PHASE I REVIEW: FLUID FLOW IN UNSATURATED FRACTURED ROCK (STUDY PLAN 8.3.1.2.2.8, REVISION 0)

by

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Introduction

The stated purpose of the DOE Study Plan 8.3.1.2.2.8, Revision 0, titled "Fluid Flow in Unsaturated Fractured Rock," is to develop, refine, and validate conceptual and numerical models describing gas flow as well as liquid water and solute movement in unsaturated, fractured rock at the proposed Yucca Mountain site. This is one of nine studies planned to characterize the unsaturated zone at Yucca Mountain. No data will be collected under the study. Rather, it will incorporate data collected under other studies to help develop conceptual and numerical models of flow and transport conditions in the unsaturated zone. Information to be obtained in this study will support Study 8.3.1.2.2.9 (Unsaturated-zone modeling and synthesis) which will generate predictions of pre-waste-emplacement groundwater travel time (Performance Issue 1.6) and predictions of radionuclide releases to the accessible environment (Performance Issue 1.1). As described later in this review, other performance and design issues are indirectly supported by work under this study.

This study entails two activities. The first activity will develop conceptual and numerical models of fluid flow and nonreactive tracer transport through unsaturated fractured rock at Yucca Mountain. These models will be used to help design and interpret hydrologic and pneumatic tests over a variety of scales. Strategies that have been proposed to resolve technical issues in the unsaturated zone include the development of the following kinds of models: (1) variable-aperture models; (2) double-porosity models; (3) fracture network models; (4) channel models; and (5) stochastic fracture continuum models.

The second activity under this study plan addresses model validation and concerns the validity of the conceptual and numerical models developed under the first activity. Validation studies involve the comparison of model output with measured field and laboratory data. Although there are no data collection activities directly associated with this study, experiments are planned under other studies that could be used to evaluate models developed here. The DOE will have to develop criteria to determine whether residual differences between model outputs and observed data are acceptably small. In practical terms, only partial validation is achievable for models used to predict geohydrologic conditions over thousands of years.

No objection-level concerns have been identified with the work described in this study plan. The DOE did not propose to close any open items with the issuance of this plan, and in fact did not identify any related Site Characterization Analysis (SCA) open items. However, this review has identified SCA open items that are closely related to the study. This study plan is a candidate for a detailed technical review based on criteria 1, 2, and 3 from step 6 of part 4.2 of the Review Plan. This review has shown that the study plan is related to key site-related issues. However, because no field tests will be conducted under this study, there should be no adverse effects on repository performance and no irreversible or unmitigable effects on site characterization. There is also no evidence that this study could disrupt characterization schedules.

Although this study is a candidate for a detailed review, it is recommended that such a review not be performed until the NRC receives and reviews the closely related plan for study 8.3.1.2.2.9, "Site Unsaturated-Zone Modeling and Synthesis." Our concern is that the relationships between the present study under review and study 8.3.1.2.2.9 are unclear. The present study involves the development and validation of conceptual and numerical flow models of the unsaturated zone over various scales. As discussed on page 8.3.1.2-341 of DOE's Site Characterization Plan (SCP), the models to be developed under this study are mostly to be applied at laboratory and sub-REV (representative elementary volume) scales. The SCP describes study 8.3.1.2.2.9 as developing models for site-scale analyses. It also refers to code testing and code verification. Both studies refer to the development of conceptual and numerical models. In general, it is not clear how work will be coordinated between these studies in the development of conceptual models, code development and verification, and the development, application, and validation of numerical models. It is recommended that any Phase II reviews of studies 8.3.1.2.2.8 and 8.3.1.2.2.9 be performed concurrently.

A list of applicable technical procedures is not provided in the study plan. This is inconsistent with DOE's SCP, which provides a list of technical procedures for each of the two activities (SCP, Volume IV, Part B). The status of these procedures should be requested and received from the DOE before starting a Phase II review of this study.

This Phase I review of the study plan was done with respect to (A) DOE/NRC agreement on the content of study plans; (B) identification of objections; (C) closure of NRC open Items; and (D) the need for a Detailed Review (See Review plan for NRC staff review of DOE study plans, revision I, 12/6/90).

Evaluation of Study Plans Relative to the Agreement and to the Responsible DOE Contractors QA Program (Objectives 1 and 5)

Criterion 1 The content of the study plan under review is reasonably consistent, as appropriate for the activities, tests and analyses described, with the Agreement (NRC-DOE meeting on the level of detail for site characterization plans (SCP) and study plans, May 7-8, 1986).

Staff Review:

Attached is an itemized checklist (Attachment A) of the study plan content as compared to the agreement on content resulting from the NRC/DOE level of detail meeting. With one exception regarding technical procedures, the content of the study plan is reasonably consistent with the agreement.

A list of applicable technical procedures is not provided in the study plan. This is inconsistent with DOE's SCP, which provides a list of technical procedures for each of the two activities (SCP, Volume IV, Part B). The status of these procedures should be requested and received from the DOE before starting a Phase II review of this study.

No field tests are planned under this study. Rather, the study will rely on data collected under other studies. Technical procedures for data collection should be cited under those studies. Under the QA requirements of section 7 in this study plan, quality management procedures (QMP's) are cited that relate to software QA, peer review, scientific notebooks, etc.

As described under quality assurance requirements (Section 7), determination of the quality status for activities under this study will be made separately, according to AP-6.17Q, "Determination of the Importance of Items and Activities," which implements NUREG-1318, "Technical Position on Items and Activities in the High-Level Waste Geologic Repository Program Subject to Quality Assurance Requirements." Results of that determination will be provided in the following controlled documents: Q-list, Quality Activities List, and Project Requirements List. Further, QA grading packages for the activities of this study plan will be prepared separately, according to AP-5.28Q, "Quality Assurance Grading."

Criterion 2 All study plan references have been provided when the study plan was issued.

Staff Review:

Most of the study plan references should be readily obtainable by the U.S. NRC library. The following reference may not be readily obtainable and should be provided to the NRC:

Voss, R. F., 1985, Random fractals: Characterization and measurement, Proceedings NATO A. S. I. Scaling Properties of Disordered Media, Geilo, Norway, April, 1985.

Criterion 3 Open items relative to the QA program of the DOE contractor responsible for the study plan, that could call into question the quality of the study plan, have been resolved.

Staff Review:

Based on a discussion with Ken Hooks, Quality Assurance Section, there are currently no open quality assurance items that would call into question the quality of the investigation to be performed under this study plan.

Identification of Objections (Objectives 2 through 6)

Staff Review:

In summary, the NRC staff did not identify any "objection" level concerns related to this study plan. Each criterion is discussed below:

Criterion 1 Potential adverse effects on repository performance.

Staff Review:

Because no field tests or activities are planned, work under this study should have no adverse impacts on repository performance. This study depends on the data collection efforts of other studies.

Criterion 2 Potential significant and irreversible/unmitigable effects on characterization that would physically preclude obtaining information necessary for licensing.

Staff Review:

No field tests are planned under this study. Accordingly, there should be no potential for significant and irreversible/unmitigable effects on characterization.

Criterion 3 Potential significant disruption to characterization schedules or sequencing of studies that would substantially reduce the ability of DOE to obtain information necessary for licensing.

Staff Review:

No field tests are planned under this study, and the work should not affect the schedules of other planned testing activities. In fact, this study depends on the data collection efforts of other studies. In general, there is no evidence of a potential to significantly disrupt characterization schedules.

Criterion 4 Inadequacies in the QA program which must be resolved before work begins.

Staff Review:

Based on a discussion with Ken Hooks, Quality Assurance Section, there are currently no deficiencies that would call into question the quality of the investigation to be conducted under this study plan.

Closure of NRC Open Items (Objectives 8 and 11)

Staff Review:

Not applicable - In its transmittal letter DOE did not propose to close any open items with this study.

Need for Detailed Technical Review

A study plan is a candidate for a detailed technical review if it meets any of the following 5 criteria from step 6 of part 4.2 of the Review Plan. In summary, this study plan is a candidate for a detailed technical review because it meets criteria 1, 2, and 3. Each criterion is discussed below:

Criterion 1 The study plan may be related to one or more key site related issues.

Staff Review:

The study plan is related to a number of key site-related issues. Relationships to the issues are briefly discussed below:

Performance Issue 1.1 (total system performance) requires that the geologic setting, engineered barrier system, shafts, boreholes, and seals be selected and designed so as to limit the cumulative releases of radionuclides for 10,000 years following permanent closure of the repository. This study will supply descriptive and numerical models of fluid flow in the unsaturated zone that can be incorporated within site-

scale models. Such models could be applied to evaluate performance measures for liquid and gas pathways in the unsaturated zone.

Performance Issue 1.4 (waste-package containment) concerns assessment of waste package performance under anticipated processes and events over 1000 years following closure of a repository. Models produced under this study can provide information on the quantity of water that can contact containers or waste in the unsaturated zone.

Performance Issue 1.5 (waste-package and repository engineered-barrier performance) refers to the rate of radionuclide releases from the waste package and engineered-barrier system. Models produced under this study can be used to predict flow and transport and the quantity of gas phase and liquid water within the near-field host rock.

Performance Issue 1.6 (pre-waste-emplacement groundwater travel time) addresses a key NRC performance objective. Models developed under this study can be used to help predict the cumulative distribution of groundwater travel time in the unsaturated zone. This is a key study that will directly support Study 8.3.1.2.2.9 (Unsaturated-zone modeling and synthesis).

Performance Issue 1.8 (NRC siting criteria) relates to evaluations of siting criteria for favorable conditions and potentially adverse conditions. As presented in Section 1.3 of the study plan, this study relates to three favorable conditions and 11 potentially adverse conditions.

Design Issue 1.10 (characteristics and configuration of the waste package) will be supported by models developed under this study which can be used to predict conditions in the near-field environment. These conditions include the quantity and quality of water that can contact waste containers or waste.

Design Issue 1.12 (characteristics and configurations of shaft and borehole seals) will indirectly be supported by unsaturated zone models developed under this study. The study should help improve understanding of fluid flow in fractures and the influence of fracture flow on the quantity of water that may enter the shaft and contact borehole seals.

Criterion 2 The study plan pertains to some NRC open items.

Staff Review:

In the letter transmitting the study plan to the NRC, the DOE stated that no related open items from NRC's Site Characterization Analysis (SCA) were identified. However, this reviewer has determined that several SCA open items are pertinent to this study. Relationships to the items are briefly discussed below:

SCA Question 8: This open item relates to the SCP (DOE, 1988) investigation (8.3.1.4.3) that will develop three-dimensional models of rock characteristics at the repository site. These rock characteristics include geohydrologic properties. This open item expresses concern about how data uncertainties will be transmitted to users of these models.

SCA Comment 18: This open item expresses concern that planned hydrogeologic activities are insufficient to provide technical justification for initial modeling strategies. Comment 18 addresses three SCP activities, one of which is activity 8.3.1.2.2.9.3 under the study "Site unsaturated-zone modeling and synthesis." The objectives of this activity are as follows: (1) simulate and investigate the present state of the hydrogeologic system, and (2) predict probable future and past states of the system under changes in the environmental conditions. These objectives are closely related to model development and validation work under "Fluid Flow in Unsaturated Fractured Rock."

SCA Comment 120: This open item stated that the SCP lacks an adequate description of the plans for completing model and code validation. The NRC recommended that an SCP update should provide a comprehensive, integrated plan for model and code validation. Also, after DOE has identified a full range of conceptual models, it should ensure that adequate plans have been developed for validating the models and the codes associated with them. The study "Fluid Flow in Unsaturated Fractured Rock" focuses on the

development and validation of conceptual and numerical models of the vadose zone.

Criterion 3 The study plan describes unique, state-of-the-art tests or analysis methods that do not have a supportive scientific history of providing data usable in licensing.

Staff Review:

No field tests or other data collection activities will be performed under this study. Rather, the work will utilize data collected under other studies to develop and validate conceptual and numerical models of fluid flow and transport in the vadose zone. Although mathematical and numerical modeling have always played an important role in licensing, there are no previous examples where performance projections over thousands of years have had to be made as part of an NRC license application.

Criterion 4 The study plan describes a study critical to the evaluation of site performance that cannot be repeated for a number of years due to its disruption of the natural baseline.

Staff Review:

The work described in this study plan does not include any field testing. Therefore, it cannot result in disruption of any baseline conditions.

Criterion 5 The study has some other critical relationship to potential licensing concerns.

Staff Review:

The staff has not identified any licensing concerns in regard to this study plan other than those listed above.

REFERENCES

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

ATTACHMENT A
ITEMIZED CHECKLIST OF STUDY PLAN CONTENT
"FLUID FLOW IN UNSATURATED FRACTURED ROCK"

I. PURPOSE AND OBJECTIVE

Is the information to be obtained in the study described?
Yes__X__ No____ N/A____

Is the rationale for information to be obtained provided?
Yes__X__ No____ N/A____

II. RATIONALE FOR STUDY/INVESTIGATION

Does the study plan provide the rationale for tests and analysis, indicating alternatives considered and options, advantages, and limitations?
Yes__X__ No____ N/A____

Does the study plan provide the rationale for the number, location, duration and timing of tests, considering uncertainty, and identify obvious alternatives?
Yes_____ No_____ N/A__X__

No field tests are planned under this study.

Does the study plan describe the constraints for the study?
Yes__X__ No_____ N/A____

In describing the constraints for the study, does the study plan consider potential site impacts?
Yes__X__ No_____ N/A____

In describing the constraints for the study, does the study plan consider the need to simulate repository conditions?
Yes__X__ No_____ N/A_____

In describing the constraints for the study, does the study plan consider the required accuracy and precision?
Yes__X__ No_____ N/A_____

In describing the constraints for the study, does the study plan consider the limits of analytical methods?
Yes__X__ No_____ N/A_____

In describing the constraints for the study, does the study plan consider the capability of analytical methods?
Yes__X__ No_____ N/A_____

In describing the constraints for the study, does the study plan consider time required vs. time available?

Yes__X__ No_____ N/A_____

In describing the constraints for the study, does the study plan consider the scale of phenomena and parameters?

Yes__X__ No_____ N/A_____

In describing the constraints for the study, does the study plan consider interference among tests?

Yes_____ No_____ N/A__X__

No field tests are planned under this study.

In describing the constraints for the study, does the study plan consider interference between tests and exploratory shaft

Yes_____ No_____ N/A__X__

No field tests are planned under this study.

III. DESCRIPTION OF TESTS AND ANALYSIS

For each type of test does the study plan describe the general approach that will be used?

Yes_____ No_____ N/A__X__

No field tests are planned under this study. Rather, the study will rely on the data gathering activities of other studies.

For each type of test does the study plan describe the key parameters that will be measured in the test and experimental conditions under which the test will be conducted?

Yes_____ No_____ N/A__X__

No field tests are planned under this study.

For each type of test does the study plan indicate the number of tests and locations?

Yes_____ No_____ N/A__X__

No field tests are planned under this study.

For each type of test does the study plan summarize the test methods if non-standard procedure, summarize steps of the test, how it will be modified, and reference technical procedure?

Yes_____ No_____ N/A__X__

No field tests are planned under this study.

For each type of test does the study plan indicate the level of QA and provide the rationale for any tests not QA level one?

Yes_____ No_____ N/A__X__

No field tests are planned under this study.

For each type of test does the study plan reference the applicable specific QA requirements applied to the test?

Yes_____ No_____ N/A__X__

No field tests are planned under this study.

For each type of test does the study plan specify the tolerance, accuracy, and precision required in the test?

Yes_____ No_____ N/A__X__

No field tests are planned under this study.

For each type of test does the study plan indicate the range of expected results and the basis for those results?

Yes_____ No_____ N/A__X__

No field tests are planned under this study.

For each type of test does the study plan list the equipment requirements, briefly describing special equipment?

Yes_____ No_____ N/A__X__

No field tests are planned under this study.

For each type of test does the study plan describe the techniques to be used for data reduction and analysis?

Yes_____ No_____ N/A__X__

No field tests are planned under this study.

For each type of test does the study plan describe the representativeness of test, indicating limitations and uncertainties that apply to use of results?

Yes_____ No_____ N/A__X__

No field tests are planned under this study.

For each type of test does the study plan provide illustrations of test locations?

Yes_____ No_____ N/A__X__

No field tests are planned under this study.

For each type of test does the study plan discuss the relationship of the test to set performance goals and confidence levels?

Yes_____ No_____ N/A__X__

No field tests are planned under this study.

For each type of analysis does the study plan state the purpose of analysis, indicate conditions to be evaluated and describe any uncertainty analysis?

Yes__X__ No_____ N/A_____

For each type of analysis does the study plan describe the methods of analysis, including analytical expressions and numerical models to be used?

Yes__X__ No_____ N/A_____

For each type of analysis does the study plan reference the technical procedures document that will be followed during analysis?

Yes_____ No__X__ N/A_____

A list of applicable technical procedures is not provided in the study plan. This is inconsistent with DOE's SCP, which provides a list of technical procedures for each of the two activities (SCP, Volume IV, Part B).

No field tests are planned under this study. Rather, the study will rely on data collected under other studies. Technical procedures for data collection should be cited under those studies. Under the QA requirements of section 7 in this study plan, quality management procedures (QMP's) are cited that relate to software QA, peer review, scientific notebooks, etc.

For each type of analysis does the study plan indicate the levels of QA applied?

Yes_____ No__X___ N/A_____

The following statement appears on page 7.1-1 of the study plan: "Determination of the quality status for the activities of this study will be made separately, according to AP-6.17Q, 'Determination of the Importance of Items and Activities,' which implements NUREG-1318, 'Technical Position on Items

and Activities in the High-Level Waste Geologic Repository Program Subject to Quality Assurance Requirements.' The results of that determination will be contained in the Q-List, Quality Activities List, and Project Requirements List, which will be controlled documents."

For each type of analysis does the study plan identify data input requirements?
Yes__X__ No_____ N/A_____

For each type of analysis does the study plan describe the expected output and accuracy?
Yes__X__ No_____ N/A_____

For each type of analysis does the study plan describe the representativeness of the analytical approach, indicating limitations and uncertainties that apply to results?
Yes__X__ No_____ N/A_____

IV. APPLICATION OF RESULTS

Does the study plan briefly discuss where results from the study will be used to support other studies?
Yes__X__ No_____ N/A_____

Does the study plan refer to specific performance assessment analyses?
Yes__X__ No_____ N/A_____

Does the study plan describe where information from the study will be used in construction equipment and engineering system design and development?
Yes__X__ No_____ N/A_____

Does the study plan describe where information from the study will be used in planning other characterization activities?
Yes__X__ No_____ N/A_____

V. SCHEDULES AND MILESTONES

Does the study plan provide durations of and interrelationships among principal activities associated with this study?
Yes__X__ No_____ N/A_____

Does the study plan list key milestones including decision points associated with study activities?
Yes__X__ No_____ N/A_____

Does the study plan describe the timing of the study relative to other studies and other program activities?

Yes__X__ No_____ N/A_____

Does the study plan provide dates for activities for the study plan: reference section 8.5 in SCP?

Yes_____ No__X__ N/A_____

Although specific dates are not provided for the activities, the approximate schedule of activities by fiscal year is provided as a "summary network" in Section 5 of the study plan.