REVIEW OF:

THE STUDY PLAN FOR SITE UNSATURATED-ZONE MODELING AND SYNTHESIS (8.3.1.2.2.9)

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1 INTRODUCTION

Assessments of the ability of the proposed high-level waste repository at Yucca Mountain, Nevada to safely contain spent fuel for a 10,000 year period will, in part, be based on predictions of the flow of water and gas and the transport of radionuclides made using numerical models. Inasmuch as the proposed Yucca Mountain repository is planned to be located within the 700 meter thick unsaturated-zone to take advantage of the presumably favorable geochemical conditions, potential transport pathways of either gaseous or aqueous phase radionuclides from the repository to the accessible environment must transit some portion of the unsaturated-zone. To ensure that numerical models are capable of accurately describing the specific complex physico-chemical processes within the unsaturated-zone at Yucca Mountain, development of models must be done in concert with site characterization.

2 REVIEW BACKGROUND

A Preliminary Acceptance of the Study Plan for Site Unsaturated-Zone Modeling and Synthesis was completed (Memorandum M. Federline to J. Holnich, September 13, 1993).

The study plan has retained the identical structure described for 8.3.1.2.2.9 in the Site Characterization Plan (SCP; DOE, 1988). In addition, much of the original wording used to describe the objectives of each activity in SCP has been retained in the study plan.

In terms of open items, the Site Characterization Analysis (SCA; NRC, 1989) contained one comment (#18) which is related to 8.3.1.2.2.9.

3 REVIEW CRITERIA

The detailed review of this Study Plan is based on the Review Plan for NRC Staff Review of DOE Study Plans, Revision 2 (NRC, 1993). Specifically, the detailed review considers:

- whether the objectives of the study plan are consistent with the investigation presented in the SCP and are technically defensible in the context of the overall site characterization program;
- whether the activities, tests, and analyses proposed in the study plan are able to provide the data necessary for licensing;
- progress towards resolution of open items.

4 DISCUSSION

The stated purpose for which the models developed in this study plan "...will be used [is] to estimate the quantity and spatial distribution of moisture that can potentially reach the engineered barrier system, test hypotheses concerning the hydrologic behavior of the site, and through calibration against measured state variables, produce estimates of hydrologic parameters that may be useful for design and performance assessment calculations." The specific model(s) that will be constructed is a "...three-dimensional, site-scale model of Yucca Mountain that will consider transport of gases, heat, and environmental tracers..." The study plan does clearly indicate that the purpose is not simply to construct a model of the site, but rather, to construct a model which may be used to address specific issues affecting the performance of the repository.

It is stated in the study plan that "[i]nformation derived from the study will principally support the performance determinations of pre-waste-emplacement, ground-water travel time...and the predictions of radionuclide releases to the accessible environment." In addition the results from this study will be indirectly used to address waste-package design, releases from the engineered barrier system, and repository design.

The study plan is divided into five activities.

- Develop conceptual models for the overall moisture-flow system within the unsaturated-zone at Yucca Mountain
- Select, evaluate, and adapt existing numerical hydrologic modeling codes, or develop new codes, as needed, to simulate particular aspects of the Yucca Mountain system
- Construct appropriate hydrologic models for the natural site hydrogeologic system to simulate and investigate the existing state of the system and predict probable future and past states of the system
- Assess the probable limits of uncertainty of numerical model predictions due to uncertainties in the material-property and boundary condition data
- Integrate all applicable site data and analyses in order to synthesize a continually updated, comprehensive representation for the site unsaturated-zone hydrogeologic system

The structure of this study plan is designed to permit conceptual model development, numerical implementation, and model testing to be conducted in an iterative manner so that recently obtained site characterization data may be readily incorporated into the modeling process. There are no activities in the study plan which explicitly call for those constructing flow models to conduct experiments at the site to gather data needed for model refinement or model calibration. Moreover, there is no explicit provision made in the study plan for those constructing the models to suggest to those conducting site characterization work the type of data which should be gathered in order to reduce conceptual model uncertainties. Although it is stated under the objectives section of the study plan that "...this model will be used to guide in (sic) the site-characterization effort," there is no specific task that ensures that feedback from this study will be used to affect the experiments in surface or subsurface based unsaturated-zone testing programs.

Because there are no in-situ experiments that will be conducted within the scope of this study plan, none of the activities will have a negative impact on the repository block. If, indeed, the models which are constructed are used to guide site characterization, then this study plan may indirectly impact the repository block.

5 SUMMARY

The methods described in this study plan are generally appropriate for the development and testing of site-scale conceptual and numerical models of flow and transport in unsaturated, fractured rock. Issues in the study plan that specifically address model validation methods and the application of these models to determine the ground water travel time from the disturbed zone to the accessible environment will be re-visited once these open items are resolved. This study plan was found to be consistent with the SCP.

6 REFERENCES

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Study Plan 8.3.1.2.2.9 Site Unsaturated-Zone Modeling and Synthesis

Comment 1

The list of hydrologic issues to be resolved by this study plan appears to neglect several issues which are important to repository performance, and should presumably be incorporated into site-scale unsaturated flow and transport models.

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:

- The role of faults in the hydrologic system.
- The role of the Paintbrush tuff non-welded unit on the hydrologic system.
- Investigation of the expected relative contributions of liquid-water and water-vapor fluxes to the net moisture flow within the unsaturated-zone system.
- 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.
- The potential for downward flow to bypass the zeolitic facies of the Calico Hills unit.

The first, third, fourth, and fifth issues deal with specific site-scale features which have the potential to either favorably or adversely impact the fate and transport of radionuclides from the repository to the accessible environment. Although the first issue addresses the general role of faults in the hydrologic system, the potential role of the Solitario Canyon fault in acting as a short-circuit for water to infiltrate laterally into the repository horizon may need to be specifically addressed. None of the identified issues explicitly requires an assessment of the role of highly conductive fracture networks extending from the surface, through the non-welded units, into the repository horizon and down to the water table, on the rate and spatial distribution of recharge.

Recommendation

The possibility that the Solitario Canyon fault will act as a short-circuit for water to infiltrate laterally into the repository block may need to be included in issue 1. If not addressed elsewhere, a sixth hydrologic issue may need to be developed to address the role of highly conductive fracture networks in allowing the rapid transmission of water from the surface, through the repository block and down to the water table.

Study Plan 8.3.1.2.2.9 Site Unsaturated-Zone Modeling and Synthesis

Question 1

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. However, it is also common for wetting front instabilities to form wherever a fine-grained unit overlies a coarse-grained unit (Hillel, 1980). These wetting front instabilities often produce vertically extensive wetted channels or "fingers" along which flux rates may be quite rapid. Will the numerical models developed in this study plan be able to account for the generation of wetting-front instabilities?

Basis

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 matric 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 m^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."

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. Standard numerical models may be unable to predict the likelihood that wetting front instabilities will develop at the transition from a bedded tuff unit to a densely welded, highly fractured unit unless the model explicitly incorporates lateral variations in air entry pressures along the interface of the units.

Recommendation

The numerical models described in the study plan may be unable to explicitly account for the effect of wetting front instabilities, which may result in fast pathways through the repository. An examination of the importance of fingering should be included in the study plan. If it is determined that wetting front instabilities may occur in the Yucca Mountain hydrologic regime, it is recommended that modelling approaches be developed to incorporate this effect.

Study Plan 8.3.1.2.2.9 Site Unsaturated-Zone Modeling and Synthesis

Question 2

How will local potential gradients in the liquid or vapor phase 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, if fractures play a significant role in transporting water throughout the mountain, *in situ* water potentials within the fractures must also be measured.

Recommendation

Give a thorough description of the methods that will be used to measure the liquid and vapor phase water potential in fractures.

Study Plan 8.3.1.2.2.9 Site Unsaturated-Zone Modeling and Synthesis

Question 3

How will "large time factors" preclude the inclusion of experimentally induced perturbations in the calibration process? Will experimentally induced perturbations be used in the calibration process for smaller scale sub-models?

Basis

On page 2.1-6, in the incomplete paragraph at the top of the page, 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." While it is probably true that the surface and subsurface tests that will be conducted at the site will not last long enough to induce changes to the entire flow regime, the local response of the system to these tests should still be used to calibrate smaller scale sub-models.

Recommendation

Discuss whether or not calibrating small scale sub-models to experimentally induced perturbations may provide valuable information for the site-scale model.

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Question 4

How will uncertainty analysis be used to assess the accuracy of a model?

Basis

On page 2.2-1, in the first paragraph, it is stated that "...the model yields an approximate representation of the physical system of which the accuracy of the approximation can be assessed through uncertainty analysis." Uncertainty analyses may provide the modeler with an estimate of the uncertainty of model predictions based on estimates of the nature of uncertainty in the model's parameters, boundary conditions, and forcing functions. However, the accuracy of the model can only be assessed by directly comparing its predictions to measurements of the state of the physical system being modeled.

Recommendation

Outline those characteristics of the model that will be tested using uncertainty analysis and explain how uncertainty analysis will be used to demonstrate the accuracy of the model.

Study Plan 8.3.1.2.2.9 Site Unsaturated-Zone Modeling and Synthesis

Question 5

How will those aspects of the hydrologic system which have little effect on the site-scale flow regime be determined?

Basis

On page 2.2-2, in the last paragraph, it is stated that "...characteristics which have a negligible effect on the system will be omitted." The determination of which characteristics to omit in order to simplify the system depends entirely upon the conceptual model which has been developed for the system. Moreover, the determination of which mechanisms are unimportant may also depend on what type of decision will be made from the predictions of the model.

Recommendation

Describe the qualitative and quantitative (e.g. sensitivity analyses) methods which will be used to determine those characteristics of the flow system that may be omitted from the numerical models.

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Question 6

Are models being developed that will be able to model the non-Darcian flow regime that may occur at seepage faces formed in wide, rubble-filled fault zones?

Basis

The dynamics of flow on a seepage face will be determined strongly by water viscosity and gravity. 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. Modeling such a coupling should be feasible for persistent large scale features. The capacity of spatially persistent features to control vertical movement of water is of importance to realistically assess the role of the thick unsaturated-zone on the performance of the proposed waste disposal system.

Recommendation

Describe the methods that will be used to model the flow of liquid water in fault zones which are either sufficiently wide or filled with rubble that is coarse enough to permit seepage faces to form.

Study Plan 8.3.1.2.2.9 Site Unsaturated-Zone Modeling and Synthesis

Question 7

Will new site characterization data be used both to confirm model predictions and refine existing conceptual and mathematical models? If so, will a formal procedure be developed to ensure that data used to calibrate existing models is not also used to validate these models?

Basis

Numerous references are made throughout the study plan to the need to assess the accuracy of the models. Conceptual and numerical models will need to be calibrated and updated as new site characterization data become available. However, data that are used to calibrate these models must not also be used in validation exercises to demonstrate model accuracy. Hydraulic head data obtained from single hole or cross-hole pumping tests may be used to calibrate a numerical model of the saturated flow regime. However, any predictions made with the calibrated model are not independent of the pump test data and thus direct comparison of model predictions to this same pump test data cannot be used to build confidence in the model.

Recommendation

Describe what procedure will be used to ensure that the same data are not used for model calibration and model validation exercises.