REVIEW OF:

DOE STUDY PLAN 8.3.1.2.2.8, FLUID FLOW IN UNSATURATED, FRACTURED ROCK

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1 INTRODUCTION

This study plan describes the following site-characterization research activities: (i) Development of conceptual and numerical models of fluid flow in unsaturated, fractured rock; and (ii) Validation of conceptual and numerical models of fluid flow through unsaturated, fractured rock.

The study plan describes the research plans for two site-characterization activities with specific objectives "to develop, refine, and validate conceptual and numerical models describing gas flow as well as liquid water and solute movement in unsaturated, fractured rock." This study plan aspires to produce models that will help design and/or understand the results of hydrologic tests, and to provide information regarding the modeling parameters to be used in the modeling activities discussed under Study 8.3.1.2.2.9 (Site unsaturated-zone modeling and synthesis).

2 REVIEW BACKGROUND

A Preliminary Acceptance of the Study Plan for Fluid Flow in Unsaturated, Fractured Rock was completed (Memorandum M. Federline to J. Holonich, November 13, 1992).

The study plan has retained the structure described for Section 8.3.1.2.2.8 in the Site Characterization Plan (SCP; U.S. Department of Energy, 1988). In addition, much of the original wording used to describe the objectives of each activity in the SCP has been retained in this study plan.

In terms of open items, the Site Characterization Analysis (SCA; U.S. Nuclear Regulatory Commission, 1989) contained no comments pertaining to study plan 8.3.1.2.2.8.

3 REVIEW CRITERIA

The review of this study plan is based on the "Review Plan for NRC Staff Review of DOE Study Plans, Revision 2" (U.S. Nuclear Regulatory Commission, 1993). The portion of the review conducted at the Center for Nuclear Waste Regulatory Analyses (CNWRA) is concerned with the ability of the activities, tests and analyses proposed in the study plan to provide the data for licensing that the study plan should, and was designed to, provide.

Specifically, this review considers: (i) whether progress towards resolution of open items has been made; (ii) whether the activities and tests proposed in this study plan are able to provide the data required in the licensing process; (iii) whether the proposed SCP activities are consistent with the objectives of this study plan; and (iv) whether the activities proposed in this study plan are defensible within the context of the overall Site Characterization program.

4 DISCUSSION

The purposes of the United States Geological Survey studies, related to the Yucca Mountain Project, are to provide hydrologic, geologic, and geochemical information to be used for the technical evaluation of the suitability of Yucca Mountain as a candidate site for a high-level nuclear waste repository. In particular, Study Plan 8.3.1.2.2.8 follows the outline presented in the Site Characterization Plan (SCP; U.S. Department of Energy, 1988), and is divided into two activities. These are:

> Activity 8.3.1.2.2.8.1 - Development of conceptual and numerical models of fluid flow in unsaturated, fractured rock; and
>
> Activity 8.3.1.2.2.8.2 - Validation of conceptual and numerical models of fluid flow through unsaturated, fractured rock;

The two activities proposed in this study plan will be used to test various hydrologic hypotheses and conceptual models against the results of experimentation at the laboratory and field scales. The study plan is comprehensive and generally very broad in nature and is likely to provide information needed for the development and validation of conceptual and numerical models for fluid flow in unsaturated, fractured rock. However, there are some concerns expressed in the form of questions, summarized on a per activity basis below.

4.1 DEVELOPMENT OF CONCEPTUAL AND NUMERICAL MODELS OF FLUID FLOW IN UNSATURATED, FRACTURED ROCK (ACTIVITY 8.3.1.2.2.8.1)

This activity presents a plan for the development of detailed conceptual and numerical models for studying fluid flow and conservative tracer transport in unsaturated, fractured rock. An important function of these models is to "assist in the design and interpretation of hydrologic and pneumatic tests." There is a concern regarding exactly how the newly designed tests will be determined to be appropriate, and whether these tests could be classified as prototype tests (see Question #4). Another important function of the models to be developed under this activity is to integrate data collected at a variety of scales, ranging from the laboratory to the field scale. However, there is no discussion in this study plan regarding the process by which data from a variety of scales will be integrated (see Question #1). Finally, a third function of these models is to study flow processes that can affect fluid fluxes and travel times. In one of the proposed modeling strategies, namely the fracture-network models, a method similar to the one used by Cacas et al. (1990) for the determination of pneumatic and hydraulic aperture distribution is to be employed. This particular method has been developed and tested only in saturated rock. There is, therefore, concern regarding the applicability of this method for unsaturated conditions (see Question #5).

4.2 VALIDATION OF CONCEPTUAL AND NUMERICAL MODELS OF FLUID FLOW THROUGH UNSATURATED, FRACTURED ROCK (ACTIVITY 8.3.1.2.2.8.2)

The objective of this activity is to evaluate the applicability and appropriateness of the conceptual and numerical models developed in Activity 8.3.1.2.2.8.1 for studying and describing fluid flow and conservative tracer transport in unsaturated, fractured rock. There is some inconsistency between the modeling strategies to be used during the modeling and validation exercises. There is a concern that validation of modeling results obtained with the help of a modeling strategy which is different from the strategy used during the modeling exercises may not be consistent (see Question #2). Furthermore, it is not clear in this study plan what type of determination methodology will be used to assign various modeling strategies to each of the modeling and validation exercises (see Question #3). Finally, the iterative process whereby a particular experiment may be continuously redesigned and refined, until a satisfactory match between experimental and numerical results is obtained, is questionable. This study plan does not provide sufficient information, or is not written with enough specificity, so that one can be assured that an experiment will not be redesigned until the results appear to support preconceived concepts or previously acquired data (see Question #6).

5 SUMMARY

The methods described in this study plan are generally appropriate for development and validation of numerical and conceptual models for fluid flow in unsaturated, fractured rock. The information derived from this study regarding the development of models for fluid flow in unsaturated, fractured rock and the validation of these models will remain of concern until it is determined that the model validation approach the U.S. DOE is advocating is the appropriate one. Finally, with respect to the consistency criterion, this study plan was found to be consistent with the SCP.

6 REFERENCES

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

Nuclear Regulatory Commission (NRC). 1993. *Review Plan for NRC Staff Review of DOE Study Plans, Revision 2, March 10, 1993*. Division of High-Level Waste Management, Office of Nuclear Material Safety and Safeguards. Washington, D.C.

7 SPECIFIC OBJECTIONS, COMMENTS, AND QUESTIONS

7.1 OBJECTIONS

No objections were identified.

7.2 COMMENTS

No comments were identified.

7.3 QUESTIONS

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). 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). 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). 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.

Study Plan 8.3.1.2.2.8 Fluid Flow in Unsaturated, Fractured Rock

Question 2

Why are the seven technical issues associated with Fluid Flow through Unsaturated Fractured Rock supported by one set of modeling strategies for the modeling exercise, but a different set of modeling strategies for the validation exercise?

Basis

Specific modeling strategies are selected to resolve the seven identified technical issues (Table 3-1.1) and to validate the results of these modeling exercises (Table 3-2.1). The strategies selected for the modeling exercises, however, are different than the strategies selected for the validation exercises. 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 3-1.1. 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

If strategies used in modeling exercises are different from those used in validation exercises, explain how the different modeling strategies can be implemented without biasing the process.

Study Plan 8.3.1.2.2.8 Fluid Flow in Unsaturated, Fractured Rock

Question 3

What is the proposed level of model development and the process by which a particular modeling strategy is assigned to a modeling or validation exercise?

Basis

Resolution and validation of the results of models directed at the seven technical issues associated with Fluid Flow through Unsaturated Fractured Rock are to be accomplished using the five modeling strategies discussed in Section 3.1.7, in addition to the stress deformation model identified in Table 3-2.1 and any other newly developed modeling strategies. This suggests that all of the modeling strategies will be sufficiently developed in order to perform these calculations and supporting validation exercises. However, it is not clear that all of the modeling strategies will be developed enough to be validated and used to resolve critical issues. In particular, the stress deformation model is introduced in Table 3-2.1 but not described elsewhere in the text of this study plan. It is not clear whether any of the modeling approaches would be abandoned if their potential for issue resolution is not promising.

If different modeling strategies are assigned to resolve issues and validate results, the process by which the particular modeling strategy is selected and assigned to a particular modeling exercise should be described. For example, in Section 3.1.4 technical issue (1), "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. The text should explain why these two modeling strategies were selected over other strategies, such as fracture-network- or channel-based models.

Recommendation

Provide a discussion on the anticipated level of model development and the process by which a particular modeling strategy is assigned to a particular modeling or validation exercise.

Study Plan 8.3.1.2.2.8 Fluid Flow in Unsaturated, Fractured Rock

Question 4

How will newly designed (prototype) tests and their results be determined to be appropriate?

Basis

In Section 1.2, one of the main objectives of this study is stated to be: "... will help to design and interpret hydrologic and pneumatic tests and provide information about hydrologic properties and processes that can be incorporated into site-scale models." Furthermore, in Section 1.3, Performance Issue 1.6, it is stated that "[t]he purpose of the present study will be to aid in the design and interpretation of hydrologic and pneumatic tests, particularly those which are slated to be conducted in the exploratory studies facility (ESF)."

It is not clear if this study plan proposes to design and conduct prototype testing. Moreover, if prototype testing is to be conducted, there is no discussion regarding the "appropriateness" of such testing results, especially for tests designed to define a new concept or process. Finally, it is not clear whether prototype testing procedures and results will be open to the scientific community and scrutinized through a peer-review process before results from such testing are used for various analyses dictated by other study plans.

Recommendation

Clarify how prototype testing, especially testing beyond the current state-of-the-art, is to be determined to be appropriate.

Study Plan 8.3.1.2.2.8 Fluid Flow in Unsaturated, Fractured Rock

Question 5

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 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. 1990. Modeling Fracture Flow with a Stochastic Discrete Fracture Network: Calibration and Validation, 1. The Flow Model. *Water Resources Research*. 26(3): 479-489.

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

Study Plan 8.3.1.2.2.8 Fluid Flow in Unsaturated, Fractured Rock

Question 6

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 that leaves the validity of the comparisons intact. The study plan should state the criteria that will be used to decide whether an experiment will be redesigned or not.