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CENTER FOR NUCLEAR WASTE REGULATORY ANALYSES

TRIP REPORT

SUBJECT: Trip to Workshop on Significant Issues and Available Data (20-5708-861)

DATE/PLACE: November 13–16, 1996
Berkeley, CA

AUTHOR: S. Stothoff

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PERSONS PRESENT:

The meeting was attended by S. Stothoff (CNWRA); Department of Energy (DOE) staff and contractors; an invited panel of experts on unsaturated-zone hydrology; facilitating personnel from Geomatrix; and interested observers. Approximately 50 persons were present in total.

BACKGROUND AND PURPOSE OF TRIP:

A panel of experts on unsaturated-zone hydrology has been convened by DOE with the express purpose of providing a basis for determining what approaches to modeling the unsaturated zone are reasonable. In particular, the panel is to be elicited on issues regarding percolation flux at the repository horizon. The finding of the panel may be presented to regulators to justify the approaches that DOE might take in license-application activities. The elicitation is also intended to be incorporated into total-system performance-assessment (TSPA) modeling efforts for the viability assessment TSPA (TSPA-VA).

The workshop on significant issues and available data represents the first of three workshops to be spaced over several months. This first workshop had the stated purpose of familiarizing the seven experts with the site and data that has been collected in the process of site characterization. As most of the experts are unfamiliar with the site, some overview of modeling ideas was presented, with the bulk of the modeling presentations reserved for a second workshop scheduled for December 18 to 20, 1996. An expert-elicitation session will occur in mid-January, which apparently will not be open to observers. The third planned workshop, which will occur in mid-February, is to provide feedback of the panel findings. The issues that the panel are to consider are related to site characterization, so that future climate and the impacts of the repository are not to be considered by the panel.

Three additional expert-elicitation panels will be conducted by DOE over the next year or two. The other panels will investigate thermohydrologic, waste-package, and saturated-zone issues. The panels are being convened to address the issues that are considered most significant for repository performance by the DOE; thus, each workshop is of great interest to the NRC and CNWRA.

SUMMARY OF PERTINENT POINTS:

Agenda and Handouts

The agenda for the meeting is attached. A list of the materials provided to the panel is also attached an attendence list. Hard copies of the overhead slides were not available at the workshop, but will be distributed within 2 weeks of the workshop and will be available from the author once these are received.

Expert Elicitation Panel

The panel comprises G. Campbell (Washington State University), G. Gee (Battelle, Pacific Northwest Laboratories), J. Mercer (GeoTrans), S. Neuman [University of Arizona (UAZ)], K. Pruess [(Lawrence Berkeley National Laboratories (LBNL)], D. Stephens (Dan Stephens, Inc.), and E. Weeks [United States Geological Survey (USGS)].

Methodology Development Team (MDT)

The MDT is responsible for selecting the panel, organizing the workshops, conducting the expert elicitation, and collating results. MDT members include R. Andrews (Intera), T. Bjerstedt (DOE), G. Bodvarsson (LBNL), K. Coppersmith (Geomatrix), D. Hoxie (USGS), E. Kwicklis (USGS), P. Morris (Applied Decision Analysis), M. Pendleton (WCKS/M&O), R. Perman (Geomatrix), T. Sullivan (DOE), and R. Youngs (Geomatrix).

Presenters

The sessions were run by representatives of Geomatrix. Staffs of M&O and Los Alamos National Laboratory (LANL), LBNL, and the USGS made presentations. In addition, a representative of Nye County made a presentation.

SUMMARY OF ACTIVITIES:

The author attended all presentations and discussions.

CONCLUSIONS:

Overall Impressions

The workshop was well run and quite informative, although it was evident that the short startup schedule (the process began in October) hampered preparation of presentations, coordination among the various presenters, and preparation of handouts. The presenters were open in their presentations and questions received frank responses.

Noteworthy Highlights

Much of the material presented to the panel has been presented to various oversight panels such as the Advisory Committee on Nuclear Waste and the Nuclear Waste Technical Review Board. The intent for the workshop presentations was somewhat different, as the panel is to provide an opinion that is integratory in nature. Consistent with oversight-panel presentations, lines of evidence all seem to indicate

that percolation fluxes at the repository horizon are expected to be in the range of about 1 mm/yr to something slightly more than 10 mm/yr.

The issue of fast pathways was perhaps the most contradictory issue discussed. Based on barometric information, core samples, and ^{36}Cl observations, the PTn is interpreted to be a significant buffer to moisture flow with scattered fast pathways associated with faults. However, based on geochemical measurements, perched water at the TSw/CH interface (below the ESF elevation) is considerably younger than PTn water and appears to have largely bypassed the PTn unit, implying that either the PTn allows a great deal of moisture to pass quickly, or that a significant amount of lateral flow is occurring below the PTn unit (perhaps in the perched body). Fracture-coating data in the ESF similarly suggests that the coatings are formed by water that does not interact strongly with the matrix, although it does appear that fracture flows are relatively steady over time as would occur with significant buffering of flow pulses.

As with the issue of fast pathways, connectedness of the fracture network also yielded contradictory lines of evidence. Extrapolation of discrete fracture networks from statistics using ESF fracture maps suggests that the fracture network should exhibit sparse connectivity patterns even at the scale of 200 m, while pneumatic observations do not confirm this sparseness anywhere except at the single-heater test location, where the sparseness is at a scale of less than 10 m.

The matrix permeability in the TSw unit is of great interest. The matrix permeability measured in core samples suggests that fracture flow is fairly widespread, while the inverse modeling of the 3D UZ site-scale model predicts much larger bulk permeabilities indicating little fracture flow should occur. Some of the discrepancy between these two lines of evidence may be due to an inappropriate conceptual model for flow in the site-scale model and some may be due to an apparent mismatch between conventional relationships between matric pressures, saturation, and relative permeability for welded tuffs (used in the site-scale model) and relationships measured by the USGS. The measured relationships yield orders of magnitude greater relative permeability under unsaturated conditions. The experimental procedure is currently being examined for sources of error.

Formal Presentations

K. Coppersmith (Geomatrix) introduced the format for the workshops. The process to be followed consists of (i) select the panel of experts, (ii) conduct meetings with the experts to present information, (iii) elicit expert interpretations, (iv) provide feedback and finalize interpretations, (v) subsequent calculations and aggregations using the elicitations, and (vi) document the process. Experts were selected based on experience in arid-zone infiltration, characterization of variably saturated fractured rock, analysis of numerical models of variably saturated flow, and analysis of unsaturated flow data.

R. Andrews (M&O) provided an overview of the role of unsaturated-zone (UZ) flow modeling relative to TSPA and briefly discussed conceptual models of UZ flow used in TSPA analyses. Andrews emphasized that the role of the experts is to assist in defining the "reasonableness" of the current UZ flow model, the "reasonable" likelihood of alternative conceptual models, and assist in generating "reasonable" parameter uncertainty ranges and distributions. In questioning, it was determined that the UZ flow model to be examined is the LBNL site-scale model; the transport modeling is being performed by LANL.

G. Bodvarsson (LBNL) presented current results from the 3D UZ site-scale model, with all results extracted from a recent synthesis report that was provided to the panel. Example predictions and data matching that Bodvarsson discussed included borehole moisture contents, gas pneumatics, and temperature

profiles. Discussion of temperature profiles revealed that new data is far superior to early data and is of sufficiently high quality to make relatively good estimates of percolation fluxes assuming that gas circulation is not an important mechanism for moisture redistribution. Gas-age measurements in the TSw unit are felt to be an important additional source of information that should be gathered in order to assess the value of the thermal profile for estimating percolation fluxes. Bodvarsson further noted that lateral diversion would only be expected above the zeolitic regions below the repository (thereby bypassing a zone of potentially significant radionuclide retardation).

E. Kwicklis (USGS) provided an overview of the history of site-characterization activities to orient the panel. Percolation-flux issues that he terms unresolved include: (i) matches of the computer models to observed matrix potentials and saturations due to not considering fractures, (ii) the ability of temperature profiles to provide percolation estimates due to the possibility of confounding mechanisms, (iii) assumptions required for ^{36}Cl modeling, (iv) assumptions required for estimating flux using accumulations of secondary minerals, and (v) interpretations of heat-flux profiles. Kwicklis presented issues familiar to YM hydrologists, including the role of the PTn in lateral diversion, interpretation of radioisotope tracer studies, the use of barometric data to infer permeability distributions, and the potential for lower-UZ flow pathways to bypass the zeolitic zones due to associated lower permeabilities especially with high percolation rates.

R. Clayton (M&O) discussed the 3D Geologic Framework Model that has been developed to provide a consistent source of information across all DOE investigators. The model is based on the EarthVision software, and includes 61 faults, 36 lithostratigraphic units, 65 square miles, and a maximum depth of 13,000 ft. The model is based on 50 significant boreholes, with only one borehole extending to the basement formation. Most of the fault blocks are uncontrolled; a few are controlled with borehole information or gravity surveys.

L. Flint (USGS) presented measurements and interpretations from the matrix-core sampling program. The information is collected in a FY96 milestone synthesis report with associated electronic database. Flint noted that 10,000 cores have been processed over the life of the sampling program. Based on the cores from 31 boreholes, 30 hydrogeologic lithostratigraphic layers have been delineated, with core-sample properties changing about 100 times faster in the vertical than in the horizontal due to depositional effects even though individual cores do not show anisotropy. For the purposes of numerical modeling, regression formulae have been developed relating all thermohydraulic properties to easily measured porosity. It was emphasized that zeolitization has a strong impact on hydraulic properties and there are complex zeolitization patterns above the water table. A controversial set of measurements suggest that neither the van Genuchten nor the Brooks-Corey models provide consistent moisture retention and relative-permeability relationships, with measured values of relative permeability orders of magnitude larger than predicted at low saturations by these models. Flint feels that the discrepancy may be due to systematic measurement bias, however.

L. Anna (USGS) presented controversial modeling results aimed at extracting simulated 3D discrete-fracture networks using properties derived from Exploratory Study Facility (ESF) mapping exercises. Anna proposes the scale-independent measures of fracture area per rock volume, and exposed length per fracture area, and calibrated stochastic models using these ideas. Based on his modeling results, he generates relatively sparse networks of continuous fractures, and these networks do not appear to behave as a continuum at scales less than 200 m. The modeled fracture networks generated controversy due to lower calculated permeabilities than measured and due to the sparsity of connection (apparently no packed-off air-permeability test zone has ever been found that is disconnected from the fracture network,

as Anna's results would suggest). S. Neuman noted that modeling work has suggested that even discontinuous networks embedded in a porous medium can transmissiblity a fracture continuum.

A. Flint (USGS) provided an overview of his recent synthesis report on shallow infiltration. He discussed the sources of information used in predictions, including soil maps, vegetation maps, and surface-based measurements. He noted that a full set of measurements of the neutron-probe network requires 5 to 6 people for more than a week. Flint also noted that the data collected includes the wettest year ever recorded in the vicinity, and suggests synthetic weather records to overcome this bias. He opined that channel flow may provide more water in upland channels with little cover, but is relatively more significant in deep alluvium. Observations of bomb-pulse ^{36}Cl concentrations have been found everywhere that measurements have been made in the TCw unit and the pulse has usually penetrated the PTn unit. Flint noted that winter runoff is usually much more significant than summer, despite much lower storm intensities, due to filling up soil storage. A brief description of the numerical prediction models was presented as well, and he noted that the detailed Richards-equation-based model is simply too slow for use as more than a verification tool for the simpler bucket model. Flint suggested that the point of no return for infiltrating water is 2 m into bedrock and 6 m into alluvium.

J. Rousseau (USGS) presented the results of studies examining *in situ* gas-pressure, temperature, and water-potential measurements. The gas-pressure measurements are used to examine fluctuations due to barometric influences, and are being used to examine the bulk permeability of the fractures and faults. The change in the signal characteristics when the Tunnel Boring Machine (TBM) penetrates distinct features (e.g., the PTn unit, faults) is used to infer permeabilities, with indications of fast pathways along faults. Interpretations of perched-water zones existing above the TSw/CH interface are supported by a lack of pneumatic communication across this zone. In contrast to implications of the modeling work of L. Anna, Rousseau has not observed local "dead zones" when packing off intervals of boreholes, suggesting that the fracture system is very inter-connected. Temperature-profile data in boreholes, using sensors accurate to about 0.001 degrees C, also are being used to estimate total infiltration flux. Dry isothermal zones in the Tiva Canyon units are interpreted to either occur due to the process of warming infiltrating water, or due to evaporation due to bulk gas-phase movement through the formation. Calculations suggest that evaporation can only account for about 0.1 mm/yr through gas-phase movement.

G. LeCain (USGS) discussed a relatively limited set of borehole-based air-injection testing including 4 surface boreholes and boreholes drilled from Alcoves 1 and 2 in the ESF. All tests were single-hole tests except for one set of cross-borehole tests in Alcove 2 in the ESF. The collection of tests suggest that the TCw and TSw units have roughly 10 darcy and 1 darcy permeabilities, respectively, with the vertical permeability in the TSw unit approximately 10 darcy. Packed-off zones were between 2 and 4 m in length, intercepting an average of 9 fractures per test. Interpretations of the pressure records suggest that, although no flowing water was directly observed, water within the fracture system was moving to allow for the passage of air. Cross-hole tracer tests were also performed for the 2 boreholes in Alcove 2, with first arrival times on the order of 10 min and peak arrival times on the order of 40 to 80 min. Significant tortuosity effects are observed for the tracer. Interpretations are hampered by apparent unanticipated tracer adsorption. LeCain mentioned that the new lateral borehole penetrating the Ghost Dance Fault suggests that the fault is approximately 11 to 12 m across at the repository horizon.

J. Wang (LBNL) discussed monitoring work for moisture balances in the ESF, presenting temperature and relative humidity information in the ESF that display strong weekend effects. Turning off ventilation for several days apparently can return relative humidity levels in portions of the ESF to nearly 100 percent. ESF wall temperatures are typically observed to be 1 degree C cooler than air temperatures.

Wang also included calculations of equivalent evaporation rates from the ESF walls that suggest that generally 30 to 370 mm/yr is being removed from the wall areas, with expected rates on the order of 100 to 300 mm/yr. Evaporation-flux estimates include construction water. Wang discussed 2D drift-scale modeling results with assumed highly heterogeneous porous media that predict that the drift walls are capable of delivering this amount of water to evaporation, although the rate of delivery should decrease greatly over time. Wang noted that at the single-heater site, cross-borehole pneumatic testing does identify intervals with little or no communication on the scale of tens of meters, with a controlling block size of about 10 m.

P. Montazer (Multimedia Environmental Technology, Inc., contractor to Nye County) presented pneumatic-pressure observations and interpretations based on NRG-4 and ONC-1 boreholes and TBM-mounted devices. Montazer agrees that faults provide highly permeable pathways, although inferred permeabilities are perhaps an order of magnitude smaller than DOE estimates. Discussion of this point suggests that perhaps the porosities disagree by about the same order of magnitude, thereby providing compensating errors. Montazer also presented preliminary modeling results that he suggests strongly indicate that maximum temperatures could be as low as 30 degrees C if adequate ventilation was maintained during repository operation.

G. Patterson (USGS) discussed perched-water observations and inferences. Perching has been observed or inferred in boreholes UZ-1, UZ-14, SD-9, NRG-7a, SD-12, and SD-7, all typically in the location of the basal vitrophyre of the TSw unit, at elevations ranging from 2,800 to 3,170 m. All dry-drilled boreholes deep enough to hit the perched zone have zones of observed perching, although earlier deep boreholes drilled using wet drilling fluids do not. Pumping tests in the perched-water bodies have been performed in UZ-14 and SD-7. Analysis of the results suggest that pumping periods were too short to identify the influences of nearby faults. Patterson also briefly presented interpretations by J. Czarnecki (USGS) that suggest the large hydraulic gradient north of the repository footprint may in fact represent a large perched zone at a comparable lithostratigraphic location as, and perhaps even connected with, the other perched-water bodies.

J. Fabryka-Martin (LANL) discussed observations and interpretations of radioisotope measurements. To date, 22 systematically collected samples, 82 samples collected at features, and 22 samples associated with PTn contacts have been analyzed for stations between 2+00 and 51+00. Fabryka-Martin presented an overlay of her ^{36}Cl observations and A. Flint's estimates of infiltration over the ESF, suggesting that there apparently is not a strong correlation between the two. Modeling results for ^{36}Cl transport, using 1D simulations, were also presented. A reconstructed atmospheric ^{36}Cl signal over approximately 100 ka was used as input. The signal was constrained using dating information from 4 packrat middens at differing elevations and locations, and features an apparent systematic increase in atmospheric ^{36}Cl at about 10 ka. Assuming the variable ^{36}Cl signal but constant infiltration rates, 5 mm/yr is sufficient to provide bomb-pulse signals at the ESF horizon if a dual-permeability model is used assuming that there is some fracturing in the PTn. Based on the modeling predictions, the working hypothesis is that the combination of at least 1 mm/yr infiltration and a fast pathway through the PTn is required to observe bomb pulse tracers at the ESF.

A. Yang (USGS) discussed data and interpretations based on pore-water analyses, primarily obtained using squeezed waters (although he presented information suggesting that waters obtained through centrifugation provide essentially identical analyses). Through lines of evidence including ^{3}H, ^{36}Cl, and water chemistry analyses, Yang concluded that waters in the perched-water bodies are young (e.g., 500 a) while waters in the PTn are much older. The evidence also suggests that most of the water was

precipitated during the winter, rather than the summer. The implication that the PTn is largely bypassed by infiltrating waters sparked a good deal of discussion, as this implication is in direct contradiction to the 3D UZ site-scale model and barometric observations. One explanatory hypothesis is that all of the boreholes from which PTn data was obtained are in low-infiltration areas; another is that waters in the perched zone may have come in laterally from the north.

Z. Peterman (USGS) presented data and interpretations based on studies of low-temperature fracture fillings, calcite and opal, obtained from the ESF. Age dating uses ^{14}C, U-series, and $^{206}Pb/^{238}U$ ratios to obtain a sequence of ages to 9 Ma, although the slow deposition rates introduce unavoidable smearing in the results. There does not appear to be a systematic spatial trend in the coatings and there is no apparent correlation to ^{36}Cl observations. The coatings generally occur in fractures with apertures of several mm and in the wide portions of single apertures. Using several isotopic signals obtained from the fracture coatings ($\delta^{13}C$, $\delta^{18}O$, $\delta^{87}Sr$, $^{234}U/^{238}U$), it was inferred that there is apparently little interaction between the percolating waters and the rock below the soil zone. It is also inferred that the deposition process is slow but continuous. The current best estimate of long-term-average percolation flux in the fractures is about 2 mm/yr, although this is considered a potentially minimum flux. There is reportedly strong evidence that water will enter open cavities (i.e., lithophysae), with estimates of fluxes on the order of 0.4 mm/yr; however, such observations appear to be linked to nearby fractures. Near-future work is aimed at estimating time histories of the fracture fluxes using the age-dating information.

PROBLEMS ENCOUNTERED:

None

PENDING ACTIONS:

None

RECOMMENDATIONS:

None

ATTACHMENTS:

Meeting Agenda
List of materials given to experts.

See author for copies of presentation overheads.

REFERENCES:

None.

SIGNATURES:

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Date

FINAL AGENDA
WORKSHOP ON SIGNIFICANT ISSUES AND AVAILABLE DATA

UNSATURATED ZONE FLOW MODEL (UZFM)
EXPERT ELICITATION PROJECT

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GEOMATRIX

FINAL AGENDA
WORKSHOP ON SIGNIFICANT ISSUES AND AVAILABLE DATA

UNSATURATED ZONE FLOW MODEL (UZFM)
EXPERT ELICITATION PROJECT

November 14 and 15, 1996
Lawrence Berkeley National Laboratory
Berkeley, California

PURPOSE: The purposes of this workshop are to: (1) introduce the expert panel members to the UZFM Expert Elicitation Project; (2) summarize the significant issues related to the unsaturated zone process models for the Total System Performance Assessment (TSPA); and (3) summarize the various available datasets related to these significant issues.

APPROACH: The approach taken is to first introduce the significant issues that have emerged from previous modeling of the unsaturated zone flow system and from incorporation of that modeling into the TSPA. The majority of the workshop then consists of presentations and discussions of the various data developed over the past several years to characterize the unsaturated zone in the Yucca Mountain region. The workshop provides an opportunity for the expert panel members to gain a first-hand understanding of the data, their uncertainties, and the course of the remainder of the project.

THURSDAY, NOVEMBER 14

8:30 - 8:35 Welcome

8:30 - 8:45 Introduction to the UZFM Project (K. Coppersmith, Geomatrix)

8:45 - 9:15 Purpose of UZFM Project to TSPA-VA (R. Andrews, M&O)

9:15 - 10:15 UZ Flow Model Overview (B. Bodvarsson, LBNL)

10:15 - 10:30 Break

10:30 - 11:30 Unsaturated Zone Conceptual Model (E. Kwicklis, USGS)

11:30 - 12:15 Geologic Framework (R. Clayton, M&O)

12:15 - 1:15 Lunch

1:15 - 2:15 Hydrogeologic Units and Matrix Properties (L. Flint, USGS)

2:15 - 2:45 Fault and Fracture Hydrologic Properties (L. Anna, USGS)

2:45 - 3:00 Break

3:00 - 4:30 Net Infiltration (A. Flint, USGS)

4:30 - 5:30 In-situ Hydrologic Conditions (J. Rousseau, USGS)

5:30 - 5:45 Comments from Observers

FRIDAY, NOVEMBER 15

8:30 - 9:15 Unsaturated-Zone Gas-Flow System: Pneumatic Testing in Surface-Based Boreholes and the Exploratory Studies Facility (G. LeCain, USGS)

9:15 - 10:00 Moisture Balance in the ESF (J. Wang, LBNL)

10:00 - 10:15 Break

10:15 - 11:00 Studies Conducted by Nye County, Nevada (P. Montazer, Multimedia Environmental Technology, Inc.)

11:00 - 11:45 Identification of Water-Flow Pathways: Perched-Water Occurrences (G. Patterson, USGS)

11:45 - 12:30 Identification of Water-Flow Pathways: "Fast" Pathways (J. Fabryka-Martin, LANL)

12:30 - 1:30 Lunch

1:30 - 2:15 Identification of Water-Flow Pathways: Unsaturated-Zone Hydrochemistry (A. Yang, USGS)

2:15 - 3:00 Identification of Water-Flow Pathways: "Slow" Pathways (Z. Peterman, USGS)

3:00 - 3:15 Comments from Observers

3:15 - 3:30 Where We Go From Here (K. Coppersmith, Geomatrix)

3:30 Adjourn

UNSATURATED ZONE FLOW MODEL EXPERT ELICITATION PROJECT

REFERENCES DISTRIBUTED TO EXPERT PANEL MEMBERS

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UNSATURATED ZONE FLOW MODEL EXPERT ELICITATION PROJECT

REFERENCES DISTRIBUTED TO EXPERT PANEL MEMBERS
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