAM:

The calculations in this report are for a repository below the water table. The value of this information in the present repository is limited.

PROBLEMS, DEFICIENCIES OR LIMITATIONS OF REPORT:

The report has severe limitations with respect to application to Yucca Mountain because the proposed repository is in the unsaturated flow zone and the present report contains calculations for 300 m below the water table.

SUGGESTED FOLLOW-UP ACTIVITIES

We suggest no follow-up activities.

WMGT DOCUMENT REVIEW SHEET

FILE #:

DOCUMENT #: SAND80-2639

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Thermal convection was not modeled. Thermal radiation was modeled in the air gap between the canister and the borehole wall by using an "effective" thermal conductivity. Two dimensional models were used for the far field calculations and two and three dimensional models were used for near field and very near field calculations. Results are presented in the form of graphs of temperature rise vs. depth above and below the repository. Isotherms of the temperature distribution and the various configurations are presented also. The highest temperature to be expected at the canister is determined to be 295°C. Room and pillar three-dimensional calculations show that temperatures in the room and pillar configuration should remain below 120°C.

SIGNIFICANCE TO NRC WASTE MANAGEMENT PROGRAM:

The calculations in this report are for a repository below the water table. The value of this information in the present repository is limited.

PROBLEMS, DEFICIENCIES OR LIMITATIONS OF REPORT:

The report has severe limitations with respect to application to Yucca Mountain because the proposed repository is in the unsaturated flow zone and the present report contains calculations for 300 m below the water table.

SUGGESTED FOLLOW-UP ACTIVITIES

We suggest no follow-up activities.

WMGT DOCUMENT REVIEW SHEET

FILE #:

DOCUMENT #: SAND-81-2584

DOCUMENT: Rechard, R.P., and Schuler, K.W., 1982, Permeability Change Near Instrumentation Holes in Jointed Rock. Sandia National Laboratory, Albuquerque, NM, 19 p.

REVIEWER: Williams & Associates, Inc.

DATE REVIEW COMPLETED: May 17, 1986

ABSTRACT OF REVIEW: APPROVED BY: Roy E. Williams

The report under review presents a simplified analysis of the potential effects of a tangential intersection of a joint by a drill hole on the joint permeability in a nuclide migration experiment conducted in the field. The analysis presented in the report suggests that drill holes which intersect joints tangentially minimize changes in the stress normal to the joint which in turn minimizes changes in the joint aperture and joint permeability. The report is of primary interest to the DOE in the design and interpretation of field nuclide migration experiments.

BRIEF SUMMARY OF DOCUMENT:

The purpose of the report under review is to evaluate the effects of various experiment configurations on fracture permeability. The experiments were performed to evaluate the degree to which drill holes alter the normal stress around joints in rock at the point of intersection of the drill hole and a joint. Changes in the normal stress in the vicinity of a joint changes the joint aperture and affects the joint permeability.

According to Kranz and others (1979), fracture permeability (k) is a function of confining pressure (P_c), internal fluid pressure (P_i), temperature, aperture (e) and surface roughness. The report under review suggests that the aperture is dependent upon the loading due to present and past mechanical, thermal, and fluid stresses.

The report notes that the permeability of a fracture is controlled by the aperture; however, the dimensions of individual fractures cannot be determined in the field. Because of this fact, the authors of the report suggest that the relationship of aperture or permeability vs. applied stress must be known. The authors note, however, that permeability and aperture do not appear to be unique functions of stress.

The authors of the report evaluated the effects of stress on joint aperture by using the relationship obtained by Walsh (1981):

$$\left(\frac{Ke}{K_o e_o}\right)^{1/3} = \left(1 - \frac{\sqrt{2}\, b}{e_o}\right) \ln\left(\frac{P}{P_o}\right)_e$$

where k is the fracture intrinsic permeability, e is the crack aperture, $k_o e_o$ is permeability-aperture product at reference state, $(P/P_o)_e$ is ratio between unknown and reference effective pressures, b is the r.m.s. of fracture surface protuberances.

This equation has been modified into an expression for the aperture (e) as follows:

$$e = e_o \left[1 - \frac{\sqrt{2}\, b}{e_o} \ln\left(\frac{P}{P_o}\right)_e\right]$$

According to the report, the parameter (b) presumably would account for hysteresis effects as stress was applied and taller asperites crushed. The report notes that permeability vs. stress relationships are not available for tuff from the Nevada Test Site.

According to the report, the effects of changes in both confining pressure (P_c) and the fluid pressure in the fracture (P_f) usually are combined to give an effective pressure (P_e). The authors of the report note that it was not possible to derive an effective pressure in the analysis. Therefore, the authors assumed that P_c could be used in place of P_e as a rough approximation. This substitution implies the fluid pore pressure is atmospheric. The authors of the report suggest that the fact that Jones (1975) was successful in using confining pressure (P_c) in fitting data suggests that the substitution is acceptable.

Figure 4 of the report presents postulated changes in the permeability-aperture product (ke) from the drill hole stress perturbance for vertical-horizontal stress ratios (n) of 0.5, 1.0, and 2.0. The authors of the report conclude that a tangential joint intersection minimizes the permeability changes for $n \leq 1$. They conclude also that a tangential intersection increases permeability slightly for $n > 1$.

The authors of the report present the following conclusions and recommendations:

1. Based on the simplified analysis presented in the report, a tangential intersection of the joint by the drill hole should be used to minimize disturbances of joint permeability in the field nuclide migration experiment. This reasoning assumes that the instrumentation hole can be placed accurately along the joint.

2. The nuclide experiment might benefit from a redesign to a perpendicular intersection of the joint by both the injection and collection holes.

3. As a drill hole approaches a joint, the rock mass above the joint would be expected to be free to relax while the lower portion would not be. This situation would cause shear stresses along the joint. The shear stresses could be diminished by drilling beyond the joint.

4. It can be assumed tentatively that shear stress has less influence than normal stress on permeability.

SIGNIFICANCE TO NRC WASTE MANAGEMENT PROGRAM:

The report under review presents a simplified analysis of the effects that a tangential intersection of a joint by a drill hole would have on joint permeability in the field nuclide migration experiment. The results of the analysis suggest that a tangential intersection of the joint by the drill hole should be used to minimize disturbances of joint permeability. However the report suggests that a perpendicular intersection of the joint would eliminate normal stress concentrations, but that small shear stresses potentially could develop during drilling.

The report is of special interest to the DOE in their design of the field nuclide migration experiment. However, the report may be significant to the NRC in helping to evaluate the results of the field nuclide migration experiment.

PROBLEMS, DEFICIENCIES OR LIMITATIONS OF REPORT:

The report under review presents a simplified analysis of potential changes in joint permeability in the field nuclide migration experiment due to a tangential intersection of a joint by a drill hole. The primary limitations, as noted in the report, are that permeability vs. stress relationships are not known for tuff from the Nevada Test Site. No studies have been completed on the correspondence of lab and field fracture permeability coefficients. Thus, the necessary lab specimen size to obtain representative field values is not known (Witherspoon, 1981). It is not known if the analvsis presented in the report is valid with respect to the conditions that mav exist within fractured tuff of the Nevada Test Site.

SUGGESTED FOLLOW-UP ACTIVITIES

The report under review is of special interest to the DOE in the design and analysis of a field nuclide migration experiment.

REFERENCES CITED:

Jones, F.O., 1975, A Laboratory Study on the Effects of Confining Pressure on Fracture Flow and Storage Capacity in Carbonate Rocks. J. Petrol. Technol., vol. 21, p. 21-27.

Kranz, R.L., and others, 1979, The Permeability of Hole and Jointed Barre Granite. Int. J. Rock Mech. Min. Sci. and Geomech. Abstr., vol. 16, p. 225-234.

Walsh, J.B., 1981, Effect of Pore Pressure and Confining Pressure on Rock Permeability. Seminar presented January 20, 1981, at Sandia National Laboratories.

Witherspoon, P.A., 1981, Effect of Size on Fluid Movement in Rock Fractures. Geophysical Research Letters, vol. 8, no. 7, p. 659-661.

WMGT DOCUMENT REVIEW SHEET

FILE #:

DOCUMENT #: SAND82-0170

DOCUMENT: Thermal Analysis for a Nuclear Waste Repository in Tuff Using USW-G1 Borehole Data. Roy L. Johnson. Sandia National Laboratories, Albuquerque, NM., October 1982.

REVIEWER: Williams & Associates, Inc.

DATE REVIEW COMPLETED: April 30, 1986

ABSTRACT OF REVIEW: APPROVED BY: Roy E. Williams

This report describes the use of a finite element code on the cross section of an emplacement room to study heat flow produced by either spent fuel or other types of high level waste. An inconsistency exists in the study in that the rooms are assumed to be air filled and unventilated while at the same time the rocks are assumed to be completely saturated. With complete saturation no vaporization could occur. The report clearly was written before it was recognized that Yucca Mountain is unsaturated or before the decision to use the unsaturated zone was made; therefore the report is obsolete.

SPECIFIC COMMENTS:

The thermal studies were conducted by using a finite element code on the cross section of a typical emplacement room for either spent fuel or other high level waste. The heat generation decay properties for high level wastes are presented as are the thermal properties of the various rock units. The effect of radiation and convection within the emplacement room (assumed to be air filled and unventilated) were approximated by defining a solid conductive element with appropriate properties. This assumption of air filled, unventilated rooms is inconsistent with the assumption that the region is completely saturated; the latter assumption prevents boiling from occurring. This report was clearly completed before it was recognized that the Yucca

Mountain is in the unsaturated zone or before the decision to use the unsaturated zone was made. The fact that the repository would be in the unsaturated zone makes this work invalid from two standpoints.

1) The pressure in the water is less than atmospheric in the unsaturated zone; therefore, vaporization will occur due to heating. This effect cannot be simulated if the surrounding rock is assumed to be saturated.

2) Due to the unsaturated nature of the medium, vaporization will occur at the heat source and condensation will occur in the cooler portions of the medium.

This sequence of evaporation and condensation in effect should establish a recirculating system with liquid moving toward the repository and vapor movement away from the repository. This process should have a large effect on the temperature distribution surrounding the repository because of heat transfer via the vapor phase. The work in this report appears to be adequate done except for the fact that the incorrect assumptions make it invalid for the proposed Yucca Mountain repository.

SIGNIFICANCE TO NRC WASTE MANAGEMENT PROGRAM:

This report has no significance to the location of the repository in the unsaturated zone.

PROBLEMS, DEFICIENCIES OR LIMITATIONS OF REPORT:

The report is invalid for the present problem.

WMGT DOCUMENT REVIEW SHEET

FILE #:

DOCUMENT #: SAND82-0170

DOCUMENT: Johnson, R.L., October 1982, Thermal Analyses for a Nuclear Waste Repository in Tuff Using USW-G1 Borehole Data. Sandia National Laboratories, Albuquerque, NM.

REVIEWER: Williams & Associates, Inc.

DATE REVIEW COMPLETED: August 26, 1986

ABSTRACT OF REVIEW: APPROVED BY: Roy E. Williams

The report analyzes heat flow from a repository located below the water table in welded tuff by means of a finite element computer code. Simulated temperature distributions are presented. The work is not significant to the present proposed location of the repository above the water table.

BRIEF SUMMARY OF DOCUMENT:

This report describes thermal calculations for the temperature distribution in the regions surrounding a nuclear waste repository sited below the water table in welded tuff. The material properties used are those obtained from the USW-G1 borehole. The analysis was performed for two waste forms: 1) high level wastes, and 2) spent fuel, emplaced at two different gross thermal loadings. A finite element code was used to simulate heat from from the source. The computational mesh for both types of waste extended 250 m above and 250 m below the floor of the repository room. The results are in the form of temperature contours or isotherms, and temperature time histories for various points around the room, through the pillar, and up to the upper and lower stratigraphic interfaces. Temperatures were well below the 85°C specified as a limit.

SIGNIFICANCE TO NRC WASTE MANAGEMENT PROGRAM:

This report is not significant to the present repository location because it is well above the water table and this analysis is for a repository below the water table.

PROBLEMS, DEFICIENCIES OR LIMITATIONS OF REPORT:

The main deficiency is that the analysis is for a repository below the water table.

SUGGESTED FOLLOW-UP ACTIVITIES

No follow-up work is necessary.

SAN082-1043

WMGT DOCUMENT REVIEW SHEET

FILE NO.:

ONWI NO.:

DOCUMENT: Water Transport through Welded Tuff

REVIEWER: Williams and Associates, Inc.

DATE REVIEW COMPLETED: December, 1984

BRIEF SUMMARY OF DOCUMENT: DATE APPROVED:

Water movement into welded tuff was studied by means of three drying experiments and one imbibition experiment performed on a .15 m long core. The sample was saturated under a vacuum using a technique which made possible the measurement of the volume of water imbibed as a function of time. Profiles of saturation versus axial position along the core were determined by use of a gamma ray attenuation device. Measurements were made at various axial locations by moving the sample chamber past the gamma ray beam with a precision translation table. The sample was sealed with an epoxy substance such that only one end was open for flow. In the drying experiments the nitrogen gas was passed across the end of the sample. Results show that the saturation decreased throughout the sample due to the evaporation at the end. In the imbibition experiment the sample was oriented with the open end to the top. Water then was added by means of a funnel to the top surface. The author states, "that water appears to move through the sample under the action of both capillary forces and vapor pressure gradients induced by temperature gradients. Profiles resembling those of a receding evaporation front were observed when the temperature gradient was aligned in the direction of the moisture transport."

SIGNIFICANCE TO NRC WASTE MANAGEMENT PROGRAM:

Significance in EA's:

There does not appear to be information in this report which would be significant to either the Environmental Assessment or the overall licensing process.

PROBLEMS, DEFICIENCIES OR LIMITATIONS OF REPORT:

General Technical Discussion:

Introduction

The introduction is a brief discussion of some of the investigations necessary to determine the feasibility of siting a repository for commercial high-level nuclear wastes at Yucca Mountain. An important part of these investigations is examining the effects of nuclear waste canisters on the host formation. The author points out that in order to properly predict long-term migration of nuclides, basic mechanisms governing water transport through the host rock must be well understood. He then states, "although considerable effort has been expended in the study of water transport through soils the same level of motivation has only recently appeared for studying similar phenomena in rocks such as tuff, granite, sandstone and shale, which in some cases may be six orders of magnitude lower in permeability than soils." The emphasis on the work in the present paper is the direct measurement of saturation profiles in connection with drying phenomena in tuff.

Experimental Methods

The use of gamma ray attenuation for measuring saturation is described. This is technology which has been around for at least 20 years. The electronics involved here appear to be state of the art in that the movement of the sample through the gamma ray beam is computer controlled.

Description of Apparatus

The rock samples which had been sealed, except for one end, by means of epoxy were placed in a chamber in which the temperature could be controlled and nitrogen gas could be passed across the end of the sample. For the drying experiments the sample was in a horizontal position, whereas in the imbibition experiments the sample chamber was mounted vertically with one end cap left off to allow air to escape from the sample. The entire sample and chamber could be passed between the gamma source and the detector.

Sample Preparation and Experimental Procedure

The sample used in the study was from the welded Grouse Canyon Member of the Belted Range tuffs located in southwestern Nevada. The sample was 4.75 cm in diameter and 15.3 cm in length.

To insure that the sample was saturated a vacuum saturation technique was used. Air was initially removed from the sample and water was then allowed to flow into the sample. Several questions are raised in the discussion of this procedure concerning how long it is required for complete saturation under imbibition and during vacuum saturation. Most of these questions have been answered in the literature. It appears that the author is not familiar with the literature concerning capillary pressure-saturation relationships and some of the experimental techniques which are used. The techniques he has developed appear to be satisfactory but much of the information he obtained could be determined by analysis if he were familiar with two-phase flow theory and literature.

Experimental Results

The drying experiments which were conducted are summarized in a series of three plots of saturation versus position at various values of time. The times used were .5, 1.5, 3 and 4 hours. At .5 hours the saturation at the exposed end of the core was about .35 while in the rest of the core it was near one. At the next time the saturation at the open end of the core was .1 while the saturation in the rest of the core had decreased to about .8. At 3 hours the overall saturation had decreased to an average of about .4 while at 4 hours it was about .1. The author indicates that since the saturation did decrease throughout the core that evaporation was taking place throughout the entire core. Evaporation throughout the core would not be possible until the saturation became low enough that there was permeability to the nitrogen gas. It is much more likely that due to the drying at the exposed end the water then flowed toward the exposed end due to the capillary pressure gradient. After the saturation was lowered to the point that there was significant permeability to the nitrogen it would be possible for evaporation to take place throughout the core. However, from the way that the sample was set up in the experimental equipment it is doubtful that there would be any great amount of flow of nitrogen into the core. However, this is impossible to determine. The author does not appear to understand the basic phenomena of two phase flow relationships.

The results of the imbibition experiment are much as one would expect with the saturation at the inflow end being about .5 while the remainder of the sample is about zero. At later times the saturation throughout the sample increases until at a time of six days it is about about .8. There is nothing new in this experiment and a report by Adam et al (1969) has very similar information including the use of the gamma ray attenuation device. Some of the characteristics of the authors' curves which he leaves unexplained are explained in that report also.

Conclusion

The author concludes that this set of experiments has demonstrated clearly the usefulness of gamma ray densitometry as a saturation diagnostic for water transport through porous rock. As has been pointed out previously this is technology that has been in use in many labs for at least 20 years. The author also states "Results from the imbibition experiments show capillary forces to be important for welded tuff.... This result implies that drying theories to be used to model tight rock formations such as welded tuff should take into account the capillary effects." If the author had been familiar with two phase flow theory these statements would have been obvious to him before he began the research. There has been a project for several years at the University of Arizona to more fully describe the liquid and vapor flow in welded tuff which makes use of the two phase flow theory in the literature. The present article makes no contribution toward obtaining parameters necessary for analysis of liquid and vapor flow in welded tuff.

<u>REFERENCE</u>

Adam, K.M., Bloomsburg, G.L., and Corey, A.T., 1969, Diffusion of Trapped Gas from Porous Media: Water Resources Research, vol. 5, no. 4, p. 840-849.

POHLE #11
6/17/83

COMMENT ON SAND 82-1277 - "SCENARIOS FOR CONSEQUENCE ASSESSMENTS OF RADIOACTIVE-WASTE REPOSITORIES AT YUCCA MOUNTAIN, NEVADA TEST SITE"

GENERAL COMMENT

THIS REPORT BEGINS THE DOCUMENTATION OF SCENARIOS TO BE USED IN CONSEQUENCE ASSESSMENT OF A HIGH-LEVEL WASTE REPOSITORY AT NNWSI. IN MY OPINION, THE METHODOLOGY PRESENTED IS LOGICAL. AS NOTED IN THE REPORT, THE RELATIVE PROBABILITIES ASSIGNED TO BREACHING EVENTS AND OTHER PROCESSES ARE JUDGEMENTAL. I PERSONALLY DO NOT KNOW OF ANY OTHER WAY TO COME UP WITH "PRECISE" PROBABILITIES FOR THE OCCURRENCE OF THESE EVENTS IN THE FUTURE WITHOUT DETAILED HISTORICAL RECORDS OF PAST OCCURRENCES. ON THE WHOLE, THE JUDGEMENTS MADE IN THE REPORT ARE REASONABLE, IN RELATIVE TERMS. I DO TAKE SOME EXCEPTIONS AS EXPLAINED IN THE DETAILED COMMENTS. I HAVE TWO GENERAL QUESTIONS.

1. WILL THE SCENARIOS PRESENTED IN THIS REPORT BE ASSESSED (MODELED) IN AS COMPLEX (DETAILED) A MANNER AS "THE NORMAL FLOW SCENARIO"?

I ASK THIS QUESTION BECAUSE, AS A RESULT OF FURTHUR SITE CHARACTERIZATION, THE CONCEPTUAL MODEL OF GROUNDWATER FLOW WILL BE MORE COMPLEX AND DETAILED THAN THAT PRESENTED IN THE REPORT.

IT IS NOT CLEAR IN THE REPORT WHETHER THE BREACHING EVENTS (WHICH COULD BE NUMEROUS) WILL BE SUPERIMPOSED ON, AND ASSESSED WITH, A MORE SIMPLE CONCEPTUAL MODEL.

2. WOULD USE OF SIMPLIFIED CONCEPTUAL MODELS IN CONSEQUENCE ASSESSMENT OF BREACHING EVENTS BE ACCEPTABLE TO NRC STAFF? IF SO, UNDER WHAT CONDITIONS?

AILED COMMENTS

SECTION 3.2.1 - NORMAL FLOW OF WATER

"BREACHING EVENTS" AND OTHER POST-EMPLACEMENT PROCESSES (E.G. FORMATION OF CONVECTIVE CELLS) ARE SUPERIMPOSED ON TWO CONCEPTUAL MODELS OF THE GROUNDWATER SYSTEM. THESE TWO, SIMPLISTIC CONCEPTUAL MODELS ARE: 1) FLOW THROUGH THE REPOSITORY HORIZON (WHICH MAY BE SATURATED OR UNSATURATED DEPENDING ON FORMATION CHOSEN FOR REPOSITORY); TO A LOCAL OUTFALL (WELL OR SPRING); OR 2) DOWNWARD FLOW TO AN AQUIFER BELOW THE REPOSITORY HORIZON AND THEN TOWARDS SOME RELEASE POINT. THESE TWO CONCEPTS REPRESENT THE NORMAL FLOW SCENARIOS.

MY COMMENT IS THAT THE POSSIBLE PRESENCE OF PERCHED WATER IN UNSATURATED TUFF HAS NOT BEEN TREATED AS

A FEASIBLE PATHWAY FOR RADIONUCLIDE MIGRATION. THIS IS IMPLIED BY ASSIGNING A RELATIVE PROBABILITY OF 10^{-6} TO UNSATURATED UNITS FOR EVENT 4 (FLOW TO A LOCAL OUTFLOW). THE REASON FOR THIS IS STATED ON PAGE 19, "WATER IN THE UNSATURATED TUFFS DOES NOT MOVE DIRECTLY TO LOCAL OUTFALLS UNDER HYDRAULIC CONDITIONS AS THEY ARE CURRENTLY UNDERSTOOD; IT MUST FIRST FLOW TO A LOWER AQUIFER". CONVERSLY, IF A TUFF UNIT IS SATURATED, IT IS ASSUMED THAT THE RELATIVE PROBABILITY OF EXISTENCE OF LOCAL OUTFALLS IS HIGH. I CAN ONLY CONCLUDE THAT THE CONCEPTUAL MODEL WILL NOT ALLOW LATERAL FLOW DUE TO PERCHED WATER IN UNSATURATED TUFF TO BE ASSESSED. HOWEVER, THE REPORT DOES DISCUSS PERCHED WATER. THE REPORT INDICATES THAT PERCHED WATER IS A POTENTIAL FACTOR IN RADIONUCLIDE RELEASE IF THE NORMAL FLOW SYSTEM IS ALTERED IN SUCH A WAY AS TO ALLOW PERCHED WATER TO ENTER THE REPOSITORY, WHICH COULD INCREASE DISSOLUTION RATES. THIS EVENT WAS GIVEN A HIGH PROBABILITY (1) OF OCCURRENCE IF THE REPOSITORY HORIZON WAS LOCATED IN THE CALICO HILLS, BULLFROG OR TRAM UNITS.

ANOTHER AREA OF COMMENT IS EVENT 25 (WATER FROM LOWER CARBONATE AQUIFER ENTERS REPOSITORY) WHICH IS DISCUSSED ON PAGE 28. IN EFFECT, THE REPORT CONCLUDES THAT WATER FROM THE LOWER CARBONATE AQUIFER CANNOT REACH UNSATURATED TUFF (0 PROBABILITY) BECAUSE THE UNSATURATED

TUFF "PROBABLY LIES ABOVE THE HEAD IN THE LOWER CARBONATE AQUIFER". FURTHUR, THE REPORT CONCLUDES THAT WATER FROM THE LOWER CARBONATE AQUIFER MIGHT REACH THE SATURATED TUFF (ASSIGNED A UNIT PROBABILITY) BUT NO BASIS IS GIVEN FOR THAT CONCLUSION. IN ADDITION, THERE ARE NO MECHANISMS MENTIONED IN THE REPORT WHEREIN THE WATER LEVELS IN EITHER THE LOWER CARBONATE AQUIFER OR THE SATURATED TUFFS COULD CHANGE (EITHER INCREASE OR DECREASE WITH TIME). IT IS IMPLICIT IN THEIR ANALYSIS THAT CURRENT HEAD RELATIONSHIPS ARE FIXED IN TIME [redacted] AND THE ONLY WAY WATER IN THE LOWER CARBONATE AQUIFER COULD MOVE UP TO A REPOSITORY IS IF FUTURE FAULTS OR FRACTURES PENETRATE TO THE CARBONATE FROM REPOSITORY LEVEL AND AN UPWARD GRADIENT CURRENTLY EXISTS. THE POSSIBILITY OF WATER FROM THE SATURATED TUFF MOVING UPWARD TO A REPOSITORY IN UNSATURATED TUFF IS NOT DISCUSSED.

THE CONCEPTUAL RELATIONSHIP BETWEEN THE TUFF AND LOWER CARBONATE AQUIFER, AS DISCUSSED IN THE REPORT, IMPLIES THAT THE CARBONATE AND TUFFS ARE SEPARATE AND DISTINCT AQUIFERS IN THE VERTICAL DIMENSION. BASED ON A PUBLISHED REPORT BY WADDELL (1983), THE USGS HAS TREATED THE CARBONATE AND TUFFS AS A SINGLE HETEROGENEOUS AQUIFER (ON A REGIONAL BASIS) WHOSE PROPERTIES VARY HORIZONTALLY. IT IS CLEAR THAT CONCEPTUAL UNDERSTANDING OF THE RELATIONSHIP

BETWEEN THE TUFFS AND CARBONATES IS UNCERTAIN.

SECTION 3.2.6 - DRILLING

DRILLING HAS BEEN CONSIDERED AS A POSSIBLE BREACHING EVENT BECAUSE IT "COULD ESTABLISH A SIMPLE AND DIRECT HYDRAULIC CONNECTION BETWEEN THE REPOSITORY AND THE LOWER AQUIFER SYSTEM; IT COULD ALSO BRING WASTE MATERIALS DIRECTLY TO THE SURFACE" (p. 77). THE RELATIVE PROBABILITY OF DRILLING AS A RESULT OF MINERAL OR WATER RESOURCE EXPLORATION HAS BEEN CONSIDERED. HOWEVER, DRILL HOLES HAVE BEEN TREATED MUCH LIKE A FRACTURE OR FAULT IN THEIR ABILITY TO ALTER THE NORMAL FLOW SYSTEM. IN PARTICULAR, THE PROBABILITY OF FUTURE WATER RESOURCE DEVELOPMENT AND THE NEED TO ASSESS THE CONSEQUENCES OF GROUNDWATER WITHDRAWALS HAS NOT BEEN DEVELOPED OR DISCUSSED.

SECTION 3.4 - EVENTS DISMISSED FROM FURTHUR ANALYSIS

IT STATES ON PAGE 105 THAT "NATURAL ALTERATIONS OF LOCAL HYDRAULICS DURING THE PLEISTOCENE WERE MINIMAL AT THE NTS (WINOGRAD AND DOTY, 1980)." THERE IS NO FURTHUR DISCUSSION OF POTENTIAL, FUTURE CLIMATIC CHANGES AND NO PLANS TO ASSESS THE CONSEQUENCES OF SUCH CHANGES IN THIS REPORT.

AS AN ADJUNCT TO THIS REVIEW, I HAVE REVIEWED THE WINOGRAD AND DOTY REPORT. THEY NOTED THAT

IT HAS BEEN WELL DOCUMENTED THAT THE CLIMATE OF THE REGION WAS "SIGNIFICANTLY WETTER" DURING THE PLEISTOCENE. THEIR STUDY SUGGESTS THAT DISCHARGE FROM THE REGIONAL CARBONATE AQUIFER OCCURRED AT DISTANCES AS MUCH AS 14 KM NORTHEAST OF ASH MEADOWS, THE PRESENT DISCHARGE AREA AND AT ALTITUDES UP TO 50 METERS HIGHER THAN AT PRESENT. ALTHOUGH IT IS UNDERSTOOD THAT THESE ESTIMATES WERE BASED ON SIMPLISTIC ASSUMPTIONS AND THAT RISES IN WATER LEVELS DO NOT NECESSARILY PRECLUDE USE OF THE SITE AS A REPOSITORY, WINOGRAD AND DOTY DID RECOMMEND THAT "SUCH CHANGES, IF SIGNIFICANT, SHOULD BE TAKEN INTO ACCOUNT IN PREDICTING THE RESIDENCE TIME OF SELECTED RADIONUCLIDES EMPLACED WITHIN THE GROUNDWATER FLOW SYSTEM ENCOMPASSING THE NTS". BASED ON MY REVIEW OF WINOGRAD AND DOTY'S REPORT I CONCLUDE THAT FUTURE WETTER PERIODS ARE REASONABLY FORESEEABLE. THE CHANGES, OR CONSEQUENCES, DUE TO CLIMATIC VARIATIONS ARE UNCERTAIN. SANDIA'S USE OF WINOGRAD AND DOTY'S REPORT AS THE BASIS FOR ELIMINATING THE CONSEQUENCE ASSESSMENT OF FUTURE CLIMATIC CHANGES IS NOT APPROPRIATE.

SUMMARY OF COMMENTS

1) THE PRESENCE OF PERCHED WATER IN SOME UNSATURATED TUFF UNITS HAS BEEN ASSUMED TO BE REASONABLY FORESEEABLE. HOWEVER, THE ASSUMPTION OF

ONLY VERTICAL FLOW IN UNSATURATED TUFF IS A LIMITING RESTRICTION ON THE CONCEPTUAL MODEL WHICH IMPLIES THAT PERCHED WATER WILL NOT PLAY A ROLE IN RADIONUCLIDE MIGRATION PATHS. THE UNCERTAINTIES IN OUR UNDERSTANDING OF THE PRESENT FLOW SYSTEM, AT THIS STAGE OF SITE CHARACTERIZATION, ARE GREAT FOR NRC STAFF TO ACCEPT THIS ASSUMPTION PRIMA FACIE.

2) MUCH DISCUSSION IS CENTERED ON THE POSSIBLE UPWARD MOVEMENT OF GROUNDWATER FROM THE LOWER CARBONATE AQUIFER TO THE SATURATED TUFF. SEVERAL IMPLIED CONCLUSIONS AND ASSUMPTIONS ARE OF CONCERN.

A) THE DISCUSSION ASSUMES THE UNSATURATED ZONE WILL BE UNAFFECTED BY WATER FROM THE LOWER CARBONATE AQUIFER BECAUSE THE HEADS IN THE CARBONATE SYSTEM ARE "PROBABLY" BELOW THE UNSATURATED TUFF. BOTH THE EXISTING HEAD IN THE CARBONATE AQUIFER AND THE RELATIONSHIP BETWEEN SATURATED TUFF AND THE CARBONATE SYSTEM ARE UNKNOWN AT YUCCA MOUNTAIN.

B) THE REPORT ASSUMES THAT EXISTING HEADS (WATER LEVELS) ARE FIXED IN TIME. A POSSIBLE INCREASE IN WATER LEVELS IN THE SATURATED TUFF, WHICH MIGHT POSSIBLY AFFECT A REPOSITORY IN THE OVERLYING UNSATURATED TUFF IS NOT DISCUSSED. THE

ONLY MECHANISM PRESENTED WHICH COULD CONCEIVABLY RAISE WATER LEVELS IN THE SATURATED TUFF IS UPWARD FLOW FROM THE CARBONATE AQUIFER. INCREASED RECHARGE IS NOT DISCUSSED IN THIS CONTEXT.

3) BREACHING OF A REPOSITORY BY DRILLING RELATED TO MINERAL OR WATER RESOURCE EXPLORATION IS DISCUSSED. NO SCENARIOS INVOLVING RESOURCE DEVELOPMENT ARE PRESENTED. POTENTIAL, FUTURE WATER RESOURCE DEVELOPMENT IS A SPECIFIC ISSUE IDENTIFIED BY NRC STAFF AND SHOULD BE ADDRESSED.

ALTERATIONS OF THE PRESENT GROUNDWATER FLOW SYSTEM DUE TO CLIMATIC CHANGES IS A SCENARIO WHICH HAS BEEN DISMISSED FROM FURTHUR ANALYSIS. WINOGRAD AND DOTY'S (1980) REPORT WAS REFERENCED AS THE BASIS FOR THIS DISMISSAL. BASED ON NRC REVIEW OF WINOGRAD AND DOTY'S WORK, WE CONCLUDE THAT FUTURE WETTER PERIODS ARE REASONABLY FORESEEABLE AND THAT BOTH THE CONSEQUENCES AND SIGNIFICANCE OF THE CONSEQUENCES AT YUCCA MOUNTAIN ARE UNKNOWN. WINOGRAD AND DOTY RECOMMEND THAT THE CHANGES (CONSEQUENCES), IF SIGNIFICANT, BE ACCOUNTED FOR IN PERFORMANCE ASSESSMENT. WINOGRAD AND DOTY'S REPORT IS NOT AN ADEQUATE BASIS FOR DISMISSING ANALYSIS OF CLIMATIC CHANGES IN THE ASSESSMENT OF THE PERFORMANCE OF THIS SITE AS A HIGH-LEVEL WASTE REPOSITORY. IN PARTICULAR, THE CONSEQUENCES OF FUTURE, WETTER PERIODS ON PERCHED WATER (COMMENT 1) AND

WATER LEVELS IN THE SATURATED TUFF (COMMENT 2) SHOULD BE ASSESSED.

GeoTrans
Geohydrologic Transport Analysis

DRAFT

MEMORANDUM

TO: Jeffrey Pohle, NRC

FROM: Lisa August and Benjamin Ross

DATE: June 24, 1983

SUBJECT: Review of "Scenarios for Consequence Assessments of Radioactive-Waste Repositories of Yucca Mountain, Nevada Test Site" by Hunter, Barr, and Bingham, Report No. SAND82-1277

Summary of the Report

The report, "Scenarios for Consequence Assessments of Radioactive-Waste Repositories at Yucca Mountain, Nevada Test Site," is a compilation of the events and processes which may affect the performance of a repository placed at Yucca Mountain. The study catalogs scenarios for a repository in each of four rock units: the Topopah Spring Member, Calico Hills, Bullfrog Member and Tram unit. Each scenario is comprised of several events. A "probability" is assigned to each scenario as a measure of its relative likelihood. The "probability" is calculated as the product of individual event "probabilities".

Hunter, Barr and Bingham use seven event trees to present the scenarios. The event trees are characterized by a breaching event which is the first event for all scenarios in the tree, i.e., magmatic intrusion, drilling, etc. The main body of the report is an explanation of the construction of the event trees and of the reasoning used to assign event probabilities. Many of the events are time dependent. Therefore, probabilities are assigned at four times: 100 years, 1,000 years, 10,000 years and 100,000 years. These time units are not cumulative (e.g., 100 years refers to an event which occurs in 0 to 100 years after closure of the repository, 1,000 years refer to an event which occurs in 100 to 1,000 years after closure, etc.)

The construction of event trees is a preliminary step toward consequence analysis. The authors suggest that the modeling of only conservatively bounding scenarios for the three classes of releases (direct to biosphere, through ground water to local outfalls and through ground water to an aquifer) will simplify consequence analysis significantly. Some of the important conditions and assumptions used to assign probabilities and develop the event trees are as follows.

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- The "probabilities" are indications of relative likelihood and have little or no significance as quantitative measures of the actual probability that a scenario will occur.
- A value of zero is assigned to events thought to be physically impossible.
- A value of 10^{-6} is assigned to events which are physically possible but whose occurrence is highly unlikely.
- An event for which there is no data is assigned a "probability" of one.
- "Probabilities" are only "accurate" to one significant figure.
- "Relative probabilities" are assigned for different times and the time units are not cumulative.
- The four rock units are represented by three rock types:
  Topopah Spring Member - unsaturated, densely welded tuff
  Calico Hills - unsaturated, nonwelded tuffs
  Bullfrog and Tram Members - saturated, moderately welded tuff.
  "Relative probabilities" of events are determined for each rock type.

The authors regard the report as a preliminary effort, and they expect event trees and "probabilities" to undergo major changes as more is learned about the site.

General Comments

This report presents a logical and well-organized compilation of the processes and discrete events which form the scenarios used in consequence assessments for repository site characterization. Such an exercise provides a means of sorting out the multitude of events and creates a framework for future work. In addition, the development of conceptual models is more efficient.

Because time and money are always limited, it is necessary to select a limited number of scenarios which, when modeled, will provide a reasonable performance assessment. Used in this way, the study has the potential of being extremely useful to DOE in organizing the NNWSI program. Because of its preliminary nature and reliance on unverified hypotheses, however, it is of little use to NRC, except as an indication of the form which later, better supported, DOE submissions will take.

The assignment of "relative probabilities" to events is a useful way to prioritize scenarios. The authors believe that additional data will allow for more accurate "probability" estimates. It is our feeling that the inherent need for judgmental and "best guess" techniques will limit the value of any such refinements. With the exception of a few events (explained below), the assumptions and general expectations for the future seem reasonable.

Probability Assignments

As mentioned above, the values assigned to each event represent a system of "relative probabilities". The "probabilities" are based on little or no data and, for the most part, are derived from "best guess" techniques. So much error is inherent in this process that attempts to incorporate generic calculations only detract from the relative nature of the values.

Various references to the accuracy of the numbers or the calculation procedures imply that these "probabilities" have some absolute significance. For example, on page 26, the "probability" of event 11 is calculated using a coefficient which relates rock type and fracture resistance. Although the coefficients are relative estimates, we believe that such numerical manipulations imply an accuracy which simply does not exist. The "probability" of event 14 (p. 30) is also derived in this manner. Another example is the use of previously published probabilities. On page 61, the "probabilities" of events 152, 153 and 169 are based on the work of Crowe and Carr (1980). First, the appearance of units (10^{-9} events/sq. km/yr) implies some absolute significance. Second, it is not apparent how the values used by Crowe and Carr can simply be substituted into the relative system used in this report.

We would suggest that the assigned "probabilities" be justified by logical assumptions and judgments based on the data available. Although the use of values between zero and one is natural for probability estimates, any reference to numerical manipulation should probably be omitted. Emphasis should be placed on the consistency of assignments, not on precision.

Effects of Climate

There is no discussion of the possible effects of climatic change on repository performance in this study, and the authors do not provide a reasonable explanation for the omission. The only reference to the subject (p. 105) states that "Natural alteration of local hydraulics during the Pleistocene were minimal at the NTS" (Winograd and Doty, 1980). Our review of Winograd and Doty (1980) shows no solid basis for this statement. Their report indicates that although climatic effects are not the only explanation for increases in head during the Pleistocene, they cannot be discounted. In addition, that study does not account for climatic effects on the Yucca Mountain sub-region specifically. This area may have subsurface features which make the ground-water system sensitive to changes in recharge.

The actual events caused by climatic change are probably similar to those discussed in Section 3.3.5, "Alteration of hydraulic system." The processes affected by climatic change, however, are different from other processes which may alter the hydraulic system. Therefore it is necessary to discuss possible climatic changes indicated by historical records and to identify the probable effects (such as increase in recharge, change in flow gradient, etc.).

Lower Carbonate Aquifer

Throughout this report reference is made to the lower aquifer which is the carbonate formation which may underlie the Yucca Mountain sub-region. The discussion causes some confusion by treating this aquifer as a separate unit, unrelated to the overlying saturated tuffs. Other investigations by the U.S.G.S. (Waddell, 1982) treat this entire saturated zone as a single heterogeneous aquifer. It is necessary to resolve this confusion before consequence modeling can be done.

In the discussion of event 25, "Water from lower carbonate aquifer enters repository" (p. 28), a "probability" of zero is assigned to unsaturated tuffs based on the assumption that the distribution of heads results in a downward gradient. First, there is no foundation for this assumption since the heads for the aquifer are unknown. Second, the distribution of heads may change in the future. In addition, there is no mention of a similar event occurring in the saturated tuff. There is no reason not to consider the possibility that a fracture created by tectonic disturbance can connect the saturated tuff to a repository in unsaturated tuff.

Perched Water

The treatment of perched water (p. 27) in this study allows for flow and transport of radionuclides through such an aquifer if the water is allowed to flow directly through the repository (event 16, p. 27). The "probability" assigned to this event in the unsaturated tuff is 10^{-6} (highly unlikely). It appears that this value reflects the probability of the presence of perched water at the repository. The authors have not considered the general capability of perched water to transmit waste through the unsaturated zone. Since the occurrence of perched zones in the unsaturated tuff may be quite likely, the event of transport by perched water should be included in the normal flow scenarios.

Conclusions

Our main concern with this study is that its technical value may be overestimated. It is imperative that the nature of the "probability" assignments be fully understood. They cannot be used to predict the occurrence of events or scenarios. These are "relative probabilities" based on little or no data. It would avoid some misunderstanding if another word were used to describe them.

There is, in our view, much more possibility of refinement in the enumeration and classification of scenarios than in the "probabilities." Additional work is especially necessary in three areas. The effects of climate and climatic changes which may cause alterations to the hydraulic system should be identified. The nature of the aquifer(s) underlying Yucca Mountain should be clarified and the related events re-evaluated. Finally, events concerning perched water should be expanded to include transport in perched zones throughout a rock unit, specifically the unsaturated zone.

The bounding scenarios described in the report are representative of the repository's performance but they are extremely simplified. Although the authors refer to the modeling of scenarios, it should be remembered that the scenarios are not conceptual models. A conceptual model is an idealized characterization of the ground-water system. Scenarios are simply a list of events which may alter that system. Therefore, the consequence assessments will rely upon an accurate ground-water flow model of the sub-region. The effects of events in a scenario will be characterized by a conceptual model and then superimposed on the normal flow model. Thus a refinement of the scenarios presented here must proceed along with further work on development of conceptual flow models.

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WMHL DOCUMENT REVIEW SUMMARY

DOCUMENT: Scenarios for Consequence Assessment of Radioactive-Waste Repositories at Yucca Mountain, Nevada Test Site; Hunter, R. L., Barr, G. E., Bingham, F. W.; SAND82-1277; 117 pp.

DATE REVIEW COMPLETED: 9/6/83

REVIEWER: Peter M. Ornstein

SIGNIFICANCE OF INFORMATION TO NRC PROGRAM:

Document indicates approach DOE is taking in analyzing and screening potential radionuclide release scenarios. Document is significant in that it may provide a basis for DOE's selection of most likely-to-occur scenarios, and a justification for the non-selection of other scenarios.

ACTION RECOMMENDED: Discuss document with DOE at the next NNWSI performance assessment workshop.

ACTION TAKEN: Document was reviewed by NRC's NNWSI review team and by NRC contractor Geotrans.

REFERRED TO (FOR INFO):

Name	Pages

SUMMARY AND REVIEW OF DOCUMENT:

A summary of the document and review of the hydrogeologic portions can be found in the review submitted by Geotrans (attached). Comments not specifically touched on by the Geotrans review will be discussed below.

SPECIFIC COMMENTS

§3.2.2 - A fixed water table in the tuffs and fixed piezometric surface in the carbonates is assumed. These assumptions ignore the possibility of transient conditions which might allow for saturation of presently unsaturated units. These assumptions are not substantiated by existing data.

§3.2.6 - The probability of future resource development and the need to assess the consequences of groundwater withdrawals has not been developed or discussed.

§3.4 - Using Winograd and Doty (1980) as a reference, the document assumed that future climatic changes would only minimally affect local hydraulics. However, Winograd and Doty acknowledged regional hydrologic changes during the Pleistocene and recommended assessing the impact of these changes on possible radionuclide residence times. Also, Winograd and Doty's study focused on the hydrologic changes in carbonates and not on the hydrologic changes that occurred or might occur in tuff. Therefore, Sandia's use of the Winograd and Doty study as the basis for eliminating future climatic changes from NNWSI's scenario consideration is not appropriate.

§3.2.3 - The thermomechanical section does not consider a number of possible events which may result in radionuclide releases such as:

- canister shearing due to an unstable rock mass
- canister corrosion
- increased permeability due to alteration of rock composition and/or structure (fabric)
- other non-joint related transport events utilizing pre-existing permeability (e.g., heat piping).

- Releases due to leaching is overly simplified. Waste decomposition mechanisms for HLW forms include: leaching, selective leaching (matrix dissolution), devitrification (as a function of temperature), hydration, and radiation. The dominant decomposition process is probably a combination of these mechanisms depending on the site specific environment scenario.

- Corrosion of the canister need not result in waste package failure since the waste package includes fuel form, canister, overpack, and packing.

- Chemical processes are ignored for waste package scenarios.

<u>OTHER COMMENTS</u>

- Emphasis should be placed on data collection. Event values when compared to one another should indicate critical areas of data collection and analysis.

- The synergistic relationship between two or more events occurring at the same time is ignored. The processes and relative probabilities presented treat each process as an independent phenomenon and ignore dependent relationships. Such dependent relationships may cause the relative likelihood of an event to be greatly elevated. For example, consider the simultaneous occurrance two events: 1) intrusion by drilling; and 2) canister failure. The drilling scenario has a greater likelihood of encountering waste since the waste is no longer confined solely to the canister. The relative likelihood of this combined scenario is not considered and may be significantly higher than exhumation by canister contact alone.

- Many of the assigned relative probabilities appear to be arbitrary. This is especially true for values where the underlying physical basis is not defined or the supporting data is lacking.

CONCLUSION

The document presents a logical methodology for determining the relative importance of scenarios in terms of likelihood of occurrance. As the above comments imply, specific details of both the methodolgy and the individual scenarios need to be refined before a set of most likely to occur scenarios is incorperated into the NNWSI program.

By its very nature, this document lends itself to be misreferenced by future studies as a comprehensive analysis that establishes the absolute likelihood of the occurrence of a given event. However, the document establishes only <u>relative</u> likelihoods for comparison purposes. This is an important distinction which must be kept in mind if the document is to have any utility.

WMGT DOCUMENT REVIEW SHEET

FILE #:

DOCUMENT #: SAND82-1434

DOCUMENT: Bulk and Thermal Properties of the Functional Tuffaceous Beds in Holes USW G-1, UE-25a#1, and USW G-2, Yucca Mountain, Nevada. A.R. Lappin, Earth Sciences Division and F.B. Nimick, NNWSI, Geotechnical Projects Division, Sandia National Laboratory, Albuquerque, NM, April 1985.

REVIEWER: Williams & Associates, Inc.

DATE REVIEW COMPLETED: May 28, 1986

ABSTRACT OF REVIEW: APPROVED BY: Roy E Williams

Bulk and thermal property data are presented for one of four tuff units that initially were being reviewed for the location of the high level waste repository in Yucca Mountain. The tuffaceous beds of the Calico Hills unit are reviewed. Lithologic logs, mineralogic analyses, downhole density logs and bulk property measurements were used for the characterization of the unit. Measurements were made at boreholes USW G-1 and USW G-2. Data from this report could be used for thermal-mechanical modeling studies of the repository. The proposed repository is not in the unit studied in this report.

BRIEF SUMMARY OF DOCUMENT:

An evaluation is conducted of the relative merits of four tuff units at Yucca Mountain as candidate horizons for the repository. This report documents bulk and thermal property data used in evaluating the tuffaceous beds of the Calico Hills unit. The average thermal properties, vertical distribution of bulk properties and estimated uncertainties in all measurements are defined. The tuffaceous beds include the lower zeolitized ash flow top in the overlving Topopah Spring Member of the Paintbrush tuff, the zeolitized upper portion of the ash flow top and the underlying Prow Pass unit of the Crater Flat Tuff. These functional tuffaceous beds are more complex and thicker than the ash flow portions of the tuffaceous beds of the Calico Hills unit. Four sources of data used to distinguish these beds are: 1) lithologic logs, 2) mineralogical analyses, 3) downhole density logs, and 4) bulk property measurements. The overall thickness of the tuffaceous beds ranges from 143 m in USW G-1 to 312 m in borehole USW G-2. The upper sub unit ranges from 104 to 312 m. Frequency distribution data for the grain density and porosity serve as input to the sensitivity analysis that related the predicted excavation stability to variations in tuff properties. Results show that the cumulative frequency distribution of porosity in this formation shows little variation among holes. Thermal conductivities have been measured from 13 strongly zeolitized tuffs from the two holes; the values do not differ significantly. No correlation between grain density and matrix conductivity is apparent. Thermal expansion is an important parameter in the analysis for waste emplacement; it also is a major factor in the control of thermally induced strains. The thermal expansion behavior of zeolitized tuff is expected to be quite complex because of the presence of one or more hydrated phases. The structural state of the tuffs may depend on both temperature and relative humidity due to the occurrence of clay. The authors state in summary that "data provided in this report are intended to serve largely as a basis for near field and/or very near field thermal mechanical modeling studies based on average properties and sensitivity analyses to be performed as part of evaluated potential repository horizons in tuff. The amount of data is limited in all cases. The approach taken demonstrates a method by which other required functional stratigraphies can be developed."

SIGNIFICANCE TO NRC WASTE MANAGEMENT PROGRAM:

This report presents a study of the thermal and mechanical properties of the zeolitized tuffs which probably will be of use in determining the structural characteristics of the repository. However the proposed repository would not be located in the material which was investigated.

PROBLEMS, DEFICIENCIES OR LIMITATIONS OF REPORT:

No limitations in the analysis are obvious.

SUGGESTED FOLLOW-UP ACTIVITIES

Engineers designing the repository should be made aware of the data included in this report on structural and thermal characteristics of the Calico Hills tuff.

WMGT DOCUMENT REVIEW SHEET

FILE #:

DOCUMENT #: SAND82-1434

DOCUMENT: Bulk and Thermal Properties of the Functional Tuffaceous Beds in Holes USW G-1, UE-25a#1, and USW G-2, Yucca Mountain, Nevada. A.R. Lappin, Earth Sciences Division and F.B. Nimick, NNWSI, Geotechnical Projects Division, Sandia National Laboratory, Albuquerque, NM, April 1985.

REVIEWER: Williams & Associates, Inc.

DATE REVIEW COMPLETED: May 28, 1986

ABSTRACT OF REVIEW: APPROVED BY: Roy E Williams

Bulk and thermal property data are presented for one of four tuff units that initially were being reviewed for the location of the high level waste repository in Yucca Mountain. The tuffaceous beds of the Calico Hills unit are reviewed. Lithologic logs, mineralogic analyses, downhole density logs and bulk property measurements were used for the characterization of the unit. Measurements were made at boreholes USW G-1 and USW G-2. Data from this report could be used for thermal-mechanical modeling studies of the repository. The proposed repository is not in the unit studied in this report.

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SIGNIFICANCE TO NRC WASTE MANAGEMENT PROGRAM:

This report presents a study of the thermal and mechanical properties of the zeolitized tuffs which probably will be of use in determining the structural characteristics of the repository. However the proposed repository would not be located in the material which was investigated.

PROBLEMS, DEFICIENCIES OR LIMITATIONS OF REPORT:

No limitations in the analysis are obvious.

SUGGESTED FOLLOW-UP ACTIVITIES

Engineers designing the repositorv should be made aware of the data included in this report on structural and thermal characteristics of the Calico Hills tuff.

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WMHT DOCUMENT REVIEW SHEET

FILE: 3001.5 , 413.2

DOCUMENT: Sinnock, Scott, 1982, Geology of the Nevada Test Site and nearby areas, southern Nevada, SAND 82-2207, Sandia National Laboratories, Albuquerque, NM

REVIEWER: M. Pendleton

DATE REVIEW COMPLETED: 2/9/83

DATE APPROVED 2/15/83

BRIEF SUMMARY OF DOCUMENTS

This report is a brief synthesis of the geologic setting of the Nevada Test Site (NTS). It was written to provide a summary of the geologic information currently available to assess the impact of geologY on long term waste isolation at NTS. As such, the report consisely summarizes the physiography, stratigraphy, structure, and tectonics of the NTS and vicinity. A brief summary of the hydrology of the NTS is included as an appendix.

SIGNIFICANCE TO NRC WASTE MANAGEMENT PROGRAM:

~~As a general and brief~~ summary of the geologic setting at NTS, this document is good background reading for those members of the NTS team who need to become familiar with the geology at NTS. Specific details of the geology of Yuccca Mountain are not provided, thus the report is marginally useful to staff members who have all ready developed an understanding of the geologic setting at NTS.

ACTION TAKEN:

This report was distributed to Paul Prestholt, Jeff Pohle, Peter Ornstein, and Michael Weber for review and comment.

FOLLOW-UP ACTIVITY:

Detailed comments from Peter Ornstein and Michael Weber will be incorporated, as appropriate, into the agenda for the NTS Geologic Stability Workshop tentatively scheduled for March of 1983.

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WMGT DOCUMENT REVIEW SHEET

FILE #:

DOCUMENT #: SAND82-2771

DOCUMENT: Code Development in Support of Nuclear Waste Storage Investigations for a Repository in Tuff. Roger R. Eaton, Mario J. Martinez, Rodney K. Wilson, Jace W. Nunziato, Sandia National Laboratories, Albuquerque, NM, July 1983.

REVIEWER: Williams & Associates, Inc.

DATE REVIEW COMPLETED: April 30, 1986

ABSTRACT OF REVIEW: APPROVED BY: Roy E. Williams

This report consists of a series of memos which were circulated through the staff at Sandia National Laboratories for the purpose of discussing the various types of models that should be developed for use in the study of water and heat flow in Yucca Mountain. The code which is discussed most in these series of memos is SAGUARO, a finite element code for the analysis of time dependent water flow and energy transport in a partially saturated rigid porous media. The authors had trouble with numerical instabilities, in several of the simulations, which were prevented by using piecewise linearization of the hydraulic property curves. Experimental work was conducted for flow into a 14 cm long core of tuff. This effort essentially duplicates experiments in the existing literature which evidently was not reviewed by the authors.

BRIEF SUMMARY OF DOCUMENT:

The derivation of the SAGUARO program appears to be fairly standard. The Richard's equation for unsaturated flow is used as the basis. The flow of air is neglected and the usual capillary pressure-saturation and capillary pressure-conductivity curves are used. The energy portion of the SAGUARO code is standard and is very similar to the fluid flow equation. The difference is primarily a matter of using different terminology and a difference in the type of data input.

Field and laboratory data requirements for implementing computational flow field codes list geometry, boundary conditions, initial conditions, and hydraulic properties. When geometry is considered, the comment is made that it is essential to know the location of the water table in order to determine whether or not the saturated or unsaturated code is to be used. The authors should be aware that most unsaturated codes will consider flow below the water table; therefore it is not necessary to use a separate saturated code if a portion of the flow field is saturated.

The specific input requirements for the saturated flow program called COYOTE are discussed also. MARIAH is a modification of COYOTE for unsaturated flow. FEMWASTE is a program which simulates transport of solutes through a two dimensional saturated/unsaturated porous medium. Convection, hydrodynamic dispersion, chemical sorption and first order radioactive decay are included in FEMWASTE. This report essentially is a statement of the data that are needed for operating these programs.

The second section of the report discusses the highly non linear equations that describe one dimensional infiltration using the Crank Nicholson finite difference scheme or the Galerkin finite element technique. A sample problem is run with each of these techniques; similar results are obtained. In this analysis the capillary pressure/conductivity curves and moisture content curves were linearized piecewise in order to carry out the comparison.

The next memo is a statement of the current status of computational capabilities for predicting energy and mass flux through partially saturated porous medium. The revision of the COYOTE program for unsaturated flow and the MARIAH code to consider heat and mass transport through porous material also is discussed. This revision ultimately was named SAGUARO. A sample problem is run which considers rain falling on the ground surface and the resulting infiltration into the ground. The hydraulic conductivity and moisture content vs. pressure head curves were again piecewise linearized and the results compared with the previous simulation.

Numerical calculations are compared with experimentally obtained results from inhibition experiments on partially saturated welded tuff. In this discussion, the authors use measured capillary pressure saturation and measured conductivity data for tuff. The capillary pressure saturation data were obtained by mercury intrusion. These data were then converted to the data necessary for the air/water system. In running the SAGUARO code, problems apparently developed with numerical stability because the actual moisture content/pressure head curves again were piecewise linearized. It should be noted that several codes exist for unsaturated flow that have been available for well over 10 years that would do as good a job of simulating infiltration as SAGUARO.

This section also presents experimental data for flow into a 14 cm long core of tuff. The experiment consisted of allowing water to flow into one end of the tuff and monitoring the moisture content with a gamma ray attenuation device. It appears that the authors are not familiar with the literature in relation to this experiment because the process of water movement into porous materials has been investigated previously under this type of situation (Adams, Bloomsburg and Corey, 1969). It also appears that they do not understand the process of imbibition. In an infiltration process such as this, air will be trapped and the conductivity will not reach the saturated value (maximum) for a long period of time (several months). Their numerical model does not consider entrapped air or the fact that air must move out of the porous material by being dissolved in the water. The air then may diffuse through the water or be carried out by the water. This process has been explained in the reference cited above. Their computer model output appears to resemble the laboratory experimental data (data from 14 core). This resemblance probably is a coincidence because they are simulating a process that is different from the one that is occurring in the laboratory experiment. Their experimental data on the core also appear to be quite erratic; thereby indicating that possible nonhomogeneities may exist in the tuff or water may be flowing up the side of the core and then into the core of tuff from the side. In their experiment they do not indicate whether evaporation from the top of the sample was prevented. Evaporation, if not prevented, could have a large effect on the rate at which air was removed because water would be moving up through the core. The diagram of the apparatus presented in the report indicates that evaporation probably was not prevented. In general the work in this section was unnecessary. The work also could have been done more effectively.

The next section consists of a discussion of the importance of accurate hydraulic property curves and boundary conditions for performing computations in unsaturated media. The same infiltration process is discussed (see discussion above). The authors attempt to determine the effect of shifts in the moisture characteristic curves. In general, shifting the curves has little effect on the infiltration in most cases.

The effect of short term water depth fluctuations at the ground surface on pore water motion at repository horizons is considered in the last section. This effect is interesting in that they attempt to determine the effect of transient conditions at the surface on the pressure at depth in Yucca Mountain. In the first case the infiltration was varied from 7.7 inches to -6.3 inches per year with an average influx of .7 inches per year. In the second case the influx was held constant at .7 inches per year. Computations were carried out for a ten year period. At a depth of 100 m apparently no fluctuation of pressure occurred.

SIGNIFICANCE TO NRC WASTE MANAGEMENT PROGRAM:

Computer models will be required to simulate water and heat flow in volcanic tuff. The work in this report is a step in that direction. However, the authors have repeated work that is in the literature.

PROBLEMS, DEFICIENCIES OR LIMITATIONS OF REPORT:

The major deficiencies of the report are the absence of an adequate literature review and an incomplete review of existing computer codes.

SUGGESTED FOLLOW-UP ACTIVITIES:

A more complete literature review should be encouraged.

REFERENCES:

Adams, K.M., Bloomsburg, G.L., and Corey, A.T., August 1969, Diffusion of Trapped Gas from Porous Media: Water Resources Research, vol. 4.

WMGT DOCUMENT REVIEW SHEET

FILE #:

DOCUMENT #: SAND82-2772

DOCUMENT: SAGUARO--A Finite Element Computer Program for Partially Saturated Porous Flow Problems. R.R. Eaton, D.K. Gartling, D.E. Larson, Sandia National Laboratory, Albuquerque, New Mexico, June 1983.

REVIEWER: Williams & Associates, Inc.

DATE REVIEW COMPLETED: April 30, 1986

ABSTRACT OF REVIEW: APPROVED BY: Roy E. Williams

SAGUARO is a finite element computer program designed to calculate two-dimensional flow of mass or energy through porous media. The media may be saturated or partially saturated. The program solves the parabolic time dependent mass transport equation which accounts for the presence of partially saturated zones through the use of highly nonlinear material characteristic curves. Program capabilities, user instructions, and a sample program are presented in the manual.

BRIEF SUMMARY OF DOCUMENT:

SAGUARO is a general purpose finite element code developed to solve problems of incompressible single phase water and energy transport through partially or fully saturated porous media. The nonlinear parabolic equations are solved in finite element form using an algorithm related to the standard Crank-Nicolson method. Program results provide temporal and spatial distributions of hydraulic head, temperatures, velocities, and moisture contents. Richard's equation is used for the fluid flow part of the problem. The heat flow equation reflects an energy balance for the unit volume containing a porous matrix and liquid; it neglects the heat capacity of the air. It also is assumed that the matrix and liquids are in thermal equilibrium. Energy transport by both conduction and convection are included. The program contains the following limitations and assumptions:

1) The porous matrix is assumed to be homogeneous and rigid and is limited to two dimensions.

2) The porous material is assumed to be saturated or partially saturated with a single one-phase fluid flowing at laminar conditions.

3) For non-isothermal flows, the fluid and solid material are assumed to be in local thermal equilibrium; the presence of air is neglected.

The program has its own mesh generator, data analysis and plotting packages. The mesh generator uses an isoparametric mapping procedure that allows very general meshes to be prepared easily and accurately. A plotting routine provides graphic output of element meshes, nodal point location, contour plots of temperature, hydraulic head or stream function, profile plots and time histories of any dependent variable. The input guide is brief but it probably is sufficient for a person who is familiar with the Cray or CDC computers.
Material data cards may be of two types corresponding to the specification of fluid and matrix solid properties. These properties may be given either as constants, as pressure dependent, or as temperature dependent. Any consistent set of units may be used with SAGUARO. Each part or region of the mesh is specified by three data cards which control the minimum and maximum coordinate value in each of the two directions. The node points then are generated by the program.

Several different types of elements may be used; they can be three-sided six node elements, four-sided eight node elements, three-sided three node elements, or four-sided four node elements. The boundary condition options (PVARY, UVARY, TVARY, and QUARY) permit hydraulic head, fluid velocity or temperature, or heat fluxes along any element boundary to vary with time.

It is usually advisable to limit the amount of printed output generated by SAGUARO. It is possible to specify spatial locations within the mesh other than nodal points at which output of the dependent variables is required. In order to aid in the use of computed temperatures, SAGUARO allows the computation of several heat flux quantities on an element basis.

The plotting program facilitates the interpretation of data obtained from the solution and to aid in setting up element meshes. The following basic types of plots are available in SAGUARO: node points, element, contour, outlines and profile. The program also has a restart feature so that several problems can be run in order. This option also will save a previously computed solution. SAGUARO allows the use of variable material properties, temperature and/or time dependent volumetric heat sources, dispersion models, general radiation or convection boundary conditions and time dependent boundary conditions. These are handled through user supplied subroutines.

There are several error checks and tests for bad input data and overflow storage. When an error is encountered a number of messages are printed and the program is terminated if the error is fatal.

SAGUARO is a large code, with approximately 7500 source statements that require a relatively large computer system. It is designed primarily for the CDC 7600, or Cyber 7600 computer systems or the Cray 1S computer. For problems which produce large quantities of output it is sometimes useful to use microfiche printed output.

A sample problem for one-dimensional infiltration of rain into rock with a resulting heat flow is included in the publication. The output appears to be reasonable. This code appears to be a useful program to use in various aspects of the waste repository site. Other than the heat flow aspects, the results are very similar to those from other unsaturated flow programs.

SIGNIFICANCE TO NRC WASTE MANAGEMENT PROGRAM:

SAGUARO may be useful for investigating unsaturated flux in the profile of Yucca Mountain.

PROBLEMS, DEFICIENCIES OR LIMITATIONS OF REPORT:

The program is quite large and complex. However, it appears to have good possibilities for contributing to the understanding of flow in Yucca Mountain.

SUGGESTED FOLLOW-UP ACTIVITIES:

Apply the code to field data as a trial run.