WM-Record D1021 NWCI

WM Project 10,11,16
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'86 JAN 34 A11 :21
Feb 3

January 28, 1986

009/1.3/Meetings.001
RS-NMS-85-009
Communication No. 18

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: **NNWSI Trip Report - Workshop on Unsaturated Flow and Contaminant** Transport, Tucson, Arizona, January 6-9, 1986

Dear Mr. Pohle:

Please find attached the trip report prepared by Dr. David McWhorter (Water, Waste and Land) covering his attendance and participation at the NRC-sponsored Workshop on Unsaturated Flow and Contaminant Transport related to high-level radioactive waste disposal. The workshop was hosted by the University of Arizona, Tucson, Arizona, January 6-9, 1986. The purpose of the meeting was to discuss current approaches, research and thinking relative to flow and contaminant transport in partially saturated, fractured rock. Dr. McWhorter attended the meeting under Subtask 1.1 (Site Familiarization) of Contract No. RS-NMS-85-009.

Dr. McWhorter points out five technical concerns raised during the meeting which Water, Waste and Land and Nuclear Waste Cosnultants wish to emphasize as particularly significant to conceptual model evaluation and directions for data collection in the near future:

1. Estimation of net recharge.

2. Estimation of imposed flux.

3. Evaluation of the importance of fracture flow.

4. Evaluation of effects of natural circulation of air on the water balance.

5. Evaluation of vapor-phase transport of radionuclides.

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This trip report discusses these and other technical concerns raised during the meeting. The Nuclear Waste Consultants team is preparing additional technical evaluations of the matters called out in this trip report as part of Subtask 1.2 (Data Inventory and Management) and the preliminary work of Subtask 1.4 (Conceptual Model Evaluation), already underway.

If you have any questions about this trip report, please feel free to contact me or to raise specific technical questions directly with the Water, Waste and Land staff.

Respectfully submitted,
NUCLEAR WASTE CONSULTANTS, INC.

Mark J. Logsdon, Project Manager

Att: Trip Report - Unsaturated Rock/Contaminant Transport

cc: US NRC - Director, NMSS (ATTN PSB)
DWM (ATTN Division Director)
Barry Bromberg, Contract Administrator
WMGT (ATTN Branch Chief)
bc: Lyle Davis, WWL
M. Galloway, TTI
R. Knowlton, DBS

TRIP REPORT

UNSATURATED ROCK/CONTAMINANT TRANSPORT

WORKSHOP III

TUCSON, ARIZONA

JANUARY 6-9, 1986

1.0 INTRODUCTION

Dr. David McWhorter of Water, Waste & Land, Inc., attended Workshop III on Unsaturated Flow and Contaminant Transport as related to High Level Radioactive Waste Disposal held in Tucson, Arizona, January 6-9, 1986. This workshop was sponsored by the University of Arizona, the Nuclear Regulatory Commission, and the Sandia National Laboratory. The purpose of the workshop was to discuss current approaches, research, and thinking relative to flow and contaminant transport in partially saturated, fractured rock. While the workshop was motivated by problems and concerns with HLW disposal at the Nevada Nuclear Waste Storage Investigation Project (Yucca Mountain), the organizers took special care to assure emphasis on "generic" phenomena with broad interest. A spectrum of technical people from universities, government agencies, and private contractors attended the workshop.

Dr. McWhorter participated in the workshop under Subtask 1.1 of Contract NRC-02-85-009. The specific purpose was to become familiar with the most current concepts and approaches for flow and transport in unsaturated, fractured rocks with application to the Yucca Mountain site. The meeting was highly successful in that regard, especially in view of the fact that several presentations and discussions contained materials that are not otherwise accessible at this time.

The workshop was organized into six technical sessions (see Attachment 1). Prepared presentations by four to five panel members were followed by open discussions by all participants. The following sections of this report contain a brief discussion of the impressions and conclusions believed to be particularly relevant to HLW disposal at Yucca Mountain.

2.0 CONCEPTUAL AND QUANTITATIVE MODELS

Several different models and approaches to flow and transport in unsaturated, fractured porous media were presented and/or discussed. The intent of all such models is to enhance the understanding of the system, identify the phenomena of special importance, narrow the focus for experimental investigations, and, eventually, to enable the prediction of radionuclide transport to the accessible environment. From the relatively larger emphasis on flow modeling as opposed to contaminant transport modeling, it may be concluded that most investigators believe that the flow must be understood before there is much hope of successfully predicting contaminant transport. WWL is in agreement with that emphasis.

The various models and approaches discussed at the workshop can be categorized into:

1. Continuum approach based on equivalent porous medium concept.
2. Continuum approach applied separately to fractures and matrix.
3. Stochastic.

In the first of these approaches, a representative element of volume (REV) is defined that includes both fracture and matrix space. Hydraulic parameters

(e.g., permeability function, moisture characteristic, etc.) are averaged over the entire REV, assigned to the centroid of the REV and, henceforth, regarded as point values. Dependent variables such as pressure, water content, and moisture flux are similarly averaged over the REV and then regarded as point values assigned to the centroid.

There is at least one formidable difficulty with the equivalent porous medium approach. This difficulty relates to obtaining meaningful average values for the hydraulic functions required in the model. Ideally, the measurement of these functions should be made directly on a sample at least as large as the REV. This would require a sample of, perhaps, a few to several cubic meters in size. Even if it were possible to isolate a sample of the required size, one is still faced with designing instruments capable of measuring such variables as the average pressure within the REV. It seems that the only reasonable approach is to make measurements on a scale commensurate with the usual instruments and then calculate the appropriate averages for the REV. How to calculate the appropriate averages remains an unanswered question, however. Validation of the model requires field data for such variables as pressure and flux expressed as averages over the REV. Again it appears that measurements would have to be made on a much smaller scale and then appropriate averages calculated.

The second approach would use distinct hydraulic parameters (functions) applicable to the fractures and to the matrix block. It is conceivable that such measurements could be made. The problem, then, becomes one of defining the number and geometry of each element so that the overall behavior can be calculated. This approach requires that the details of the interactions between the two continua be modeled explicitly. In other words, one attempts to model the fracture system as one continuum and the matrix as a second, but

interacting, continuum. Satisfactory modeling of the interaction between the two continua seems to be a major difficulty with this approach.

The stochastic approach is believed by this writer to hold the greatest promise. In this approach the hydraulic parameters (functions) are represented as spatially correlated, random fields and characterized by statistical parameters. These are then used as inputs to the classical balance equations to produce output fields satisfying mean balance laws with effective parameters. In a sense, this approach automatically calculates the effective or average parameters required by the equivalent porous medium approach. However, it also provides in statistical terms a measure of the variation about the mean that can be expected. No real advantage in terms of data requirements is gained, however, and the problems with model validation remain formidable as well.

2.1 Fracture vs. Matrix Flow

All of the quantitative models so far applied to the system perceived to exist at Yucca Mountain indicate an extreme sensitivity of the "seepage velocity" in the system to the value of net recharge (input flux). This sensitivity derives from the fact that very rapid fracture flow occurs when the net recharge is above a critical value. For net recharge below the critical value, flow is dominantly in the matrix and the seepage velocity is orders of magnitude smaller.

Because of the variation in fracture apertures, the above reference to a single critical value is an over simplification. Nevertheless, whether the net recharge is sufficient to sustain flow in the fractures is an important and, believed to be, unanswered question. The models generally indicate little contribution via fracture flow under the value of net recharge thought

to prevail at Yucca Mountain. On the other hand, there exists field observations of fracture flow, if not on Yucca Mountain, at nearby sites subjected to reasonably similar precipitation.

Three possible explanations for fracture flow exceeding model predictions come to mind. The first, and one deserving of a great deal of study, is the value of net recharge. Current estimates range over at least one order of magnitude. The second possible explanation relates to the permeability vs. suction functions used in the models. If the fracture system remains nearly saturated over a wider range of suctions than supposed, actual fracture flow would exceed the calculated value. The permeability vs. suction curve in relation to the actual imposed flux is critical in this regard.

The mechanism by which fractures become desaturated is via lateral flow into the matrix blocks under the influence of transverse gradients of capillary pressure. As modeled, this mechanism is sufficient to keep the fracture system practically "dry" under the most reasonable value of net recharge used as the upper boundary condition. However, we note that the saturation percentage in the matrix blocks is quite high, on the order of 80 percent. Under such conditions, the relative permeability to air in the matrix blocks may be very small. Obviously, the air must flow out of the blocks as water flows in. Perhaps the resistance to escape of the air is sufficient to cause water inflow to be much less than calculated by current models that do not include the air flow in the calculations. This would have the effect of sustaining fracture flow longer than would otherwise be the case.

3.0 QUANTITY OF NET RECHARGE

It appears that the net recharge rate on Yucca Mountain is not known within an order of magnitude. A very good summary of the results of over 20

studies relating to moisture movement in the Southern Great Basin was given by Scott Tyler. Results categorized by Tyler as hydraulic based, yielded a flux range from 1×10^{-7} cm/yr to 4×10^{-1} cm/yr. Tritium studies suggest transport velocities ranging up to 60 m/yr in fractured tuff. All other estimates fall in this range. Net recharge estimated from what Tyler refers to as "simple recharge models" indicate values on the order of 0.3 to 1.0 cm/yr. These corresponds to about 1 percent and 3 percent of average annual precipitation, respectively.

Harold Bentley discussed the generalities related to the use of chloride as a tracer to calculate recharge. Apparently, this approach has not been utilized at Yucca Mountain. We are familiar with other studies of recharge using this method (David Stone, USBM, Sorocco, New Mexico) that seem to have resulted in reasonable estimates. Application of chlorine tracer procedures at Yucca Mountain appears to hold considerable promise and should be pursued.

Again, it appears that reliable estimates of travel time depend centrally upon a reliable estimate of net recharge.

4.0 GAS PHASE PHENOMENA

Evidence for significant natural air circulation through fractured rocks was provided by Doral Kemper. The salient features of such circulation and the conditions required for it to occur were discussed. Adrian Brown and David McWhorter are familiar with such phenomena and have proposed it as a means of evaporating small quantities of liquid leachate into air passing through rubble zones engineered into large piles of retorted oil shale. While Kemper provided some preliminary water balance figures that indicate a net outflow of moisture in the circulating air, it is not clear if such a process, acting in the upper zones at Yucca Mountain, could have any effect on the net

flux experienced at depth. We believe that this deserves preliminary evaluation. Specifically, it should be determined if the conditions required for such a process to occur are present at Yucca Mountain. If so, a rough analysis of the potential effects on the water balance should be undertaken.

Potential for radionuclide release to the accessible environment via water transport has been the major concern, apparently. The whole question of radionuclide release through the gas phase has received comparatively little attention. It is known that a significant vapor phase exists for some radionuclides. Once in the gas phase, either as vapor or as an aerosol, there would exist a continuous pathway to the accessible environment. It appears that the rates and directions of gas-phase radionuclide transport warrant further investigation. Heat produced by the repository will create free convection of this gas phase and substantial convection of radionuclides may occur.

5.0 CLOSURE

Numerous topics in addition to those discussed above were undertaken at the workshop. It was the intent of this report to extract those items most clearly relevant to the hydrology of the Yucca Mountain site. This has been done in a very summary manner. It is concluded that:

1. The net recharge that is input to the fractured system at Yucca Mountain is not known to within at least one order of magnitude. Chlorine tracer work should be pursued.

2. The travel time of water through the fractured, unsaturated tuff is highly sensitive to the value of the imposed flux. This is in contrast to a normal porous media and results from the large permeability and small storage capacity of the fractures.

3. The question of fracture vs. matrix flow is unresolved. It is believed that resistance to air escape from the nearly saturated matrix blocks may play an important role in sustaining fracture flow.

4. Potential for natural circulation of air and consequent effects on the Yucca Mountain water balance warrant a preliminary investigation.

5. Radionuclide transport in the gas phase warrants further attention as a principal pathway to the accessible environment.

ATTACHMENT 1

UNSATURATED ROCK/ CONTAMINANT TRANSPORT WORKSHOP III AGENDA

UNSATURATED ROCK/CONTAMINANT TRANSPORT WORKSHOP III

Theme: Unsaturated Flow and Contaminant Transport -- as Related to High Level Radioactive Waste Disposal

Sponsors: University of Arizona, Nuclear Regulatory Commission, and Sandia National Laboratory

Dates: January 6-9, 1986

Place: Hotel Park Tucson, 5151 East Grant Rd, Tucson, AZ 85712 (602) 323-6262

Costs: Registration $75, plus living expenses

PROGRAM OUTLINE

Monday, January 6

7:45 am - 5:00 pm: Field Trip to Sunnyside Lab and Superior Field Site (optional)

5:00 pm: Registration at Hotel Park Tucson Garden Room

6:00 - 7:30 pm: Reception at Hotel Park Tucson Garden Room

7:30 - 9:30 pm: Opening Remarks at Park Theater, Hotel Park Tucson
Dan Evans--Univ. of Arizona, Chairman
Tom Nicholson--NRC
Tito Bonano--Sandia

Tuesday, January 7

8:00 - 10:00 am: Panel discussion on PHYSICAL AND CHEMICAL PROPERTIES OF UNSATURATED FRACTURED ROCK WITH EMPHASIS ON TUFF
Moderator: Harold Bentley
Panel Members: Jim Davis, Thomas Theis, Scott Tyler Dan Weber

10:00 - 10:15 am: Coffee break

10:15 am - noon: Continued Panel and Open Discussion

noon - 1:00 pm: Group luncheon at Hotel (directly above Park Theater)

1:00 - 3:00 pm: Panel discussion on MATRIX VERSUS FRACTURE FLOW
Moderator: Nancy Hayden
Panel Members: Tito Bonano, Parvis Montazer, Joe Wang

3:00 - 3:15 pm: Coffee break

3:15 - 5:00 pm: Continued Panel and Open Discussion

7:30 - 9:30 pm: Panel discussion on NATURAL ANALOGS
Moderator: Stan Davis
Panel Members: Doug Brookins, Ike Winograd, Derrik Williams

Wednesday, January 8

8:00 - 10:00 am: Panel discussion on COUPLED PROCESSES
Moderator: Art Warrick
Panel Members: Krishan Wahi, Frank Kulacki, Don Nielson, W.L. Polzer, Dan Reda

10:00 - 10:15 am: Coffee break

10:15 am - noon: Continued Panel and Open Discussion

noon - 1:00 pm: Group luncheon at Hotel

1:00 - 3:00 pm: Panel discussion on MODEL APPROACHES AND CALIBRATION
Moderator: To Be Announced
Panel Members: Ralph Peters, Todd Rasmussen, T.N. Narasimhan, Andy Tompson

3:00 - 3:15 pm: Coffee break

3:15 - 5:00 pm: Continued Panel and Open Discussion

7:30 - 9:30 pm: Panel discussion on EFFECTS OF VAPOR PHASE
Moderator: Doral Kemper
Panel Members: Karsten Pruess, Doug Smith, Ron Green, Ed Weeks

Thursday, January 9

8:00 - 10:00 am: Discussion of other related topics. Development of conclusions and research needs.
Moderators: Tito Bonano and Dan Evans
Comments: Gedeon Dagan

10:00 - 10:15 am: Coffee break

10:15 am - noon: General discussion continued

Noon: Conclusion of workshop