UNITED STATES
NUCLEAR REGULATORY COMMISSION
WASHINGTON, D. C. 20555

September 15, 1994

Mr. Ronald A. Milner, Acting Director
Office of Program Management and Integration
Office of Civilian Radioactive Waste Management
U.S. Department of Energy, RW 30
1000 Independence Avenue
Washington, D.C. 20585

SUBJECT: REVIEW OF THE U.S. DEPARTMENT OF ENERGY (DOE) STUDY PLAN ON "CHARACTERIZATION OF THE YUCCA MOUNTAIN SITE UNSATURATED ZONE (REVISION 2)" (8.3.1.2.2.4)

Dear Mr. Milner:

1-362433N

On June 23, 1994, DOE transmitted the subject study plan to the Nuclear Regulatory Commission for accelerated review and comment. The NRC staff has completed its review of the subject study plan using the "Review Plan for the NRC Staff Review of DOE Study Plans, Revision 2," (dated March 10, 1993). Based on its review of the study plan, the staff considers the material submitted consistent, to the extent possible, at this time, with the revised NRC-DOE "Level of Detail Agreement and Review Process for Study Plans," (dated March 22, 1993).

A major purpose of the review is to identify concerns with studies, tests, or analyses that, if started, could cause significant and irreparable adverse effects on the site, the site characterization program, or the eventual usability of the data for licensing. Such concerns would constitute "objections," as that term has been used in earlier NRC staff reviews of DOE documents related to site characterization, (e.g., "Consultation Draft Site Characterization Plan") and the "Site Characterization Plan for the Yucca Mountain Site.") It does not appear that the conduct of the activities described in this study plan will have adverse impacts on repository performance and the review of this study plan identified no objections with any of the activities proposed.

As part of its study plan review, the NRC staff also determines whether or not detailed comments or questions are warranted. The NRC staff's review of the subject study plan did not identify any comments or questions. However, in reviewing this study plan it is not clear how hydrologic parameters, which describe unsaturated zone fracture hydrologic properties, will be obtained from site data. The staff has recently identified an open-item comment during the review of another related study plan (e.g., Question 2 in Study Plan 8.3.1.2.2.9: "Site Unsaturated-Zone Modeling and Synthesis, Revision 0" (dated August 22, 1994)). This open item questions how hydrologic parameters which describe the hydrologic properties of fractures in the unsaturated zone, such as fracture flow as a function of water content, fracture porosity, and water movement between the fractures and the matrix will be obtained from site data?" Based on this review the question also applies to this study plan.

Finally, the NRC staff wishes to note that in its letter transmitting this study plan, DOE indicated that NRC's Site Characterization Analysis Comment 15 was addressed. Based on its review of the information contained in this study plan, the NRC staff now considers this open item to be closed (see Enclosure).

If you have any questions concerning this review, please contact Michael P. Lee at (301) 415-6677.

Sincerely,

for Joseph J. Holonich, Chief
High-Level Waste and Uranium Recovery
Projects Branch
Division of Waste Management
Office of Nuclear Material Safety
and Safeguards

Enclosure: As stated

cc: R. Loux, State of Nevada
T.J. Hickey, Nevada Legislative Committee
J. Meder, Nevada Legislative Counsel Bureau
C. Schank, Churchill County, NV
D. Bechtel, Clark County, NV
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W. Barnard, NWTRB

cc: List for Milner Letter Dated: September 15, 1994

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STUDY PLAN 8.3.1.2.2.4
CHARACTERIZATION OF THE YUCCA MOUNTAIN SITE UNSATURATED ZONE

SCA COMMENT 15
The Solitario Canyon Horizontal borehole activity is inadequate to discriminate between the hypotheses that faults are everywhere barriers to fluid flow in nonwelded tuff units or are everywhere conduits for liquid-water flow in nonwelded tuff units. Further, it is doubtful that this activity is adequate to discriminate between the hypotheses that faults are conduits or barriers to liquid water flow in welded tuff units, depending on ambient matrix saturation or alternatively, faults are everywhere conduits for liquid water flow in welded tuff units.

EVALUATION OF DOE RESPONSE
This comment expressed the concern that a single borehole would be inadequate to test the hypotheses that faults are conduits or barriers to liquid water flow in welded tuff units, depending on ambient matrix saturation or alternatively, faults are everywhere conduits for liquid water flow in welded tuff units. It also expressed the concern that because the Solitario Canyon Horizontal borehole activity does not contain any nonwelded units it would be unable to discriminate between the hypotheses that faults are everywhere barriers to fluid flow in nonwelded tuff units or are everywhere conduits for liquid-water flow in nonwelded tuff units.

The first DOE response to SCA Comment 15 agreed the Solitario Canyon borehole activity would not collect data to fully test these hypotheses and inferred that Study Plan 8.3.1.2.2.3 ("Characterization of Percolation in the Unsaturated Zone-Surface Based Study") and Activity 8.3.1.2.2.4.10 ("Hydrologic Properties of Major Faults Encountered in Main Test Level of the ESF") would provide the data to test these hypotheses. However, when the NRC staff evaluated DOE's response, the staff decided to keep this comment open until it had determined if Study Plan 8.3.1.2.2.3 and Activity 8.3.1.2.2.4.10 contained the necessary plans to address this comment.

The NRC staff completed it's review of Study Plan 8.3.1.2.2.3, Rev. 0 on March 26, 1992, and has finished it's review of Activity 8.3.1.2.2.4.10 (contained in Study Plan 8.3.1.2.2.4, Rev 1). In it's review, the NRC staff finds that several boreholes are described that will be used to test these hypotheses and that both welded and nonwelded units will be tested.

The NRC staff considers this comment closed.

ENCLOSURE

NRC COMMENT 1:

The list of hydrologic issues to be resolved by this study plan appears to neglect the possibility that the Solitario Canyon fault could act as a short-circuit for water to infiltrate laterally into the repository and the effect on the spatial distribution of flux by highly conductive fracture networks, which might extend from the surface, through the non-welded units, into the repository horizon and down to the water table.

DOE RESPONSE:

The authors agree with the recommendation to investigate the likelihood that water moving through Solitario Canyon, particularly along the fault, would compromise the ability of the repository to isolate waste. DOE is presently expanding the boundaries of the site unsaturated zone model to incorporate a greater area to the west of the fault in the model. This expanded model will be used to investigate different flow conditions at and near the Solitario Canyon Fault, as well as other large-scale faults near Yucca Mountain (e.g. the Bow Ridge fault). Recent meetings to discuss drilling schedules within the next several years have identified UZ-11, to be drilled through the Solitario Canyon Fault, as one of the top three priorities. It is presently scheduled for fiscal year 1996.

While the study plan does not explicitly refer to the Solitario Canyon Fault, neither does it refer to any other faults by name. The omission of the fault by name, therefore, does not imply it will not be investigated through drilling or numerical modeling.

NRC QUESTION 1:

Will this study plan evaluate the importance of wetting front instabilities for modelling the Yucca Mountain hydrologic regime?

DOE RESPONSE:

There are presently no plans to investigate wetting front instabilities. The authors agree it is important to look at the consequences of disruptions in lateral continuity along beds thought to be significant in promoting lateral flow, whether lateral flow is promoted as a result of permeability contrasts or capillary barrier effects. To this end, we intend to look at both the effects of heterogeneity that results from depositional and alteration influences, and of the juxtaposition of beds of contrasting permeability across faults. We have also begun to develop a list of field criteria that could be used to determine whether certain processes, such as capillary barriers, are operative in complex, heterogeneous natural systems.

Wetting front instabilities have been demonstrated to be important in carefully engineered media in which large-scale heterogeneity has been removed. This has been done primarily to demonstrate that it is indeed gravitational instabilities and not heterogeneity that is the dominant control on flow channeling. Given that such media are essentially uniform, it is not surprising that when the flux is much less than the hydraulic conductivity and flow within just a small subset of available pathways can be sustained, the locations for these water pathways are somewhat random and unpredictable. However, we do not feel that gravitational instabilities assume the same importance in media that are structured. In rock matrix, this structure results primarily from variability in the degree of welding; in fractures, by variability in aperture both within and between fractures.

The underlying concern here is that wetting front instabilities will tend to concentrate flow in a few areas. We agree it is important to investigate mechanisms that will cause preferential or concentrated flow. We also believe that in fractured media, fracture and matrix heterogeneities will dominate the development of preferential flow rather than wetting front instabilities.

NRC QUESTION 2:

How will hydrologic parameters which describe the hydrologic properties of fractures in the unsaturated zone, such as fracture flow as a function of water content, fracture porosity, and water movement between fractures and the matrix be obtained from site data?

DOE RESPONSE:

A logic diagram describing the studies that contribute fracture information and how that information is synthesized is contained in an accompanying figure.

Effective fracture porosities will be derived from cross-hole gas tracer tests conducted in the ESF and between clusters of surface-based boreholes, inferences based on travel times for gas and liquid isotopes, and from testing with aqueous tracers in the saturated zone at the C-well complex.

Water movement between fractures and matrix depends a great deal on the wetted surface area of the fractures, which in turn is a function of the degree to which flow is channelized within the fracture network. Some insight may be gained from modeling fracture networks under variably saturated conditions, but ultimately, the distribution of fracture surface coatings and environmental isotopes may suggest the degree to which fractures and matrix interact in real fracture systems.

NRC QUESTION 3:

How will local potential gradients of water within a fracture or a set of fractures be measured so that net moisture flux rates can be inferred?

DOE RESPONSE:

In situ monitoring will measure the relative humidity of the rock gas, from which water potential will be calculated through Kelvin's equation. Water potential is determined by the curvature of the air-water interface in the largest water-filled opening, regardless of whether that opening occurs in matrix pores or fracture apertures, and thus reflects the overall rock water potential. While saturation or water content are not continuous across fracture-matrix boundaries, water potential is continuous at least where moisture conditions change slowly enough so that equilibrium can be maintained. Although this may be unlikely in near surface rocks where strong transients can be expected to occur, water potential equilibrium is a reasonable assumption in the deeper subsurface where transients are more subdued.

Knowledge of water potentials and gradients can be combined with relations determined between fracture permeability and water potentials to provide estimates (sometimes only bounding) of the flux in the deeper subsurface.

NRC QUESTION 4:

Which smaller-scale hydrologic sub-models will be calibrated using experimentally induced perturbations from Yucca Mountain surface and subsurface tests?

DOE RESPONSE:

The scaling problem for the site model involves both spatial and temporal components. Not only are estimates of properties at spatial scales appropriate to the site model required, but also information on flow behavior over time scales similar to those required for waste isolation.

Some model variables, such as unsaturated permeability of fracture networks, cannot be measured at scales relevant to the site model, but must instead be inferred through models conditioned by experiments conducted at much smaller scales, as described in the response to Question 2. In these cases, sensitivity analyses or probabilistic analyses also play a role.

Values for some model variables can be inferred by attempting to model the effects of naturally occurring environmental stresses on the system. For example, the manner in which barometric pressure fluctuations at the ground surface propagate through the unsaturated zone, as recorded by the surface-based borehole instrumentation program, can be interpreted through modeling to yield larger-scale estimates of vertical permeability independent of those derived from analysis of packer tests.

Also, the ages and spatial distribution of environmental isotopes, including 14C, 36Cl and 3H, provide a record of fluid movement over decade-long and, in the case of 14C, millennia-long time scales. These data, if they can be collected in sufficient quality and quantity, can reveal a great deal about flowpaths, rates and mechanisms, and can be used to calibrate and constrain numerical models.

The ages and spatial distribution of fracture coatings provide a record of flow mechanisms and flow paths under past climatic conditions that also suggest a method of scaling observations in both space and time.

Lastly, models of cross-hole pneumatic tests involving gas tracers, conducted both within the ESF and from surface-based boreholes, can yield effective fracture porosities, and further identify the spatial structure of permeability in three dimensions, which may allow bulk-rock permeabilities to be calculated at scales appropriate to the site unsaturated zone model.

NRC QUESTION 5:

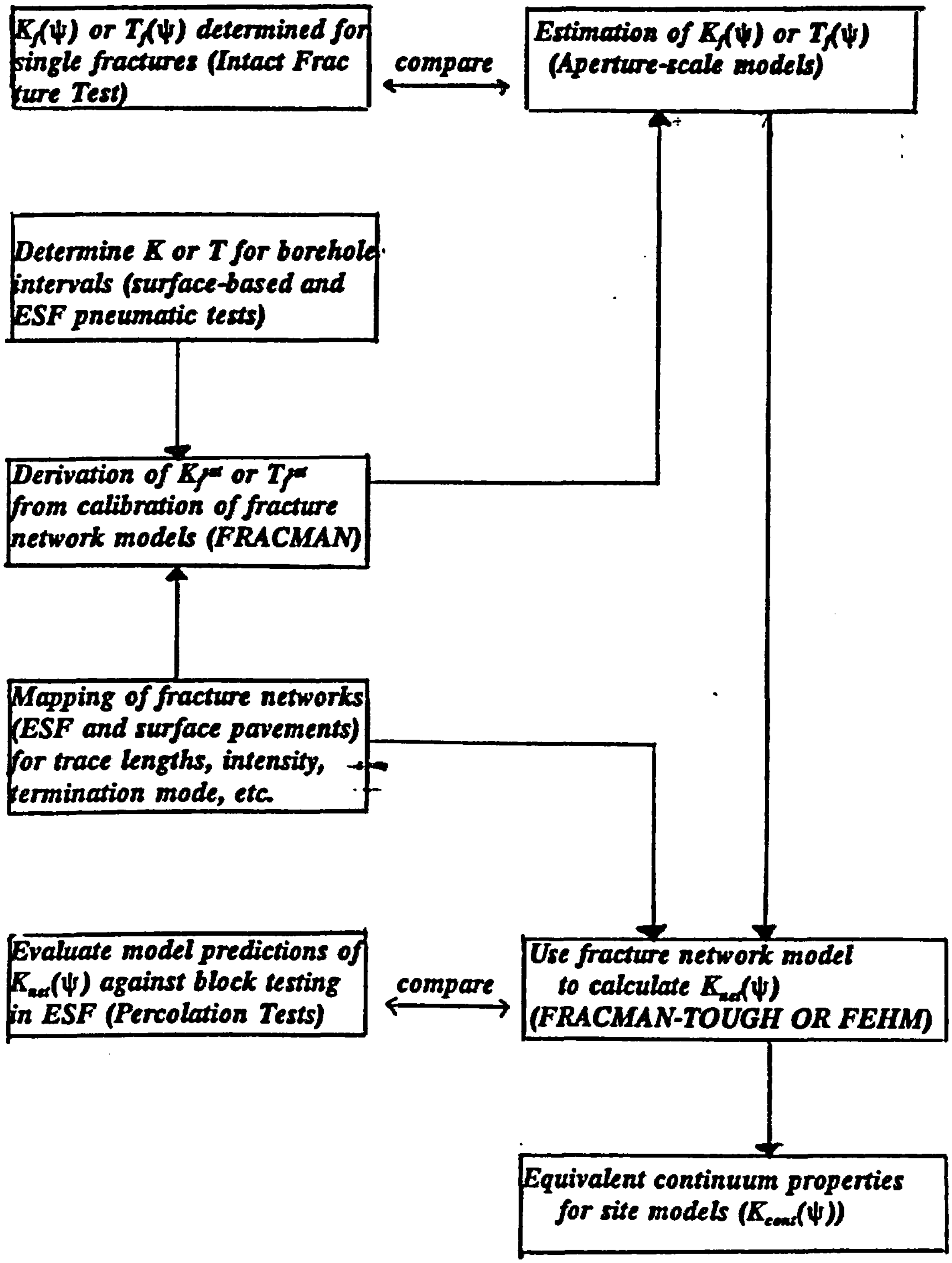
How will this study plan evaluate the importance of modeling the non-Darcian flow regime that may occur at seepage faces formed in wide, rubble-filled fault zones?

DOE RESPONSE:

By giving wide faults very high permeability and moisture characteristic properties with a small capillary attraction for water, the essential behavior of a seepage face can be captured in the site model, without the additional complexity suggested in the question. Modeled in this way, the fault is also capable of redirecting downward percolating water back into the adjacent matrix, depending on the moisture state of the wall rock.

For practical purposes, the details of moisture movement on the fault face, if it behaves as a seepage face, are unimportant. In terms of site performance, it probably matters little whether water can seep through a broken zone in a few years, or cascade down the fault in a minute. It is the exchange of moisture across the rock-fault interface that is the most decisive factor, and the control exerted by the capillary properties assigned to the rock and the faults. These will be sufficiently well described by the approach that has been outlined.

LOGIC DIAGRAM FOR CALCULATING LARGE-SCALE UNSATURATED FRACTURE CONTINUUM PROPERTIES



NRC COMMENT 1:

There appears to be a gap in the documentation of groundwater modeling work under this study.

DOE RESPONSE:

Scientific notebooks, in accordance with YMP-USGS-QMP-5.05 (current revision), will be used to document the modeling process for both regional and site-scale saturated-zone ground-water flow models. Documentation will include, but not be limited to:

- model code and computer system to be used; information on calibration criteria and approach; information on measured heads and water-budget components against which the models will be calibrated;

- summaries of important model runs, including information on changes from the previous run and rationale for those changes, model output, statistical analyses, and applicable file names; any changes; major to the conceptual model on which the flow model is based, and the rationale for those changes; and any other important information or thoughts pertinent to the modeling process.

Every model run will not need to be documented or archived. Only those that represent major changes to the conceptual model, hydrogeologic framework, or distribution of hydraulic parameters will be documented and/or archived.

NRC QUESTION 1:

How will the work under this study (regional surface water and saturated zone modeling) be integrated with the site unsaturated zone modeling under Study 8.3.1.2.2.9 (Site Unsaturated-Zone Modeling and Synthesis)?

DOE RESPONSE:

Integration between this study plan and unsaturated zone modeling under 8.3.1.2.2.9 will be done through periodic formal meetings between modeling participants as well as frequent informal communications in unstructured settings. The USGS is soon to complete organization of a modeling unit consisting of key staff in the saturated and unsaturated zone study programs to promote communication between modelers, as well as performance assessment modelers.

Information provided by the unsaturated-zone models as to infiltration to the water table at Yucca Mountain will be used as a constraint on saturated-zone model calibration in the vicinity of Yucca Mountain. Likewise, feedback from the saturated-zone models may be used as constraints for the unsaturated-zone model calibration.

NRC QUESTION 2:

How will infiltration be simulated under the surface water modeling activity?

DOE RESPONSE:

The list of potentially applicable models in the study plan (section 3.1.5) includes potentially useful models that were available at the time the study plan was prepared in December 1991. Since then modifications have been made to existing models and new models have been developed to more accurately simulate surface water runoff in arid and semiarid areas. Machete and Sorooshian (1994) compare two potentially applicable models (KINEROS and SCS) and describe the benefits and shortcomings of these models as used in a semiarid area. In addition, at least two studies have been made of the surface water runoff dynamics and infiltration components of the upper Amargosa River watershed in the vicinity of Yucca Mountain. The following is a synopsis of these studies describing what is generally known about infiltration in this desert setting.

A comparison of the volume of precipitation versus the volume of runoff for a watershed imparts, as an indirect measure, the amount of water lost due to infiltration into the stream bed, intrastream areas, and uplands, as well as the amount of water lost to direct (atmospheric) evaporation and transpiration by plants. Water that infiltrates during a storm may be stored temporarily in the unsaturated zone or become groundwater by deep percolation into the saturated zone. If one assumes that this water is removed from the surface-water budget (that is, the water does not resurface downstream), then the remaining water will constitute the total streamflow from the basin. On the basis of these dynamics, the surface water modeling effort of Study 8.3.1.5.2.2 will inevitably require a direct or indirect simulation of infiltration losses. USGS investigators believe that infiltration can be simulated indirectly at a regional scale using recorded meteorologic (precipitation) and hydrologic (runoff) data (for example, Schick, 1988; Grasso, 1994). Conversely, larger-scale (direct) simulation of infiltration losses for individual stream segments and infiltration through macropores (fracture zones) may also be possible using onsite measurements of alluvial channel geometry (for example, Lane, 1982; Hedman and Osterkamp, 1982; Osterkamp and other, 1994).

Using a regional approach, Grasso (1994) evaluated precipitation-runoff conditions for the upper Amargosa River drainage basin above Tecopa, California; an area that includes the tributary subbasins that drain Yucca Mountain. The investigation involved basin-wide computer simulations (kriging) of the volume and distribution of precipitation over the basin and a numerical comparison with stream gage data for small, medium, and large storms. The results of these rainfall-runoff simulations show that for low magnitude storms, where average precipitation over the basin ranges from about 0.5 to 0.75 inches, little or no runoff will occur because the basins surface material can absorb this amount of rainfall (that is, the infiltration rate and capacity of the surface material is not exceeded). Conversely, large floods occur when 3-5 inches of rain falls over the basin during a single, usually multi-day storm. Under these conditions the infiltration rate and capacity of the basins surface material is exceeded. Although these simulations give measurements for the volumes of runoff and infiltration for individual storms, they do not give specific channel-segment information to simulate infiltration into macropores (fracture zones).

In a recent study of recharge in the Amargosa River basin, Osterkamp and others (1994) used a geomorphic/distributed parameter simulation approach to estimate mean streamflow conditions at 53 selected channel sites along the Amargosa River and its major tributaries surrounding Yucca Mountain. Primary inputs for calibration of the transmission-loss model used were empirical estimates of mean streamflow from onsite channel morphology measurements (Hedman and Osterkamp, 1982) that imply changes in streamflow in a downstream direction (Osterkamp and others, 1994, p. 486). The results of the study show that infiltration is highest along alluvial channel reaches and lowest in bedrock-dominated uplands. Furthermore, this work shows that surface water lost into an alluvial streambed may resurface downstream as a result of being forced to the surface by bedrock.

The studies described above show that infiltration can be estimated from recorded rainfall-runoff data and onsite channel geometry measurements. These data, in combination with available digital (for example, digital elevation models and Landsat satellite images) and analog (map) data for the watershed should provide sufficient information on which to simulate precipitation-runoff conditions for a wide range of storm events and related infiltration conditions.

References:

Grasso, D.N., 1994, Grasso, D.N., 1994, Hydrology of Modern and Late Holocene Lakes, Death Valley, California. U.S. Geological Survey Water-Resources Investigations Report 94-xxxx (in review).

Hedman, E.R., 1970, Mean annual runoff as related to channel geometry in selected streams in California. U.S. Geological Survey Water-Supply Paper 1999-E, 17 p.

Hedman, E.R., and Osterkamp, W.R., 1982, Streamflow characteristics related to channel geometry of streams in

Western United States. U.S. Geological Survey Water-Supply Paper 2193, 17 p.

Michaud, Jene, and Sorooshian, Soroosh, 1994, Comparison of simple versus complex distributed runoff models on a midsized semiarid watershed. Water Resources Research, v. 30, n. 3, p. 593-605.

Osterkamp, W.R., Lane, L.J., and Savard, C.S., 1994, Recharge estimates using a geomorphic/distributed parameter simulation approach, Amargosa River Basin. Water Resources Bulletin, v. 30, no. 3, p. 493-507

Schick, A.P., 1988, Hydrologic aspects of floods in extreme arid environments: p. 189-203, in Baker, V., Kochel, C.R., and Patton, P.C., Flood geomorphology. A Wiley-Interscience Publication, John Wiley and Sons, New York, 503 p.

STUDY PLAN 8.3.1.8.5.2
CHARACTERIZATION OF IGNEOUS INTRUSIVE FEATURES, REVISION 1

Question 1
What plans exist to conduct heat flow measurements in the area of the Lathrop Wells Cone?

Basis
On page 2-3 of the study plan, there is an indication that additional boreholes may be drilled to obtain heat flow data; however, this plan specifically mentions Crater Flat as the location of such activity.

The staff is unable to find, within the study plan, an indication that heat flow measurements would be considered in either existing or planned boreholes near the Lathrop Wells cone.

If the Lathrop Wells cone is as young as has been suggested from some U.S. Department of Energy (DOE) studies (e.g. 2-4,000 years) it may still have a thermal signature. If a thermal signature still exists, significant information could be obtained on the history of volcanic activity in the area of Yucca Mountain.

Recommendation
DOE should consider obtaining heat flow data in the area of Lathrop Wells cone.

ENCLOSURE

STUDY PLAN 8.3.1.8.5.2
CHARACTERIZATION OF IGNEOUS INTRUSIVE FEATURES, REVISION 1

Question 2
What plans does DOE have for obtaining estimates of the Curie Temperature Isotherm?

Basis
The staff agrees that it may be prudent to hold activities on evaluating the Curie Temperature Isotherm until completion of the geophysical review.

The staff also agrees that it may not be cost effective to obtain additional aeromagnetic data specifically for determining the Curie Temperature Isotherm.

The staff is concerned, however, that there appear to be no plans for obtaining an estimate of this information.

The staff suggests that it should be feasible to obtain at least an approximation of this property from an analysis of existing data, and consider that such an analytical exercise is justified.

Recommendation
During the evaluation of the geophysical program, some means of obtaining an estimate of the Curie Temperature Isotherm should be considered.

STUDY PLAN 8.3.1.8.5.2
CHARACTERIZATION OF IGNEOUS INTRUSIVE FEATURES, REVISION 1

Question 3
How will heat flow conditions in the Paleozoic carbonate aquifer at the site be adequately characterized using only existing and planned boreholes?

Basis
The objective of this study is to analyze the thermal regime at Yucca Mountain and determine whether there is evidence of fault-controlled groundwater flow paths, molten rock, or cooling magma bodies in the upper part of the crust.

Previous studies have interpreted that the near-surface heat flow in the Yucca Mountain region is strongly influenced by hydrologic processes, which may prevent identification of possible igneous effects. The staff notes, however, that the variations in near-surface heat flow are only assumed to be caused by hydrologic processes. This assumption has not been verified, and other causes cannot be ruled out.

Data from the Yucca Mountain area show heat flow values that are lower than those typically found in the western United States (Sass *et al.*, 1981, p. 512). The site occurs on the southern boundary of the so-called "Eureka Low," a zone located between Mercury and Eureka, Nevada, within which measured heat flows are less than 1.5 HFU's (heat flow units) (Sass *et al.*, 1971).

There are, however, significant heat flow variations at the Yucca Mountain site, the causes of which have not been confirmed. Near Yucca Mountain, temperature gradients in the unsaturated zone vary from 15°C/km to nearly 60°C/km (Sass, *et al.*, 1988, p. 2). Hydrologic processes have been suggested as the cause of this variability. At well USW G-4, the curvature of the temperature profile suggests an upward component of seepage velocity in the saturated zone of about 100 mm/yr (Sass *et al.*, 1988, p. 35).

Only one well at the site (UE25-p#1) penetrates the deep carbonate aquifer. Sass *et al.* (1988) refer to an apparent thermal high in the vicinity of this borehole. They state (p. 19) that "below ... about 1200 m[eters] ... the temperature profile becomes nearly isothermal, then reverses indicating a complex pattern of lateral throughflow of higher temperature water ...." They speculated that the anomaly could be explained by a long-lived transient thermal response to annular uphole flow caused by the drilling-induced breach of a hydraulic barrier in the lower part of the volcanic tuffs. They noted that this hypothesis could be confirmed only by completing a well in the carbonate aquifer and grouting in a water-filled access pipe. It is known that an upward hydraulic gradient exists between the Paleozoic carbonate aquifer and the overlying tuffs.

The study plan states (p. 2-2) that no new drill holes are planned that would be solely dedicated to heat-flow studies (although the possibility of one or more holes in Crater Flat is mentioned). Holes drilled for other site-characterization purposes will be used. However, dependence on existing wells will give a view of thermal (and hydraulic) conditions that is biased for shallow zones, because only one well penetrates the deep carbonate aquifer (UE25-p#1). This deep zone is of special interest, because anomalous heat sources at depth should be more easily detected via deep boreholes.

Recommendation

Describe how heat flow conditions in the Paleozoic carbonate aquifer will be characterized.

References

Sass, J.H., D.D. Blackwell, D.S. Chapman, J.K. Costain, E.R. Decker, L.A. Lawver, and C.A. Swanberg, "Heat Flow from the Crust of the United States (Chapter 13) in "Physical Properties of Rocks and Minerals," 1981, p. 503-548.

Sass, J.H., A.H. Lachenbruch, W.W. Dudley, Jr., S.S. Priest, and R.J. Munroe, "Temperature, Thermal Conductivity, and Heat Flow Near Yucca Mountain, Nevada: Some Tectonic and Hydrologic Implications," U.S. Geological Survey, Open File Report 87-649, 1988, 118 p.

Sass, J.H., A.H. Lachenbruch, R.J. Munroe, G.W. Greene, and T.H. Moses, Jr., "Heat Flow in the Western United States," *Journal of Geophysical Research*, 76(26):6376-6413 [1971].

STUDY PLAN 8.3.1.8.5.2
CHARACTERIZATION OF IGNEOUS INTRUSIVE FEATURES, REVISION 1

Comment 52
No specific geophysical program appears to be planned to identify volcanic/igneous features and their extent under or close to the site.

Basis
This comment restates the concern expressed in CDSCP Comment 51.

The SCP includes re-written Activity 8.3.1.8.1.1.3 and also includes a cross reference between Activities 8.3.1.8.1.1.3 and 8.3.1.17.4.3.1; however, the SCP is not specific about a planned program for volcanic/igneous features identification.

Activities 8.3.1.8.1.1.3 and 8.3.1.17.4.3.1 indicate that a number of geophysical parameters exist for the activities; however, there is no indication of a coherent plan in these two sections or elsewhere in the SCP to indicate that the volcanic/igneous investigations will be accomplished in a consistent and coherent manner.

Recommendation
The DOE should include and integrate into its geophysical program a subprogram designed specifically for consideration of volcanic/igneous features.

Evaluation of the DOE March 1994 Response
The study plan addresses how heat flow measurements will be integrated with other investigations. It does not address how heat flow measurements will be integrated with or fit into the entire geophysical program.

This study plan, as well as previous study plans, refers to an ongoing review by an independent consultant to assess the needs for geophysical investigations to resolve volcanic concerns. While this review may help to resolve NRC concerns, until the report is available for the NRC and a determination by DOE is made as to how the geophysical program will be restructured and implemented, the concerns raised in this comment cannot be resolved.

The NRC staff consider this comment still open.

NRC QUESTION 1:

What plans exist to conduct heat flow measurements in the area of the Lathrop Wells Cone?

DOE RESPONSE:

The statement in Study Plan 8.3.1.8.5.2 (p. 2-3) that "It might be necessary to drill one or more heat-flow wells in the Crater Flat area . . ." was made to emphasize that the additional data would potentially be useful in further studies of the young volcanic features that are present there, but was also made with the knowledge that a significant increase of scope would be required. The siting of drill holes is not currently within the purview of this study, and none is planned for the vicinity of the Lathrop Wells cone. If the presence or absence of a magma chamber beneath the cone is a critical issue, then any heat-flow determinations would have to be from significantly greater depths than those reached by the existing wells in Crater Flat, USW VH-1 and USW VH-2. These wells bottom in Crater Flat Tuff at depths less than 4,000 feet, and their thermal regime is dominated by lateral and vertical water movement.

NRC QUESTION 2:

What plans does DOE have for obtaining estimates of the Curie Temperature Isotherm?

DOE RESPONSE:

Extending the aeromagnetic coverage to obtain the necessary data for evaluating the depth of the Curie temperature isotherm beneath Yucca Mountain would be very costly, especially in relation to the probable benefit inasmuch as the results of this technique have been found to be ambiguous and at a scale too general to be useful for the intended application to site characterization. At these local scales, extrapolation of regional heat flow values using reasonable assumptions regarding thermal conductivity will result in a much more accurate range of depths to the Curie isotherm than any interpretations of aeromagnetic data. Better estimates of heat flow than presently exist will, of course, provide even better resolution of this depth range.

NRC QUESTION 3:

How will heat flow conditions in the Paleozoic carbonate aquifer at the site be adequately characterized using only existing and planned boreholes?

DOE RESPONSE:

If future boreholes (e.g., G-5, G-6, and G-7) were to be drilled to sufficient depths in the Paleozoic strata so as to avoid the influence of ground-water flow that might skew the heat flow measurements in these rocks, then the resulting data should provide an adequate characterization of the deep thermal regime beneath Yucca Mountain. A related issue is the nature of the hydrologic coupling between the carbonate aquifer and the overlying tuffs. High-resolution temperature logs and precise heat-flow determinations are vital to characterizing this important relation. As stated in the response to Question 1, however, the siting of drill holes is not a responsibility given to Study 8.3.1.8.5.2, and the heat-flow studies will necessarily be confined to boreholes primarily drilled for other purposes.

NRC COMMENT 52:

No specific geophysical program appears to be planned to identify volcanic/igneous features and their extent under or close to the site.

DOE SUPPLEMENTAL RESPONSE:

Geophysical surveys will not be conducted as part of Study 8.3.1.8.5.2. A seismic reflection line is planned to cross Crater Flat and Yucca Mountain as part of Study 8.3.1.4.2.1, Characterization of the Vertical and Lateral Distribution of Stratigraphic Units within the Site Area. To the extent that geophysical data are available during the course of investigations for Study 8.3.1.8.5.2, such data will be applied as they are relevant to the characterization of the thermal regime of the Yucca Mountain area.

NRC QUESTION 3:

How will surface water models be calibrated and validated?

DOE RESPONSE:

Modeling of any type always involves a certain level of generalization and uncertainty. For Study 8.3.1.5.2.2, the parameters needed for the model are also subject to variability that may be caused, for example, by meteorological (seasonal and storm) differences, changes in geology from place-to-place in the basin, and variations in vegetation type and percent surface cover. In precipitation-runoff modeling, surface-water losses due to infiltration, atmospheric evaporation, and transpiration by plants are subject to considerable variability. Additionally, the infiltration rate and capacity of the basin surface material, and the evapotranspiration rate within the basin, will vary relative to seasonal meteorological conditions.

To characterize the future regional hydrology of the site will require the use of assumptions and the application of an empirical approach. Validation and calibration of the model (or models) that may be used in the study will have to be made on the basis of recorded meteorological and hydrologic data. Precipitation interpolations (kriging) can be made to evenly distribute precipitation across the watershed from existing irregularly spaced (NOAA and NTS) weather stations; streamflow estimates at ungaged sites can be made on the basis of geometric parameters measured from existing stream channels; and other landscape attributes, such as elevation, slope, channel roughness, roughness of overland flow planes, rates of evapotranspiration, and vegetation cover amounts can be made on the basis of classification techniques (generalization) using available digital elevation models, calibration, for example, Refsgaard (1994) notes that 3-5 years of data are adequate and that even a single year of calibration data is valuable (see Machete and Sorooshian, 1994, p. 594).

In studying the regional hydrology of the upper Amargosa River basin above Tecopa, California, a basin that includes tributary subbasins that directly drain from Yucca Mountain, Grasso (1994) showed that considerable precipitation-runoff differences exist between winter and summer seasons. The study involved analyses of precipitation-runoff conditions for 34 recorded (19 winter and 15 summer) storms that occurred between 1962-83. The results of the study show that winter storms tend to be of longer duration and produce larger discharge volumes to peak discharges than summer storms. Conversely, summer thunderstorms tend to produce more intense, shorter-duration rainfalls, larger peak discharges, and lower discharge volumes relative to peak discharges. These relationships indicate that runoff is intricately connected to differences in seasonal meteorological conditions, the duration and intensity of storms, and to variations in the infiltration rate of the basins surface material (or saturated hydraulic conductivity); the latter governed by soil texture and meteorological conditions prior to the storm.

Osterkamp and others (1994, p. 496-497), using techniques derived largely from a distributed-parameter runoff-simulation model for estimation of runoff volumes and peak discharges from arid and semiarid watersheds (Lane, 1982), estimated the mean rates of ground-water recharge in the Amargosa River basin above Shoshone, California. At 53 water-balance-calculation sites in the basin they estimated mean discharge using channel-morphology techniques in which channel dimensions, related to discharge characteristics at gaged streamflow sites, are employed as proxies to evaluate discharge at selected ungaged sites (Hedman, 1970; Osterkamp and Hedman, 1982; Hedman and Osterkamp, 1982). The result of their work indicates that infiltration is highest along stream channels and lowest in bedrock-dominated upland areas. Thus, infiltration in this arid hydrologic basin is controlled largely by underlying geology and the distribution of drainage channels. Not surprisingly, the highest infiltration rates occur in the streambeds of channel segments that cross areas of deep unconsolidated alluvial fill.

The two approaches described above use recorded hydrologic and meteorological data that span the last three decades, as well as onsite measurements of stream channel geometry. For an arid area, this hydrologic basin has an unusual number of precipitation gaging sites with long records. These data can be used to model the distribution and volume of rainfall from individual (historical) storms and combined with available runoff data to calibrate and validate the surface-water model used in the study.

References:

Grasso, D.N., 1994, Grasso, D.N., 1994, Hydrology of Modern and Late Holocene Lakes, Death Valley, California. U.S. Geological Survey Water-Resources Investigations Report 94-xxxx (in review).

Hedman, E.R., 1970, Mean annual runoff as related to channel geometry in selected streams in California. U.S. Geological Survey Water-Supply Paper 1999-E, 17 p.

Hedman, E.R., and Osterkamp, W.R., 1982, Streamflow characteristics related to channel geometry of streams in Western United States.

U.S. Geological Survey Water-Supply Paper 2193, 17 p.

Lane, L.J., 1982, Distributed model for small semiarid watershed. Journal of the Hydraulics Division., American Society of Civil Engineers 108(HY 10):1114-1131.

Michaud, Jene, and Sorooshian, Soroosh, 1994, Comparison of simple versus complex distributed runoff models on a midsized semiarid watershed. Water Resources Research, v. 30, n. 3, p. 593-605.

Osterkamp, W.R., Lane, L.J., and Savard, C.S., 1994, Recharge estimates using a geomorphic/distributed parameter simulation approach, Amargosa River Basin. Water Resources Bulletin, vol. 30, no. 3, p. 493-507.

DOE RESPONSES TO NRC QUESTIONS ON

STUDY PLAN 8.3.1.15.1.2 (LABORATORY THERMAL TESTING, REVISION 2)

ENCLOSURE 5

UNITED STATES
NUCLEAR REGULATORY COMMISSION
WASHINGTON, D.C. 20555-0001

AUG 22 1994

Mr. Ronald A. Milner, Acting Director
Office of Program Management and Integration
Office of Civilian Radioactive Waste Management
U.S. Department of Energy, RW 30
1000 Independence Avenue
Washington, D.C. 20585

Dear Mr. Milner:

SUBJECT: REVIEW OF THE U.S. DEPARTMENT OF ENERGY (DOE) STUDY PLAN ON "SITE SATURATED-ZONE HYDROLOGIC SYSTEM SYNTHESIS AND MODELING, REVISION 0" (8.3.1.2.3.3)

On January 28, 1993, DOE transmitted the subject study plan to the Nuclear Regulatory Commission for review and comment. The NRC staff has completed its review of the study plan using the "Review Plan for the NRC Staff Review of DOE Study Plans, Revision 2" (dated March 10, 1993). Based on its review, the staff considers the material submitted consistent, to the extent possible, at this time, with the revised NRC-DOE "Level of Detail Agreement and Review Process for Study Plans" (dated March 22, 1993).

A major purpose of the review is to identify concerns with studies, tests, or analyses that, if started, could cause significant and irreparable adverse effects on the site, the site characterization program, or the eventual usability of the data for licensing. Such concerns would constitute "objections," as that term has been used in earlier NRC staff reviews of DOE documents related to site characterization (e.g., "Consultation Draft Site Characterization Plan" and the "Site Characterization Plan (SCP) for the Yucca Mountain Site"). It does not appear that the conduct of the activities described in this study plan will have adverse impacts on repository performance and the review of this study plan identified no objections with any of the activities proposed.

As part of its study plan review, the NRC staff also determines whether or not detailed comments or questions are warranted. The NRC staff's review of the subject study plan has resulted in the identification of one comment and six questions. The enclosed comment and questions will be tracked by the NRC staff as open items similar to those previously raised by the NRC staff in its 1989 Site Characterization Analysis (SCA). (An number of editorial corrections were also identified; see Enclosure 2.)

As part of its review, the staff have recently identified a concern, in this and other synthesis and modeling study plans, regarding documentation of DOE modeling efforts. For example, this study plan states that technical procedures do not apply to any of the three work activities. However, it is the staff's understanding that in instances where technical procedures do not

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apply, scientific notebooks will be employed in their place. Based on the staff's review of the activities described in this study plan, much of the work does appear to meet the scope of the procedure for scientific notebooks (see YMP-USGS-QMP-5.05, Rev. 3). Therefore, there appears to be a gap in the documentation of the modeling work. (The NRC staff have also identified a similar gap as part of its on-going review of Study Plans 8.3.1.5.2.2 ("Characterization of Future Regional Hydrology due to Climate Changes," dated December 1992) and 8.3.1.2.2.9 ("Site Unsaturated-Zone Modeling and Synthesis," dated July 1993).) For each of these synthesis and modeling study plans, and perhaps others under the Yucca Mountain project, DOE should describe how in-progress work will be documented. The relationship of the study plans to scientific notebook procedures should also be described.

Finally, the NRC staff wishes to note that in its transmittal letter, DOE did not identify any SCA open items related to this study plan. The NRC staff considers that several SCA open items are directly related to development of conceptual models under this study plan, and to the related SCP Study 8.3.1.2.3.1.1-6, "Characterization of the Site Saturated-Zone Groundwater Flow System" (Revision 0) (dated May 1990). For example, SCA Comment 19 states that activities for the study of the saturated zone are not adequate to characterize hydrologic boundaries, flow directions and magnitudes, and flow paths. One of the recommendations made under Comment 19 was that one or more additional multiple-well sites (similar to the C-hole site) should be constructed. Moreover, SCA Comment 20 states that the potentiometric surface in the controlled area is not adequately defined by existing well locations, and will not be adequately defined by proposed additional well sites. This study, therefore, does not make progress toward resolution of these two SCA open items.

If you have any questions concerning this review, please contact Michael P. Lee at (301) 415-6677.

Sincerely,

Joseph J. Holonich

Joseph J. Holonich, Chief
High-Level Waste and Uranium Recovery
Projects Branch
Division of Waste Management
Office of Nuclear Material Safety
and Safeguards

Enclosures (2): As stated

cc: See Attached List

cc: List for Milner Letter Dated: AUG 22 1001

cc: R. Loux, State of Nevada
T.J. Hickey, Nevada Legislative Committee
J. Meder, Nevada Legislative Counsel Bureau
C. Schank, Churchill County, NV
D. Bechtel, Clark County, NV
J. Hoffman, Esmeralda County, NV
L. Fiorenzi, Eureka County, NV
B. Mettam, Inyo County, CA
M. Baughman, Lincoln County, NV
R. Williams, Lander County, NV
V. Poe, Mineral County, NV
L. Bradshaw, Nye County, NV
M. Murphy, Nye County, NV
P. Niedzielski-Eichner, Nye County, NV
F. Sperry, White Pine County, NV
R. Nelson, YMPO
D. Weigel, GAO
W. Barnard, NWTRB

STUDY PLAN 8.3.1.2.3.3
SITE SATURATED-ZONE HYDROLOGIC SYSTEM SYNTHESIS AND MODELING

Comment 1
Hydrochemical data should be used to support conceptual and numerical groundwater models for the saturated zone. This is an important element in the synthesis of these models.

Basis
Section 3.1.3.2 discusses the development and validation of conceptual and numerical models. The only reference to using geochemical data occurs in the last paragraph on page 3.1-10. "Matching of simulated versus observed hydraulic heads, fluxes, gradients, and possibly geochemistry, and comparison of model results with past data will constitute the calibration process. Closeness of the simulated model results to the observed data will be judged by the investigators and by the methods discussed in Section 2.1.6." Section 2.1.6 refers to geochemical data only once: "In addition, the calibration process will involve an examination of the observed versus predicted water levels, gradients, fluxes, and possibly geochemistry produced from the flow model."

The plan does not state whether conceptual or numerical groundwater models will be evaluated by comparing them with hydrochemical data that can provide insight about recharge sources, discharge areas, flow paths, the degree of mixing between hydrologic units, groundwater ages, and groundwater travel times. This would consist of a broad range of hydrochemical information from the saturated and unsaturated zones, including data on stable and radioactive isotopes (i.e., environmental tracers such as tritium, chlorine-36, carbon-14, iodine-129, oxygen-18, and deuterium)((Pearson and White, 1967; Bath *et al.*, 1979; Freeze and Cherry, 1979; Fritz and Fontes, 1980; Kyser, 1987). The geochemistry of minerals within fractures and general alteration of rock chemistry may also provide insights about flow conditions.

Several DOE studies will evaluate hydrochemistry at the site. These include Study 8.3.1.2.3.2 ("Characterization of the Yucca Mountain Saturated-Zone Hydrochemistry") and Study 8.3.1.2.2.7 ("Hydrochemical Characterization of the Unsaturated Zone"). These plans are not referenced in the study plan, and only one of these appears in Figure 1.1-1, which shows the position of Study 8.3.1.2.3.3 within the overall saturated-zone hydrology investigation. Most importantly, these two hydrochemical studies are not cited in Section 2.1.7, which describes contributions to this study from other studies.

Recommendation
The Study Plan should explicitly describe how hydrochemical data will be used to help develop and substantiate conceptual and numerical models. Other study plans related to hydrochemical characterization should be referenced in this study plan. Specifically, Studies 8.3.1.2.3.2 and 8.3.1.2.2.7 should be added to Section 2.1.7 of this study plan.

References

Bath, A.H., W.M. Edmunds, and J.N. Andrews, "Paleoclimatic Trends Deduced from the Hydrochemistry of a Triassic Sandstone Aquifer, United Kingdom," *Isotope Hydrology 1978*, Vienna, Austria, International Atomic Energy Agency, 2:545-568 [1979].

U.S. Department of Energy, "Hydrochemical Characterization of the Unsaturated Zone," Office of Civilian Radioactive Waste Management, Study Plan 8.3.1.2.2.7 (Rev. 0), September 1990. [Prepared by the U.S. Geological Survey.]

U.S. Department of Energy, "Characterization of the Yucca Mountain Saturated-Zone Hydrochemistry," Office of Civilian Radioactive Waste Management, Study Plan 8.3.1.2.2.7 (Rev. 0), April 1992.

Freeze, R.A., and J.A. Cherry, *Groundwater*, Englewood Cliffs, NJ, Prentice-Hall, Inc, 1979.

Fritz, P., and J.Ch. Fontes, "The Terrestrial Environment," in *Handbook of Environmental Isotope Geochemistry*, 1(A):66-67 [1980].

Kyser, T.K., "Short Course in Stable Isotope Geochemistry of Low Temperature Fluids," Mineralogical Association of Canada, vol. 13, 1987.

Pearson, F.J., and D.E. White, "Carbon-14 Ages and Flow Rates of Water in Carrizo Sand, Atascosa County, Texas," *Water Resources Research*, 3(1):251-261 [1967].

STUDY PLAN 8.3.1.2.3.3
SITE SATURATED-ZONE HYDROLOGIC SYSTEM SYNTHESIS AND MODELING

Question 1
Under this study plan, which hydrologic codes may be used to simulate complex heterogeneities in the saturated zone? Are stochastic or geostatistical simulation techniques being considered?

Basis
In Section 3.3.3.2, page 3.3-11, it is stated as hypothesis 1 that "three-dimensional numerical models capable of reproducing complex heterogeneity may be needed." However, it is not clear which existing codes may be used under this study plan, and whether they will incorporate stochastic or geostatistical techniques.

Three-dimensional geostratigraphic models provide a framework for representing complex heterogeneities, which include the structural and stratigraphic elements of a natural system. However, these models typically assume homogeneous structural units, which may lead to non-conservative estimates of groundwater velocities.

Gelhar (1993) provided an excellent discussion on the stochastic approach. In many applications, the goal of modeling subsurface hydrological processes is, according to Gelhar, "... to develop methods that can be used to quantify large-scale flow and transport in complex, naturally variable, subsurface flow systems...." The mean behavior of such flow systems, as estimated by stochastic approaches, is often in agreement with the classical deterministic model results. However, Gelhar considers estimating the degree of variability in a predicted quantity to be an important issue. According to Gelhar, this is because "... local variations in hydraulic properties can have an important influence ..." and, therefore, should be accounted for when attempting to "... have some quantitative measure of the degree of variability around the predicted large-scale mean behavior ...."

Others have also recognized the importance of local variability in hydraulic properties. Gotway (1994) presented an overview of the geostatistical simulation approach and summarized some results of efforts associated with the Waste Isolation Pilot Plant (WIPP). In these modeling efforts, GWTT estimates are characterized by cumulative distribution functions ranging from 10,000 to 35,000 years. Similarly, Bagtzoglou and Baca (1994) presented an analysis of GWTT for a system analogous to Yucca Mountain. According to their analyses, a mild heterogeneity (as inferred by the variance of the logarithm of hydraulic conductivities being less than unity) reduces the GWTT estimate by 30 percent when stochastic heterogeneities are included. Even though these findings are preliminary, they demonstrate the non-conservative nature of deterministically-calculated flow and transport processes.

Geologically-based stratigraphic models of the saturated zone at Yucca Mountain need to be enhanced by intra-layer heterogeneity (stochastically or deterministically generated) if a conservative estimate of groundwater velocities is required.

Recommendation
Clarify which hydrologic codes may be used to simulate complex heterogeneities. Describe the

manner in which each code incorporates these heterogeneities. Identify any stochastic or geostatistical simulation techniques that are being considered.

References

Bagtzoglou, A.C., and R.G. Baca, "Probabilistic Calculations of Groundwater Travel Time in Heterogeneous Three-Dimensional Porous Media," *Materials Research Society Symposium Proceedings*, 333:849-854 [1994].

Gelhar, L.W., *Stochastic Subsurface Hydrology*, Prentice Hall, Englewood Cliffs, NJ, 1993.

Gotway, C.A., "The Use of Conditional Simulation in Nuclear-Waste-Site Performance Assessment," *Technometrics*, 36(2):129-141 [1994].

STUDY PLAN 8.3.1.2.3.3
SITE SATURATED-ZONE HYDROLOGIC SYSTEM SYNTHESIS AND MODELING

Question 2
What methods will be used to incorporate "soft" information in the analysis of hydrologic parameters? Will indicator kriging be used, or perhaps more exotic techniques (e.g., Journel, 1983; 1986)?

Basis
In Section 3.1.3.1, page 3.1-7, the study plan suggests that in order to compensate for the sparsity of data, methods "to incorporate soft information into the analysis" can be implemented. Various types of soft data are suggested (i.e., results from geologic and seismic work) as useful sources of information, yet no specific technique of performing such a procedure is mentioned.

Recommendation
State what method(s) this study will use to incorporate "soft" information into the conceptual and numerical models.

References
Journel, A.G. "Non-Parametric Estimation of Spatial Distributions," *Mathematical Geology* 15(3):445-468 [1983].

Journel, A.G., "Constrained Interpolation and Qualitative Information -- The Soft Kriging Approach," *Mathematical Geology*, 18(3):269-286 [1986].

STUDY PLAN 8.3.1.2.3.3
SITE SATURATED-ZONE HYDROLOGIC SYSTEM SYNTHESIS AND MODELING

Question 3
The integration of this study with other planned site characterization activities is not clear and does not appear to be complete. How will this integration be assured?

Basis
On page 2.1-14, this study plan refers to other studies that will be providing contributions. Not present within the list is Study Plan 8.3.1.4.3.1 "Systematic Acquisition of Site-Specific Subsurface Information." While data from Study Plan 8.3.1.4.3.1 will be incorporated into many of the modeling studies, it would appear to be a key data source for this study plan.

On page 3.2-7, this study plan indicates that "stiffness theory" is described in Study Plan 8.3.1.4.2.2 ("Characterization of Structural Features in the Site Area"). Stiffness theory is only briefly mentioned in Study Plan 8.3.1.4.2.2 and the key reference, Schoenberg (1980), is not included in Study Plan 8.3.1.4.2.2.

On page 3.2-7, this study plan indicates that the construction of a geophysical model of fracture-network geometry using seismic tomography performed under Study Plan 8.3.1.4.2.2 is a key component. Study Plan 8.3.1.4.2.2 refers to the seismic tomography study at the C-hole locations as a test and that "it is hoped" that details of fracturing (such as orientation and density) can be defined.

Recommendation
Clarify what appears to be incomplete integration between this study plan and Study Plans 8.3.1.4.2.2 and 8.3.1.4.3.1, and recognize that the geophysical models of fracture network geometry are dependent on the results of the planned tests in Study Plan 8.3.1.4.2.2.

STUDY PLAN 8.3.1.2.3.3
SITE SATURATED-ZONE HYDROLOGIC SYSTEM SYNTHESIS AND MODELING

Question 4
What is meant by "actual results should be bounded in a statistical sense by predicted results."

Basis
In Section 3.2.3.2.2, page 3.2-17, it is stated "If the models are valid representations of the actual system, actual results should be bounded in a statistical sense by predicted results." In the preceding paragraph, it is stated that "...predictions probably will be expressed statistically, either as a range of probable results or as a best estimate of results and associated confidence regions." The statistical methods to be used in this process are not identified.

Recommendation
Provide an explanation of the statistical methods that will be used.

STUDY PLAN 8.3.1.2.3.3
SITE SATURATED-ZONE HYDROLOGIC SYSTEM SYNTHESIS AND MODELING

Question 5
How will upper and lower boundary conditions be selected for a three-dimensional groundwater model at the scale of the controlled area? Will the Paleozoic aquifer system be included in the model?

Basis
On page 3.1-2 it is stated that boundary and initial conditions for site-scale numerical modeling will be derived from studies of Quaternary regional hydrology and regional hydrologic synthesis and modeling. "Physical boundaries will be selected specific to this study, but fluxes across those boundaries will be calculated from the regional models." The current regional model is the base-case model of Czarnecki (1985), which is a vertically integrated, two-dimensional model of the Alkali Flat-Furnace Creek Ranch subbasin. In that model, Czarnecki assumed a uniform thickness of 1000 meters for the unconfined aquifer. No upward recharge from lower depths was considered.

It is understood that a three-dimensional (3-D), regional groundwater model is under development by the DOE, and that methods to estimate regional boundary conditions have been evaluated (Downey *et al.*, 1990). However, the NRC staff previously developed an open item regarding 3-D regional modeling (see NRC, 1993). One of the staff's recommendations was that DOE should be able to demonstrate that sufficient data have been obtained to support planned 3-D regional modeling, particularly for the Paleozoic carbonate aquifer. This concern exists because of a statement contained in the study plan to characterize the regional flow system (DOE, 1991, p. 3.1-6):

> "Little is known about the distribution of hydraulic head with depth within the flow system. Hydraulic-head data in the vertical dimension are critical for calibrating three-dimensional models of ground-water flow. At present, only a handful of points exist where hydraulic head has been determined at various depths."

In the site vicinity, only one borehole penetrates the Paleozoic aquifer system. As described on page 3-201 of the Site Characterization Plan (DOE, 1988), drillhole UE-25p#1 penetrated the Paleozoic aquifer, revealing that the hydraulic head in that aquifer is about 19 meters higher than in the overlying tuffs. Head data from drillholes USW H-1 and USW H-3 indicate an upward hydraulic gradient in tuff units well below the proposed repository horizon. These vertical hydraulic gradients suggest that an upward gradient at depth may exist over a large area. However, it is not known whether the vertical hydraulic characteristics of the deep rocks allow an upward flux to occur that is large enough to influence the shallower flow regime.

With respect to the upper model boundary, Czarnecki (1985, p. 21) performed a hydraulic-head sensitivity analysis of his steady-state, regional model. The result was that changes made to fluxes from the northern boundary (Timber Mountain) and from Forty Mile Wash "had the greatest effect on the water-table position in the vicinity of the primary repository area." This suggests that the site-scale model will need to include recharge from Forty Mile Wash. If the regional model showed great sensitivity to the assumed recharge along the wash, then the site-scale model should be even more sensitive to this parameter. Czarnecki (1985) had assumed an average annual (steady-state) recharge rate of 410 mm/yr for Forty Mile Wash. This relatively high recharge rate was assumed because the wash becomes a zone of enhanced recharge during major precipitation and runoff events.

Recommendation

Provide a rationale for selecting upper and lower boundary conditions for a three-dimensional, site-scale groundwater model.

References

Czarnecki, J. B., "Simulated Effects of Increased Recharge on Ground-Water Flow System of Yucca Mountain and Vicinity, Nevada-California," U.S. Geological Survey, Water-Resources Investigations Report 84-4344, 1985.

Downey, J. S., K. E. Kolm, and E. D. Gutentag, "Selection of Geohydrologic Boundaries for Ground-Water Flow Models, Yucca Mountain, Nevada," in *Waste Management '90, Proceedings of the Symposium on Waste Management,* Tucson, Arizona, Vol. 2, p. 725-734, 1990.

Holonich, J.J., U.S. Nuclear Regulatory Commission/Division of High-Level Waste Management, Letter to D.E. Shelor, U.S. Department of Energy/Office of Civilian Radioactive Waste Management, [Subject: "NRC Staff Review of Study Plan for Regional Hydrologic System Synthesis and Modeling"], April 6, 1993.

U.S. Department of Energy, "Chapter 3 (Hydrology)" in "Site Characterization Plan, Yucca Mountain Site, Nevada Research and Development Area, Nevada," Office of Civilian Radioactive Waste Management, DOE/RW-0199, Vol. II, December 1988.

U.S. Department of Energy, "Characterization of the Yucca Mountain Regional Ground Water Flow System," Office of Civilian Radioactive Waste Management, Study Plan 8.3.1.2.1.3 (Rev. 0), 1991. [Prepared by the U.S. Geological Survey.]

STUDY PLAN 8.3.1.2.3.3
SITE SATURATED-ZONE HYDROLOGIC SYSTEM SYNTHESIS AND MODELING

Question 6
If additional multiple-well sites are not constructed, how will DOE demonstrate that fracture-network models represent the saturated groundwater system in portions of the controlled area beyond the vicinity of the C-well complex?

Basis
On page 3.2-16 of the study plan, it is stated that the plan for site characterization includes an option to drill and test other multiple-well sites. The decision to do so "will depend on success in developing reliable conceptual models at the C-well complex and the ability of the single-well tests to give reliable estimates of hydraulic properties as compared to tests at the C-well complex." It is further stated that "In addition to providing site-characterization data, the purpose of drilling and testing other multiple-well locations is to validate geophysical and hydrologic models."

This question is related to an existing open item. In SCA Comment 19 (NRC, 1989), the staff questioned the ability of single-well tests to adequately characterize hydraulic properties of the site saturated-zone groundwater flow system. The staff recommended that one or more additional multiple-well sites be constructed.

Recommendation
Describe how verification of fracture-network models can be performed based on data from only one multiple-well site. Also describe how DOE would demonstrate whether the models are representative of the controlled area.

References
U.S. Nuclear Regulatory Commission, "NRC Staff Site Characterization Analysis of the Department of Energy's Site Characterization Plan, Yucca Mountain, Nevada," Office of Nuclear Material Safety and Safeguards, NUREG-1347, 1988.

STUDY PLAN 8.3.1.2.3.3
EDITORIAL COMMENTS

The following editorial corrections were noted during the review and should be addressed in future revisions of the study plan.

- In Section 3.1.3.2, page 3.1-10, Study 8.3.1.2.2.9 is misidentified as 8.3.1.2.9.9.
- Table 2.1-1 is misidentified as Table 2.3-1 in Section 1.3, page 1.3-2.
- Table 1.1-1 has no caption on page 1.3-1.
- In the captions for Table 3.3-1 (pages 3.3-15 and 3.3-16), the SCP section number should be changed to "(SCP 8.3.1.2.3.3.3)."
- Table 3.3-1, page 3.3-15, "Ground-water flux velocities" should read "Ground-water flow velocities."
- Table 3.3-1, page 3.2-19, "multiple-sell" should read "multiple-well."
- Page 3.2-13, Geldon (in press) should have a date.

NRC COMMENT 1:

Hydrochemical data should be used to support conceptual and numerical groundwater models for the saturated zone. This is an important element in the synthesis of these models.

DOE RESPONSE:

Site saturated-zone modeling will use any data available to help develop and substantiate the models, including hydrochemical data. For example, age dates of ground water will be compared to ground-water travel times calculated from the model output as a check on the reliability of the model results. These age dates will also be included in the conceptual model. Information on groundwater flow paths that may be derived from hydrochemical data and modeling will also be used to form and test conceptual models.

NRC QUESTION 1:

Under this study plan, which hydrologic codes may be used to simulate complex heterogeneities in the saturated zone? Are stochastic or geostatistical simulation techniques being considered?

DOE RESPONSE:

Simulation codes being developed independently by Lawrence Berkeley Laboratory (TRINET) and Golder Associates (MAFIC) are being evaluated for use in this study. Both codes will be required to simulate the complex heterogeneities found in the saturated zone. Geostatistical techniques are used to develop the fracture networks that will be used with these codes.

NRC QUESTION 2:

What methods will be used to incorporate "soft" information in the analysis of hydrologic parameters? Will indicator kriging be used, or perhaps more exotic techniques (e.g., Journel, 1983; 1986)?

DOE RESPONSE:

"Soft" data, or perhaps more accurately for the examples provided (e.g., seismic or other geophysical data) remotely-sensed data, will be incorporated in the form of the locations of stratigraphic horizons within the geohydrologic framework models or will be qualitatively used in assigning hydraulic characteristics (is the rock highly, moderately, or slightly fractured?). Also see response to Comment 1.

NRC QUESTION 3:

The integration of this study with other planned site characterization activities is not clear and does not appear to be complete. How will this integration be assured?

DOE RESPONSE:

The link to Study Plan 8.3.1.4.3.1 should have come indirectly through Study Plan 8.3.1.4.2.3; however, a direct and explicit link between those study plans appears to be missing. In any case, information obtained through the systematic drilling program will certainly be incorporated into any fracture-network modeling. DOE recognizes that the geophysical models of fracture-network geometry are dependent on the tests planned in Study Plan 8.3.1.4.2.2. Advances in geophysical techniques for tomographic analysis (such as seismic tomography or borehole radar) since that study plan was written indicate a good chance for successful fracture delineation in that study.

NRC QUESTION 4:

What is meant by "actual results should be bounded in a statistical sense be predicted results"?

DOE RESPONSE:

In the first paragraph on page 3.2-17, it is stated that "predictions probably will be expressed statistically, either as a range of probable results or as a best estimate of results and associated confidence regions." The observed test data will simply be compared to the ranges and means of model results, and checked to verify that they are in general agreement.

NRC QUESTION 5:

How will upper and lower boundary conditions be selected for a three-dimensional groundwater model at the scale of the controlled area? Will the Paleozoic aquifer system be included in the model?

DOE RESPONSE:

The upper boundary conditions, in the form of recharge or discharge boundaries, will be provided from studies in the unsaturated zone (providing infiltration data), data from studies of evapotranspiration from the Characterization of the Regional Ground-Water Flow System study, and from spring discharge measurements being collected by the USGS. Lower boundaries will be developed through the use of geophysical and well data. The Paleozoic aquifer will be included in the model, unless analysis of the data indicates that it is hydraulically isolated from the volcanic-rock aquifer.

NRC QUESTION 6:

If additional multiple-well sites are not constructed, how will DOE demonstrate that fracture-network models represent the saturated groundwater system in portions of the controlled area beyond the vicinity of the C-well complex?

DOE RESPONSE:

This question is only a restatement of the open item discussed in SCA Comment 19. That open item is more appropriately addressed by Study Plan 8.3.1.2.3.1, not by this study plan.

DOE RESPONSES TO NRC QUESTIONS ON STUDY PLAN 8.3.1.2.2.8 (FLUID FLOW IN UNSATURATED, FRACTURED ROCK), REVISIONS 0 AND 1

ENCLOSURE 2

UNITED STATES
NUCLEAR REGULATORY COMMISSION
WASHINGTON, D.C. 20555-0001

AUG 23 1994

Mr. Ronald A. Milner, Acting Director
Office of Program Management and Integration
Office of Civilian Radioactive Waste Management
U.S. Department of Energy, RW 30
1000 Independence Avenue
Washington, D.C. 20585

Dear Mr. Milner:

SUBJECT: REVIEW OF THE U.S. DEPARTMENT OF ENERGY (DOE) STUDY PLAN ON "FLUID FLOW IN UNSATURATED, FRACTURED ROCK (REVISIONS 0 AND 1)" (8.3.1.2.2.8)

On September 1, 1992, DOE transmitted Revision 0 of the subject study plan to the Nuclear Regulatory Commission for review and comment. On December 29, 1992, Revision 0 was superceded by Revision 1. The NRC staff has completed its review of this study plan using the "Review Plan for the NRC Staff Review of DOE Study Plans, Revision 2" (dated March 10, 1993). Based on its review of the study plan, the staff considers the material submitted consistent, to the extent possible, at this time, with the revised NRC-DOE "Level of Detail Agreement and Review Process for Study Plans" (dated March 22, 1993).

A major purpose of the review is to identify concerns with studies, tests, or analyses that, if started, could cause significant and irreparable adverse effects on the site, the site characterization program, or the eventual usability of the data for licensing. Such concerns would constitute "objections," as that term has been used in earlier NRC staff reviews of DOE documents related to site characterization (e.g., "Consultation Draft Site Characterization Plan" and the "Site Characterization Plan (SCP) for the Yucca Mountain Site"). It does not appear that the conduct of the activities described in this study plan will have adverse impacts on repository performance and the review of this study plan identified no objections with any of the activities proposed.

As part of its study plan review, the NRC staff also determines whether or not detailed comments or questions are warranted. The NRC staff's review of the subject study plan has resulted in the identification of five questions. The enclosed comment and questions will be tracked by the NRC staff as open items similar to those previously raised by the NRC staff in its 1989 Site Characterization Analysis.

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If you have any questions concerning this review, please contact Michael P. Lee at (301) 415-6677.

Sincerely,

Joseph J. Holonich

Joseph J. Holonich, Chief
High-Level Waste and Uranium Recovery
Projects Branch
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Office of Nuclear Material Safety
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Enclosure: As stated

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Study Plan 8.3.1.2.2.8
Fluid Flow in Unsaturated, Fractured Rock (Revision 1)

Question 1
How will laboratory-scale models and data be used to estimate model parameters in the corresponding site-scale models?

Basis
It is stated that "[t]he principal hydrologic modeling effort, however, and the objective of this study, is to construct mathematical representations to simulate the physical processes which govern fluid flow through partially-saturated fractured rock. The primary function of these models will be to help design and interpret hydrologic and pneumatic tests and to provide information about model parameters that can be incorporated into site-scale models" (Section 2.1.2, page 2.1-2). One of the functions of these models is "to integrate data collected from a variety of scales and estimate model parameters at those scales that are not amenable to direct testing" (Section 3.1.1, page 3.1-1). It is, further, stated that "[b]ecause site-scale models are applied at temporal and spatial scales that are not compatible with scales at which controlled experiments can be conducted, direct comparison with experimental data is not possible for these models" (Section 2.2.1, page 2.2-1). It is well-known that when the same numerical and mathematical model is applied to samples obtained from a site, and to the site itself, constitutive parameters which are required for the site-scale model to match field observations can be orders of magnitude different from the corresponding constitutive parameters in the laboratory-scale model; one explanation attributes this phenomenon to parameter heterogeneity across the site. However, neither the process by which data from a variety of scales will be integrated by the models developed in this study, nor the process by which model parameters will be estimated at scales not amenable to direct testing, are discussed in the study plan. As it is not planned to directly compare site-scale models with experimental data, there is concern that radionuclide mass fluxes may be under-predicted due to inappropriate site-scale parameters, thus affecting predicted releases from the accessible environment.

Recommendation
Explain how laboratory-scale models and data will be used to assign model parameters in the corresponding site-scale models.

ENCLOSURE

Study Plan 8.3.1.2.2.8
Fluid Flow in Unsaturated, Fractured Rock (Revision 1)

Question 2
Why have particular modeling strategies been assigned to address particular technical issues?

Basis
This study plan will develop or adapt models to address seven technical issues relevant to studies involved with ground-water flux and ground-water travel time (Section 3.1.4). Table 3.1-1 identifies several modeling strategies to evaluate these technical issues. In any choice of modeling strategies, different conceptual and modeling approaches are excluded and others included. However, it is not clear from the study plan why these modeling strategies have been selected and other modeling approaches have not. For example, Technical Issue (1) will try to, "determine the conditions under which flow within fractures located within the unsaturated zone is likely to occur," will be assigned two modeling strategies, namely the variable-aperture and double porosity models, for resolution. However, the text does not explain why these two modeling strategies were selected over other strategies, such as fracture-network- or channel-based models.

Recommendation
Provide a discussion of why particular modeling strategies has been assigned to address a particular technical issue.

Study Plan 8.3.1.2.2.8
Fluid Flow in Unsaturated, Fractured Rock (Revision 1)

Question 3
Is the method used by Cacas *et al.*(1990), for the determination of fracture network hydraulic aperture distributions, applicable for unsaturated flow?

Basis
Section 3.1.7.2 (page 3.1-14) states that an approach similar to that proposed by Cacas *et al.* (1990) will be used to estimate the fracture hydraulic aperture distributions. This approach replaces the fracture system by a series of interconnected conduits. By introducing an adjustable parameter accounting for the shape of the conduits, this method has been shown to provide for the calibration of a transport model for saturated rock at the Fanay-Augeres site in France. However, in unsaturated rock, a direct recreation of the variance in the observed flow rates may not be possible due to extreme nonlinearities introduced in the flow problem, especially for very small apertures, where the deviations from the cubic law may be more pronounced (Gale *et al.*, 1985).

Recommendation
Explain how the methodology proposed by Cacas *et al.* (1990) will be modified, and why the modified method will be applicable to unsaturated flow conditions.

References
Cacas, M.C., Ledoux, E., de Marsily, G., Tillie, B., Barbreau, A., Durand, E., Feuga, B., and Peaudecerf, P. "Modeling Fracture Flow with a Stochastic Discrete Fracture Network: Calibration and Validation, 1. The Flow Model," *Water Resources Research,* 26(3): 479-489 [1990].

Gale, J.E., Rouleau, A., and Atkinson, L.C., "Hydraulic Properties of Fractures," in International Association of Hydrogeologists, *Proceedings of the Symposium on Hydrogeology of Rocks of Low Permeability*, Tucson, Arizona, Volume XVII, Part 1, pp. 1-16, 1985.

Study Plan 8.3.1.2.2.8
Fluid Flow in Unsaturated, Fractured Rock (Revision 1)

Question 4
How can one build confidence in conceptual models if every time a conceptual model is refuted by experimental data, the experiment is redesigned as inappropriate or not sensitive enough to capture the essence of the model?

Basis
In Section 2.1.3, it is stated that "[i]f experimental and modeled results should not satisfactorily agree, the hypothesis/model may be judged not to be a valid description of the properties and processes under experiment, and may be significantly revised or else considered disproved. The investigators may also reexamine and possibly revise the design of the experiment if they believe that it has not isolated and measured the selected hydrologic parameters with sufficient sensitivity." The above statement is written generally enough that conceptual models, *a priori* assumed to be appropriate, can be proven to be justified by the experimental results. This is because Section 2.1.3 seems to imply that one could, in principle, keep redesigning an experiment until some preconceived conceptual model is proven to be valid. Well-posed, testable hypotheses, and testing criteria can provide the necessary platform for performing such comparisons.

Recommendation
Experiments should be designed with the conceptual models under testing clearly defined. They should be redesigned only in a manner that is well controlled and that leaves the validity of the comparisons intact.

Study Plan 8.3.1.2.2.8
Fluid Flow in Unsaturated, Fractured Rock (Revision 1)

Question 5
What modeling strategies will be used to address technical issues one, two, and five?

Basis
In Tables 3.1-1 and 3.2-1 modeling strategies are identified that will resolve seven technical issues. For issue one this activity will develop or adapt models to determine the conditions under which flow within fractures located within the unsaturated zone is likely to occur. For issue two this activity will develop or adapt models to study the nature of channeling processes and the implications of channeling for the transport of water and radionuclides. For issue five, this activity will develop or adapt models to describe the effect of stress changes on the permeability and relative permeability of rough-walled natural fractures. However, the two tables do not agree in the different modeling strategies that will address technical issues one, two, and five. Therefore, it is not possible to identify which modeling strategies will address these three technical issues.

Table 3.1-1 associates technical issues with modeling strategies for issue resolution, required data, and data source. Table 3.2-1 associates technical issues with modeling strategies for issue resolution, required validation data, and validation data source. If these two tables have correctly identified different strategies for these three technical issues, then validation of modeling results using a modeling strategy which is different from the strategy used to obtain the initial results may not be consistent.

For example, in Table 3-1.1, one modeling strategy used to address technical issue (1) is the double porosity model. Inferences gained from a modeling exercise implementing this strategy, however, may be misleading when compared to results produced using a fracture-network strategy during the validation exercises as indicated in Table 3-1.2. In particular, matrix-fracture interaction effects are explicitly included in the double-porosity model but may or may not be in the fracture-network model. Other inconsistencies such as this could arise when the modeling strategy used in the modeling exercises differs from the strategy used in the validation exercises.

Recommendation
Identify the modeling strategies that will be used to address technical issues one, two, and five. If strategies used in modeling exercises designed to address the technical issue are different from those used in validation exercises, explain how different modeling strategies can be implemented without biasing the process.

UNITED STATES
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WASHINGTON, D.C. 20555-0001

AUG 22 1994

Mr. Ronald A. Milner, Acting Director
Office of Program Management and Integration
Office of Civilian Radioactive Waste Management
U.S. Department of Energy, RW 30
1000 Independence Avenue
Washington, D.C. 20585

Dear Mr. Milner:

SUBJECT: REVIEW OF THE U.S. DEPARTMENT OF ENERGY (DOE) STUDY PLAN ON "SITE UNSATURATED-ZONE MODELING AND SYNTHESIS (REVISION 0)" (8.3.1.2.2.9)

On July 14, 1993, DOE transmitted the subject study plan to the Nuclear Regulatory Commission for review and comment. The NRC staff has completed its review of the subject study plan using the "Review Plan for the NRC Staff Review of DOE Study Plans, Revision 2," (dated March 10, 1993). Based on its review of the study plan, the staff considers the material submitted consistent, to the extent possible, at this time, with the revised NRC-DOE "Level of Detail Agreement and Review Process for Study Plans," (dated March 22, 1993).

A major purpose of the review is to identify concerns with studies, tests, or analyses that, if started, could cause significant and irreparable adverse effects on the site, the site characterization program, or the eventual usability of the data for licensing. Such concerns would constitute "objections," as that term has been used in earlier NRC staff reviews of DOE documents related to site characterization, (e.g., "Consultation Draft Site Characterization Plan") and the "Site Characterization Plan for the Yucca Mountain Site.") It does not appear that the conduct of the activities described in this study plan will have adverse impacts on repository performance and the review of this study plan identified no objections with any of the activities proposed.

As part of its study plan review, the NRC staff also determines whether or not detailed comments or questions are warranted. The NRC staff's review of the subject study plan has resulted in the identification of one comment and five questions. The enclosed comment and questions will be tracked by the NRC staff as open items similar to those previously raised by the NRC staff in its 1989 Site Characterization Analysis.

Finally, the staff's review of the activities described in this study plan indicate that much of the work appears to meet the scope of the procedure for scientific notebooks, (see YMP-USGS-QMP-5.05, Rev. 3). However, there is no information in the study plan regarding how the development of models under this study will be documented. The staff

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has recently identified an open-item comment during reviews of other related study plans, (e.g., 8.3.1.2.3.3, "Site Saturated-Zone Hydrologic System Synthesis and Modeling," dated, January 1993 and 8.3.1.5.2.2, "Characterization of Future Regional Hydrology due to Climate Changes," dated December 1994). This open item expresses the concern that the process of creating groundwater models may not be reproducible unless it is adequately documented. Unless these types of study plans contain information on how the modeling work is to be documented, then this open item applies to all modeling and synthesis studies under the DOE's high-level waste program.

If you have any questions concerning this review, please contact Michael P. Lee at (301) 415-6677.

Sincerely,

Joseph J. Holonich

Joseph J. Holonich, Chief
High-Level Waste and Uranium Recovery
Projects Branch
Division of Waste Management
Office of Nuclear Material Safety
and Safeguards

Enclosure: As stated

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cc: List for Milner Letter Dated: JUN 2 2 [illegible]

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Study Plan 8.3.1.2.2.9
Site Unsaturated-Zone Modeling and Synthesis, Revision 0

Comment 1
The list of hydrologic issues to be resolved by this study plan appears to neglect the possibility that the Solitario Canyon fault could act as a short-circuit for water to infiltrate laterally into the repository and the effect on the spatial distribution of flux by highly conductive fracture networks, which might extend from the surface, through the non-welded units, into the repository horizon and down to the water table.

Basis
In section 3.1.3.2, on pages 3.1-7 through 3.1.-10, five hydrologic issues that were previously identified in the SCP are listed. As is stated on page 3.1-6, "[r]esolution of these issues may be considered one of the principal objectives of this activity." The five issues are: (1) "the role of faults in the hydrologic system;" (2) "the role of the Paintbrush tuff non-welded unit on the hydrologic system;" (3) "investigation of the expected relative contributions of liquid-water and water-vapor fluxes to the net moisture flow within the unsaturated-zone system;" (4) "assessment of the likelihood for the occurrence of geothermally or barometrically driven convection cells involving the upward flow of water vapor with a corresponding downward return flow of water;" and (5) the "potential for downward flow to bypass the zeolitic facies of the Calico Hills unit."

However, these issues do not appear to address the possibility that the Solitario Canyon fault could act as a short-circuit for water to infiltrate laterally into the repository horizon or the effect of highly conductive fracture networks extending from the surface, to the water table, on the rate and spatial distribution of flux. Both of these issues (conceptual models) have the potential to increase the flux of water through the repository and therefore increase the rate of radionuclide release from waste packages and the rate of radionuclide transport to the accessible environment.

Recommendation
Describe how the possibility that the Solitario Canyon fault could act as a short-circuit for water to infiltrate laterally into the repository will be considered. Describe how the potential effect on the spatial distribution of flux by highly conductive fracture networks, which might extend from the land surface to the water table will be considered.

ENCLOSURE

Study Plan 8.3.1.2.2.9
Site Unsaturated-Zone Modeling and Synthesis, Revision 0

Question 1
Will this study plan evaluate the importance of wetting front instabilities for modeling the Yucca Mountain hydrologic regime?

Basis
This study plan identifies five hydrologic issues; resolution of which is considered to be a principal objectives of this study plan. One of these issues is the "role of the Paintbrush tuff nonwelded unit (PTn)" on the hydrologic system. This issue will investigate the possibility that downward-flowing water may be diverted laterally within the Paintbrush Tuff and at the contacts with adjacent units, shedding water around the potential locations of waste-emplacement drifts.

However, the study plan appears to assume that wherever a fine-grained unit overlies a coarse-grained unit in the unsaturated regime, a capillary barrier will form which, due to the mild eastward dip of all units within Yucca Mountain, will tend to divert infiltrating water away from the repository block. In Section 3.1.3.2, on page 3.1-13, it is stated that "[w]hen materials with relatively small pores overlie material with relatively large pores, water movement into the underlying material is delayed if matrix potentials at the interface between the two materials are low and the effective hydraulic conductivity of the underlying unit is too low to accept the flux." It is asserted that "[t]his condition may exist between adjacent subunits within the PTn unit, or between the PTn unit and the fractures of the underlying welded units." Moreover it is noted that "[t]he formation of capillary barriers in layered sequences can promote the lateral spreading of localized infiltration." The study plan cites analytical studies performed by Ross, (1990) which "[suggest] that a capillary barrier capable of diverting 15 to 200 meters^3 of water per year per meter thickness along the strike of the beds may be formed between the Paintbrush nonwelded unit and the underlying fractures of the Topopah Spring hydrogeologic unit."

However, wetting front instabilities often form along capillary barriers. These wetting front instabilities produce vertically extensive wetted channels or "fingers" along which flux rates may be quite rapid. The phenomenon of wetting front instabilities as evidenced by the generation of fingers has been observed in laboratory experiments in which water is introduced at the top of a column composed of a fine-grained sand overlying a coarse-grained sand [Miller and Gardner (1962), Peck (1965), Hill and Parlange (1972), Diment and Watson (1983), Glass *et al.* (1989), and Baker and Hillel (1990)]. According to Hillel and Baker (1988) the larger air-entry value for the coarser underlying layer restricts transmission of water across the soil interface until the water pressure in the overlying layer is great enough to wet the adjacent, larger pores. However, because the spatial distribution of pore-sizes along the interface is not uniform, transmission of water across the interface will not occur simultaneously at all locations. Factors that may attenuate the growth of fingers are decreasing material pore-size and decreasing hydraulic conductivity encountered by the fingers as they propagate. In the absence of these factors, fingers may propagate very rapidly through the medium and thus serve as fast pathways both to and from the repository. Unfortunately, unless the model explicitly incorporates lateral variations in air entry pressures along the interface of the units, standard numerical models may be unable to model the potential for wetting front instabilities to develop at the transition from a bedded tuff unit to a densely welded, highly fractured unit.

Recommendation

Explain why wetting front instabilities are not important to modeling the Yucca Mountain flow regime or explain how it will be determined if they are important or unimportant to modeling flow. If it is determined that wetting front instabilities may result in fast pathways through the repository or are significant for other reasons to modeling the Yucca Mountain hydrologic regime, it is recommended that modelling approaches be developed to incorporate this effect.

References

Baker, R.S. and D. Hillel, "Laboratory Tests of a Theory of Fingering During Infiltration into Layered Systems," *Journal of the Soil Science Society of America*, 54:20-30 [1990].

Diment, G.E. and K.K Watson, "Stability Analysis of Water Movement in Unsaturated Porous Materials -- 3: Experimental Studies," *Water Resources Research*, 21(7):979-984 [1983].

Glass, R.J., J.Y. Parlange and T.S. Steenhuis, "Wetting Front Instability -- 2: Experimental Determination of Relationships Between System Parameters and Two Dimensional Unstable Flow Field Behavior in Initially Dry Porous Media," *Water Resources Research*, 25(6):1195-1207 [1989].

Hill, D.E. and J.Y. Parlange, "Wetting Front Instability in Layered Soils," *Proceedings of the Soil Science Society of America*, 36:697-702 [1972].

Miller, D.E. and W.H. Gardner, "Water Infiltration into Stratified Soils," *Proceedings of the Soil Science Society of America*, 26:115-119 [1962].

Peck, A.J. "Moisture Profile Development and Air Compression During Uptake by Bounded Porous Bodies -- 3: Vertical Columns," *Soil Science*, 100:44-51 [1965].

Ross, B., "The Diversion Capacity of Capillary Barriers," *Water Resources Research*, 26(10):2625-2629 [1990].

Study Plan 8.3.1.2.2.9
Site Unsaturated-Zone Modeling and Synthesis, Revision 0

Question 2
How will hydrologic parameters which describe the hydrologic properties of fractures in the unsaturated zone, such as fracture flow as a function of water content, fracture porosity, and water movement between the fractures and the matrix be obtained from site data?

Basis
Models of ground water flow through Yucca Mountain will be dependent on site characterization activities to provide information, which can be used to derive hydrologic parameters needed by the models. Therefore, successful site characterization will be dependent on the development of techniques to both gather data and to derive hydrologic parameters from the data. Determining, under what conditions fracture flow could occur and the direction and rate of flow, will be important for calculating the anticipated performance of Yucca Mountain. However, the NRC staff is not aware of any techniques to obtain hydrologic parameters that describe the resistance to flow (hydraulic conductivity) through a fracture as a function of water content, fracture porosity, or how water moves between the fractures and the matrix (in a porous equivalent code this would be equivalent to the characteristic curves, fracture porosity, and resistance to flow between the fracture and matrix).

The staff recognizes that many models of Yucca Mountain will probably not model single fractures, but will use parameters that represent the hydrologic properties of large numbers of fractures. However, again the NRC staff is not aware of any techniques to determine for large numbers of fractures, hydrologic parameters that describe the resistance to flow (hydraulic conductivity) as a function of water content, porosity, or how water moves between the fractures and the matrix. In single continuum porous equivalent codes, this would be equivalent to the combined hydraulic conductivity characteristic curves of fractures and matrix and the combined porosities of fractures and matrix. For dual continuum porous equivalent codes this would be equivalent to the characteristic curves representing the fractures, porosities of the fractures, and a transfer term representing resistance to flow between fractures and matrix.

The staff recognizes that other modeling approaches than those mentioned above may be used to model unsaturated flow through Yucca Mountain. However, whatever the modeling approach, the ability to derive the fracture hydrologic parameters will be key to determining flow direction, flow magnitude, and when fracture flow is initiated.

Recommendation
Explain how hydrologic parameters, which describe unsaturated zone fracture hydrologic properties, will be obtained from site data.

Study Plan 8.3.1.2.2.9
Site Unsaturated-Zone Modeling and Synthesis, Revision 0

Question 3
How will local potential gradients of water within a fracture or a set of fractures be measured so that net moisture flux rates can be inferred?

Basis
On page 2.1-1, in the second paragraph, it is stated that "[n]et moisture flux, occurring in both liquid and vapor phases, is not accessible to direct *in-situ* measurement and, therefore, must be inferred from the local potential gradients and hydraulic conductivities or effective vapor diffusion coefficients." *In-situ* measurement of local potentials, while difficult to perform, can be obtained from the rock matrix. If water flows primarily through the rock matrix, such measurements may be sufficient for characterizing the net moisture flux through Yucca Mountain. However, using this approach, if fractures play a significant role in transporting water throughout the mountain, *in-situ* water potentials within the fractures must also be measured. At this time the NRC staff is not aware of any methods that can measure *in-situ* fracture water potentials.

Recommendation
Give a thorough description of the methods that will be used to measure water potential in fractures.

Study Plan 8.3.1.2.2.9
Site Unsaturated-Zone Modeling and Synthesis, Revision 0

Question 4
Which smaller-scale hydrologic sub-models will be calibrated using experimentally induced perturbations from Yucca Mountain surface and subsurface tests?

Basis
In the paragraph at the top of the page 2.1-6, it is stated that "[i]t is not expected that experimentally induced perturbations can practically be included in the calibration process because of the long time factors involved." It is probably true that the surface and subsurface tests which will be conducted at the site will not last long enough to induce changes that can be used to calibrate a large scale site model. However, these tests could still be used to calibrate smaller scale sub-models, which will be used to design the large scale site model.

Recommendation
If experimentally induced perturbations by Yucca Mountain surface and subsurface tests will be used to calibrate smaller scale sub-models, then DOE should: (1) identify those submodels relevant to this study plan that will be calibrated in this manner; and (2) generally describe how they will be used to design the large scale site model.

Study Plan 8.3.1.2.2.9
Site Unsaturated-Zone Modeling and Synthesis, Revision 0

Question 5
How will this study plan evaluate the importance of modeling the non-Darcian flow regime that may occur at seepage faces formed in wide, rubble-filled fault zones?

Basis
This study plan identifies five hydrologic issues; resolution of which are considered to be principal objectives of this study plan. One of these issues is the "role of faults in the hydrologic system." This issue will investigate the possibility that "if faults are open they may intercept water flowing parallel to unit contacts and redirect this flow downward" and the possibility that if fault openings are so large that they function as seepage faces, perched-water bodies may form on the up dip side of the fault.

In reviewing the study plan, it appears that Darcian or equivalent porous media codes will be used to investigate these possibilities. However, the dynamics of flow on a seepage face will be determined strongly by water viscosity and gravity. Therefore, it may be easier to analyze this as a fluid continuum problem, than to devise a defensible effective porous continuum equivalent for such a phenomenon. The fluid continuum may be coupled to the porous matrix via moisture diffusion if the seeping water encounters an unsaturated-zone.

Recommendation
Explain how it will be determined if seepage faces formed in wide rubble-filled fault zones are important to modeling the Yucca Mountain hydrologic regime. If seepage faces may be important, explain the need to consider non-darcian flow modeling approaches.

UNITED STATES
NUCLEAR REGULATORY COMMISSION
WASHINGTON, D.C. 20555-0001

AUG 22 1994

Mr. Ronald A. Milner, Acting Director
Office of Program Management and Integration
Office of Civilian Radioactive Waste Management
U.S. Department of Energy, RW 30
1000 Independence Avenue
Washington, D.C. 20585

Dear Mr. Milner:

SUBJECT: REVIEW OF THE U.S. DEPARTMENT OF ENERGY (DOE) STUDY PLAN ON "CHARACTERIZATION OF FUTURE REGIONAL HYDROLOGY DUE TO CLIMATE CHANGES" (8.3.1.5.2.2)

On December 24, 1992, DOE transmitted the subject study plan to the Nuclear Regulatory Commission for review and comment. The NRC staff has completed its review of the subject study plan using the "Review Plan for the NRC Staff Review of DOE Study Plans, Revision 2" (dated March 10, 1993). Based on its review of the study plan, the staff considers the material submitted consistent, to the extent possible, at this time, with the revised NRC-DOE "Level of Detail Agreement and Review Process for Study Plans" (dated March 22, 1993).

A major purpose of the review is to identify concerns with studies, tests, or analyses that, if started, could cause significant and irreparable adverse effects on the site, the site characterization program, or the eventual usability of the data for licensing. Such concerns would constitute "objections," as that term has been used in earlier NRC staff reviews of DOE documents related to site characterization (e.g., "Consultation Draft Site Characterization Plan" and the "Site Characterization Plan (SCP) for the Yucca Mountain Site"). It does not appear that the conduct of the activities described in this study plan will have adverse impacts on repository performance and the review of this study plan identified no objections with any of the activities proposed.

As part of its study plan review, the NRC staff also determines whether or not detailed comments or questions are warranted. The NRC staff's review of the subject study plan has resulted in the identification of one comment and three questions. The enclosed comment and questions will be tracked by the NRC staff as open items similar to those previously raised by the NRC staff in its 1989 Site Characterization Analysis (SCA).

As part of its review (see Comment 1), the staff have recently identified a concern, in this and other synthesis and modeling study plans, regarding documentation of DOE modeling efforts. For example, this study plan states that technical procedures do not apply to either of the work activities. However, it is the staff's understanding that in instances where technical procedures do not apply, scientific notebooks will be employed in their

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place. Based on the staff's review of the activities described in this study plan, much of the work does appear to meet the scope of the procedure for scientific notebooks (see YMP-USGS-QMP-5.05, Rev. 3). Therefore, there appears to be a gap in the documentation of the modeling work. (The NRC staff have also identified a similar gap as part of its on-going review of Study Plans 8.3.1.2.3.3 ("Site Saturated-Zone Hydrologic System Synthesis and Modeling," dated January 1993) and 8.3.1.2.2.9 ("Site Unsaturated-Zone Modeling and Synthesis," dated July 1993).) For each of these synthesis and modeling study plans, and perhaps others under the Yucca Mountain project, DOE should describe how in-progress work will be documented. The relationship of the study plans to scientific notebook procedures should also be described.

Finally, the NRC staff wishes to note that in its transmittal letter, DOE did not identify any SCA open items related to this study plan. The NRC staff considers that several SCA open items are directly related to development of conceptual models under this study plan, and to the related SCP Study 8.3.1.2.3.1.1-6, "Characterization of the Site Saturated-Zone Groundwater Flow System" (Revision 0) (dated May 1990). For example, SCA Comment 19 states that activities for the study of the saturated zone are not adequate to characterize hydrologic boundaries, flow directions and magnitudes, and flow paths. One of the recommendations made under Comment 19 was that one or more additional multiple-well sites (similar to the C-hole site) should be constructed. Moreover, SCA Comment 20 states that the potentiometric surface in the controlled area is not adequately defined by existing well locations, and will not be adequately defined by proposed additional well sites. This study, therefore, does not make progress toward resolution of these two SCA open items.

If you have any questions concerning this review, please contact Michael P. Lee at (301) 415-6677.

Sincerely,

Joseph J. Holonich

Joseph J. Holonich, Chief
High-Level Waste and Uranium Recovery
Projects Branch
Division of Waste Management
Office of Nuclear Material Safety
and Safeguards

Enclosure: As stated

cc: See Attached List

DOE RESPONSES TO STUDY PLAN 8.3.1.5.2.2

(CHARACTERIZATION OF FUTURE REGIONAL HYDROLOGY DUE TO CLIMATE CHANGES)

ENCLOSURE 4

Mr. Ronald Milner

cc: List for Milner Letter Dated: AUG 22 1994

R. Loux, State of Nevada
T.J. Hickey, Nevada Legislative Committee
J. Meder, Nevada Legislative Counsel Bureau
C. Schank, Churchill County, NV
D. Bechtel, Clark County, NV
J. Hoffman, Esmeralda County, NV
L. Fiorenzi, Eureka County, NV
B. Mettam, Inyo County, CA
M. Baughman, Lincoln County, NV
R. Williams, Lander County, NV
V. Poe, Mineral County, NV
L. Bradshaw, Nye County, NV
M. Murphy, Nye County, NV
P. Niedzielski-Eichner, Nye County, NV
F. Sperry, White Pine County, NV
R. Nelson, YMPO
D. Weigel, GAO
W. Barnard, NWTRB

STUDY PLAN 8.3.1.5.2.2
CHARACTERIZATION OF FUTURE REGIONAL HYDROLOGY DUE TO CLIMATE CHANGE

Comment 1
There appears to be a gap in the documentation of groundwater modeling work under this study.

Basis
In general, groundwater modeling consists of three main phases:

(1) Development and verification of software (hydrologic process codes);

(2) Creation of groundwater models using appropriate process codes -- this process includes making assumptions about the dimensionality and layering of a model, recharge and discharge boundary conditions, physical properties, and future changes to the hydrologic flow system; this phase also includes model calibration; and

(3) Peer review and approval of modeling publications.

Procedures to document Phases 1 and 3 are listed in Appendix 7.1 of the study plan. However, there appears to be no requirement to document work in progress under Phase 2, the creation of groundwater models.

Appendix 7.1 to the study plan lists quality-assurance requirements. The procedure for a scientific notebook system (YMP-USGS-QMP-5.05, Rev. 3) is not included under the requirements. Much of the work under this study meets the scope of this procedure, which states: "This QMP [procedure] applies to the YMP-USGS and supporting organizations assigned to perform the work related to quality assurance (QA) graded technical activities that produce data, maps, or other products which are the basis for the YMP site characterization, licensing, or environmental monitoring. The Scientific Notebook shall be used when scientific investigations include: (1) trial-and-error, experimental, or innovative methods; (2) emerging technologies; or (3) developmental research. Technical activities conducted as standard, routine, and/or industry accepted practices require Technical Procedures as described in QMP-5.01." With regard to the content of scientific notebooks, this procedure states that "Each entry shall provide sufficient detail to allow another scientist of appropriate experience and qualification to retrace or recreate the investigation process and to properly evaluate the original and new results, without the consultation or guidance of the original PI [Principal Investigator]." The NRC staff considers that documentation similar to that required in scientific notebooks will be required at the time of licensing for staff review of the calibration and validation of models.

In a letter dated November 3, 1993 [D. Shelor (DOE) to J. Holonich (NRC)], DOE indicated that YMP-USGS-QMP-3.03 (Rev. 3) addresses QA for computer codes. However, the staff is concerned that QMP-3.03 covers only code development, validation, and maintenance. There appears to be little documentation of the elaborate process of selecting and rejecting conceptual models and developing modeling parameters to simulate the Yucca Mountain region, based on available field data. The process includes making assumptions about the dimensionality of a model, boundary conditions, physical properties, and future changes to the hydrologic flow system. The Shelor to Holonich letter also mentions QMP-3.04 (Rev. 4) procedure for technical review, approval, and distribution of YMP-USGS publications. It documents the process for approving reports (etc.) for external publication. This procedure governs review of final draft products, but does not document the interactive and elaborate process of creating models.

Given the importance of this study with respect to scenario development and, therefore, performance evaluations and licensing of a HLW repository, it is not clear why model development work is not being documented more thoroughly. Without this kind of documentation, it may be difficult for NRC to evaluate the validity of hydrologic synthesis and modeling work. There is also the question of project continuity. If a PI for a synthesis and modeling project should depart the program, how would the new PI continue the work without documentation of work in progress?

Documentation of model development is discussed by Anderson and Woessner (1992, p. 276). They state that "Keeping a journal or a log during the modeling study is well worth some extra time because it will facilitate report preparation, allow reconstruction of the model at a later time, and also reduce calibration time." They also state that, without appropriate records, it "may be impossible for another modeler to reconstruct the original modeler's thought process." The NRC staff consider that journals or logs would also provide solid foundations for modelers to defend their work during technical audits and peer reviews.

Documentation will also be needed because site models for the unsaturated zone are proposed to be developed under another study (Study Plan 8.3.1.2.2.9 (DOE, 1993)). The surface water, unsaturated zone, and saturated zone regimes actually represent a continuum and must be treated accordingly. The documentation should show that proper coordination between studies has been performed, and ensure that the various models are compatible. For example, the net liquid flux across the earth-atmosphere interface defines the upper boundary condition for flow through the unsaturated zone. Future flux conditions will need to be estimated under the future surface water activity and applied to the unsaturated zone models developed under Study 8.3.1.2.2.9. In turn, output from these models must feed back into the regional saturated zone activity of Study 8.3.1.5.2.2.

Recommendation

The elaborate process of developing groundwater models under this study plan needs to be

Recommendation

The elaborate process of developing groundwater models under this study plan needs to be documented. DOE should describe how this work will be documented, including the relationship to the procedure for scientific notebooks (YMP-USGS-QMP-5.05, Rev. 3).

References

Anderson, M.P. and W.W. Woessner, *Applied Groundwater Modeling: Simulation of Flow and Advective Transport,* Academic Press, Inc., San Diego, CA, 381 p.

U.S. Department of Energy, "Study Plan for Study 8.3.1.2.2.9: Site Unsaturated-Zone Modeling and Synthesis," Office of Civilian Radioactive Waste Management, May 1993. [Prepared by U. S. Geological Survey.]

STUDY PLAN 8.3.1.5.2.2
CHARACTERIZATION OF FUTURE REGIONAL HYDROLOGY DUE TO CLIMATE CHANGE

Question 1
How will the work under this study (regional surface water and saturated zone modeling) be integrated with the site unsaturated zone modeling under Study 8.3.1.2.2.9 ("Site Unsaturated-Zone Modeling and Synthesis")?

Basis
The following comment appears on page 1.1-1 of the subject study plan:

> "This activity [8.3.1.5.2.2.2, "Analysis of Future Unsaturated-Zone Hydrology due to Climate Changes"] has not been included in the study plan because its scientific content has been incorporated in YMP-USGS SP 8.3.1.2.2.9 ("Site Unsaturated-Zone Modeling and Synthesis"). The logic for this change is explained in Section 1.2."

But the only references to unsaturated zone hydrology in Section 1.2 are:

> "The modeling of the site unsaturated zone under conditions of greater-than-present effective precipitation (SCP Activity 8.3.1.5.2.2.2) is not included in this study; it will be performed in Study 8.3.1.2.2.9 (YMP-USGS SP 8.3.1.2.2.9, "Site Unsaturated-Zone Modeling and Synthesis"), and this effort will be integrated as appropriate with the efforts of the present study." (page 1.2-1)

> "The unsaturated-zone modeling efforts of Study 8.3.1.2.2.9 are expected to provide a range of estimates for possible values of future infiltration, percolation, and saturation." (page 1.2-1)

Despite the reference (page 1.1-1) to the "logic for this change", no such logic for the exclusion of unsaturated zone hydrology is found in Section 1.2. Finally, Section 3.2 states that:

> "The modeling of the future unsaturated-zone hydrology due to climate changes is described in Section 3.5 ("Site Unsaturated-Zone Integration and Synthesis") of Study 8.3.1.2.2.9 (YMP-USGS SP 8.3.1.2.2.9, "Site Unsaturated-Zone Modeling and Synthesis"). Activity 8.3.1.5.2.2.2 has been omitted from the present study plan for this reason." (page 3.2-1)

These statements also do not give the logic for omitting Activity 8.3.1.5.2.2.2 from this study plan. In general, it does not seem rational to evaluate future climatic effects on the unsaturated zone separately from the effects on surface water hydrology and the saturated zone. As stated in the technical rationale for this study (page 2.1-1), "... climate changes impact surface, unsaturated-zone, and saturated zone hydrology and these impacts may affect the performance of the repository." Crucial, and in some cases poorly understood, relationships exist between the flow of surface water and flow in the unsaturated and saturated zones. These three flow regimes are intimately linked, requiring a carefully integrated assessment.

DOE's 1988 Site Characterization Plan (p. 8.3.1.5-120) notes that a calibrated model of unsaturated-zone, present-day conditions will be developed under Activity 8.3.1.2.2.9.3. That model was intended to be used under Activity 8.3.1.5.2.2.2 to simulate transient infiltration scenarios over a 10,000 year period. The study plan under review revises this approach because it omits Activity 8.3.1.5.2.2.2 and commits to performing the work under Study 8.3.1.2.2.9. However, Study Plan 8.3.1.2.2.9 (DOE, 1993) does not list Study 8.3.1.5.2.2 under its discussion of contributions from other studies (p. 2.1-11). It should have been included because of the need to couple surface water models to unsaturated zone models. DOE (1993) does state that (p. 4.2-3) "... modeled results of the forward extrapolation of unsaturated-zone conditions may contribute to the modeling of future saturated-zone hydrology in Study 8.3.1.5.2.2 ...."

Placing the future unsaturated zone assessment in a different study plan may result in incomplete coupling between the surface water hydrologic system and the ground water components. Water that infiltrates from the surface must pass through the unsaturated zone before recharge of the saturated zone can occur. This requires proper linkages between surface water, unsaturated zone, and saturated zone models. In particular, estimation of future flux across the atmosphere-earth interface is of primary concern to repository performance. The infiltration component from surface water models needs to be coupled to unsaturated zone models of the site. While a general reference is made in Section 2.1.4 that external activities will be linked to the surface water and saturated zone studies, the manner in which this will be done is not explained. It is also not clear that output from site-scale models of the unsaturated zone will provide adequate input to support regional-scale modeling of the saturated zone.

This open item is a specific example of NRC's concern about technical integration, that was raised in the cover letter to the Site Characterization Analysis (NRC, 1989, p. xi).

Recommendations
Provide the logic for excluding Activity 8.3.1.5.2.2.2 from this study plan. Explain what advantage could accrue by analyzing physically interdependent flow regimes under separate study plans. Also, describe how site-scale models of the unsaturated zone (from Study 8.3.1.2.2.9) will adequately support the regional-scale modeling activity for the saturated zone under this study.

References

U.S. Department of Energy, "Site Characterization Plan, Yucca Mountain Site, Nevada Research and Development Area, Nevada," Office of Civilian Radioactive Waste Management, DOE/RW-0199, 9 vols. December 1988.

U.S. Department of Energy, "Study Plan for Study 8.3.1.2.2.9: Site Unsaturated-Zone Modeling and Synthesis," Office of Civilian Radioactive Waste Management, May 1993. [Prepared by U. S. Geological Survey.]

Nuclear Regulatory Commission, "NRC Staff Site Characterization Analysis of the Department of Energy's Site Characterization Plan, Yucca Mountain Site, Nevada," Office Of Nuclear Material Safety and Safeguards/Division of High-Level Waste Management, NUREG-1347, August 1989.

STUDY PLAN 8.3.1.5.2.2
CHARACTERIZATION OF FUTURE REGIONAL HYDROLOGY DUE TO CLIMATE CHANGE

Question 2
How will infiltration be simulated under the surface water modeling activity?

Basis
The identified models for predicting runoff were developed in climatic regions that are very different from the climate of the Yucca Mountain region. The models apparently do not consider the influence of macroporosity (such as fractures, soil structure, root holes, animal burrows) on the infiltration characteristics of the watershed. They were developed for agricultural lands where the macropores could be neglected because they were destroyed in the plowed soil horizon. The transfer of agricultural runoff models to field sites in natural soils in arid regions must be performed with caution, due to the different conditions present at the site. The presence of macropores can result in rapid drainage of surface water to great depths, beyond the zone of evapotranspiration. Evidence from the Apache Leap Tuff Site shows that eighty percent of the largest annual rainfall events, and higher percentages for smaller events, is diverted into fractures (Rasmussen and Evans, 1993). This significant flow into fractures will not be modeled or incorporated in the models as currently designed. Specific locations of macropores are difficult to predict and to quantify. This is especially true for open fractures that underlie channel beds. As stated on page 3.1-11 of the study plan, one of the three potential modeling problems is that "the models either do not account for or only partially account for stream losses due to channel bed infiltration..."

Recommendation
Describe how infiltration will be simulated in the surface water modeling work. Specifically address how infiltration through macropores (such as fracture zones) will be treated.

Reference
Rasmussen, T. C. and D.D. Evans, "Water Infiltration into Exposed Fractured Rock Surfaces," *Soil Sci. Soc. of Am. J.*, 57(2):324-329 [1993].

STUDY PLAN 8.3.1.5.2.2
CHARACTERIZATION OF FUTURE REGIONAL HYDROLOGY DUE TO CLIMATE CHANGE

Question 3
How will surface water models be calibrated and validated?

Basis
On page 2.2-1, it is stated that "The calculation methods for calibrating the precipitation-runoff model will use meteorology and streamflow data collected from drainages at, and peripheral to, the Yucca Mountain site. Thus, the modeling will be undertaken at full scale using data representative of the site." However, due to the limited number of storms and runoff events which can be sampled at the site, inadequate data may be available for the calibration and validation of surface water models. This is recognized in the study plan. On page 3.1-2, it is stated that "...the present streamflow gaging network (Activity 8.3.1.2.1.2.1) has been in place for too short a time to adequately establish long-range hydrologic modeling parameters." Extrapolation of limited rainfall-runoff data to changing future climatic conditions will contain high levels of uncertainty.

Section 3.1.5.1.3 of the study plan is intended to describe the kinds of data needed to calibrate a surface water model. These include: (1) slope, elevation, vegetation, and soil data to describe hydrologic response units; (2) roughness of overland flow planes; (3) physical parameters of channel beds; and (4) climatic data. The NRC staff point out that these are the kinds of data needed to design a surface water model. For calibration purposes, information is needed on the response of surface water flow to precipitation events of varying magnitudes. That kind of information is not described in Section 3.1.5.1.3.

Recommendation
Describe the approaches and assumptions that will be used to calibrate and validate surface water models in the vicinity of Yucca Mountain. This information should be incorporated in Section 3.1.5.1.3 of the study plan if a future revision of the plan is issued.

UNITED STATES
NUCLEAR REGULATORY COMMISSION
WASHINGTON, D.C. 20555-0001

AUG 22 1994

Mr. Ronald A. Milner, Acting Director
Office of Program Management and Integration
Office of Civilian Radioactive Waste Management
U.S. Department of Energy, RW 30
1000 Independence Avenue
Washington, D.C. 20585

Dear Mr. Milner:

SUBJECT: REVIEW OF THE U.S. DEPARTMENT OF ENERGY (DOE) STUDY PLAN ON "LABORATORY THERMAL EXPANSION TESTING, REVISION 1" (8.3.1.15.1.2)

On September 7, 1993, DOE transmitted the subject study plan to the Nuclear Regulatory Commission for review and comment. The NRC staff has completed its review of the subject study plan using the "Review Plan for the NRC Staff Review of DOE Study Plans, Revision 2" (dated March 10, 1993). Based on its review of the study plan, the staff considers the material submitted to be generally consistent, to the extent possible, at this time, with the revised NRC-DOE "Level of Detail Agreement and Review Process for Study Plans" (letter from Shelor to Holonich; dated March 22, 1993).

A major purpose of the review is to identify concerns with studies, tests, or analyses that, if started, could cause significant and irreparable adverse effects on the site, the site characterization program, or the eventual usability of the data for licensing. Such concerns would constitute "objections," as that term has been used in earlier NRC staff reviews of DOE documents related to site characterization (e.g., "Consultation Draft Site Characterization Plan" and the "Site Characterization Plan (SCP) for the Yucca Mountain Site"). It does not appear that the conduct of the activities described in this study plan will have adverse impacts on repository performance and the review of this study plan identified no objections with any of the activities proposed.

As part of its study plan review, the NRC staff also determines whether or not detailed comments or questions are warranted. The NRC staff's review of the subject study plan has resulted in the identification of four questions. The enclosed questions will be tracked by the NRC staff as open items similar to those previously raised by the NRC staff in its 1989 Site Characterization Analysis (SCA).

Additionally, in light of the review of this and other related study plans (e.g., "Excavation Investigations" (8.3.1.15.1.5)) and "Laboratory Thermal Properties" (8.3.1.15.1.1)), the staff is concerned about the continuing need for improved technical integration and coordination of similar information-gathering activities and procedures. The NRC staff identified this concern

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earlier, in its SCA, following the review of DOE's 1988 SCP. The NRC staff expects DOE to address this concern in future SCP Progress Reports.

Finally, the NRC staff wishes to note that in its letter transmitting this study plan, DOE indicated that SCA Comment 55 was addressed; however, DOE did not request closure of this open item. Based on its review of the information contained in the study plan (see Enclosure), the NRC staff considers SCA Comment 55 still open.

If you have any questions concerning this review, please contact Michael P. Lee at 301/415-6677.

Sincerely,

Joseph R. Holonich

Joseph J. Holonich, Chief
High-Level Waste and Uranium Recovery
Projects Branch
Division of Waste Management
Office of Nuclear Material Safety
and Safeguards

Enclosure: As stated

cc: R. Loux, State of Nevada
T.J. Hickey, Nevada Legislative Committee
J. Meder, Nevada Legislative Counsel Bureau
C. Schank, Churchill County, NV
D. Bechtel, Clark County, NV
J. Hoffman, Esmeralda County, NV
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D. Weigel, GAO
W. Barnard, NWTRB

STUDY PLAN 8.3.1.15.1.2
LABORATORY THERMAL EXPANSION TESTING, REVISION 2

Question 1
Will this Study Plan investigate the effects of anisotropy and natural fractures on the thermal expansion characteristics of the samples collected from the exploratory studies facility (ESF) Main Access, ESF Main Drifts, and additional sampling locations and the thermal/mechanical units other than Unit TSw2 of the Topopah Spring?

Basis
Scoping studies will be conducted to examine the effects of confining pressure, sample size, and the saturation level on thermal expansion behavior, and establish test baseline conditions.

For each new core hole, the presence of anisotropy, natural fractures, and their effects on the coefficient of thermal expansion will be examined for the Unit TSw2. However, the Study Plan does not address whether the anisotropy and natural fractures will be examined on the ESF Main Access samples (Section 2.2.2.2), ESF Main Drifts samples (Section 2.2.2.3), and additional location samples (Section 2.2.2.4). It is unclear whether the anisotropy and natural fractures will be examined on the thermal/mechanical units other than Unit TSw2.

Recommendation
It is recommended that DOE should include a discussion in the Study Plan on whether the anisotropy and natural fractures will be examined while testing samples from the ESF Main Access, additional locations, and the units other than Unit TSw2 in new core holes.

STUDY PLAN 8.3.1.15.1.2
LABORATORY THERMAL EXPANSION TESTING, REVISION 2

Question 2
Does the program described in Table 2.2-4 provide enough flexibility to accommodate the U.S. Department of Energy's (DOE's) high-thermal-loading option for the repository design?

Basis
DOE has not decided to use the hot- or cold-thermal-loading option on the repository design (NWTRB, 1992). The multi-purpose canisters (MPC) design concept suggests that DOE may choose the high-thermal-loading option. If DOE decides to choose a high thermal loading for the repository design, the maximum temperature on the surrounding rock may be higher than the current 300°C design level. Therefore, the proposed 300°C thermal range of laboratory experiments of the current Study Plan may need to be revised.

Recommendation
It is recommended that the DOE's alternatives on thermal-loading option be considered in the Study Plan.

References
Nuclear Waste Technical Review Board, *Fifth Report to the U.S. Congress and the U.S. Secretary of Energy*, U.S. Government Printing Office, June 1992.

STUDY PLAN 8.3.1.15.1.2
LABORATORY THERMAL EXPANSION TESTING, REVISION 2

Question 3
What is the rationale for applying the confining pressure normal to the fractures?

Basis
The Study Plan states that all tests on fractured samples will include a small stress ($\leq$ 7 MPa) normal to the fracture in order to simulate *in-situ* conditions. The fractures in the Yucca Mountain are nearly in the vertical direction. The overburden stress is nearly parallel to the fractures. DOE doesn't provide the rationale why the confining pressure is normal to the fractures. DOE doesn't explain why the overburden stress 7 MPa is a small stress. DOE doesn't explain why higher stresses are not considered.

Recommendation
It is recommended that DOE provide appropriate rationales for the magnitude and direction of the confining stresses considered.

STUDY PLAN 8.3.1.15.1.2
LABORATORY THERMAL EXPANSION TESTING, REVISION 2

Question 4
What is the rationale for heating up and cooling down the TSw2 Unit first, then using the same samples for examining the radiation effects on thermal expansion?

Basis
The Study Plan states that 20 TSw2 samples will be tested for thermal expansion. After thermal expansion test, ten TSw2 samples will be irradiated. Then, the ten irradiated and ten nonirradiated samples will be retested to examine the radiation effect on thermal expansion.

The thermal effects on the geochemical properties of fracture filling may be irreversible. After heating up the rock samples during thermal expansion measurement, the fracture filling such as clay may be dehydrated and more fractures may be induced during the heating and cooling process. Some uncertainty may be introduced after the first thermal cycle. It may not be meaningful to compare the thermal expansion results under first and subsequent thermal cycles because the initial conditions such as degree of saturation, number of fractures, and fracture filling for the later thermal cycles could change. Therefore, the radiation effects on thermal expansion may be very difficult to quantify.

Recommendation
DOE needs to address the uncertainty of multi-cycle thermal effects on the thermal expansion test. Some test methods may be used to eliminate the uncertainty for the thermal expansion tests. One method may be to vertically split a larger-diameter TSw2 rock samples into two sets of smaller diameter samples for examining the radiation effects on thermal expansion. It is also feasible to re-core a larger diameter sample into two sets of smaller diameter samples. One set of smaller-diameter samples could be subjected to gamma radiation while the other set could be the base case. The two sets of samples should be tested under the same test control conditions to examine the radiation effects on thermal expansion.

STUDY PLAN 8.3.1.15.1.2
LABORATORY THERMAL EXPANSION TESTING, REVISION 2

SCA Open Comment 55
The discussion and/or use of statistics in this chapter is not clear. A statistical approach has been suggested to determine numbers of tests required to determine various rock properties, but the approach suggested is confusing and apparently overlooks several considerations that should be factored into such an approach. Also, needed confidences of "low,""medium," or "high" have been assigned without explaining the basis for such assignment (see NRC, 1989).

DOE's Response
- In response to SCA Comment 55 on Section 8.3.1.15.1 of the 1988 Site Characterization Plan, DOE explained the rationale and basic assumptions of statistical analysis to determine the numbers of tests.

- The Study Plan makes the following assumptions:

  a. The thermal expansion properties are evenly distributed throughout the mass of each thermal/mechanical unit. This assumption will not apply to the entire rock mass.

  b. The measured values are not a function of testing sample size or direction. If scoping studies find that testing sample size or direction will have a significant effect on the thermal expansion behavior, the sampling and test program will be modified.

  c. The populations are normally distributed. The existing thermal expansion data show the populations are normally distributed.

  d. The sampling is not biased due to jointing, hole direction, etc. Each thermal/mechanical unit will be divided into *n* potential sampling intervals, where *n* is the number of samples specified in Table 2.2-2 of the Study Plan. If sampling locations are close to the center of each interval, the bias of sampling can be avoided. Adjustments of sampling program may be necessary.

  e. The determination of the necessary number of samples is based on a Gaussian tolerance level. Two-sided statistical tolerance limits are used in these estimates.

- The Study Plan also states that "data requirements and associated qualitative confidence levels were based on the expert judgement of repository personnel with little or no support in the form of sensitivity analysis. If additional analyses indicate a change in sensitivity to thermal expansion behavior from that assumed in the SCP, the numbers of samples required for experiments will be adjusted appropriately."

Evaluation of DOE Response

- In response to SCA Comment 55, DOE doesn't explain how the *n* sampling intervals would be divided in a thermal/mechanical unit. It is unclear whether *n* sampling intervals will have equal thickness or not. If *n* equal intervals were selected in a nonuniform thermal/mechanical unit, an artificial bias may be introduced. There is no guarantee that the statistical bias will be eliminated even if the sampling location is close to the center of each interval. In the field, jointing may not be uniformly distributed in a thermal/mechanical unit. Therefore, best representative rock samples picked in a thermal/mechanical unit may not necessarily be in the central part of each interval. On the other hand, if unequal intervals will be selected, what are the criteria for selection of intervals? DOE should pay more attention on the samples which have fractures and joints and take into account their directions.

- NRC staff agrees that the sampling program needs to be modified, if core samples show that the statistical assumptions are invalid. Staff suggests that DOE explain how the *n* intervals are divided. Staff believes that SCA Comment 55 will not be resolved until the statistical assumptions are verified. Therefore, the NRC staff considers this comment open.

References

Nuclear Regulatory Commission, "NRC Staff Site Characterization Analysis of the Department of Energy's Site Characterization Plan, Yucca Mountain Site, Nevada," Office Of Nuclear Material Safety and Safeguards/Division of High-Level Waste Management, NUREG-1347, August 1989.

NRC QUESTION 1:

Will this Study Plan investigate the effects of anistropy and natural fractures on the thermal expansion characteristics of the samples collected from the Exploratory Studies Facility (ESF) Main Access, ESF Main Drifts, and additional sampling locations and the thermal/mechanical units other than Unit TSw2 of the Tonopah Spring?

DOE RESPONSE:

Currently, no data needs have been identified that would require the investigation of anistropy and natural fractures on units other than TSw2.

NRC QUESTION 2:

Does the program described in Table 2.2-4 provide enough flexibility to accommodate the U.S. Department of Energy's (DOE's) high-thermal-loading option for the repository design?

DOE RESPONSE:

There are some combinations of proposed waste streams and thermal loadings which will produce maximum drift wall temperatures higher than 300oC. The program is looking at a range of possible thermal loads. However, there is also a thermal goal to keep drift wall temperatures below 200oC (Site Characterization Plan Thermal Goals Reevaluation, B00000000-1717-5705-00005, Rev. 00, Civilian Waste Management System Management and Operating Contractor, September 8, 1993, Table 3, p. 22) (letter, Shelor to Holonich, dated 4/15/94). Until this thermal goal is changed, the test program is flexible. If this thermal goal is changed, the study will be modified to reflect this change.

NRC QUESTION 3:

What is the rationale for applying the confining pressure normal to the fractures?

DOE RESPONSE:

Under thermal loading, the maximum principal compressive stress rotates from vertical to horizontal. Seven MPa is of the order of the predicted maximum principal compressive stress at the bottom of the North Ramp. Higher stresses are not considered because they are not expected to have any additional effect.

NRC QUESTION 4:

What is the rationale for heating up and cooling down the TSw2 Unit first, then using the same samples for examine the radiation effects on thermal expansion?

DOE RESPONSE:

Experiments conducted to date do indicate significant differences between the first and subsequent thermal cycles. Differences in thermal expansion have also been found in samples that were located near each other. The best manner to examine the effect of radiation, without introducing additional uncertainties, can be determined after additional testing has been completed.

DOE RESPONSES TO NRC QUESTIONS ON

STUDY PLAN 8.3.1.15.1.5 (EXCAVATION INVESTIGATIONS, REVISION 1)

ENCLOSURE 6

UNITED STATES
NUCLEAR REGULATORY COMMISSION
WASHINGTON, D.C. 20555-0001

AUG 19 1994

Mr. Ronald A. Milner, Acting Director
Office of Program Management and Integration
Office of Civilian Radioactive Waste Management
U.S. Department of Energy, RW 30
1000 Independence Avenue
Washington, D.C. 20585

Dear Mr. Milner:

SUBJECT: REVIEW OF THE U.S. DEPARTMENT OF ENERGY (DOE) STUDY PLAN ON "EXCAVATION INVESTIGATIONS, REVISION 1" (8.3.1.15.1.5)

On May 4, 1994, DOE transmitted the subject study plan to the Nuclear Regulatory Commission for accelerated review and comment. The NRC staff has completed its review of the subject study plan using the "Review Plan for the NRC Staff Review of DOE Study Plans, Revision 2" (dated March 10, 1993). Based on its review of the study plan, the staff considers the material submitted to be generally consistent, to the extent possible, at this time, with the revised NRC-DOE "Level of Detail Agreement and Review Process for Study Plans" (letter from Shelor to Holonich; dated March 22, 1993).

A major purpose of the review is to identify concerns with studies, tests, or analyses that, if started, could cause significant and irreparable adverse effects on the site, the site characterization program, or the eventual usability of the data for licensing. Such concerns would constitute "objections," as that term has been used in earlier NRC staff reviews of DOE documents related to site characterization (e.g., "Consultation Draft Site Characterization Plan" and the "Site Characterization Plan (SCP) for the Yucca Mountain Site"). It does not appear that the conduct of the activities described in this study plan will have adverse impacts on repository performance and the review of this study plan identified no objections with any of the activities proposed.

As part of its study plan review, the NRC staff also determines whether or not detailed comments or questions are warranted. The NRC staff's review of the subject study plan has resulted in the identification of one question. The enclosed question will be tracked by the NRC staff as open items similar to those previously raised by the NRC staff in its 1989 Site Characterization Analysis (SCA).

Additionally, in light of the review of this and other related study plans (e.g., "Laboratory Thermal Expansion Testing" (8.3.1.15.1.2) and "Laboratory Thermal Properties" (8.3.1.15.1.1)), the staff is concerned about the continuing need for improved technical integration and coordination of similar information-gathering activities and procedures. The NRC staff identified this concern earlier, in its SCA, following the review of DOE's 1988

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SCP. The NRC staff expects DOE to address this concern in future SCP Progress Reports.

If you have any questions concerning this review, please contact Michael P. Lee at 301/415-6677.

Sincerely,

Robert Lane Johnson

for Joseph J. Holonich, Chief
High-Level Waste and Uranium Recovery Projects Branch
Division of Waste Management
Office of Nuclear Material Safety and Safeguards

Enclosure: As stated

cc: R. Loux, State of Nevada
T.J. Hickey, Nevada Legislative Committee
J. Meder, Nevada Legislative Counsel Bureau
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D. Bechtel, Clark County, NV
J. Hoffman, Esmeralda County, NV
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AUG 1 9 1994

STUDY PLAN 8.3.1.15.1.5
EXCAVATION INVESTIGATIONS, REVISION 1

Question
Since neither additional data nor analytical methods are cited which would provide the means to extrapolate the data to be collected in this study, to the time periods of interest, it is not clear that the study plan will acquire all the data needed for the stated purpose. Hence, the data collected in this study plan might be insufficient to validate the geomechanical constitutive model given the small time and spatial scales for testing and the larger time and spatial scales involved in the application of the model and given that, other data and analytical methods are not cited. Thus, how will these limited data accomplished the goal of validation?

Basis
The study plan indicates that the data to be gathered will be used to validate the constitutive models describing the mechanical behavior of rock.

The scope of this study plan is discussed in Section 8.3.1.15.1.5 of the SCP (pp. 8.3.1.15-45 to 8.3.1.15-52). The SCP states that "... data will contribute to validation of computer codes to be used to calculate mechanical responses, as well as contributing to empirical evaluations related to nonradiological health and safety ..." (p. 8.3.1.15-50). Although other study plans are cited, additional data do not appear to provide the support for extrapolating results over long time periods. This study plan does not cite Section 8.3.5.20 of the SCP, which addresses validation of models and on which the NRC staff commented extensively.

The study plan is clear that it relates to both the pre- and post-closure requirements for repository performance. In particular, this study plan is intended to gather information needed to show compliance with the requirements of 10 CFR 60.111, 60.112, 60.122, and 60.133 (Section 1.2.2). Some of the concerns addressed are safety of the mined facility during operation, maintenance of the retrieval option for the required period, and determination of the extent of excavation-induced damage to rocks around emplacement drifts (Section 1.2.1).

The data to be gathered will account for rock behavior for the limited duration of the proposed experiments; such times are "a few weeks to several months" (Section 2.3.3), or in selected cases a few years.

Application of the models will be for the time period, at least, up to permanent closure. Extrapolation to longer times may be necessary to demonstrate compliance with 10 CFR 60.112. The means of extrapolating data for these longer times is not addressed in justifying the data collection in this study plan.

Validation of the constitutive models for rock properties will require extrapolation, in time, of the data gathered in these tests; direct application of the data derived from the proposed tests will be unable, alone, to validate the models for the time period of interest.

Other issues relating this study plan to validation of models, and bearing on the sufficiency of the data collected, are not discussed or cited. These include: (1) How will data be partitioned, so that some data are used to determine constants in the constitutive models, while other data are used to confirm predictions with those models?; (2) How will data obtained over limited time and space scales be extrapolated to larger scales, considering that many properties of geologic media are scale dependent?; and (3) What role will peer review play in the validation process and is this an appropriate role (Section 3.3.7)?

Recommendation

DOE should explain how these limited data will accomplish the goal of validation. Alternative responses include: (1) acquisition of data, described in other study plans, for longer time periods; (2) analysis methods, described in other study plans, for using limited-scale data to validate models; or (3) expansion of the data collected in this study plan.

NRC QUESTION 1:

Since neither additional data nor analytical methods are cited which would provide the means to extrapolate the data collected in this study, to the time periods of interest, it is not clear that the study plan will acquire all the data needed for the stated purpose. Hence, the data collected in this study plan might be insufficient to validate the geochemical constitutive model given the small time and spatial scales for testing and the larger time and spatial scales involved in the application of the model and given that, other data and analytical methods are not cited. Thus, how will these limited data accomplish the goal of validation?

DOE RESPONSE:

The models to be evaluated under the Excavation Investigations study are not time-dependent. The models only simulate the immediate short-term rock-mass response. Therefore, the time frames for these tests are sufficient.

Data gathered under other study plans will supplement the data collected here. Data being taken under the In Situ Design Verification study (8.3.1.15.1.8) includes the long-term (time-dependent) response of the rock mass and is being collected as soon as possible after excavation. Current plans are to measure this response throughout the site characterization program and beyond.

Since the purpose of Study 8.3.1.15.1.5 is to validate only time-independent models, the experiments will end after this response has been measured. It is reasonable to expect, however, that once in place, the instruments will continue to be read as long as they operate.

Analysis methods and techniques are being developed. Such issues as how data will be partitioned, and the role peer review will play, have not been fully resolved. Current thoughts on model validation can be found in the paper, "An Approach to Validation of Thermomechanical Models" (L.S. Costin, et al., Focus "93: Site Characterization and Model Validation, Las Vegas, Nevada, September 26-29, 1993).

NNA.930903.0060

An Approach to Validation of Thermomechanical Models

L. S. Costin*, M. P. Hardy**, and C. E. Brechtel**
*Sandia National Laboratories
**J.F.T. Agapito & Associates, Inc.

Abstract

Thermomechanical models are being developed to support the design of an Exploratory Studies Facility (ESF) and a potential high-level nuclear waste repository at Yucca Mountain, Nevada. These models are used for preclosure design of underground openings, such as access drifts, emplacement drifts, and waste emplacement boreholes; and in support of postclosure issue resolution relating to waste canister performance, disturbance of the hydrological properties of the host rock, and overall system performance assessment. For both design and performance assessment, the purpose of using models in analyses is to better understand and quantify some phenomenon or process. Therefore, validation is an important process that must be pursued in conjunction with the development and application of models. The Site Characterization Plan (SCP) addressed some general aspects of model validation, but no specific approach has, as yet, been developed for either design or performance assessment models. This paper will discuss a proposed process for thermomechanical model validation and will focus on the use of laboratory and in situ experiments as part of the validation process. The process may be generic enough in nature that it could be applied to the validation of other types of models, for example, models of unsaturated hydrologic flow.

Because of the limitations and uncertainties in characterizing rock properties, geology, hydrology, and other factors that affect the behavior of the rock mass, the approach to validation must be somewhat different than the classical approach developed for "engineered" materials and structures. Even under the best circumstances, repository design and performance analyses will be conducted in a very "data-limited" environment[1].

That is, there will never be enough known about the rock mass that it can be modeled unambiguously. This is a common situation in engineering practice in general and in practical rock mechanics problems. Thus, using thermomechanical models to make absolute predictions, which are then compared to test results (a more classical form of validation), is unlikely to produce meaningful results and could lead to disqualification of useful analytical tools. Instead, validation is to be considered a process of developing sufficient confidence in the models that they can be used to explore and evaluate potential trade-offs and alternatives. Figure 1 shows the generalized validation process for thermomechanical models. Validation must be targeted at demonstrating that the key phenomena, processes and properties are incorporated in the simulation and that the accuracy of the results are sufficient to meet the design or performance assessment needs. It may take considerable modeling and characterization effort to determine what key elements must be part of the validation process.

The validation process itself is viewed as having three main components: peer review, evaluation relative to empirical evidence and case histories (including natural analogues), and evaluation relative to experimental data obtained from in situ and laboratory tests. Depending on the particular model, one or more of these components may be applied. For most thermomechanical models, the focus will be on comparisons with the results of specific laboratory and in situ experiments. Validation of a model, however, cannot rely completely on what can be obtained from one or more experiments. The model has to have been judged adequate by past experience in design or scientific studies in related or similar circumstances or, to add credibility to its adequacy, used to back-analyze well-documented case studies.

Because of the data-limited environment, a large part of the validation process involves the application of judgment to determine the adequacy of the model, and the limitations and uncertainties associated with its use. These judgments must be tempered by the context in which the models are applied. In addition, the validation process must be adaptive and evolutionary with the process resulting in improvements in the model to enhance confidence in the model. Model validation may never be strictly complete, but if a decision is made to proceed to license application, sufficient evidence must be available to support a claim that the models are valid for the specific applications used to support the license application.

For thermomechanical models, a major emphasis in the model validation process will be in the evaluation of models relative to results from laboratory and in situ experiments. Figure 2 provides a detailed description of the process. Model validation was used in the SCP as partial justification for a number of thermomechanical in situ and laboratory tests. However, at the time the SCP was published, there was only a limited understanding of the key processes affecting thermomechanical behavior of the rock mass. Therefore, little indication was provided of what the needs for model validation might be. Now in the development of study plans and experimental procedures, the model validation needs for each in situ test must be integrated with other objectives of these tests. In situ thermomechanical tests are designed to provide in situ rock mass properties, to provide demonstrations of adequate performance of repository system components (such as drift stability and ground support) under expected thermal loads, and to provide data for model validation. In some cases these objectives may be conflicting, thereby requiring some compromise in the test objectives or expansion of the suite of thermomechanical tests to accommodate all objectives.

By way of illustration, the paper will describe several thermomechanical models in use for repository design, the status of model validation of those models, and the in situ thermomechanical tests planned in the ESF to support model validation. The suite of

DOE RESPONSES TO NRC QUESTIONS AND COMMENT ON STUDY PLAN 8.3.1.8.5.2 (CHARACTERIZATION OF IGNEOUS INTRUSIVE FEATURES, REVISION 1)

ENCLOSURE 7

UNITED STATES
NUCLEAR REGULATORY COMMISSION
WASHINGTON, D.C. 20555-0001

AUG 22 1994

Mr. Ronald A. Milner, Acting Director
Office of Program Management and Integration
Office of Civilian Radioactive Waste Management
U.S. Department of Energy, RW 30
1000 Independence Avenue
Washington, D.C. 20585

Dear Mr. Milner:

SUBJECT: REVIEW OF THE U.S. DEPARTMENT OF ENERGY (DOE) STUDY PLAN ON "CHARACTERIZATION OF IGNEOUS INTRUSIVE FEATURES, REVISION 1" (8.3.1.8.5.2)

On March 17, 1994, DOE transmitted the subject study plan to the Nuclear Regulatory Commission for review and comment. The NRC staff has completed its review of the subject study plan using the "Review Plan for the NRC Staff Review of DOE Study Plans, Revision 2" (dated March 10, 1993). Based on its review of the study plan, the staff considers the material submitted to be generally consistent, to the extent possible, at this time, with the revised NRC-DOE "Level of Detail Agreement and Review Process for Study Plans" (letter from Shelor to Holonich; dated March 22, 1993).

A major purpose of the review is to identify concerns with studies, tests, or analyses that, if started, could cause significant and irreparable adverse effects on the site, the site characterization program, or the eventual usability of the data for licensing. Such concerns would constitute "objections," as that term has been used in earlier NRC staff reviews of DOE documents related to site characterization (e.g., "Consultation Draft Site Characterization Plan" and the "Site Characterization Plan (SCP) for the Yucca Mountain Site"). It does not appear that the conduct of the activities described in this study plan will have adverse impacts on repository performance and the review of this study plan identified no objections with any of the activities proposed.

As part of its study plan review, the NRC staff also determines whether or not detailed comments or questions are warranted. The NRC staff's review of the subject study plan has resulted in the identification of three questions (see Enclosure). They will be tracked by the NRC staff as open items similar to those previously raised by the NRC staff in its 1989 Site Characterization Analysis (SCA).

Additionally, the NRC staff wishes to note that in its letter transmitting this study plan, DOE indicated that SCA Comment 52 was partially addressed. Based on its review of the information contained in the study plan (also enclosed), the NRC staff considers SCA Comment 52 still open.

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Finally, the staff notes that while this Study Plan indicates that Activities 8.3.1.8.5.2.1 and 8.3.1.8.5.2.2 (e.g., "Characterization of Igneous Intrusive Features: 'Evaluation of depth of curie temperature isotherm' and 'Chemical and Physical changes around dikes'," respectively) have been suspended, this is not in agreement with the information presented in DOE Progress Report 9 (dated February 1994). As the study plan appears to be more current than the information in the Progress Report, the staff would expect that future Progress Reports be updated to reflect the information in the study plan.

If you have any questions concerning this review, please contact Michael P. Lee at 301/415-6677.

Sincerely,

Joseph J. Holonich

Joseph J. Holonich, Chief
High-Level Waste and Uranium Recovery
Projects Branch
Division of Waste Management
Office of Nuclear Material Safety
and Safeguards

Enclosure: As stated

cc: R. Loux, State of Nevada
T.J. Hickey, Nevada Legislative Committee
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F. Sperry, White Pine County, NV
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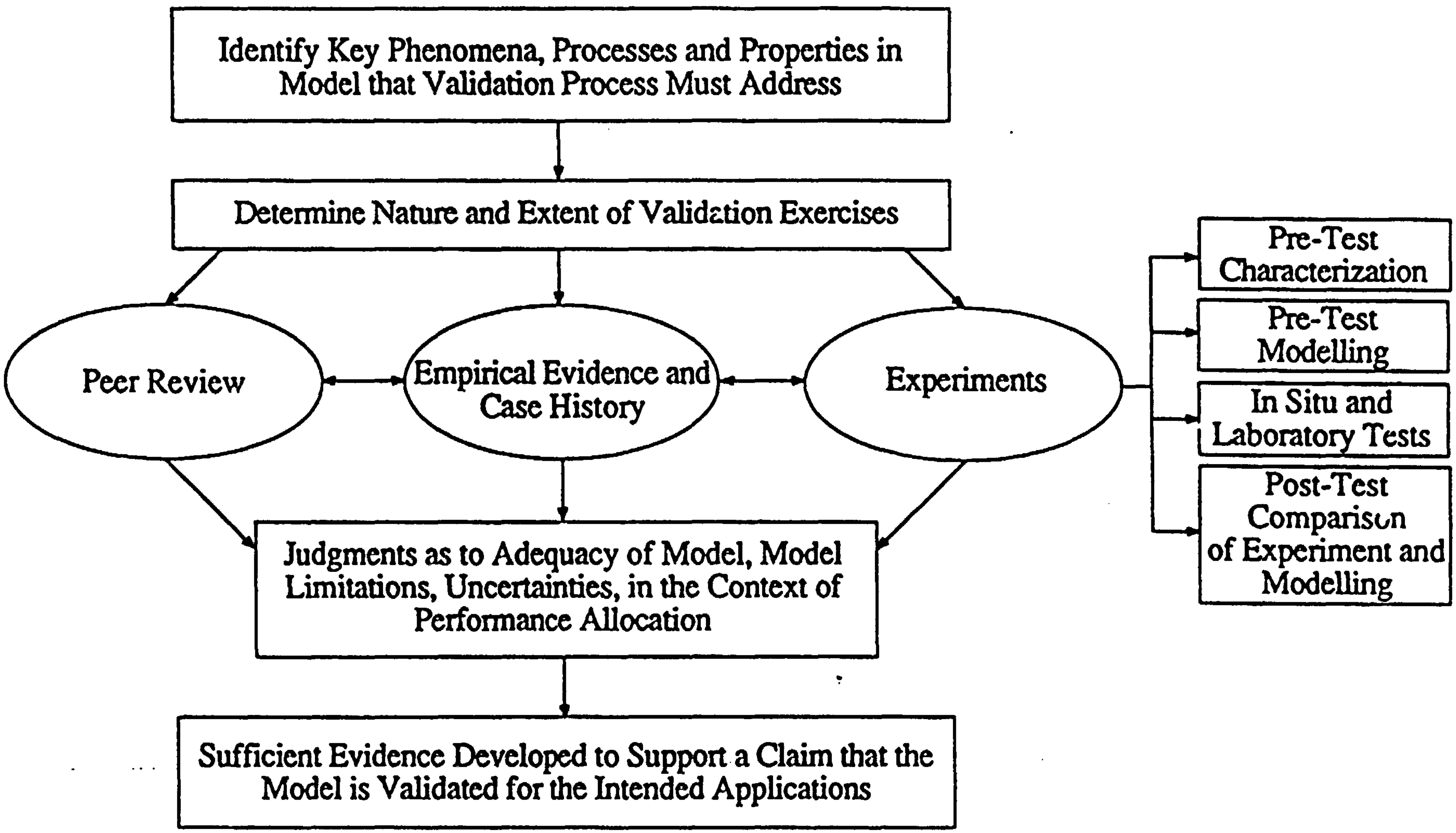

Figure 1. Generalized Validation Process.

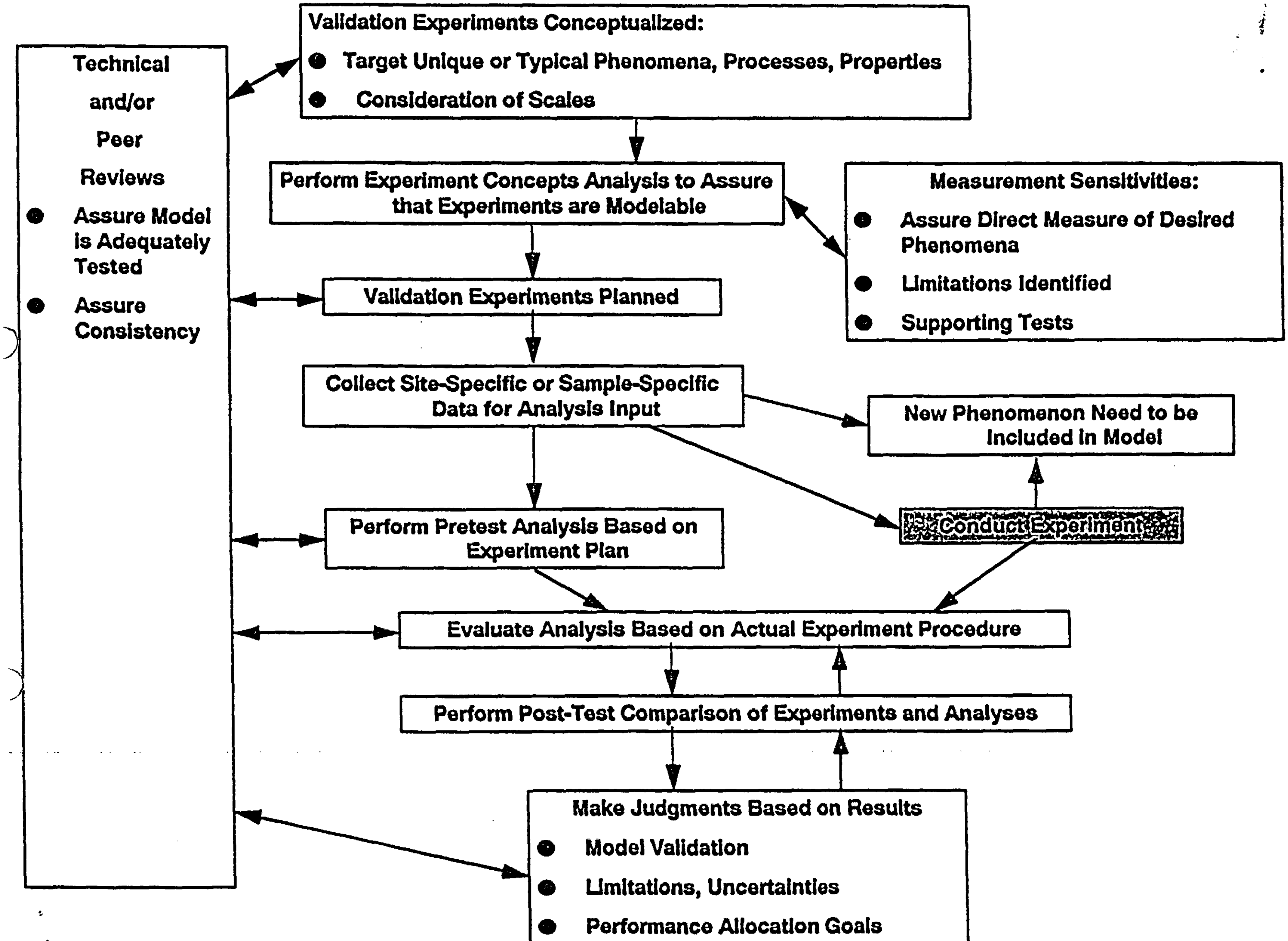

Figure 2. Depiction of a Validation Exercise with Experiments.

thermomechanical tests is consistent with those outlined in the SCP, but differs in detail to accommodate the multiple objectives of each test and changes in repository construction methods. Finally, some thoughts on how to make meaningful comparisons of model and test results will be presented.

<u>References</u>

1. Starfield, A. M. and P. A. Cundall, Int. J. Rock Mech. Min. Sci. & Geomech. Abstr., Vol. 25, No. 3, pp. 99-106, 1988.