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MINUTES OF THE DECEMBER 14, 1993 MEETING OF THE ACNW WORKING GROUP ON UNSATURATED ZONE FLOW AT THE POTENTIAL YUCCA MOUNTAIN HLW REPOSITORY SITE LAS VEGAS, NEVADA

[Ms. Lynn Deering was the Acting Designated Federal Official for this meeting.]

Dr. William Hinze, Working Group Chairman, opened the meeting by introducing himself and asking the three consultants to introduce themselves, Paul Davis, SNL, William Sackett, University of South Florida, and Darrell Leap, Purdue University.

Dr. Hinze noted that the characterization of the subsurface hydrology and hydrochemistry are among the very most important topics in siting a HLW repository at Yucca mountain. He noted three basic areas of interest to track throughout the day: 1) advances made in understanding the processes of the fluid flow and their controls in the welded and nonwelded tuffs in the unsaturated zone, 2) status of the data being acquired and the modeling, and 3) uncertainties in the unsaturated zone (UZ) flow and transport at the present time and projections about the uncertainties that are likely to persist throughout site characterization.

He added that the committee was only looking at one small aspect of the subsurface hydrology, and future Working Group meetings are planned to look at a more comprehensive view of the geohydrology and the hydrochemistry. Upon saying that, Dr. Hinze introduced the first speaker, Mr. Ernie Hardin, University of Arizona.

Ernie Hardin, University of Arizona, Overview of Apache Leap Research Program

Mr. Hardin indicated that he would focus his discussion on the Apache Leap program that deals with hydrochemistry travel time and groundwater flow paths, as opposed to air permeability testing and stochastic modeling, which is also being studied at the field site.

Highlights from his presentation include:

- The Apache Leap research program has been funded by the NRC under several contracts for the past ten years.
- The key question they are trying addressing is can stabilized isotopic signatures be used to understand travel time and groundwater flow paths, and what is the relationship between these signatures and radiocarbon and other radioisotope signatures useful in delineating flow paths and travel times.

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- The Apache Leap tuff in Arizona has been dated to be about 24 million years old using potassium argon, and is about 400 meters thick, It is all one cooling unit. The area is a copper mining district, with a tunnel extending under an ephemeral creek, Queen Creek. When the creek flows, discharge can be seen in the tunnel in major fractures. Young, old, and mixtures of the two waters can be observed in the tunnel. The older water is discharged from a perched aquifer. Water flow in the creek and in the fractures in the tunnel is monitored, along with electrical conductivity measurements. Mr. Hardin noted that fracture and matrix flow is being modeled using a dual continuum model.

- A deep slant borehole was put in at a 45 degree angle to intersect steeply dipping fractures zones. He noted that there is a very thin soil cover at the site, due to erosion. The site gets about 24 cm of rain per year. He explained the drilling and coring process. A TV camera is used to survey the core. The upper aquifer has been sampled at multiple locations. Two hundred meters of core have been collected.

- Geophysical logging being done includes natural gamma, spectral gamma, gamma-gamma density, neutron, dual detector, and the EM-300 induction tool. He noted the neutron log shows where the water is, which compares well with core data. He noted the goal of the logging is to identify channels for infiltrating water through the vadose zone and sample those for hydrochemical analyses. He noted the EM-39 log is very repeatable, and has been run ten times. Next steps include running geophysical tomography to resolve the geometry of the electrical properties of the site.

- Eight zones for core squeezing have been identified based on geophysics. They borrowed Al Yang's core squeezing cell. The maximum amount of water to be squeezed has been 17 ml, but many samples yield nothing. Preliminary data is as expected based on the evolution of water, that is, water entering the matrix is slightly more evolved than that flowing rapidly through fractures.

- Some anomalies exist, including high nitrate concentrations. Nitrates are much higher in cores taken below the upper perched aquifer. However, other samples of the aquifer reveal high nitrates. Sulfates are also high. They also found as much as 50 ppm of dissolved organic carbon in samples and do not know where it is coming from. He speculates that it may be due to carbon humic units getting trapped in interstices of the rock matrix after the water is imbibed, then remobilized or evaporated, and the carbon remains trapped there.

- They are looking to methods other than squeezing to get water from the cores, because more water is needed to do carbon

isotopes, radiocarbon, carbon 13, total carbon, and inorganic carbon and major anion and cation analyses. Vacuum extraction is one technique being considered.

- Other analyses include use of argon gases and CFCs to assist in flow path and travel delineation studies.

Questions:

- Mr. Davis indicated that he was having trouble understanding the relationship between Apache Leap and Yucca Mountain, and asked for an example of what has been learned at Apache Leap that affects our understanding of Yucca Mountain. Mr. Hardin responded that the field site may help to understand the presence of high dissolved organic carbon, if also present at Yucca Mountain. He also noted that there have been many years of testing of parameters at Apache Leap, which supports the work of Dr. S. Nueman, UAZ, in his 3-D stochastic transport modeling for Yucca Mountain. He added that they have also developed methods and methodologies, and focus on how methodologies affect results, which can be applied to Yucca Mountain.

- Dr. Leap asked how closely the mineralogy matches the Yucca Mountain site. Mr. Hardin indicated that the biggest difference between the two sites is stratigraphy but he thinks there are similarities in mineralogy.

- Dr. Sackett asked if they have considered using uranium thorium series to assess rates of the different processes, such as solution rates. Mr. Hardin indicated that he was measuring uranium in the squeezed water from the cores, as well as other waters. He indicated he is looking for a split between UR 234 and UR 238 as the water evolves.

- Bill Ford of NRC staff asked whether they have had trouble obtaining samples of any specific isotopes from the rock. Mr. Hardin indicated that they have been able to sample the isotopes they have set out to sample. He added they believe C-14 will be the most useful isotope.

- Mr. Johnson asked whether they have a gas phase model, which might be more analogous than a moisture model to Yucca Mountain. Mr. Hardin responded that no work was being done at this time, but a thesis was focused on this about five years ago.

Joe Dlugosz, YMPO, Unsaturated Zone Program Overview

Mr. Dlugosz indicated that the purpose of this meeting is to examine the current understanding of matrix and fracture flow in the unsaturated zone and to address concerns raised by the State of

Nevada and the NRC regarding characterization and conceptual and numerical models, and DOE's accelerated surface based testing program to address some of these issues.

Highlights from his presentation include:

- Key issues to be addressed at the Working Group include mechanisms for infiltration in the unsaturated zone, how these mechanisms may change in the future, passive and active field tests, current conceptual models considered, interfaces between site characterization and performance assessment modeling, and current results of groundwater age dating.

- Mr. Dlugosz noted three major points, 1) a large part of the hydrology program is directed to the unsaturated zone, 2) the UZ program is an integrated and well coordinated effort, an example being how the discovery of perched water in UZ-14 was handled, and 3) success is dependent on the sampling and testing systems utilized in the field at multiple scales. He emphasized the importance of scale with respect to collecting matrix and fracture data in the field and being able to use these data in the models.

- Mr. Dlugosz discussed the accelerated surface based testing program which was initiated in response to comments received by the State and NRC. Comments from NRC include DOE's need to look at the effects of tunnel ventilation and consider effects of ventilation on ability to do testing, prior to tunnel construction, the need for DOE to evaluate the potential for air movement from the ESF to adversely impact the collection of geochemical data necessary for site characterization. Both comments remain open. The State expressed concern in a February 4, 1993 letter for the continued priority assigned to early excavation of the ESF, the lack of a pre-disturbed pneumatic database, the current schedule possibly preventing adequate characterization to support performance assessments and regulatory findings, and delays in the tunneling to allow for a carefully designed surface based testing program with specific mention of pneumatic conductivity of the bedded zone. In response to these comments, DOE is planning to accelerate the surface based testing program to establish baseline conditions in the unsaturated zone.

  DOE plans to conduct pneumatic testing in holes 2, 4, 5, and 6, and UZ-14. Schedules for surface based testing and ESF construction are under review to ensure pre-disturbance pneumatic data is obtained.

April Gil, YMPO, Regulatory Issues Being Addressed by DOE/YMPO Unsaturated Zone Studies

Ms. Gil discussed the regulatory framework for the work that going on in the unsaturated zone.

Highlights from her presentation include:

- Repository regulations include 40 CFR 191, EPA's regulation, 10 CFR 960, the DOE's regulation for general guidelines for the recommendation of sites for nuclear waste repositories, and 10 CFR 60, NRC's regulation that governs the repository, which was the focus of her presentation.

- Relevant 10 CFR 60 requirements include 60.122, overall system performance objective, and 60.113, subsystem performance objective which requires at least a 1000 year pre-waste emplacement groundwater travel time. Siting Criteria 10 CFR 60.122 requires that the combination of favorable conditions and engineered barriers provide reasonable assurance that performance objectives for waste isolation are met. Favorable Conditions include 60.122(b)(7), a pre-waste groundwater travel time that substantially exceeds 1000 years, 60.122(b)(8), low moisture flux, absence of fully saturated voids contiguous with water table, low permeability hydrologic unit above host rock, host rock that provides for free drainage, and climatic regime in which precipitation is small percentage of potential evapotranspiration. Potential adverse conditions must be adequately investigated to determine the extent to which they are present, and the impact must be assessed within the context of performance objectives. Relevant PACS include 10 CFR 60.122(c)(2), Potential for human activity to adversely affect groundwater flow, 10 CFR 60.122(c)(3), potential for natural phenomena to adversely affect groundwater flow, 10 CFR 60.122(c)(4) potential for structural deformation to adversely affect groundwater flow, 10 CFR 122(c)(5), potential for changes in hydrologic conditions that would affect the migration of radionuclides, 10 CFR 60.122(c)(6) potential for changes in hydrologic conditions from climatic changes, 10 CFR 60.122 (c)(7), groundwater conditions in host rock that could increase the solubility or chemical reactivity of the EBS, 10 CFR 60.122(c)(8), geochemical processes that would reduce sorption of radionuclides, degrade host rock, or adversely affect EBS, 10 CFR 60.122 (c)(9), groundwater conditions in host rock that are not reducing, 10 CFR 60.122 (c)(20) rock or groundwater conditions that would require complex engineering measures, 10 CFR 60.122 (c)(22), potential for water table rise to repository, 10 CFR 60.122(c)(23) potential for perched water to saturate repository or provide faster flow path to accessible environment, and 10 CFR 60.122(c)(24), potential

for movement of gaseous radionuclides through unsaturated zone to the accessible environment.

- Dr. Hinze asked who is responsible for integrating the unsaturated zone studies. Ms. Gil responded that everyone in the program in general, and the Work Breakdown Structure (WBS) managers at DOE, which includes Joe Dlugosz, Claudia Newberry, and the USGS Principal Investigators (PIs). She added that the M&O contractors have the overall responsibility for overall integration of the program, including planning, budgeting, scheduling, and allocation of resources.

Mike Chornack, USGS, Overview of Unsaturated Zone Studies at the Yucca Mountain Site

Mr. Chornack discussed the nine separate studies involving UZ hydrology, and the PIs of each study. He explained that all of the studies feed into a site scale model, being developed under the modeling and synthesis study plan by the USGS and Lawrence Berkeley Labs (LBL). The modeling is in turn used to refine the kind and amount of data being collected under each study. The studies include 1) meteorology and shallow UZ study, 2) water movement tracer study, 3) gas phase circulation, 4) deep borehole studies, 5) hydrochemical analysis of gas and water samples, 6) air permeability testing to examine fracture permeabilities along the borehole, 7&8) ESF studies on diffusion tests and construction and post-construction phase testing, and 9) the modeling studies including small scale fracture rock modeling to support ESF studies, and larger site scale modeling.

Highlights from Mr. Chornack's presentation include:

- The ESF starter tunnel was just completed and the first alcove is being mined. ESF tests are expected to start as early as January or February, 1994.

- The stratigraphy is divided into two units: the stratigraphic unit, based on eruptive histories, and the geohydrologic unit, comprised of welded and nonwelded tuffs that have similar hydrogeologic properties. Flow is predominately through fractures in the welded units, and through the matrix in the nonwelded units.

- Fractures in the welded units consist of cooling joints, and tectonically induced fractures. The fractures tend to die out in the welded units rather than propagate to the nonwelded material. Where the fractures terminate a barrier to rapid fracture flow forms. While faults extend through both units, a clay gouge and fracture filling tend to impede rapid downward fracture flow and upward movement of vapor and gases. Dr. Hinze asked if this was a generalization and Mr. Chornack agreed that it was, based on what is observed in borehole

conditions and surface mapping. Dr. Hinze questioned how vertical boreholes could be used to characterize vertical fractures. Mr. Chornack clarified that his statements are based on his own observations of outcrops of the Tiva Canyon welded and the Paint Brush non-welded unit.

- Dr. Pomeroy asked how the data flows from the investigators to the modelers to the performance assessors and back. Mr. Chornack noted one way is to hold quarterly modeling meetings.

- Dr. Moeller asked how much independence the USGS has to do their studies. Dr. Chornack responded that they have a lot of flexibility within certain guidelines. Larry Hayes of USGS added that an agreement is in place that says if there is a technical dispute between DOE and USGS, USGS will publish the report as they wish. Mr. Paul Davis asked whether the USGS was free to investigate the concerns raised by the State of Nevada. Dr. Chornack responded yes, noting as an example the implementation of accelerated surface based testing program, recommended by the State, and supported by the USGS. A discussion on funding and priorities followed.

- Dr. Steindler asked how the USGS publishes data and conclusions, and what is the delay time. Dr. Chornack indicated the mechanism is open file reports and Water Resources Investigations Reports. Larry Hayes noted the delay time has been a problem, but they are trying now to accelerate getting data out by submitting data to a local records center and then to the Las Vegas Central Records Facility. Another approach is use of analysis papers to get out interpretive information quickly.

- Mr. Davis asked whether the USGS could stop the proceeding of the ESF excavation if it had not completed ambient testing. April Gil, YMPO, noted that encountering perched water would stop the ESF construction, as would any PI that had questions significant enough to necessitate stopping the tunnel boring machine (TBM). Mr. Davis asked whether USGS/DOE has already assessed the risk associated with the onset of ESF construction prior to fully defining ambient conditions, and whether an analysis will be done prior to ESF construction of whether the conditions have been defined. Larry Hayes responded that yes, the data would be analyzed before the TBM comes in.

- Dr. Steindler asked whether chemical analysis is done on rainfall. Mr. Chornack responded that analysis is done to examine winter versus summer rainfall, and spatial differences. Dr. Steindler asked whether they could estimate the rainfall chemistry in the recent and distant past, and whether it is possible to tell how chemical composition of the rainfall may impact infiltration. Mr. Alan Flint, USGS, noted

that USGS has not collected data to look at long term trends in rainfall chemistry.

- In discussing an overview of the deep UZ percolation study, Mr. Chornack mentioned plans to drill a deep horizontal bore hole from the surface to the welded Topapah Spring unit to examine fracture frequency and characteristics of high angle fractures. Dr. Hinze questioned why the horizontal hole was needed, given plans for drifting in the Solitario Canyon, and how the two activities will complement or be coordinated with each other. Mr. Chornack noted that the horizontal hole was also going to be instrumented for long term monitoring. Mr. Joe Rousseau noted that this study was planned before the shaft design concept was planned for the ESF, thus the horizontal hole may be dropped.

Alan Flint, USGS, DOE/YMPO Characterization of the Unsaturated Zone

Dr. Flint described his study, which consists of characterization of surficial materials, characterization of natural infiltration, and characterization of artificial infiltration. The objectives of the study are to evaluate past, present, and possible future net infiltration. Net infiltration is water infiltrating below the zone where it can be readily removed by evapotranspiration processes. Evaluating net infiltration involves evaluation of mechanisms by which precipitation becomes net infiltration, assessing spatial distribution of net infiltration, assessing temporal distribution of net infiltration, and modeling infiltration by using conditional simulations of precipitation and a site calibrated watershed model.

Dr. Flint spent most of his time discussing the approaches used to evaluate net infiltration and results. The approaches include:

1) Identify the field mechanisms that contribute to net infiltration, 2) identify the physical and hydrologic properties that influence net infiltration for soils and bedrock to develop infiltration maps, and use as input to flow models, 3) evaluate methods to quantify net infiltration such as water balance, and use of 1, 2, and 3 D flow models to predict borehole saturations and fluxes on various time scales, and 4) model surface net infiltration on a site scale under varying conditions.

Highlights from Dr. Flint's presentation include:

Field Mechanisms that Contribute to Net Infiltration

- Net infiltration depends on how fast water can penetrate below the zone of evapotranspiration. factors influencing net infiltration in the desert include depth of alluvium, fractured bedrock, variable bedrock porosities, various

topographic positions (ridge top, side slopes, terraces, and channels), and timing of precipitation.

- Results of neutron probe monitoring indicate: 1) ridge tops have the deepest penetration of the wetting front and largest increase in saturation, and the movement of the wetting front is fastest in the ridge tops. 2) the penetration is influenced by the timing of the precipitation, potential for runoff, storage capacity, which is influenced by the depth of alluvium (thinner soils allow for higher saturation and greater net infiltration), and layering and porosity of the bedrock, and 3) the occurrence of fractures, and the water potential of the wetting front when reaches the bedrock. Water can enter open fractures only if the soil layer above is fully saturated. Ridge tops see higher rainfall, and are usually the upper cliff unit of the Tiva Canyon, a high porosity material. Ridge tops have a greater volume change of water content because of the higher porosity material and fractures. Water can enter fractures and can penetrate deeply into the ground. A large rainfall event is needed to get infiltration into fractures. Thus ridge tops (and side slopes) are important to infiltration at Yucca Mountain. Other results include: 4) terraces and channels do not usually see penetration of water below about three meters, likely due to carbonates that are formed in layers that stop flow, and high storage capacity and low precipitation. The water can readily be removed by plants due to ET. 5) side slopes see increase in water content down to about 12 meters in one area, and 5-6 meters in another area on the south facing slope. Eighty percent of the site is side slopes, they cannot get drill rigs there to monitor.

Physical and Hydrologic Properties Influencing Net Infiltration

- Summary of 2-D horizontal characterization of soils: 1) precipitation sets the initial distribution of surface water content, 2) the available energy controls evapotranspiration processes until the soil reaches a critical water content, and then the soil properties control evapotranspiration, and 3) soil properties control the drainage away from strong evapotranspiration properties, i.e., coarse soil allows for rapid drainage.

- Summary of 1 and 2-D vertical analyses of the hydrologic character of soils: The objective was to determine the hydrologic properties needed for numerical modeling of a desert alluvium, and develop a methodology to transfer the information to other locations. Approach includes: 1) define important hydrologic properties needed for modeling, 2) establish field and laboratory measurements to obtain information, 3) conduct field and lab measurements to collect data, 4) develop transfer methodology using geophysics and

soil properties, 5) establish a modeling scheme to incorporate the data, calibrate model, and use model to predict important properties including hydraulic conductivity and moisture retention characteristics, and boundary conditions. Modeling scheme (not done yet) will include use of TOUGH code for 1, 2, and perhaps 3 D models to incorporate liquid, vapor, and heat flow. Results: 1) large scale soil layering may cause lateral flow in washes, 2) without model verification the methodologies used produce uncertain results, 3) borehole geophysics can provide the initial boundary conditions and guidance for layer delineation, 4) rock fragments need to be accounted for in these soils when determining water retention characteristics, 5) there are no data to support the use of textural information to estimate hydrologic properties for this site, and 6) in locations with no access to subsurface samples, inverse modeling of flow experiments and borehole geophysics may be the only way to assess hydrologic properties of desert alluvium.

Physical and Hydrologic Properties Influencing Net Infiltration -Bedrock

- The objective of this study is to estimate surface moisture flux. Steps include: 1) group surficial tuffs into potential flux units based on saturated matrix permeability, 2) estimate current water potential and water content of surficial units at a depth where annual fluctuations are reduced, or at the tuff alluvium contact. Assume a unit gradient and use relative permeability as a second approximation of flux, 3) add fracture densities and permeabilities and incorporate matrix properties as a third approximation of flux, and 4) refine field measurements to better determine properties and the potential gradient for flux.

  Observations: The PTn unit is the most permeable bedrock unit on the site - expect to see the highest flow rates here. Tiva Welded Tuff is one of the lowest permeability units. Expect perching to occur in these areas.

- Dr. Hinze asked whether this approach accounted for the permeability of faults. Dr. Flint responded that faults behave differently at different times, and at different locations. He believes the faults at the surface of Yucca Mountain are filled with low-permeability carbonate materials. Faults at depth are open, and may get perched water bodies building up behind the fault, or water may flow into the fault. He suggested a possible conceptual model is contaminated water reaching the low permeability basal vitrophere layer of the Topapah Spring unit, and become perched, and may move downdip laterally, and bypass the Calico Hills unit. He emphasized the importance in understanding how the faults operate.

Quantify Net Infiltration

- The water balance approach is used to quantify infiltration, that is, precipitation minus evaporation minus run-off plus change in storage. Neutron moisture meters are used to measure change in storage, precipitation is measured with rain gauges, evapotranspiration with a Bowen ratio station, and runoff with a flume. He noted that they did fairly well matching the calculated infiltration with predictive 1-D models.

- Mechanisms for net infiltration must consider variable depth to alluvium, fractured bedrock, variable bedrock porosities underneath the alluvium, variety of topographic positions, which provide differences in radiation loads, soil depth, slope, runoff, and runon, and timing of precipitation.

- Modeling of infiltration into the mountain and water flow through the mountain is a major part of site characterization. Dr. Flint's modeling work includes use of models to predict borehole saturations and fluxes are various time scales.

Questions:

- Dr. Pomeroy asked whether the PA modelers were using the data and models he described, or if this was going to happen in the future. Dr. Flint responded that the PA modelers are using a lot of the data that he has generated, but a lot of times the modeling efforts are so far along that they don't have time to incorporate the newer data. The PA people are working in a higher level of modeling and he on a lower level to try to understand the processes, and verify that they can predict properties. He noted he is trying to understand the hydrologic system, and the PA people are trying to look at repository performance, and the two are not connected at this point, although they are working very hard to try to get the detailed site information into the ongoing PA modeling. Dr. Pomeroy asked them how valid the results of the PA modeling are if it is not connected to site processes? Dr. Flint responded that he does not think the PA models represent the site or the processes that are at work today, and he does not think the results of the PA models can be useful to determine the suitability of the site at this time. He believes these models would have to incorporate the 2 and 3 dimensionality of the site, the valid flux rate, and the time scale in which the flux rate changes.

- Bill Ford of the NRC staff showed diagrams of the UZ-16 hole: porosity versus depth, volumetric water content voice. porosity, and water saturation voice. depth for UZ-16. Mr. Ford explained that literature suggests a relationship between degree of welding, which can be represented by porosity, and

saturation, i.e., higher welding equates to lower porosity. He explained that the lower the porosity, the more likely the unit will be saturated, because less moisture is needed to fill the pore space. However, in the plots, the Calico Hills nonwelded unit is nearly saturated. Mr. Ford noted that they expected to see higher porosity values and lower saturations in this unit. High porosity is seen in the PTn nonwelded unit, with low saturation, as would be expected, due to rapid dryout, and the welded TS unit, lower porosity unit is nearly saturated, again, as is expected. Mr. Ford seemed to suggest that perching is seen in UZ-16 in the Calico Hills because it perhaps is a lower porosity tuff than assumed with fewer fractures, thus water enters the matrix and quickly saturates the pores of the rock. Also, he noted that the Prow Pass unit below the Calico Hills reflects low saturation and then deeper in the column it wets up again, corresponding to an observed decrease in porosity. Mr. Ford also suggested that water may not move much deeper beyond the low porosity Prow Pass unit, hence this unit controls water table elevations. Dr. Flint indicated that the high saturation in the Calico Hills is not inconsistent with being so close to the water table, from capillary rise alone. He noted that the high saturation is probably due to conditions of past flux. Dr. Flint discussed how his modeling of UZ-16 in the INTERVAL project was able to match fairly well what is actually seen, noting that if you put as much information as you know into the model, i.e., layering, fractures, measured permeabilities, etc., and use deterministic processes rather than stochastic, you will do a better job of modeling. He indicated he has papers written on use of deterministic voice. stochastic approaches.

Ed Kwicklis, USGS, Site Scale Unsaturated Zone Modeling

Mr. Kwicklis discussed the general objectives of the Site UZ Modeling and Synthesis study, for which he and Mr. Bo Bodvarsson of LBL are responsible for, and then specific information on water potential and water saturation profiles from four unsaturated zone boreholes, UZ-4, UZ-5, UZ-7, and UZ-13.

Objectives of the study include: 1) develop credible quantitative models of the natural flow system, 2) integrate site data and analysis to guide the site characterization effort, 3) estimate fluid fluxes, 4) test hypothesis concerning the hydrologic behavior of the site, 5) produce estimates of hydrologic parameters.

Mr. Kwicklis noted that he believes development of credible models of the natural flow system and validation of these models greatly enhances the confidence of the scientific community and the public in the use of performance assessment models to assess long term site behavior, for which no experimental or observational data are going to be available.

The specific objective of developing the water potential and water saturation profiles for selected boreholes is to examine internal consistency of data collected from field and laboratory measurements, and estimate liquid water fluxes to the nonwelded and bedded units in the unsaturated zone, and better understand recharge mechanisms and redistribution of infiltration beneath the surface of Yucca Mountain.

This study involves plotting water saturation, porosity, and water potential with depth, and assessing measurement error. He looked at two unrelated holes and derived relations based on regression between hydrologic parameters for the Van Genuchten functions, which describe moisture characteristics and effective permeability as a function of saturation. He then applied these regression results to the four UZ holes to estimate water potentials and compare to measured potentials, and estimate effective hydraulic conductivities, then estimate flux using Darcy's law, evaluate uncertainty and compare results to isotope data. Results are described in the highlights below.

Highlights:

- Examination of porosity, saturation, water potential, with depth, shows: 1) stratigraphy changes with geographic location, due to distance from the volcanic eruption, 2) stratigraphic horizons of geologically similar origin show variability in porosity, and presumably other properties, 3) microstratigraphy, as reflected in porosity, significantly influences local values of saturation and to a lesser extent, water potential.

- Summary of Regression results: 1) limitations of some existing data have been identified, 2) correlations have been identified between some important hydro parameters, 3) flux profiles have been created which indicate large, recent influxes of water beneath the wash at UZ-4 and UZ-5, 4) the near-static equilibrium water potential profile at U-Z7 suggests that the vitric caprock of the Topopah Springs Member may be an important capillary barrier, 5) flow above and within the nonwelded and bedded units at UZ-4 and UZ-5 is multidimensional and transient, thus 1-D analysis should be viewed with skepticism. Results showed large liquid fluxes computed for UZ- 4 and UZ-5S at the base of the Tiva Canyon unit, which become smaller at the base of the Yucca Mountain unit, and then increase again in the middle bedded unit, then decrease and eventually flux becomes upward at the base of the Pah Canyon member. He is interpreting these jumps and reversals in flux as indicative of a lot of lateral flow causing these jumps and causing the upward flow gradient, and nonequilibrium fracture flow occurring in the overlying Tiva Canyon member. He noted that Al Yang's tritium data indicate high tritium at the same places where there is high flux.

- Mr. Kwicklis noted that one of the activities under the study was to assess parameter uncertainty by doing a sensitivity analysis and stochastic analysis. Dr. Steindler questioned why Dr. Flint recommended not using stochastic analysis, and asked why the apparent inconsistency. Mr. Kwicklis responded that it may ultimately be that most of the variation can be accounted for in a deterministic way and a stochastic analysis is not needed, especially with matrix properties. However, the spatial variability in the fracture network stochastic methods may be needed to account for the variability.

- Dr. Hinze asked about the nature of the spatial stratigraphic variations. Mr. Kwicklis and Mr. Boak responded that the stratigraphic variations are due to the genesis of volcanic rock. Mr. Boak noted that the deterministic trends discussed by Dr. Flint can be tied in with the variations in stratigraphy, thus there is a certain amount of stochastic variation, but the deterministic trends often override this. Mr. Davis asked whether the hydrostratigraphic units coincided with the stratigraphic variations. Mr. Kwicklis acknowledged that the deterministic trends do not necessarily coincide with the hydrostratigraphic units, which are based on hydrologic properties of the rock. However, the hydrologic properties are strongly tied to the variations in porosity. Mr. Larry Hayes noted that Rick Spengler, USGS, has shown a correlation between the hydrologic characteristics and the geologic/ lithologic characteristics.

Joe Rousseau, USGS, DOE/YMPO Surface Based Data Collection Studies in Unsaturated Zone Percolation

Mr. Rousseau described the study objectives, the borehole siting strategy and criteria, overview of the percolation studies, UZ processes, and aspects of the in situ measurement program of UZ fluid potentials.

The purpose of Dr. Rousseau's work is to characterize present day flux in the unsaturated zone at Yucca Mountain, through field and laboratory measurements of 1) matrix hydrologic properties, 2) in-situ permeability, and 3) in-situ fluid flow potentials. Emphasis is placed on understanding concentrated voice. uniform flux.

Highlights include:

- The borehole siting strategy is to target those areas of interest with the greatest potential to provide the evidence needed to assess the suitability of Yucca Mountain as a repository. He pointed out that they are trying to understand what short circuits may exist in the system, with emphasis on structural features. The basic siting criteria are large

scale structural features, surface drainage features, and topographic features.

- UZ-1, 14, 4, and 5 to the north were chosen to depict the distinct hydrologic regime to the north, which Mr. Rousseau noted is likely quite different than the regime in the mid section of Yucca Mountain. UZ-16 was sited in the Imbricate fault structure, UZ-7 and 8 were sited to go through the Ghost Dance fault, UZ-11 and 12 through Solitario Canyon fault, UZ-6, 2, 3, and 15 on top of Yucca Crest. He noted that they may be able to take holes away from the south and move them to the north, depending on the data recovered.

- Mr. Rousseau described the percolation studies, objectives of each study, and the measurement scale. The studies consist of measuring matrix hydrologic properties, air permeability testing, fluid flow potentials, vertical seismic profiling, Cl-36, hydrochemistry, and gaseous phase flow.

- Percolation processes are similar to shallow infiltration processes but don't have the same thermodynamics and no pneumatic pressure. Processes include matrix-matrix liquid flow, vertical and lateral, for which most of the modeling to date has been focused on, matrix fracture liquid flow, and vapor transport via diffusion and convection.

- In-situ measurement of UZ fluid flow potentials include pneumatic pressure, temperature, and water potential. Pneumatic pressure is the primary driver in convective gas flow. Conductive heat flow is driven by temperature. Water potential measurements are used to define the liquid and vapor flow system.

- UZ-16, located in the Imbricate fault zone, was dry drilled and cored to the saturated zone. Preliminary findings indicate the Imbricate faults are almost vertical, the fracture density in the Topapah Spring is much greater than previously estimated. The range is from 50 to 250 fractures per cubic meter. This greater density is expected due to Imbricate fault location. Water was encountered in fractures in the Prow Pass unit. Prow Pass is a unsaturated matrix environment. They encountered flowing water into the borehole, between dry cores above and below. Mr. Rousseau believes the source of water is coming from the Calico Hills unit above as opposed to the water table below in the Prow Pass. Data from Al Yang also supports this.

<u>Al Yang, DOE/YMPO Hydrochemical Characterization of the Unsaturated Zone</u>

The objectives of Dr. Yang's study are to: 1) understand gas

transport mechanism, direction, flux, and travel time within the unsaturated zone, 2) design and implement methods for extracting pore water from tuff, 3) provide independent evidence of flow direction, flux, and travel time of water in the unsaturated zone, and 4) determine the extent of water-rock interaction, and to model geochemical evolution of the water in the unsaturated zone.

Dr. Yang described methods for gas and aqueous phase investigations including collection of a gas sample, transporting it, preparing it for lab analysis and analyzing it.

Dr. Yang described gaseous data from UZ-1 and water data from UZ-4, 5, and 16 where samples could be extracted, and tritium, carbon 14 and oxygen ratios are measured.

High Tritium values are seen in UZ-4 and 5 near the bedded tuff unit, and high moisture contents, which are also seen in UZ-16. Also see high tritium in the Calico Hills unit, although other measurements suggest the water in the Calico Hills unit is very old. Therefore it is likely that water leaks down through fractures to the Calico Hills. This needs further investigation. Regarding results of CL-36 data in UZ -16, CL-36 concentrations drop off and rise back up again at the Calico Hills unit.

In UZ-16, oxygen-18 data reveal Calico Hills water depleted in oxygen-18, thus this water is from a cold climate, perhaps the last ice age, 18, 000 years ago. Perched water appears to be the same age as the groundwater, showing the same signal for oxygen-18 and Delta-D. Thus based on water chemistry perched water is the same age as the water table.

Summary and conclusions:

- Gas Phase C-14 in UZ-1 indicate faster transport of CO2 in the Topopah Spring unit than in Tiva Canyon or bedded units. Gas transport mechanism is likely by diffusion.

- The tritium and CL-36 data from UZ-4, UZ-5 and UZ-16 indicate a preferential flow path via fractures. High tritium values are seen in the Calico Hills unit, and need to be further investigated since pore water chemistries and stable isotopic data indicate very old water in this unit.

- Pore water chemistries from UZ-16 cores indicate calcium bicarbonate type young water near the top 200 feet and sodium carbonate type old water in the Calico Hills unit.

- Alan Flint clarified the conceptual model. He believes that the saturated zone is recharged from mesas to the north. Water reaches the water table and travels under Yucca Mountain and discharges to the south. Thus downward flow through the unsaturated zone may not be related, and part of a separate

system.

- Dr. Hinze asked when and how the investigators were going to assess the source of the young water in the Calico Hills unit. Al indicated they would use CL-36 and other dating methods to compare for consistency. Suites of samples were taken so the tritium will be reanalyzed after squeezing out another sample.
- Mr. Ford asked whether Dr. Yang's data agreed with Dr. Flint's earlier explanation of water contents in the Calico Hills unit being due to downward movement of water through the matrix. Al Yang responded that he needs more data between 200 and 600 feet.

Mike Chornack, USGS, Unsaturated Zone testing to be Conducted in the Exploratory Studies Facility

Mr. Chornack gave a brief overview of the testing strategy for the ESF UZ studies. He explained that the tests were divided into the construction phase tests, and post-construction phase and main level tests. Construction phase tests consist of radial borehole, excavation-effects, perched water, hydrochemistry, and major faults. The post-construction tests consist of intact fracture tests, percolation tests and bulk permeability tests. The purpose of UZ testing in the ESF is to 1) provide hydrologic parameter input for the resolution of design and performance issues, 2) provide an understanding of the impacts of ramp and drift construction on the in-situ hydrologic characteristics, and 3) contribute to an understanding of the in-situ hydrologic characteristics of the unsaturated zone. The objectives of the study are to 1) determine in situ UZ hydrologic conditions from core and fluid samples, borehole geophysical logs, and in-situ borehole test, 2) determine the spatial distribution of present day water flow within the unsaturated zone, and 3) characterize gas and vapor flow in the unsaturated zone, 4) provide hydrologic data for calculations of the UZ groundwater travel time, 5) provide hydrologic data for predictions of radionuclide releases to the accessible environment, and 6) provide hydrologic properties data to design analyses of underground facilities, repository seals, and waste packages.

Mr. Chornack briefly described testing activities.

In summary he noted that the results of the tests will be used in the resolution of performance and design issues concerned with fluid flow in the unsaturated zone. The principal application will be assessment of groundwater and gas travel times. Finally, issues concerned with waste package containment and engineered barrier system (EBS) will use information resulting from this study.

Bo Bodvarsson, LBL, Three Dimensional Model of Unsaturated Zone Flow

Dr. Bodvarsson described that the 3-D site model will be used: to integrate the available data and information on Yucca Mountain, to provide estimates of moisture, heat, and gas flow within the mountain, to guide site characterization, and to predict thermodynamic conditions in new boreholes in the ESF to gain confidence in the model.

He explained the interactions that take place between the modelers and the principal investigator, and the iterative approach used to develop the site scale model. Steps include data collection and analysis, data integration into conceptual models, selection of numerical codes, peer review, use of submodels to do hypotheses testing, uncertainty analysis, and performance assessment.

Highlights from Dr. Bodvarsson's talk include:

- Important issues to be investigated with the model include uncertainties in flux determination, densely fractured welded units, flow characteristics of major faults, matrix voice. fracture flow, gas flow, thermal effects on fluid flow, lateral flow and perched water, and fracture and capillary barriers. He noted that flow characteristics of faults is the most significant uncertainty at this time.

- Modeling steps include: development of a moisture flow model, incorporation of a geothermal gradient, incorporation of gas flow components, periodic calibration of the model against observed data, continuous use of model for prediction of parameters at new borehole locations and the ESF, periodic use of the model for sensitivity analysis, and continuous use of submodels for hypothesis testing.

- Essential data needs include data contributed from other studies, hydrogeologic maps, and hydrogeologic parameters. A great deal of time is spent between modelers and geologists in developing detailed hydrogeologic maps.

- Considerations in gridding the model include locations of existing and future boreholes, alignment of major faults, infiltration data, and stratigraphy. He noted that a great deal of time was spent initially to set up computer generated three dimensional grid, so that subsequent modifications to the grid can be done quickly.

- Results for 2-D simulation show lateral flow in the bedded unit depending on what is assumed for the fault characteristics. There are three assumptions that can be made about the faults, in the absence of data on fault characteristics: 1) assume no flow into the fracture because of high capillarity, 2) assume fractures are filled with a high permeability material, and 3) water flows in fracture. The 3-D model results show lateral flow and concentrated

recharge due to tilting of beds, when it is assumed faults are barriers to flow.

- Dr. Hinze asked how these results compare to actual observed data. Dr. Bodvarsson showed a prediction of flux in UZ-14 assuming uniform flow. The model did not predict the perched water observed in the hole. Then they assumed nonuniform flow, assuming concentrated flow occurs due to exposure of the bedded unit in the washes. The result was the saturation matched the observed data in UZ-14, and by reducing the permeability below the perched zone by one order of magnitude, the perched condition was simulated. But it was not sufficient just to concentrate flow in the washes, the permeability also had to be changed. Additional testing of this continues.

- The main data used to calibrate the code is capillary pressures and saturations, but there is very little of this data for boreholes.

- Current work includes completing a report on the first phase of the model, moisture flow, and another report on decoupling the TOUGH code to include only moisture flow. A report on grid effects was completed. Now completing 3-D simulations to determine where 1, 2, and 3 D flows occur in the mountain, and the simulation comparing predicted results with observed data in UZ-14.

- Future work includes incorporation of geothermal gradient, incorporation of gas flow, development of a new numerical grid incorporating the ESF, model sensitivity analysis, and periodic release of model data to performance assessors.

- In summary, the 3-D site scale model is operational and being used to predict conditions at new boreholes and for sensitivity studies. The major purpose of the model is to integrate the available data and guide the site characterization process, and the model is under continuous development with current incorporation of gas flow, geothermal gradient, and the ESF.

- Dr. Bodvarsson noted the importance of getting the ESF into the grid, in order to predict the effects of the ESF before it is tunnelled. It was noted that this still may be possible, in that the TBM is not due until August. He noted he also hopes to have for the International High Level Waste Conference this year a map showing various zones of 1, 2, and 3 D infiltration, and use this information to determine site characterization needs. Mr. Davis suggested that this approach presupposes that the model is right. Dr. Bodvarsson suggested that the 1 D as well as 2 and 3 D should be tested against the existing boreholes. Mr. Davis noted

that he did not see an end point to this because he did not see how this modeling was tied into performance assessment modeling, which is supposed to say how much data is enough to make a regulatory decision.

- Mr. Davis asked about how many different types of conceptual models could be tested using the model, without having to re-grid the entire mountain. Dr. Bodvarsson noted that the geology was fixed, but infiltration and permeability could be varied, as well as grid patterns. Bill Nelson, M&O, added that there is some 126 different conceptual models to be looked at.

Claudia Newberry, YMPO, Integration of Unsaturated Zone data Modeling Studies and Performance Assessment

Ms. Newberry explained that the data collection part of the program involves a lot of modeling activities. Detailed models of the unsaturated zone feed into the site models used by Bo Bodvarsson and Ed Kwicklis. The site models then feed into process models, which feed into total system performance assessment models. Performance assessment uses site models to refine process level models, perform sensitivity analysis using process level models, provides feedback to the Site program and site modeling effort, and abstracts process level models to obtain input and establish initial boundary conditions for total system models.

Highlights of Ms. Newberry's presentation include:

- Three levels of modeling include total system, which are the simplest in detail, but most complex in the combining of processes, process models, which are complex and may address a single process or several processes, and site models, which are most complex in terms of data and stratigraphic detail.

- The three steps to performance assessment include: 1) use lowest level data and models to create, test, and modify process level models, 2) abstract from process model tests the information needed for total system models, and 3) perform total system analyses.

  The definition of performance assessment is a systematic process that identifies and models features, events, and processes that could affect the safety, performance and environmental acceptability of a radioactive waste repository.

- Mr. Davis asked how a process level model differs from a site model. Ms. Newberry noted that the site models have stratigraphy and physical properties assigned to geometric units. A process model implements this into a code that looks at events.

- Two codes are being used for UZ flow: TOUGH2 (LBL) and FEHM (LANL). They will be used for benchmarking. Both codes use the same physics, and test the same conceptual model. In addition, FRACMAN is being added to look at discreet fracture flow, coupled with TOUGH2 and/or FEHM.

- A Groundwater Travel Time Issue Resolution Working Group has been formed to examine technical aspects of groundwater flow. One of the objectives of this group is to develop an approach to demonstrate compliance with this requirement. A draft action plan has been developed, which suggests that groundwater travel time as described in 10 CFR 60 and 10 CFR 960 is not an adequate measure of site performance, in that they both emphasize pre-waste emplacement. Ms. Newberry indicated that DOE plans to raise this with the NRC during an upcoming technical exchange in March, 1994. A report is expected out in FY 95.

- A result of TSPA 91 is that a strong connection exists between flux and release (normalized release, which is the release of radionuclide divided by the release limits in table 1 of 40 CFR 191) from engineered barriers. This information was fed back into the site program as an indicator that more detailed information is needed on flux in the unsaturated zone, in that it is a critical parameter to site performance. The hydrology flux is used as input to engineered barrier system performance assessment models, such as YMIM and AREST. While a strong connection is evident between fluxes and normalized release, the TSPA results still indicate that the site complies in every case. Mr. Davis asked why any additional work was being done if the normalize releases are below 1. DOE did not have an answer.

- DOE plans to use TSPA results to make near term decisions, such as site suitability, underground facility and engineered design, and prioritizing and evaluating the test program. Longer term decisions include advanced conceptual design and License Application designs, site recommendation report, EIS, and the License Application Safety Analysis Report.

- Summary and Conclusions: 1) site and performance assessment are linked through the site program data interpretation and modeling, 2) site data and models are used to refine process level performance assessment models, 3) process-level models are tested and abstracted to provide initial and boundary conditions and input data for system level models, 4) primary objective of performance assessment program modeling effort is to update and test codes based on site data and models and to test models and provide feedback to site program.

- Dr. Steindler asked whether DOE had criteria to determine whether a model has been validated. Ms. Newberry noted that

validation activities include predicting parameters measured in boreholes before the borehole is drilled, and long term validation is difficult and requires natural analogs.

- Mr. Davis asked whether one conceptual model is being used to drive data collection, and whether a systematic approach will be used to test multiple conceptual models and to drive site characterization. Mr. Flint responded that yes, he thought this was so. Mr. Davis also asked how the uncertainty of a submodel is translated into uncertainty in total systems performance assessment models. Mr. Jeromy Boak, YMPO replied that the uncertainty analysis is done on the detailed modeling level, and not at the systems level. Abe Van Luik, M&O, concluded by suggesting the process of abstraction could be dealt with in other forums, to explain the philosophy of roll up models, as opposed to stringing process models together.

- Mr. Davis asked why any additional work is being done when the results shown for the TSPA showed compliance with the release standards.

Martin Mifflin, State of Nevada and Nye County

Mr. Mifflin discussed the importance of fracture flow and the conditions under which it should occur, including climate conditions and thermal loading scenarios.

Highlights of his presentation include:

- There are billions of fractures under the original 2000 acre repository block. Bedded (nonwelded units) have fractures as well as the welded tuff units.

- Mr. Mifflin presented an example of a simple conceptual model of what can occur in a fractured system when recharge or flux is varied. Using early data of ranges of hydraulic conductivity of various units, and assuming a unit gradient, he compared assumed various fluxes from .5 to 10 mm/yr, to see if the surface area could accept the flux. If the flux is greater than the hydraulic conductivity, then he assumed fracture flow could occur.

- Considering climate scenarios that could result in fracture flow, 65-85% of the time over the past 2.4 million years the climate has been cooler or wetter, worldwide. However, it is not possible to predict based on the available data, what climate change may occur on a local basis over the next 10,000 years. Thus he assumed a full pluvial climate, 10-30 times higher than today (1 mm/yr) with some zones much dryer and some much wetter. When the 10-30 mm/yr values are compared with the hydraulic conductivity data, fracture flow could occur in most of the units, except in the bedded units

(Paintbrush tuff and Calico Hills vitric). Mr. Mifflin notes in his slides that given a 10-30 fold increase in infiltration the current water table could rise to greater than 100 meters, there would be a marked increase in the extent of perched water zones, with extensive perching in Paintbrush bedded tuff, and on the bedded tuffs of the Calico Hills, and localized perching in the welded tuffs. With respect to fracture flow, he estimates that there would be a marked increase in ephemeral and perennial fracture flow, localized, seasonal pulsed fracture flow, with minor exchange between the matrix water and fracture water throughout much of Yucca Mountain due to small hydraulic conductivities.

Next he looked at thermal loading scenarios, where fracture flow might be initiated, in combination with climate change. He looked at the reference thermal load in the SCP, the cold repository and the extended dry repository concepts. For the cold repository, expected scenarios include increased saturation and perching, reduced gas phase transport due to increased saturation, increased fracture flow in the most permeable fracture/fault zones, and carbonate mineral precipitation, increased liquid phase transport time due to local zones with fracture flow dominating, and radionuclide containment would be very dependent on waste package lifetime and radionuclide retardation in the Calico Hills and saturation zone. Welded units would probably remain unsaturated, and the repository would likely not flood, based on the available database.

For the SCP design, above boiling zone is expected to be present with a halo of localized saturation caused by condensation. Upon cool down to boiling near the repository horizon, there would be partial flooding. Saturation halos may occur above, laterally, beyond, and below the 96 degree isotherm, and flooding of repository may occur upon cool down.

For the extended dry design, Mr. Mifflin predicts a prolonged hydrothermal discharge at the surface along faults and fracture zones, and in a pluvial climate thermal effects would reach to the water table, causing a buoyancy effect of the water derived from the water table, and accumulation of water above the Paintbrush tuff and Tiva Canyon Welded tuff, resulting in partial or total repository flooding upon cool down after 10,000 years and subsequent radionuclide release via saturated zone flow paths.

- In summary Mr. Mifflin pointed out the difficulty in modeling existing conditions, let alone trying to superimpose a greater availability of water on the system and other complexities.

Linda Lehman, L. Lehman & Associates, Effects of Alternative Conceptual Models and Modeling Assumptions on Performance Assessments

Ms. Lehman discussed three general topics in her presentation: 1) model assumptions which impact performance assessment, 2) effect of alternative conceptual models on flux, based on an exercise for the INTERVAL project, and 3) need for an analysis of bias and a fair evaluation of alternative conceptual models.

Some assumptions that can affect model results include: 1) matrix voice. fracture flow, 2) dimensionality, i.e., whether flow is vertical or lateral and vertical, 3) distribution and amounts of infiltration, 4) equilibrium assumptions governing interactions between matrix and fractures, which is controlled by pressures, conductivity of matrix and fractures, residence time, fracture coatings, and transient voice. steady-state infiltration, 5) boundary conditions, such as no flow, and wet voice. dry fractures, and parameter models, or parameters that are modeled rather than measured, such as infiltration, conductivity, water retention properties, and porosity. Ms. Lehman gave examples of each. For example, if little interaction is assumed between matrix and fractures, then large amounts of water can move through the fracture. On the other hand, if large interaction is assumed, then little water can run down a fracture, and the water will move readily into the matrix. Another example includes whether faults are no flow boundaries or assumed to be a flux or pressure boundary, allowing infiltration to come through the side, as opposed to through the top only. Ms. Lehman noted that in her organization's work, they have found that the error in using an incorrect conceptual model can be quite large.

Ms. Lehman presented the results of her modeling done for INTERVAL. The exercise involved: 1) calibration of models against water content profiles measured in shallow boreholes UZN-53, UZN-54, and UZN-55, and 2) use the calibrated models to perform a blind prediction of water content profile in borehole UZ-16. The intent of the exercise was to find the best flux to match the water content profiles, although it was known that the results would provide a non-unique solution. Ms. Lehman performed the exercise to look at the range of possible fluxes using simplistic models. They were unable to match the measured profiles using a simple, layered 1 or 2 D model, but were much more successful in matching water contents in the column assuming fracture flow, using actual fracture spacings and apertures from site data, and evapotranspiration.

They also used a depression focused recharge model to look at the range of possible flux assuming focused recharge modeling the Solitario Canyon catchment basin. The model uses a climate simulator, and accounts for infiltration, runoff, and slope, to calculate how much water can go through the depression and become

recharge. The model predicted a range of 12-30 cm/yr recharge. She noted this range was about five orders of magnitude higher than ever considered possible there. She noted that most of the numbers to date used have been derived from inverse modeling, using 1 D flow matrix flow models, thus have been very low.

Additional highlights include:

- Ms. Lehman noted that she thought the RIP total system PA code is biased toward matrix flow, in that it assumes equilibrium between matrix and fracture flow, i.e., the matrix must be saturated before flow can occur in fractures. If a low infiltration value is assumed, fracture flow would not occur.

- Ms. Lehman noted that a process to sort out various conceptual models should do the following: 1) examine potential sources of bias, 2) utilize confirmatory and consistency type data to bolster results, and 3) be iterative and build confidence over time. In addition, only the model that agrees with the confirmatory data and is most consistent with all other information should be preferred and validated.

- Ms. Lehman summarized by saying that the conceptual model chosen has a large impact on certain parameters, illustrated by the five order of magnitude range of flux. A methodology must be developed for the fair treatment and consideration of conceptual models, and an analysis of bias in the way conceptual models are treated in performance assessment needs to be done.

Questions:

- Dr. Leap asked whether Ms. Lehman felt that the areas of focused recharge have been adequately delineated. She responded that they have not in her opinion. She added that the higher areas of Forty Mile Wash were likely to be focus areas, and the whole west side of the mountain has not been looked at in this regard. She noted that the actual placement of the wells are very important and can greatly affect results, based on results from Apache Leap.

<u>David Kreamer, UNLV, Early Site Suitability Evaluation (ESSE) and Trace Element Analysis</u>

Dr. Kreamer first discussed some of his observations made on the hydrology sections of the ESSE, which was a peer review exercise done about two years ago. Some of his comments on the ESSE include:

- Uncertainty -there was (and still is) a great deal of uncertainty due to lack of site-specific data. The review team assigned the hydrology section as having a "low degree of

acceptability" because of the lack of data and uncertainty associated with it. Specific data needs noted include:

-need for more data on gas flow.

-increased emphasis on looking at fracture coatings. He noted that fracture coatings may change over time, thereby changing the permeability of the fractures, and the pressure equivalency across the matrix fracture interface needs to be better understood, and we need to be cautious in accepting the assumption of continuum between matrix and fractures used in many of the models.

-preferential flow paths, including identification of horizontal flow paths in holes using TV logs. He noted at that time many of the holes had not been TV logged.

- A favorable condition that the system will be characterized and modeled with reasonable certainty. Dr. Kreamer commented in the ESSE that the site may never be characterized without significant uncertainty. If this is the case, then what degree of uncertainty is acceptable needs to be determined.

- There was not enough defensible information two years ago to determine site suitability. For the hydrology area, the site was determined to have a low level of acceptability for continued evaluation.

Next Dr. Kreamer presented a new approach of looking at trace elements as part of characterizing saturated or unsaturated flow. He presented data collected from six springs located in Death Valley National Monument. He examined rare earth and transition elements in parts per billion and trillion range to examine possible linkages between the trace elements in the rock, and pore water of the rock.

Dr. Kreamer described a statistical technique used (variance maximizing rotation) to weight each element, and reduce as much as 90 percent of the variance in the data set. He then plotted principal component data against each other and was able to group the three carbonate springs together, the two Tertiary volcanic springs and the alluvial springs separately. He noted that this was simply an approach to look at chemical data for trends -- and suggested this technique could be used to better understand source and pathways of water.

Mr. Davis asked whether the site suitability of Yucca Mountain would be done again. Mr. Jeromy Boak responded that DOE is in the planning stages of another ESSE, and a third will be done before a finding on site suitability is reached. Mr. Davis asked if the decision of site suitability would be made at the same time DOE presents its final CCDF for licensing. Mr. Boak responded that it

could be roughly synchronous. Mr. Davis asked Mr. Boak how DOE is addressing the point raised by Dr. Kreamer that the site may not ever be characterized to an acceptable degree of uncertainty. Mr. Boak noted that one of the conditions that would lead to a finding of unsuitability is not being able to show that the site is suitable, and that the uncertainties are so large that it is not worth it to continue characterizing. Mr. Boak added that at this time there is not enough data to know the outcome. If the best estimates showed compliance by six orders of magnitude, then perhaps some of the large uncertainties are still not a problem.

Roundtable Discussion

Mr. Joe Dlugosz was the first speaker during the roundtable discussion.

Mr. Dlugosz noted the upcoming first DOE technical program review February 14-18, 1994, and asked the ACNW for input with respect to how DOE has addressed some of ACNW's concerns during the meeting, so that this information could be factored into DOE's technical program review.

Dr. Hinze asked each of the three consultants for their summary comments.

Mr. Paul Davis provided the following comments: 1) there is an apparent lack of integration of the work; he felt there was a "shot gun" approach when speakers stood up and said they all had the same objectives to their work. Mr. Davis also felt there appears to be no prioritization of work. 2) It was not obvious from any speaker that anyone knows how to determine when they are done with site characterization. He saw many flow diagrams showing infinite loops, with no decision point for quitting, including the modeling. He expressed the need for a focus on the program for resolving issues, for establishing closure, and determining whether the site is safe or not. 3) He noted that he heard speakers say that conceptual model uncertainty will be treated but he has not seen evidence of this yet. He would like to see Dr. Bodvarsson's model being done in parallel with several conceptual models to drive site characterization instead of only one conceptual model which may drive site characterization in the wrong way if it is the wrong conceptual model. He would like to see a systematic, formal approach to treat conceptual model uncertainty as we go forward through site characterization including folding the State's concerns and testing their conceptual models.

Dr. Darrell Leap made the following observations: 1) The massive data collection effort appears disjointed, and poorly integrated, 2) he is concerned about the lack of knowledge of fault hydrology, because faults could serve as major conduits, especially in a climate change, 3) climate change should not be discounted, because climatologists predict a wetter future climate at Yucca Mountain,

and someone needs to look at the effect of increased precipitation on the permeability of fractures and other pathways. If precipitation is increased by 1%, the soil zones could increase on top of the mountain, and vegetation, and CO2 produced by vegetation, and CO2 taken into the subsurface could affect the calcite and caliche layers thereby affecting permeability and infiltration. In addition, a rise in the water table could increase the pressure which could cause fracture widening. 3) He added he was happy to see the increase in data overall.

Dr. Sackett commented that his expertise is in the area of isotope measurements and he would have designed the isotope program differently. For example, uranium thorium series nuclides are really powerful in trying to understand fluid movement through the ground. New techniques exist for C-14 dating, such as accelerator mass spectrometry, which does not appear to be being used. Helium 3, tritium ratios are better than liquid scintillation for counting tritium levels. Apache Leap started over 10 years ago before Yucca Mountain was selected as the only site, and does not appear to be a good analog for Yucca Mountain.

Highlights from the Roundtable Discussion include:

- Dr. Pomeroy posed a question to Alan Flint or Larry Hayes, USGS what do they perceive as being the greatest source of uncertainty ten years from now, if we proceed on the present course. Dr. Flint responded that in the area of infiltration, the greatest uncertainties will probably be in distribution of infiltration, and properties of fault systems. He added that he thinks they are making tremendous progress in understanding the variability of fault properties. He noted the 3 D geologic model was helpful in distributing geologic properties in space, but the saturation data are the most highly variable parameter. For example, why fresh water is in the rock in one area but not in another area in the very same rock. He indicated that this is due to the variability in the flux rate. The saturation of Yucca Mountain today is a reflection of the last several hundred thousand years or more in terms of climate change. So the variability in flux rate is a very critical uncertainty. Climate change scenarios are also an uncertainty, thus the climate program is very important. In summary, the important uncertainties include how faults behave at the surface, and the subsurface, distribution of flux, and climate change.

  Larry Hayes provided a broader perspective. He thinks the biggest uncertainty or concern is lack of new subsurface data in a distributive pattern both laterally and vertically. The drilling program is doing the best it can with the funding it has. So in the next 5-10 years, we need to get more from the drilling program, more wells. We are making predictions with models based on very little data. The ESF will provide a lot

of subsurface information, but only in a limited area. For example, climate change will not be addressed with ESF data, we need to collect more regional data.

- Dr. Hinze made the observation that a lot of progress has been made. However, he is concerned that, in shifting from a shaft to a ramp ESF design, DOE will not be able to collect critical data it otherwise would have with the vertical shafts above the repository. He would like DOE to consider how to take all the data it will collect form the ESF and project that above and below the repository horizon.

- Dr. Flint noted that there was additional information on the UZ program, including isotope data, that the ACNW did not ask for and was thus not presented at the Working Group. He noted that the UZ studies were DOE's fourth priority, and keeping the UZ projects funded is difficult, given DOE's priority to get underground. Dr. Pomeroy asked whether any isotope data exists that confirms Al Yang's data. Dr. Flint responded that Zel Peterman of USGS would have to be consulted. Alan added that his own modeling suggested a travel time of about 20,000 years for surface infiltration to get to the Calico Hills, which is consistent with Al Yang's data that indicate the Calico Hills water is approximately 18,000 years old. However, Dr. Yang also has data indicating very young water may have reached the Calico Hills, however, this data consists of only one data point and more work is planned. Larry Hayes noted that about 50 million dollars of the total 270 million dollars for the program this year went toward site characterization.

- Cady Johnson of Woodward-Clyde commented that the perception of a lack of integration in the program may be due to poor communication, because a lot of work is being done to integrate the program.

- Dr. Leap asked how difficult it is to transfer data from one part of the program to another. Dr. Flint responded that from within the program, it is very easy, data are readily shared. Ms. Lehman commented, however, that obtaining data has been very difficult for outside participants, and some of the State's data requests have been outstanding for over ten years. As for site-specific data from new boreholes, she has only been given the INTERVAL data package for UZ-16. It is necessary to submit written requests for data. Ms. Newberry responded that a data catalog exists which is provided every quarter, and the state can get this information upon written request. However, it is not available on line to outsiders. Data provided upon written request must be reviewed and approved by the USGS, or whoever generated it. DOE is trying to disseminate data in the Technical Data base in Las Vegas, which should make obtaining data easier.

- William Ford commented that the NRC staff does not have visibility of the research required to know how to collect some of the UZ parameters. This information is not normally presented in study plans. He noted it is important for NRC to hear what techniques are used to measure bulk fracture properties of the rock, how these values are put together to account for bulk fracture properties for various saturations, and how the modelers plan to test their codes against that data or develop experiments to test the codes.

- Ms. Gil clarified that DOE works at all levels to achieve program integration. The WBS managers work actively with the PIs and the Technical Project Officers (TPO), and the M&O and Labs on a daily basis. She added that successes in the issue resolution process, where groups from within the program work together to resolve issues, demonstrates the progress in integration.

The meeting was brought to a close.

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Senior Staff Scientist
United States Nuclear Regulatory Commission
Advisory Committee on Nuclear Waste
Washington, DC 20555

Subject: Consultant Report on the Yucca Mountain High Level Waste Repository Site Characterization Meeting Held by the ACNW in Las Vegas, Nevada on December 14, 1993

Dear Lynn:

Enclosed are my comments on the Yucca Mountain Site Characterization Meeting that was held by the ACNW in Las Vegas on December 14, 1993. I will try to organize my comments around the outline that you provided to the consultants on November 29, 1993. As I understand it, the purpose of the meeting was to examine the current understanding of the processes controlling matrix and fracture flow in the unsaturated zone at Yucca Mountain and the status of data collection and modeling activities. In addition, you asked the working group to: 1) explore the overall strategy that the DOE used to characterize and model flow in the unsaturated zone at Yucca Mountain; 2) evaluate the concerns raised by the State of Nevada on matrix flow vs. fracture flow and alternative conceptional models, and; 3) to comment on any NRC prospectives that were offered at the meeting. First, I will attempt to answer your key questions and issues as listed in the November 29 letter. Your questions are shown in italics with my response following.

What are the mechanisms for infiltration in the unsaturated zone at Yucca Mountain and their current relative significance to site performance?"

After hearing the presentations on the 14th by the DOE, my conclusion with regard to this question is that all of the mechanisms for infiltration are not yet understood. In general, two have been proposed: namely, flow through the matrix in the unsaturated zone at a relatively low rate, and focused flow along faults and fractures. It is important to note that most, if not all, of the characterization effort of DOE has focused on matrix flow. No discussion was held at the meeting, nor did I hear comments about alternative mechanisms for infiltration.

What is known regarding the relationship between precipitation, infiltration, percolation, and recharge at the Yucca Mountain Site, and what is the status of studies underway to ascertain these relationships?

I believe a large effort on the relationship between precipitation, infiltration, percolation and recharge is underway by Allen Flint of the USGS. However, I believe that it will not lead to the reduction of uncertainty in the estimates of flux through the repository, which is the quantity of significance. My opinion is based on two points: First, the location of most of the study areas shown by Dr. Flint did not systematically look for areas of potential focused recharge along fractures. This may be the dominant mechanism of getting water to the repository. In most of the areas that were described, the

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surface is covered with unfractured, porous material and in this type of environment it is very likely that much of the water will evaporate directly back off to the atmosphere instead of continuing on down to the repository. However, in the areas where recharge may be focused, and especially areas above or directly on outcrops that contain fractures or faults, it is much more likely that the water would rapidly migrate downward and not be affected by surface evaporation. My second point with regard to this study is that most studies of this nature, and by that I mean surface water balance studies have large irreducible uncertainties associated with them. For example, precise measurements of the upward flux of vapor from the land surface are very difficult to obtain. Other methods, such as just looking at the moisture content and the unsaturated conductivity, or especially chloride mass balance, stable isotope analysis or radioisotope analysis would probably provide much less uncertain estimates.

What significant uncertainties exist regarding infiltration in unsaturated zone flow and transport at Yucca Mountain, and how will they be addressed?

I have difficulty addressing the word "significant" with regard to uncertainty. Let me explain. I believe that large uncertainties are acceptable all the way through repository licensing, if the uncertainties can be shown not to contribute to a violation of the standard. Given that we were only reviewing site characterization in absence of performance assessments. I cannot assess whether or not the uncertainties discussed were significant or not. I can only imply that if increased recharge leads to increased discharge from the repository, that would be significant. I do not believe that the significant uncertainties in that context (i.e., the potential for a fracture flow along discrete parts of individual fractures) are being addressed by this program. Certainly, there was discussion of these issues, but no specific programs designed to address them.

How might these mechanisms and their significance change in the future through environmental modification of the near field repository?

What impact could increased precipitation have, and to what extent have these scenarios been tested?

Obviously, increased precipitation could lead to increased release from the repository. Whether or not these scenarios have been tested was beyond the charter of this particular group which focused on site characterization. However, one point is in order. That is, whether or not increased recipitation will be treated depends totally on the probability distribution (pdf) of recharge currently used by the YMP. This pdf is very low based almost solely on a conceptual model of matrix flow. If climate change is based on an increase in the upper end of the distribution, then climate change would have little effect on site performance. On the other hand, if the recharge pdf would have been based on fracture flow, then the effect of increased precipitation due to climate change would have a much more dramatic effect on the site performance.

How necessary are ongoing studies to assess possible climate change over the next 10,000 years to hydrologists characterizing the unsaturated zone, and to performance assessment modelers?

With respect to Allen Flint's studies, I would say that they are totally divorced from any climate change that could occur over the next 10,000 years. That is because he is not focusing on the key

mechanism of recharge that affect site performance; that is, fracture flow. If one only relied on his studies, then the precipitation could increase dramatically due to climate change and have little effect upon the recharge. However, this is in direct conflict with the evidence provided by isotopic measurements of the groundwater that were taken by Yang of the USGS. Not only are the isotopic measurements much more important to understanding today's conditions, but because they reflect recharge that has occurred over the past, they are also much more important with respect to understanding what future climates could be.

What approaches are being used to evaluate the unsaturated zone hydrology at Yucca Mountain, both passively and actively?

What we heard was a combination of studies based on classic soil physics, that is the measurement of tensions, moisture contents, and unsaturated conductivities used to estimate fluxes through the unsaturated zone, surface studies used to determine the water balance at the near surface which, in turn, would be used to estimate the amount of water available for infiltration, and isotopic measurements which were used to infer how water had arrived at the place of sampling and how long it had taken to get there. Your sub bullet under this question asks, "Do adequate methods exist to obtain hydrologic data needed to support complex and performance assessment modeling at the Yucca Mountain site?" In my opinion, adequacy in this context depends upon the conceptual model that is employed for understanding and simulating the behavior of the Yucca Mountain site. For example, if one were to accept DOE's equivalent porous media concept, then certainly we have adequate methods to characterize that movement of water through the unsaturated zone. On the other hand, if fractures play an important role in channeling water from the surface to the repository and beyond to the water table, then questions arise with regard to the adequacy of methods to characterize fracture flow and the ability to even find and define fractures in this complex geology. In fact, if transport of radionuclides is dominantly along isolated sections of isolated fractures, we have neither the models nor site characterization tools to assess this movement.

What current conceptual models are being considered to model flow in the unsaturated zone at Yucca Mountain?

What is the status of data collection and prototype testing to support use of these models?

As stated previously, the models being used are equivalent porous media models. In one case the geology is represented as a simple porous media (i.e., the tuff matrix is assumed to dominate the migration of water from the surface to the water table), and in the other the geology is represented as an equivalent porous media model where fractures are considered to contribute to the transport of water and radionuclides from the surface to the water table. Note that in this case the fractures are simply represented as a more permeable equivalent porous media with respect to saturated flow and actually as less permeable media with respect to unsaturated conditions. With the regard to the status of data collection and prototype testing needed to support these models, I would say that they are both in the very earliest stages and that no information has been gathered that supports the use of either of these models. On the other hand, the isotopic measurements could be viewed in as evidence against both models. These measurements imply ground-water flow distributions and rates that neither of these models could reproduce. Also, a quick look at the implied rates of ground water

movement indicates that they are faster than any of the simulations produced by the total systems codes to date. (Note: one of the total systems models, WEEPS, assesses discrete fracture flow in a very limited and non-conservative manner but this model was not discussed at this meeting)

What are the interfaces between site characterization and performance assessment modeling of flow in the unsaturated zone?

How will the results of the complex 3-D infiltration modeling will be integrated with performance assessment modeling of flow in the unsaturated zone (WEEPS, Composite porosity models?

How is site characterization data is integrated into performance assessment modeling, and, in turn, how performance assessment is used to drive data collection activities?

As implied by Allen Flint in the meeting, there is no connection between site characterization and performance assessment modeling. He stated, unequivocally, that he had no confidence or belief in any of the total systems performance assessment modeling that had been done to date. He also said that all of his site characterization data was to be used by another model being developed by B. Bodvarssan. The link between the Bodvarssan model and the performance assessment models is undefined at this time and given the structure of these models (i.e., fully 3-D Vs. multiple 1-D columns) linking them will be difficult. Therefore, I would conclude there is no link between performance assessment and site characterization at Yucca Mountain at this time.

What are the current results of groundwater age dating studies? Do they provide evidence of rapid, noncontinuum flow?

How are these results being factored into unsaturated zone testing and analyses?

I believe I have already provided the answer to the first two questions. The results from I. Yang of the USGS indicate rapid noncontinuum movement of water through fractures reaching relatively great depths in short times. These measurements are inconsistent with the results of the work by Allen Flint and the current modeling efforts. As for how these results are being factored into unsaturated zone testing and analyses it appeared that the DOE was attempting to discount them altogether. In fact, Allen Flint implied that these analyses may not be accurate and that retesting would be done in the future. This certainly seems like the wrong focus for the site characterization program. Instead, much more effort should be focused on explaining these results, gathering more of these types of data, and factoring them into performance assessment and further site characterization.

This concludes my response to the specific questions as outlined in your cover letter. Next, I would like to proceed to a brief description of my impressions of the individual talks that were presented on December 14 by the NRC, the DOE and their contractors and, the State of Nevada.

Overview of Apache Leap Research Program by Ernie Harden, University of Arizona

Apache Leap is an NRC research program and therefore its purpose and the basis for my evaluation of this talk is fundamentally different than it is for the DOE YMP presentations. My assumption about the need for independent NRC work at a tiff site is that it should address NRC's key unresolved issues such as understanding the dominate mechanisms for flow through unsaturated fractured tiff or the

adequacy of current techniques used to characterize such a system. In my opinion NRC research should address these issues in such a way that it sheds light on DOE's current approaches and understanding of Yucca Mountain.

This program has been going on since the early 1980's and as yet, I am not aware of one particular technical issue that has been resolved by this program. Instead this program still appears to be just a site characterization exercise. Furthermore, Apache Leap may not be an appropriate analog for Yucca Mountain given that Apache Leap receives 24 centimeters a year of rain and has an ephemeral stream on it. In my opinion any lessons learned at Apache Leap will be difficult to transfer to Yucca Mountain. Therefore, I believe that it would be much more productive to initiate an NRC research project at Yucca Mountain to address the issues that DOE is missing.

DOE Opening Remarks and Introductions by Joe Dlugosz

The only point I would like to make with regard to these opening remarks is the comment made by Mr. Dlugosz that the success of the program was dependent upon the DOE's ability to sample multiple scales in the field. However, none of the remaining talks discuss sampling at different scales, nor was there any talk about scaling up of lab measurements to field scale, or field scale measurements to model scale. In fact, there was no apparent integration or the use of different scales at all.

Regulatory Issues Being Addressed by DOE/YMPO Unsaturated Zone studies by April Gil.

In this talk, Ms. Gill pointed out an important conflict in the NRC/DOE program. Namely, there is an apparent conflict between the siting criteria and the disposal criteria. In fact, the confusion is greater since DOE has its own siting criteria as well as NRC's siting criteria. I think both DOE and NRC should work on this issue to assure consistency between the different sets of criteria, or more importantly, simply eliminate the siting criteria because they have no direct relevance of safety of the site. Another point made by April Gil concerned me greatly is that she said the integration of the different work efforts was to be done by individual work breakdown structure leaders, and, in fact, no-one was in charge of the integration of all of the work. This apparent lack of integration became more and more evident as the talks proceeded.

Overview of DOE/YMPO Studies of the Unsaturated Zone by Mike Chornack

I would like to make only two important points with regard to this talk. First, Mike pointed out that no discussions on gas phase movement would occur at this meeting, because the people were not available. However, this could be one of the most important phenomena occurring at Yucca Mountain, and was extremely important in light of the drilling of the exploratory shaft and the ability to characterize gas phase movement prior to that drilling. The second point that I would like to make is in regard to the exploratory shaft itself. Mike stated that the shaft would stop if the USGS says that it would destroy their ability to understand ambient conditions. Unfortunately, it does not appear that there will be time for the USGS to evaluate whether or not the ambient conditions have been destroyed as the ESF is being developed. For example, it is not sufficient for the USGS just to be taking in monitoring data. They must have time to analyze that data and determine what the data mean with respect to understanding ambient conditions. Certainly, given the timeframe needed to analyze this data, it appears that the ESF will go forward irrespective of the USGS concerns.

DOE/YMPO Characterization of Unsaturated Zone Infiltration by Allen Flint

Dr. Flint provided a detailed description of his characterization efforts which is focused on near-surface water movement through unsaturated soils. In this study a combined water balance and soil physics approach is being applied. However, their is little uncertainty in the quantity of infiltration through soils in this desert environment in the first place. Namely, the rate of infiltration is very close to zero and certainly well within the current probability distribution used in performance assessment; an assessment that already indicates the site complies with the EPA standard. On the other hand, considerable uncertainty remains in the understanding of flow through fractures and recharge under changing climatic conditions. Neither of these important phenomena can be assessed with the current study.

Apart from the study presented by Dr. Flint, comments made by Dr. Flint during the presentation are of particular importance. Dr. Flint stated that he had no faith in the current total system performance assessment models. Further, he went on to say he would not believe the performance assessment models until they incorporated all of the phenomena and processes that he, Dr. Flint, thinks are important. In fact, later he stated that the end use of his data would be a model being developed by B. Bodvarsson. Aside from questioning the usefulness of the performance assessment models, this raises several serious concerns. For one, these statements in and of themselves indicate a total lack of integration between site characterization and performance assessment. On the other hand, it could indicate that the performance assessment modelers know of Dr. Flint's concerns and have chosen not to address them (yet or not at all). It is also possible that Dr. Flint does not understand the purpose of performance assessment is to assess regulatory compliance and not reproduce everything we know or think we know about the natural system.

DOE/YMPO Site Scale Unsaturated Modeling by E. Kwicklis

My understanding is that the goal of this effort is to provide a model that can be used to address processes that may occur on a scale smaller than the "regional" model of Bodvarsson. For example, issues associated with the potential flow rates and patterns associated with fracture flow under varying amounts of recharge is being investigated. In theory, this information would then be used as input or guidance to the development of the larger-scale model(s). At first glance that the approach seems reasonable but the ability and usefulness of doing that transfer is in question due to: 1) the equivalent porous media representation of fracture flow in this model which can not address the potential for non-continuum behavior and; 2) the difficulty in transferring the information of the smaller scale model with its associated uncertainty to the larger scale model. To illustrate this later point take for example the results of this model that indicate that different fractures can contribute to flow under different recharge (climatic) environments. First, this result can not be reproduced by the larger scale model (which is why the smaller-scale model exists). Therefore, if this is an important issue with respect to assessing compliance then the smaller scale model must be used for compliance. One may believe that given the results of the small-scale model one could construct the large-scale model in such a way that as to "bound" the behavior of the small-scale model. However, given the nature of the small-scale model results this would have to be done separately for each set of recharge values. Also the final compliance model must also address parameter uncertainty. Therefore, adapting the large-scale model to be a surrogate of the small-scale model would require performing many small-scale simulations

which vary parameter values and recharge values in order to assure that the surrogate large-scale model captures the total possible behavior of the small-scale model. However, by this point there is no longer a need for the large-scale model because the uncertainty analysis just performed with the small-scale model has already satisfied the compliance needs. On the other hand, if the small-scale model behavior could easily be captured by the large-scale model, then there is no need for the small-scale model in the first place. Also note, the argument is even stronger for the rest of the models in the YMP so-called "pyramid" approach of going from complex models to total systems models.

Finally I would like to re-emphasize that this model is addressing fracture flow through the use of an equivalent porous-media approach to addressing fracture geometries. The potential for non-continuum behavior is not being addressed nor are the potential for momentum effects being accounted for.

DOE/YMPO Hydrochemical Characterization of the Unsaturated Zone by I. Yang

This study has provided the most valuable and enlightening data developed by the project to date because it clearly demonstrates that rapid flow of ground water occurs and that this flow has been transported along discrete interconnected fractures. Collection and analysis of isotopic data should be a major focus of the program because it provides the only direct evidence of the rate and distribution of ground-water flow. In addition, isotopic analysis may provide the most useful information on the potential effects of climate change since it reflects movement under a variety of past climates. Also this is the only data that can be used to assess fracture flow conceptual models. In fact one could argue that this data already rules out the existing conceptual models used by YMPO. Unfortunately, there is an inherent difficulty with trying to capture this type of behavior with existing characterization methods. That is, it is difficult to characterize vertical or nearly vertical movement along discrete fracture with vertical boreholes. Also the possibility that only small parts of a few of fractures may contribute most of the flow will make sampling very difficult.

Although the discussion of gas phase movement was beyond the scope of these meetings Mr. Yang made one very important point in this regard. He stated that it would take four years to get background gas samples. This appears to be in conflict with the ESF schedule and the potential of the ESF to disturb background conditions.

Three-Dimensional Model of Unsaturated Flow by B. Bodvarsson

All of the site characterization data and previous modeling efforts were said to feed this model. This model is to be calibrated with existing data and then used, in turn, to "predict" the measurements to be taken from future boreholes. In theory the error associated with this "prediction" would decrease each time and at some point become acceptable (to the DOE?, to the USGS?, to LBL?, but not to NRC). At this point this three-dimensional model of the entire Yucca Mountain is calibrated with one data point. Among the many questions about this model the most fundamental is why does it exist? This model is the same or very similar scale as the total systems performance assessment model so why not: 1) use the data to directly update the PA model? or 2) why not replace the PA model with this model. In addition, the modeling approach taken in conjunction with statements by A. Flint about Yucca Mountain being deterministic not stochastic paint an interesting picture of the philosophy behind the model development and calibration. The picture seemed to be an overly optimistic one of ignoring

fundamental uncertainties of spatial variability and scale dependence and dependence of model scale on the inference of knowledge. In my opinion, these topics, along with the topic of abstraction from complex to simple models deserves serious attention by the ACNW but it was beyond the scope of this meeting.

Integration of Unsaturated Zone Data Collection, Modeling Studies, and Performance Assessment by C. Newberry

After spending a good part of the meeting trying to figure out how all of the studies fit into performance assessment, I was looking forward to this presentation. Unfortunately, little or nothing was specified about the relationship between any of the work presented and performance assessment. If anything it appeared to be one more program based on the contention that a site is first "characterized" and then modeled. This approach is never ending as "characterized" has no unique definition and is being performed outside of the regulatory needs.

Other topics of note from this discuss included: 1) statements that the process of validation need two codes; and 2) the DOE opinion on the NRC's ground-water travel time requirement. The DOE seems to believe that this part of the multiple barrier requirements is "useless". In addition, the NRC appears to have quite a bit of confusion over this issue. In my opinion, this is a straight forward requirement that directly results from performance assessment. In fact, all of the performance assessment results I am aware of display the exact premise of the requirement. That is, if the travel time is greater than 1,000 years then the site is likely to meet the EPA containment requirement.

Alternative Conceptual Models of Unsaturated Zone Flow at Yucca Mountain by L. Lehman

The main point of this talk is that there are alternative conceptual models with regard to recharge distribution and rate that are not being addressed by the YMPO. In addition, because these models are not being taken into account, the recharge being used by the YMPO is too low. In general I agree with the statements made by Ms. Lehman. While YMPO continues to give lip service to alternative conceptual models, there is little or no evidence that they take the concern seriously.

Their approach is to base their modeling and characterization on their preferred conceptual model while hoping to stumble over evidence for alternative models if it exists. This should be contrasted with an approach that reorients its site characterization and modeling efforts to focus on finding evidence for and against alternative models.

CONCLUDING REMARKS

Most of the my concerns are already discussed in the answers to your questions and in the discussions about each talk. However, one major concern was not discussed. That is the lack of integration within site characterization and between site characterization and performance assessment. Perhaps the best way of explaining my concern is to explain the components of site characterization as I see them. Those components include: 1) a definition of data collection needs; 2) prioritization of data collection efforts; 3) optimization of data collection strategies and; 4) definition of a stopping point. For the YMPO, the site characterization report (SCR) could be considered as the definition of data collection needs but the SCR is a shopping list of all possible data (for one conceptual model) and not a list of data required to achieve regulatory compliance. Given that performance assessment is the means of

assessing compliance, the data requirements should be driven by PA. However, not one speaker mentioned collecting data as a result of a request from PA. Second, there was absolutely no mention of prioritization of data collection. Third, optimization, in terms of spatial location or sequencing of data collection was not discussed. Finally, and most important, there was no mention of a stopping point to the data collection process. in fact several viewgraphs presented logic diagrams for data collection that showed infinite loops. Without the DOE defining these critical elements of site characterization, it does not appear that site characterization will get them to regulatory compliance.

Finally, I would like to call your attention to the references on risk communication that I had previously sent you. As you and I discussed, I believe the DOE could go a long way toward improving their image and the acceptability of their presentations if they would heed the advice contained in those references. If you have any further questions or if you would like me to look in more detail at some of the topics raised (for example, the abstraction of complex to simple models) please contact me at 505-848-0754.

Sincerely,

Paul A. Davis, Manager
WIPP Technical Integration and
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Copy to:
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To: Martin J. Steindler
Chairman, ACNW
From William Hinze
Subject: Overview of the ACNW working group meeting on Unsaturated Zone Flow at the Potential Yucca Mountain HLW Repository Site
Date: 03/10/94

Characterization of the subsurface hydrology and the hydrochemistry are among the most important of the siting problems at any proposed radioactive waste repository site and certainly that is true at the proposed Yucca Mountain site. Numerous groups have and continue to review the subsurface hydrology characterization at Yucca Mountain, but we are approaching a critical period in the characterization process and its connection with the regulatory framework. The NRC must be prepared to provide appropriate guidance to the DOE on licensing concerns and how the NRC will apply the regulatory framework to Yucca Mountain. Furthermore, the NRC must be concerned that its regulations are applicable, properly understood and interpreted, and met using the highest quality scientific and technical data and information. Thus, it was appropriate that the ACNW review the progress of subsurface hydrology characterization at Yucca Mountain. The Workshop held in Las Vegas, NV on December 14, 1993, was the first step in this process.

The focus of the Workshop was on the unsaturated zone in which water infiltrating into the subsurface flows in a complex manner through matrix openings, fractures, and faults toward the ground water table and the saturated zone. The specific objectives of the Workshop were to review:

1) Advances made in understanding the processes of fluid flow and their controls in the welded and non-welded tuffs that make up the unsaturated zone.

2) The status of data acquisition and modeling.

3) The uncertainties in unsaturated zone transport and flow that currently exist and those that are likely to persist through the characterization process.

Numerous more specific questions were directed to the 14 speakers from DOE and its contractors, the State of Nevada and its contractors, and academia, as well as to the three ACNW consultants.

Minutes of the Workshop have been prepared based on review of the verbatim transcript of the meetings and notes provided by the speakers. In addition, to summarize the major issues developed at the Workshop and focus on potential future ACNW activities, the ACNW has reached the following conclusions:

1) A great deal of excellent data have and are being acquired to characterize the geologic and hydrologic nature and processes of the unsaturated zone at Yucca Mountain.

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However, a great deal of work remains to characterize this aspect of the site.

2) Integration of the program - plans, activities, analysis, interpretation, etc. - is perceived to remain an important problem. How much of this perception is a reality is unclear, but DOE has made significant progress in this area. There are so many participants and aspects to the program that often the characterization appears disjointed. Certainly more work is needed on integration.

3) The overall strategy of the unsaturated zone studies is not clear. The components of the system are in place, but the interactions among the components and the quantitative modeling of the system's behavior is not yet complete. The system does not have well-defined decision and termination points and the criteria for defining them.

4) Modeling is on a proper and useful path. Data are being folded in from the site characterization and modeling is being used to guide characterization. Multiple modeling approaches are being used. This should be encouraged, expanded, and well supported.

5) Preferential pathways are probably very important to fluid and gas flow at Yucca Mountain. Faults and their hydrology are significant and may be more important than either matrix or fracture flow. Yet these are poorly defined and remain one of the more critical uncertainties. Until they are better defined modeling and related performance assessment are subject to considerable error. Fracture and fault flow are being investigated to a significant degree through hydrologic and chemical modeling. Direct observation and testing especially directly above and below the respository are inadequate. More work needs to be planned to alleviate this concern. Considerable exploration and testing is planned for the ESF. This is important and should be initiated as soon as possible after access is obtained by tunneling. However. testing in the tunnel will not adequately characterize the unsaturated zone. Testing and exploration should also involve the rock volume between the well studied surface and near-surface ($\sim$ 100m) and the ESF and between the ESF and the ground water table.

6) Results to date of the hydrologic investigations together with inferences from geologic studies indicate that horizontal flow is probably very important to the hydrologic regime. This is a major uncertainty that can and must be removed by appropriate field investigations and modeling.

7) The velocity of fluid and gaseous flow in the unsaturated zone are important to satisfying the statutory regulations, but are poorly known at this time. The opportunity does exist to remove much of this uncertainty.

8) DOE has greatly improved access to relevant data for DOE and its contractors. However, improved access for others is an appropriate goal.

In my view the Working Group meeting satisfactorily met its objectives as indicated by the above observations.

Thus, it is worthwhile to continue the overview of the subsurface hydrology characterization at Yucca Mountain. This can be accomplished by taking part in the NWTRB overview of the saturated zone hydrology at their meeting in April, 1994. This should be followed by a Working Group meeting on dating of ground water - a particularly important and troublesome concern. The information derived from these meetings should be used to give advice to the NRC staff on the guidance they are providing to DOE and also for the consideration of the subsystem requirement of 10CFR60 dealing with the definition of the disturbed zone and ground water travel time. Consideration of the disturbed zone will necessitate further exploration of problems related to thermal loading of the respository.

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December 22,1993

Ms.Lynn Deering
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Dear Lynn:

After thinking about the working group meeting for the past few days I realize, most of all, what a great learning experience it was for me who was almost starting at zero knowledge on the Yucca Mountain high level waste repository. My general impression was that that all of the presenters were making progress and were moving towards a good understanding of unsaturated flow at the repository site.

On separate sheets I have indicated some general and specific observations on the program. I was not sure what kind of feed-back that you wanted or needed.

I look forward to seeing you again. Let me know if you would like more comments on any specific topics.

Sincerely,

William M. Sackett

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NUCLEAR WASTE WORKING GROUP MEETING

GENERAL COMMENTS

It appears that that the Yucca Mountain siting as a repository for high level nuclear wastes is well developed. PIs have been identified and funded, analytical and modelling techniques have been perfected and abundant data and models are forthcoming. Secondary questions and refinement of models are now being addressed.

If Yucca Mountain has irrevocably been chosen as the repository site I do not see the need for the Apache Leap program. It would seem that it would be advantageous to transfer efforts to the Yucca Mountain site.

SPECIFIC COMMENTS

Stable Isotope Program

Observation-Del 13C of CO2 gas in UZ-1 has a rather constant value of about -21 o/oo vs PDB from 1988 to 1991 and with depth in the hole. The -21 value is part way between the -8 for atmospheric and biologically derived CO2-the probable sources.

Questions- Was CH4 detected and what was its del 13C?
- Where did the biological oxidation occur?
- Could CO2 be coming from the underlying saturated zone?
- Do the constant del values indicate that CO2 is migrating up and down the rock column?
- Could there be a magmatic source of CO2? -

Observation-Del 18O of water changes from about -10 near the surface to about -14 at- 1800 feet in hole UZ-16 vs SMOW.

Questions-What is the del 18O of present day precipitation?
-If also -10 what does the change from -14 to-10 represent-a climate change or a change in evaporative conditions or what?
- Del D and del 18O do not fall on the present day meteoric water line-why not? - Could be the standard used in the determination be the problem?
- Does squeezing the rocks to get pore water introduce any fractionation between pore water and residual water?
- How many data points for Yucca Mt precip line-what is the distribution?

Radioisotope Program

Observation- For UZ-16, tritium activity is elevated over background levels at -250 and -650 feet and exceptionally high at -150 and -1425 feet.

Questions- Does the one or the other of the peaks correspond

to the high tritium in precipitation in the early 1960s? What could the other peak be due to?

-For UZ-16, Chlorine-36 shows high levels at the surface. Is this due to cosmic ray production or atomic weapons testing? What does the elevated level at -1175 feet indicate? Why is the distribution for Cl-36 different than H-3.

Observation-For C-14 in UZ-1 pore waters, bomb C-14 is seen near the surface, as expected. Distribution is about the same from 1988 to 1991.

Question-Does the decrease in C-14 reflect the age of the deposit, exchange with the rock or what?

RECOMMENDATIONS

1.Continue work on cosmic ray produced activities. They provide the best way of getting information on the movement of fluids through the unsaturated zone.

2. Look for the peak in bomb tritium and radiocarbon in pore waters and fracture infilling.

3. Initiate a program on uranium - thorium series nuclides in cements and other materials deposited in fractures. Disequilibria between various parent-daughter pairs will give approximate time constants for solution -redeposition processes. Nuclides of particular interest should be in the uranium series U-238,U-234,Th-230,Ra-226,Rn-222,Pb-210,Po-210 and in the thorium series Th-232,Ra-228 and Th-228.

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Jan. 1, 1994

TO: Bill Hinze

FROM: Darrell Leap

SUBJ: Reflections upon the December 14, 1993 meeting of ACNW, Las Vegas.

Pursuant to your request, I have outlined below my perceptions and conclusions concerning the presentations and the philosophy behind them, as I heard them at the Decmber 14 meeting. I will discuss them in the order in which they were presented.

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(1) 8:15 - 8:30: Ernie Hardin, (UA) -- Overview of Apache Leap Research Program.

First of all, I was duly impressed by Mr. Hardin. He obviously is a very bright and capable scientist, and has not yet received his Ph.D.. The results he presented were most interesting and certainly well-researched. However, I believe that the work in the Apache Leap site is directly applicable to Yucca Mountain in only two cases.

In the first case, the hydraulic theory developed at the Apache Leap site regarding the iteraction of fracture flow and matrix flow and the hydraulic equilibrium between them is applicable to Yucca Mountain. Essentially the same ideas prevail at Yucca Mountain -- the investigators have found that hydraulic equilibrium does not necessarily always exist between fractures and matrix, thus nullifying the possibility that flow is uniformly distributed in the entire system.

In the second case, mineralogically, the Apache Leap and Yucca Mountain sites seem to have some similarities, and chemical activity should thus be similar. In is unclear why the nitrate levels are so high at Apache Leap (20 ppm); Hardin did not know either. I wonder if it could be due to the redisdue from nitrate explosives used in mining.

They put a lot of emphasis on Carbon-14 dating of water, but have not yet looked at tritium, which they should do. I would have considered tritium before ^{14}C, because it can yield more realistic recent travel times. Dale Moeller asked a good question about breathing of gasses in and out of the mountain for which Hardin had no good answer.

ENCLOSURE

Aside from these two cases, the similarity between the two sites essentially ends. Yucca Mountain is a highly stratified system with many faults and fractures and Apache Leap is not. Thus the hydrology of Yucca Mountain is much more complex, as is the hydrogeochemistry.

Because of the conceptually complex interactions of water flow systems, gas flow systems, ion exchange, potential effects of climate change, and possibly other undiscovered factors, I believe that Apache Leap can offer little additional insight to the problems of Yucca Mountain characterization. Therefore, I believe that the NRC should consider emphasizing less Apache Leap research and more Yucca Mountain investigations.

(2) 9:15 - 9:30: Joe DLugosz, (DOE) -- Opening Remarks and Introductions.

There was little in the way of technical material in this talk. However, the outline of concerns was good. I was pleased that the DOE is considering investigating the potential effects of future climate changes. Another important point is that DOE admits that it may have underestimated the effects of ventilation throughout the site. An especially important point he brought out was the need to study the interrelationships between precipitation, infiltration, percolation and recharge.

The milestone chart seems to adequately take into account the immediate unsaturated-zone issues to be studied, but I do not know how realistic the goals really are.

(3) 9:30 -9:45: April Gill, (DOE) -- Regulatory Issues Being Addresed by DOE/YMPO Unsaturated Zone Studies.

This was a good presentation of both favorable and unfavorable conditions prevailing at the Yucca Mountain site, as presently set forth in EPA regulations and the CFR.

It is apparent the DOE believes that the unsaturated zone will prevent flow to the accessible environment for well more than 1,000 years, under present climatic conditions.

There were several items shown that supported the site's desirability in view of CFR requirements; i.e., low moisture flux, free drainage of host rock, low-permeability rock above the host rock, and precipitation which is small percentage of potential evapotranspiration.

The most pressing potentially adverse conditions, in my opinion; are (1) potential for climatic changes to adversely affect ground water flow, including water table rise to the repository level; (2) perched water; and (3) gaseous movement of radionuclides. These conclusions are predicated upon the following information:

(1) Climatological models predict a possible 10-fold increase in precipitation in the Southwest in the next 100 - 150 years if the atmospheric carbon dioxide levels continue to increase, and if nothing is done to abate its discharge into the atmosphere. There is a great deal of controversy about this prediction and some do not believe that precipitation will increase by this amount.

Regardless of the real scenario, which no one has a grasp of yet, there is a real possibility that preipitation will increase, and perhaps by a substantial amount

If indeed this increase does come about, there will undoubdtedly be a change in the flow dynamics between fractures and matrix. Local zones of saturation will likely appear and fracture flow will likely be increased over that of matrix flow as the matrix becomes saturated near the fractures.

Potential evapotranspiration will likely be reduced with increasing air humidity; and recharge to the unsaturated zone, and ultimately the saturated zone, will be greatly increased. Storativity of the presently unsaturated materials is likely to be reduced as the degree of saturation increases. The water table is likely to rise over many years--just how many years it will take to rise is unknown.

(2) Perched water may already exist within the repository block. According to Montazer's and Wilson's conceptual model, perched water may exist at the contact between a fairly impermeable layer and a fault, assuming the fault has a low permeability due to fault gouge or juxtaposition of low permeability beds. If this is true at present, and I'm not sure that I heard that anyone has proved or disproved this point, then an increase of precipitation of 10-fold will certainly exacerbate this phenomenon. The potential presence of perched water is troublesome for repository construction and safe operation.

(3) Gaseous movement (if it exists) is a problem that should be investigated. I am happy that the USGS (i.e., Rosseau, et al.) is planning an investigation of this potential problem. It would seem that this is a possible transport mode that would be less likely to occur in conditions of greater saturation, where pores has less gas in them. At this time, it seems that no one can actually quantify this process. Tracer gas analysis would certainly help in this investigation--chlorinated fluorocarbons, tritium, carbon-14, etc.

The remaining concerns of the DOE for UZ hydrology, including Potential for changes in hydrologic conditions that would affect radionuclide migration --10 CFR 60.122 (c)(5); Groundwater conditions in the host rock that could increase the solubility or chemical reactivity of the EBS -- 10 CFR 60.122 (c)(7); Geochemical processes that would reduce sorption -- 10 CFR (c)(8); Groundwater conditions that are not reducing (i.e., oxidizing) -- 10 CFR 60.122 (c)(9); and Rock or groundwater conditions that would require complex engineering measures (10 CFR 60.122 (c((20); would be most likely caused by changes in recharge rates which in turn would be the direct consequences of climatic changes.

As a final note on this presentation, it seems to me that from the organizational charts presented, the UZ program is vastly overmanaged. This is not an observation that I can quantify, but I know from experience how much of my time and effort was spent in "jumping through the hoops" and QA/QC efforts. I still do not know how DOE can expect to properly oversee all the activities in this program, or how the scientists and engineers involved can spend enough time in the investigations.

(4) 9:45 - 10:15 M. Chornack (USGS) -- Overview of DOE/YMPO Studies of the Unsaturated Zone.

This was an excellent presentation. The USGS field and laboratory scientists know what it is all about when it comes to hydrogeology of this area. It was quite a contrast from the DOE "supermanagement" presentations. Mike impressed me as a very capable scientist who has his act together. Unfortunately, he like so many other USGS personnel in the trenches is hampered by the glacial pace of the USGS upper-management decision-making process. There has always been the friction between USGS and DOE which provides the funds.

The main problem has always been **threefold: In the first place,** the USGS chafes under the restrictions DOE places on it for data release and dissemination, as well as QA/QC requirements. Traditionally, the USGS did things its own way and relied on its own internal peer review process for QA/QC, but in this program it has to take a second seat to DOE.

I asked Mike the question, "If there is ever a question of disagreement between the USGS and DOE about the interpretation of data or results, who's argument prevails (DOE or USGS)?" He deferred the question to Larry Hayes who answered that in the end, he (Hayes) would have the last say and could release or withold data or results at his discretion. He also mentioned that USGS could address independently the concerns of the state of Nevada. This statement seems to be contradictory to a later statement that the State of Nevada could not get data as easily as a project participant.

I don't know if this position has ever been put to the test, but it could cause some ill will between the two agencies if it ever came to a head. I know for a fact that data taken and analyzed by USGS for the Yucca Mountain project has to be approved by DOE for release in papers or public reports.

The second problem has to do with the very slow process of getting USGS analyses, results and interpretations of data to the DOE and cooperating laboratories and cooperating contractors. Usually, the other cooperators can produce results weeks or months before the USGS investigators can, simply due to the rigid USGS way of operating. This was brought out in questions to Mike and Larry Hayes. Although Hayes admits this is a problem and that something is being done about it, it still exists, and it is not likely to be totally resolved soon, although a data center has been set up in Las Vegas, and that interpretative papers are being sent out as analysis

papers. The major problems or bottlenecks are in Reston and Denver, not in NTS USGS offices.

The third problem is persistent lack of adequate funding. This has been a problem since the USGS first got involved, and I have never been able to figure out why this is the case. The national laboratories always seemed to have adequate fund to do a first-class job and to have the best equipment. USGS always seemed to be a poor country cousin. Larry Hayes also lamented that this is presently the case; he could drill more holes by laying off scientists.

I would think the DOE could lay off several layers of managers and put more funding into scientific research.

As Chornack described the planned studies of the UZ hydrology of the site, he was careful to cover everything possible (short of climatic change studies) that could be studied in the way of water movement. The USGS field investigation program (as described in his handout and presentation) appears to be well thought out and staffed by capable scientists and engineers, although they could use more.

I was particularly pleased that he also discussed a horizontal borehole across Solitario Canyon Fault, even though a drift is also planned across the fault. The borehole can be instrumented for changes in properties and will have less disturbing influence on the fault than a drift. I am happy to see the USGS concentrating its effort on real field-acquisition of data, rather than concentrating all their effortson modeling.

(5) 10:30 - 11:30: A. Flint (USGS) -- DOE/YMPO Characterization of Unsaturated Zone Infiltration.

Alan Flint was most impressive. He obviously knows whereof he speaks about unsaturated flow. The outline of planned activities for studying infiltration was very good, and are what is needed. I was especially impressed with information already gathered, particularly the information about the high storage capacity of the alluvium. Also, the fact that the alluvium and the carbonate layer beneath its surface can serve to hold water near the surface is an important piece of information regarding infiltration.

It is particulary noteworthy that if fractures exist beneath alluvium, water may not even reach the fractures. The fact that their modeled predictions of water content and the measured values were very close lends credence to their theories. I am happy to know that they plan to study 40-Mile Wash, because the underlying fault could be a major pathway of escape of water from Yuccal Mountain.

Another important point that Flint mentioned is that faults have low permeabilities due to calcite cementation in the faults. It would be most worthwhile to know if this condition persists in all faults, and if it can predicted. He also stated that fault permeability is not independent of water retention curve, i.e., moisture content also affects permeability.

He was careful to point out that steady-state models do not yield field-measured values of flux, but episodal events of wet times versus exfiltration must be taken in account to obtain proper results that match field-measured values.
One troubling statement he made was that performance assesment models are not taking into account real data and characterization of the site; the three-dimensional makeup of the site and known properties of the site are not being considered. This is a point that must be worked out with the DOE, USGS, and the investigators involved.

Another important statement Flint made was that the hydrogeological properties of the site are **deterministic, not stochastic.** He also suggested that this may be why USGS models work-they use real, deterministic data. This is a very enlightening statement. I have always been leery of stochastic gurus who believe that geological properties are random and that geological processes are essentially ignored. I am glad that Flint brought out this point.

The deterministic properties of the site are easy to believe when one considers the depositional history of the site; beds of tuff were laid down from fallout from the Timber Mountain Caldera so that the coarser materals were laid down nearest the source and the finer particles farther away from the source. Thus, aside from subsequent faults and fractures, we have deterministic properties within the individual beds.

The planned activities as outlined by Flint are very good.

When Paul Davis asked Flint when will he know if he has enough data, Flint said "I don't know". This is a problem for everyone--how much data will be required? Perhaps this should be a major point to discuss with the DOE. I discuss this later at the end of this report.

(6) 11:30 - 12:00: E. Kwicklis. (USGS) --DOE/YMPO Site Scale Unsaturated Zone Modeling.

I am not sure why Kwicklis wants to model the site scale using stochastic approaches after Flint mentioned that the properties are deterministic. His presentation brought out some important and needed investigations that are being conducted in the subsurface where the USGS and most others agree investigations should be concentrated.

I have no criticism of this work. The information acquired so far seems good and enlightening. It is especially noteworthy that results so far indicate that

(a) van Genuchten equation may be questionable for Yucca Mountain tuffs--predicted and masured hydraulic conductivities don't jive;
(b) there is imperfect correlation between several hydrogeological properties;
(c) tritium analyses hint at infiltration within the last 21 years.

This research should be strongly supported. It is crucial to understanding the flow inside the mountain.

(7) 12:00 -12:30: J. Rousseau, (USGS) -- DOE/YMPO Surface-Based Data Collection Studies on Unsaturated Zone Percolation.

Important areas to stress are elucidating the water in fractures in the Prow Pass unit--this is troublesome. Also, the fracture density in the Topoah Spring member is much greater than formerly anticipated. The problem of percolation addressed in this talk is very important and should be further researched, but it will require more holes than they previously have drilled. I assume additional holes will be drilled for this purpose.

The question as to whether upward flow from the saturated Prow Pass member is actually a real phenomenon has to be answered. This could really throw a monkey wrench into hydrologic interpretations.

Rosseau's experimental apparatus which he demostrated on the field trip is most impressive. I believe he is on the right track, and I have no criticism of his approach.

(8) A. Yang, (USGS) -- DOE/YMPO Hydrochemical Characterization of the Unsaturated Zone.

This was another presentation of very good science. The use of more thtn one isotope to elucidate the possible movement of water is a good move.

I learned something important that we should try in our own tritium lab in the Earth and Atmospheric Sciences Department--extracting of pore water by high pressure squeezing rather than by toluene extraction as we now do it.

Yang's research opens up more questions which must be resolved before the site can be declared satisfactory for waste emplacement:

(A) Does gaseous diffusion, as suggested by rapid transport of CO_2 play an important role today, especially in the Topopah Spring member; and is it potentially as important as gaseous convection as a transport mode?

(B) Why do tritium and Cl-36 show up in UZ-4,UZ-5, and UZ-16; and why does high tritium occur in the Calico Hills water when the chemistry indicates the presence of paleowater? Could the tritium be due to gas convection? This is very troublesome.

Data on Carbon-14 which had not yet been received back from the lab at the time of this meeting may help to shed some light on these questions.

I asked Yang the question, "If the tritium can't get in vertically (as Yang maintains), where is it coming from?" He had no explanation.

I asked another question, "If vertical percolation is ruled out, how can we account for the presence of deep old water (above the present water table); did it get there via different flow paths during wetter pluvial times?" Yang said no. He said that today heavy rainstorms run off into canyons.

Alan Flint then suggested that the deep old water may be related to flow into the site from Pahute Mesa.

I am not sure that I totally agree with the above answers, but then, I am not as close to the problem as they are. It is interesting to note that water samples taken several years ago at a depth of 13,000 feet below Pahute Mesa showed significant dissolved oxygen, indicating rapid recharge from the surface through vertical fractures. In the early 1970's Clebsch et al. found high tritium contents in water seeping into a tunnel beneath either Pahute or Ranier Mesa, indicated a depth of percolation of at least a hundred feet in seven years, as I recall--I can find these references if you want them. So, I do not believe that vertical percolation can be totally ruled out.

My subsequent question is this: Does possibly old water in the Calico Hills unit indicate that the water table was once in the unit and recharge from Pahute Mesa came in through a saturated zone, or are there other flow paths above the water table that have in past recharged the Calico Hills from Pahute Mesa, and perhaps from elsewhere?

On the other hand, although Flint and Yang discount modern vertical recharge from the surface to the Calico Hills and other units through faults and fractures (due to carbonate cementation), it does not necessarily stand to reason that the same conditions existed during the pluvial time when there was much more precipitation and thus, probably more CO_2 getting into the faults and fractures which would tend to keep the pathways more open than today.

This might seem like a moot point today, but if precipitation does increase significantly, then we can expect that more CO_2 will get into the system and perhaps dissolve out some of the carbonate. Again, as I suggested in the round-table discussion, if increased precipitation continues for several hundred or a few thousand years, then we might see soil zones develop on the surface which would produce CO_2 from decaying vegetation, which in turn might get into the system.

This is scientific c onjecture at the present time, but it should be considered along with climatic-change investigations.

It is apparent that with all the uncertainties and conflicting isotopic data taken thus far, and the presence of water in the system, that this project should also be accelerated and supported. Answers to these questions must be found before performance assessment studies can truly gain any credence.

(9) 2:00 - 2:30: M. Chornack, (USGS) -- Exploratory Studies Facility Interface - Construction Phase Activities - Main Test Level Activities.

I have no comment on these plans other than it seems to me that they have been carefully thought out, and are in place to take maximum advantage of the opportunity of the tunnel. They all seem reasonable to me.

(10) 2:30 - 3:00: B. Bodvarsson, (LBL) -- Three - Dimensional Model of Unsaturated Zone Flow.

This is a most ambitious project. I don't know if it is oversold or if it will accomplish everything that it is purported to do. Like so many models, it will be only as good as the data put into it. I have no problem with the technical expertise behind the modeling effort or the plans for the modeling effort itself, or the theory behind it.

The model takes into account about everything one can think of in the way of processes going on at Yucca Mountain -- gas flow, geothermal gradient, water flow, the ESF, etc.

However, I do seriously question the statements that it is to be used to (a) "Predict conditions at new boreholes"; and (b) "Guide in the site-characterization process". I do believe that it can help to "Integrate the available data", and in "Sensitivity studies".

My rationale for making these statements is as follows:

(a) I do not understand how the model can predict the conditions at individual boreholes in light of the new and unexpected anomalies that are constantly being found (e.g., tritium, unexpected water, gas circulation and diffusion, etc). It might help to predict such things as water table elevations in the saturated zone, but you don't need a model to do that. In addition, I do not think, in light of the data presented, that all the flow pathways have been truly delineated thus far. This is crucial to making a model work in a believable fashion. Bodvarsson did state that the character of fault flow may have to be changed in the model as more data are acquired about this subject.

(b) I simply do not know how the modeling effort can "guide the site-characterization process", unless it can be used for sensitivity studies to show how sensitive the model is to additional data: it probably can be used to advantage in that sense, and for that reason, should be used. But, the quality of the data going into the model is most crucial to making sense out of such studies.

I remember a meeting I attended ten years ago in which a consultant gave a talk in which he said that modeling could "reduce the number of observation wells needed in a project." Such a philosphy did not make sense then and still does not make sense. Remember, GIGO = Garbage In, Garbage Out!

From what I have read and gathered from my modeling colleagues, integration of available data of a particular site, and predicting response of the well-characterized site (assuming parameters don't change over time) to particular stimuli are much more realistic goals of modeling than extrapolation of the same parameters to the unkown. This point is especially pertinent to Yucca Mountain where climatic changes may cause as yet unknown changes in hydrologic parameters and flow pathways.

Recent papers by Bredehoeft and Konikow call into serious question the efficacy of predictive modeling unless the flow system is understood in the most minute detail. In light of the experience of modelers over the last 20 years, and in light of the continuing discovery of unexpected parameter values at Yucca Mountain, I would seriously question the validity of extrapolated modeling results in the unsaturated zone at Yucca Mountain.

Finally, the most critical question pertaining to the modeling effort is this: Will the DOE believe the modeling results in lieu of enough real data and use them to prove its point? With all the PR the DOE is assembling to make its case, I fear that the model could become a "source of truth" in and of itself!

(11) 3:00 - 3:30 C. Newwberry, (YMPO) -- Integration of Unsaturated Zone Data Collection, Modeling Studies, and Performance Assessment.

My major comments about this talk are; (A) the speaker did not know how to answer many of the questions put to her -- I got the feeling that she was being used as the "sacrificial lamb" by her superiors; (B) the whole infrastructure and logical flow of information and decision making, as oulined in her overheads was horribly complex and overmanaged.

The whole effort of the DOE in this aspect is to rely on models and model interaction at various scales to direct the entire site characterization process. This is not only too restrictive in light of the frequent new and unexpected discoveries that change the conceptual model of the area, but it is far too restrictive for the scientists that are obtaining "**real data**". I think it is obvious from all the real data gathered, and from the contiuing changes in the conceptual model of the site, that the flow chart of "Performance Assesment Model Integration", as Newberry showed it, is nothing short of an exercise in overmanagement.

In the final analysis, all the management and performance schemes must depend on the real field and laboratory data acquired, and the proper hydrogeologic theory to put it all together. Overmanagement of such research by DOE only slows the process. In addition, such complicated management schemes become ends in themselves, rather than means to an end.

I still do not believe, in spite of what I heard, that such management can produce the kind of communication between all parties that is needed in a project of this scope and magnitude, and I am speaking largely from my own experience in a time when the management infrastructure and QA/QC demands were considerably less complex than they are today. In short, this talk was so much DOE management "arm waving", in my opinion.

(12) 3:45 - 4:00 Joe DLugosz, (DOE) -- Review of DOE/YMPO Response to ACNW Concerns. -- deferred to Round Table Discussion.

(13) 4:00 - 4:30 Linda Lehman, (Linda Lehman and Associates) -- Alternative Conceptual Models of Unsaturated Flow at Yucca Mountain

Linda Lehman represents the State of Nevada. Her presentation, although it did bring out an interesting concept, namely "focused recharge", did not add much to the overall level of knowledge at the meeting.

Her main thesis was that alternative conceptual models might be realistic. It seems to me that the work by the USGS is capable of determining, in much more scientific manner than her approach, if alternative conceptual models are realistic are not.

It also appears that she does not have the scientific or technical backup that even comes close to that of the USGS. From what I heard from the USGS personnel, they are also looking for alternative interpretations of the hydrogeology of the site.

I don't think that I agree with her statement that "Choice of an alternative conceptual model has a large impact on certain parameters." I believe that the information presented at the meeting indicates that the parameters drive the conceptual models, and that conceptual models in turn are modified according to new data about hydrogeological parameters (e.g., Montazer's and Wilson's conceptual model is being modified in light of new data coming in).

She admitted that data is not yet sufficient to fully elucidate "focused recharge" areas, and that more work needs to be done on the west side of the mountain. She also thinks that work so far is biased toward matrix flow. From what I have been reading, it seems to me that the USGS is coming around to a closer look at fracture flow.

Her insistence in "fair treatment" of alternative conceptual models, or "analysis of bias " are moot points in light of field data. Ths is why much more emphasis must be put on subsurface investigations in order to reduce the number of possible "alternative conceptual models" that could be derived with inadequate data, in spite of all the models in the world: shades of Chamberlin's "Multiple Working Hypotheses"!

However, in this case, we want only ONE conceptual model-- the Right One! There is too much at stake to choose the wrong one.

It might be conceivable to work Linda in with some of the investigations to eliminate any feeling of "bias" on the part of USGS or DOE to her ideas, or to the concerns of the State of Nevada.

(14) 4:30 - 5:00 Marty Mifflin, (Mifflin and Associates) -- Fracture and Matrix Flow in the Unsaturated Zone at Yucca Mountain.

Marty's main contribution was the description of scenarios that might come about as the result of changes in the climate withnin the next 10,000 years. This is a noteworthy contribution. It seems to me tht far too little is being done to account for possible problems resulting from increased recharge.

If he is right that recharge in the future could be 10 times that currently, then we can expect the results he outlined -- water table rise, perched water in the Paintbrush tuff and Calicao Hills tuff, and increase in the perennial and ephemeral flow through fractures, vapor phase transport due to steam generated by the waste packages, and possible repository flooding.

These ideas should not be ignored because climatologists are predicting significant increase in precipitation in the area. Hydrogeological studies of both the saturated and the unsaturated zones, and performance assessment studies must take into account the possibility of increased precipitation and recharge.

(15) 5:00 - 5:30 D. Kreamer, (UNLV) -- ESSE Peer Review Comments on DOE's Hydrology Program.

I did not get much out of this talk. I do recall him mentioning that permeability of fractures might change with time due to fracture coatings. This, I believe, is a real possibility with increasing recharge and increasing carbon dioxide flux as I mentioned above. But how one predicts this is beyond me.

(16) 5:30 - 5:45 Wrap-Up/Round Table.

The most pertinent points in this discussion were

(A) Much more subsurface date is needed, but no one knows yet how much is needed. Perhaps this problem can be solved by sensitivity analyses by computer models, as mentioned earlier.

(B) Data is catalogued and put in a repository in Las Vegas. Supposedly it is available to all investigators through formal requests. Linda Lehman stated that she had been trying for years to get data, but was unsuccessful. The USGS has to have the data approved by the USGS before it can be given to the state and other non-project people--this is contrary to the earlier statement by Larry Hayes.

This sounds like a PR problem. Perhaps, some better way can be worked out to get data to the state and its contractors, and thus, reduce the feeling that the state is being left out of the loop. This can only cause ill will as the situation now exists.

(C) One of the more troubling problems that came up during the round-table discussion was the fact that no one knew when they would have enough data. It would seem that sensitivity analyses by computer could help to bring this issue to a head--use a model to determine how much results change with new data. If the change is within preset tolerance limits, then enough data will have been taken. I believe that this is DOE's position.

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Final Observations and Generalizations

(1) When a high-level waste repository at NTS was first being discussed, in the middle to late 70's, an attempt was made to investigate the deep unsaturated alluvium in Yucca Flat, on the eastern side of NTS, were underground nuclear weapons tests were being conducted. The Defense Nuclear Agency simply would not hear of it because they wanted to keep Yucca Flat for future weapons testing purposes.

Interest then shifted to the saturated zone in Jackass Flats, and an argillite was investigated for a possible host rock. It turned out to be too highly metamorphosed, too brittle, and too fractured for a repository.

Finally, the only place left on NTS was Yucca Mountain. Earlier in a meeting in which the proper hydrogeological setting was discussed, Pat Domenico, who was hired by the USGS as a consultant, suggested that it would be best to put the material in the unsaturated zone, rather than the saturated zone, in order to reduce the problems of boiling and transport by water.

Consequently, the unsaturated zone in Yucca Mountain was chosen for investigation, and at that time was in competition with the Basalt Waste Isolation program in eastern Washington, and the bedded salt in western Texas.

Thus, the Yucca Mountain site was chosen as a "third-round draft choice" so to speak, and on the basis of political decisions at that -- it was on goverment land.

It is becoming apparent that Yucca Mountain is as complex if not more so, than the other sites in Washington and Texas which have been removed from consideration. It is unfortunate that at the outset, more emphasis on finding the right geological conditions, regardless of the location, was not put into the project.

I still believe that thick unsaturated alluvium in some remote valley on NTS or environs would be best for a repositiory because

(A) Alluvium is dry and porous, and thus little changes can be expected in host media due to canister heat.

(B) Alluvium, as Alan Flint points out is very sorptive, has a high storativity, and greatly restricts the flow of water through it in the arid climate of southern Nevada.

(C) The water table 1,500 - 2,000 feet deep is low enough that it is unlikely to reach the repository level in time of increased precipitation

(D) Alluvium has a fairly high cation exchange capacity.

(E) The air-filled pores of alluvium makes it a natural insulator against thermal loading.

(F) Alluvium is much more homogeneous with far less discontinuities than the fractured tuffs at Yucca Mountain. As a result, the hydrogeology would be more easily understood, and it would be much more easily modeled.

(G) If a repository could be constructed in alluvium, and a heavy concrete pad built over it with diversionary channels to keep the water away from vertical percolation, then if no water were to get to the waste, it would stay put forever.

(2) Early in the program, when Don Veath was head of operations in Las Vegas, he had a sign on his office wall that stated that the goal of the DOE was to build a repository at Yucca Mountain. DOE is hell-bent to do just that, and seems to be sparing no expense to convince the public that their very complex and unwieldy management structure and computer models will assure the world of the safety and wisdom of doing just that. I believe, from my observations, that DOE wants to believe its models.

From the evidence presented at this meeting, and from what I have been reading about the unsaturated zone at Yucca Mountain, I am convinced that Yucca Mountain is just as complex as the other sites, if not more so, and that the hydrogeology may never fully understood, especially if the climate changes.

Therefore, I have serious reservations about the wisdom of using Yucca Mountain--basically because we still do not fully understand the mechanics of flow and the pathways of flow now and in the future within the site, and certainly cannot make any believable model predictions until we do. I seriously wonder if we ever will.

(3) Basically, the science being done by the USGS in the unsaturated zone is very good.

(4) Performance assessment studies at this time may be premature until more is known about UZ hydrogeology.

(5) Models can be used to advantage in sensitivity studies to indicate if enough data has been obtained, providing the hydrogeological parameters are well-enough known.