REVIEW OF THE STUDY PLAN FOR MINERALOGY, PETROLOGY, AND CHEMISTRY OF TRANSPORT PATHWAYS (8.3.1.3.2.1)

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November 27, 1990

1. Introduction

The study of mineralogy, petrology, and chemistry of transport pathways is a key site characterization activity because the geochemical environment of Yucca Mountain may be a factor in the long-term performance of the repository by affecting the chemical stability of waste packages and repository components and retarding the transport of radionuclides by groundwater. Data gathered in the study will provide information about the types, abundances, distributions, compositions, and textural relationships of minerals along potential groundwater pathways (p.1 of the study plan).

2. Review Background

An "Acceptance Review" and "Start Work Review" of the Study Plan for Mineralogy, Petrology, and Chemistry of Transport Pathways (8.3.1.3.2.1) was completed on August 20, 1990 (HLGP, 1990; HLPD, 1990). The acceptance review determined that 1) "the study plan is substantively consistent, as appropriate for the studies, tests, and analyses described, with the agreement on content resulting from the Level of Detail Meeting," and 2) "all study plan references have been provided at the time of the study plan issuance." The start work review determined that 1) work will not compromise the capability of the site to isolate waste, 2) work will not interfere with other studies and/or construction of the exploratory shaft, 3) a quality assurance program is in place, and 4) if radioactive materials are to be used, the quantities to be used and plans for retrieval are discussed.

Although the SCP describes three activities for this study, the study plan has been reorganized such that the work is divided into the following five activities:

- Quantitative mineralogy of the host rock and underlying rocks along transport pathways
- Internal stratigraphy for the candidate host rock
- Chemical variability in the host rock and along transport pathways
- Role of fractures as past transport pathways and evidence for paleo-water table(s)
- Statistical evaluation of mineralogic, petrographic, and chemical data

This reorganization allows suites of samples that will undergo similar types of analyses to be grouped together.

In terms of open items, the SCA contained no comments concerning this study. However, the detailed technical review of the study plan for Characterization of Yucca Mountain Quaternary Regional Hydrology (8.3.1.5.2.1) resulted in a comment (#1) raising the concern that characterization work to locate paleowater tables is restricted to the near surface. Information in the Study Plan for Mineralogy, Petrology, and Chemistry of Transport Pathways (8.3.1.3.2.1) applies to this open item.

3. Review Criteria

The evaluation of this study plan was based on the Draft Review Plan for NRC Staff Review of DOE Study Plans and Procedures (HLPD, 1987), and was 1) evaluated to determine whether it is adequate to provide the information for licensing it was designed to provide, 2) examined against open items in case it represents progress toward resolution, and 3) evaluated for consistency with the SCP.

4. Discussion

The study plan recognizes that groundwater flow paths at Yucca Mountain are not well defined for either present or future hydrologic conditions. These flow paths must be determined in the calculation of GWTT required in 10 CFR Part 60.113. Given the uncertainty in flow paths, the approach taken will be to "characterize the rock-matrix and fracture-lining minerals along all possible paths between the repository and the accessible environment" (p.1 of the study plan). Not being able to characterize all possible paths between the repository and the accessible environment, the study, instead, will characterize mineralogy, petrology, and chemistry of rocks occurring along the following types of potential groundwater transport pathways:

> In the unsaturated zone, downward porous matrix flow of groundwater from the repository to the water table.
>
> In the unsaturated zone, downward transport of groundwater by fracture flow from the repository to the water table.
>
> In the saturated zone, lateral transport of groundwater by porous matrix flow.
>
> In the saturated zone, lateral transport of groundwater by fracture flow.

The task of determining appropriate selection of samples that represent these generic types of flow paths will be handled in the activity on Statistical Evaluation of Mineralogic, Petrologic, and Chemical Data. The samples will come primarily from core supplied by the drilling program. Analyses of core from the early part of the drilling program will be used for determining drill sites later in the program. In the judgement of the reviewer, this procedure is a reasonable approach. However, the basis for justifying drilling more holes hinges on the statement that "additional holes cannot provide additional reliability of a calculational model for predicting releases to the accessible environment (SCP 8.3.5.13.3) if the small-scale variability (measured in many cores by the within-hole variance of the observations) is not significantly smaller than the variability between holes

drilled at the maximum feasible density" (p.11 of the study plan). Hidden in this statement is the assumption that the medium is isotropic and variance in the vertical direction is comparable to that in the horizontal direction. This raises a concern that if the assumption is incorrect, sampling may significantly bias the estimations of types, abundances, distributions, compositions, and textural relations of minerals such that calculated radionuclide retardation would be overestimated (see Attachment/Question #1).

The information from this study plan about the types, abundances, distributions, compositions, and textural relationships of minerals along potential groundwater pathways will be used in conjunction with data from sorption experiments (SCP Investigation 8.3.1.3.4) to evaluate radionuclide retardation by sorption processes along flow paths to the accessible environment (p.1 of the study plan).

It is not clear how the parameters characterizing solids determined in this study correlate with parameters important to sorption to be collected in Study Plan 8.3.1.3.4.1: Batch Sorption Studies. This raises the concern that information important for calculating sorption/retardation may not be collected (See Attachment/Question #2). The solid parameters which may be important to sorption, such as surface area, site density, cation exchange capacity (CEC), etc. will be determined on pure mineral separates in the Sorption Studies. Coupling the sorption information with information on proportions of minerals constituting the rock may be used to determine sorption coefficients for the whole rock. However, Palmer et al. 1981 has shown that sorption of the whole rock is not necessarily a linear function of the sorption coefficients of the pure minerals constituting the rock.

Work planned in Activity 8.3.1.3.4.1.1, Batch sorption measurements as a function of solid phase composition, will determine correlations of sorption coefficients with mineralogy (SCP p.8.3.1.3-70). Thus, the question about correlation of mineralogic data with sorption may be better posed in a review of the study plan on batch sorption tests activity or the modeling activities. Specifically, with regard to the question of correlation "do all clinoptilolites have the same CEC, or will this information be determined for as many samples as determined in the Mineralogy/Petrology Study Plan?"

Finally, the subject of software validation was briefly discussed in the Rationale section (p.12 and 13 of the study plan). What constitutes validation with regard to predictive modeling is highly debated (GEOVAL 1987). The study plan provides no details or references to details with respect to what is going to be done to validate software. This raises the question about how software validation differs from model validation and how software validation will be accomplished (See Question #4).

<u>Quantitative mineralogy of the host rock and underlying rocks along transport pathways</u>

In this activity, quantitative mineralogy of the host rock and rock matrix along transport pathways will be determined by analyzing core, outcrop, and exploratory shaft material using x-ray powder diffraction. Corundum internal standard will be used permitting the determination of amounts of phases present. By adding a known quantity of internal standard to a known quantity

of rock, and comparing peak areas, it is possible to determine the amounts of phases present in the rock.

This technique is appropriate for obtaining quantitative mineralogy of rocks at Yucca Mountain, but some concerns remain. For example, x-ray powder diffraction analysis requires homogenizing the rock by grinding it to a powder. The resulting analysis yields bulk rock mineralogy. However, this raises a concern that information on rock textures that might affect sorptivity (such as porosity and armoring) can not be obtained using this technique (see Attachment/Comment #1). For example, low porosity or armoring of sorptive minerals with nonsorptive phases would tend to reduce the sorptive capacity of a rock.

It is stated in the study plan that "the accuracy of mineralogical input required for transport modeling has not been determined yet, therefore the accuracy of results needed in this activity cannot be defined." This raises a concern about the adequacy of the data being collected. For example, the x-ray powder diffraction method can normally be used to detect amounts of a given mineral in excess of 1-5 weight percent of the total. Whether amounts less than the detection limit can significantly affect the sorptivity of a rock needs to be determined (see Attachment/Comment #2).

This concern has also been raised by contractors from the State of Nevada who questioned the ability of the proposed technique to determine percentages of glass in the rock (QA audit of Los Alamos, 1989). Due to its amorphous nature, glass lacks sharp x-ray peaks, and the tendency would be to underestimate the amount of glass present in a sample. Consequently, the percentages of the remaining phases, which may be relatively more sorbing, may be overestimated.

It is also stated that "analyses will be performed on samples from core and from the exploratory shaft samples whenever changes in lithology are apparent so that complete mineralogical data are available for all lithologies." This raises the question about how changes in lithologies will be ascertained (see Attachment/Question #3).

Internal Stratigraphy for the Candidate Host Rock

The candidate host rock will be analyzed petrographically by point counting thin sections cut in a vertical orientation. On phenocrysts of unknown composition, electron microprobe analysis may be performed. These techniques are appropriate for analyzing the host rock. Comment #1 recommends that these techniques be used also on rocks along flow paths between the host rock and the accessible environment. As mentioned above, petrographic analysis can be used to determine texture which may affect sorptivity. Also, as pointed out in this activity, textures can be used to determine stratigraphic location. This information is important not just in the candidate host rock, but elsewhere in the geologic setting, for characterization of tectonics and structure.

The study plan discusses the importance of representativeness and plans to study rock at several scales (thin section, rock slab, drill hole correlation). It is noted in Question #1 that thin sections will exclusively be oriented vertically. Given the possibility that significant lateral flow

may occur in the unsaturated zone, it is recommended that characterization in a lateral direction on the scale of a thin section or rock slab also be considered.

It is noted that "Figure 2 of Byers (1985)", referred to on page 17, does not exist. However, Figures 2 through 5 of Byers and Moore (1987) do exist, thus providing the supporting information.

Chemical Variability in the Host Rock and Along Transport Pathways

Whole-rock and mineral-chemical data will be used in conjunction with mineralogic data to characterize the site. The chemistry of tuffs and of their matrix minerals will be determined by X-ray fluorescence (XRF), nuclear activation analysis (NAA), atomic absorption spectroscopy (AA), and electron microprobe analysis. This is an appropriate selection of techniques to characterize the chemistry of the rocks. The fact that polished thin sections will be prepared for the electron microprobe, allows for textural characterization along with compositional characterization.

Role of Fractures and Faults as Past Transport Pathways and Evidence for Paleo-Water Table(s)

The role of fractures and faults as past transport pathways will be examined by analyzing the minerals that occur in fractures and faults and determining their sequence of deposition. Fracture-lining minerals will be identified using primarily binocular microscopy, X-ray diffraction analysis (XRD), and scanning electron microscopy. Also, the chemistry of the fracture minerals will be determined with the electron microprobe, and neutron activation analysis. Cathodoluminescence may be used to examine different generations of fracture-lining minerals. This is an appropriate selection of techniques to characterize the fracture-lining minerals.

The description of the work planned for this activity partially resolves the open item that applied to the study plan for Characterization of Yucca Mountain Quaternary Regional Hydrology (8.3.1.5.2.1), which states that evidence for establishing paleowater table elevations appears to be restricted to near-surface calcite-silica veins. What remains unresolved of the open item is that evidence for identifying paleowater table elevations may be subject to interpretation. Much depends on the skill of the investigators to accurately assemble clues to the past hydrologic systems.

Furthermore, evidence for paleowater table elevations need not be restricted to faults and fractures. Characterization of the rock matrix to identify paleowater table elevations may be part of the Study Plan on History of Mineralogic and Geochemical Alteration of Yucca Mountain (8.3.1.3.2.2).

Statistical Evaluation of Mineralogic, Petrographic, and Chemical Data

Statistical analyses of mineralogic and model petrographic data will consist of probabilistic modeling and statistical extrapolation of mineralogic, modal, and chemical data from the drill holes that exist presently or are planned. Probabilistic analysis of mineralogic data will be used to (1) detect lateral and vertical trends in mineralogy; (2) correlate mineralogic and modal petrographic data with the internal stratigraphy of the repository

host rock; and (3) detect outliers, possible measurement or reporting errors, and other anomalies in the data. Standard statistical analysis techniques are appropriately planned.

5. SUMMARY

With respect to review criterion 1, the methods described in this study plan are appropriate for characterizing the mineralogy, petrology and solid chemistry along flow paths at Yucca Mountain. With respect to review criterion 2 addressing open items, the application of the information derived from this study in modeling transport will remain of concern until it is determined how the parameters from this study correlate with those important to sorption. Also, the open item on estimating paleowater table elevations from Quaternary Regional Hydrology study plan is partially resolved, but review of the study plan on History of Mineralogic and Geochemical Alteration of Yucca Mountain (8.3.1.3.2.2) is necessary to close out other aspects of this concern. Finally, with respect to review criterion 3, the study plan was found to be consistent with the SCP.

Action Items

(1) It will be necessary to add and track to closure the comments and questions from this detailed technical review to the Open Item Tracking System.

(2) It will be necessary to review the Study Plan on History of mineralogic and geochemical alteration of Yucca Mountain (8.3.1.3.2.2) to ensure coordination with this study plan with regard to rock textures and mineral stability.

(3) It will be necessary to determine if there is a difference between software validation and model validation, and how validation will be accomplished.

(4) It will be necessary to review evidence of paleowater table elevations presented in interim reports.

(5) The prototype testing to determine sample sizes and sample densities to be used during site characterization will have to be tracked.

(6) It will be necessary to review the study plan on Batch Sorption Studies (8.3.1.3.4.1) to ascertain the correlation between parameters measured in this study and those measured in the Batch Sorption Study.

(7) It will be necessary to determine how the information obtained in this study will be used in the studies waste package investigation (8.3.4.2.).

6. REFERENCES

HLGP, 1990, Memorandum to N. King Stablein from John Bradbury on the Acceptance and Start Work Reviews of the Study Plan for Mineralogy, Petrology, and Chemistry of Transport Pathways (8.3.1.3.2.1), 5-30-90.

HLPD, 1990, Letter to Ralph Stein from John J. Linehan on the Acceptance and Start Work Reviews of the Study Plan for Mineralogy, Petrology, and Chemistry of Transport Pathways (8.3.1.3.2.1), 8-20-90.

Palmer, D.A., Shiao, S.Y., Meyer, R.E., and Wethington, J.A., 1981, Adsorption of nuclides on mixtures of minerals, Journal of Inorganic and Nuclear Chemistry, vol. 43, no. 12, p. 3317-3322.

Study Plan 8.3.1.3.2.1 Mineralogy, Petrology, and Chemistry of Transport Pathways

Comment 1

Although the study plan calls for gathering data on "textural relationships of minerals along potential groundwater pathways," which are important to establish stratigraphic location of core samples and to determine the accessibility of potentially sorbing phases to radionuclides, only the candidate host rock will be analyzed petrographically. Thus, it appears that inadequate information will be collected on rock outside the repository horizon.

Basis

The analytical techniques proposed for determining Quantitative Mineralogy of the Host Rock and Along Transport Pathways will be XRD and XRF (p.14).

In addition to XRD and XRF, the candidate host rock will also be analyzed petrographically (p.17).

Chemical variability in the host rock and along transport pathways will be determined by XRF, NAA, AA, and electron microprobe analysis (p.19).

Although "petrographic thin sections will be prepared for all of the mineralogic samples" (p. 11), except for the work to be done on the fractures and faults (p. 23), petrographic analysis is not proposed for rocks outside of the Topopah Spring unit.

"Mineral and glass compositions will be determined on polished thin sections by an automated Cameca electron microprobe" (p.20), but collecting information on textures is not planned for this study.

Textural information can be used to establish stratigraphic location of core samples and to determine the accessibility of potentially sorbing phases to radionuclides.

8.3.1.3.2.2 Study: History of mineralogic and geochemical alteration of Yucca Mountain will analyze textures, alteration sequences, and mineral zonation. This study is intimately tied to the Mineralogy, petrology, and chemistry study plan.

Recommendation

Include petrographic analysis for determining textural relationships of minerals along the transport pathways between the Topopah Spring and the accessible environment.

Activity 8.3.1.3.2.1.1 Quantitative Mineralogy of the Host Rock and Along Transport Pathways

Comment 2

The accuracy of data from this study needed for transport modeling has yet to be determined. Thus, there is no way to evaluate whether or not the data being collected will be adequate for transport modeling.

Basis

"The purpose of this Study is to characterize the mineralogy, petrology, and chemistry along potential groundwater flow paths leading from the repository to the accessible environment. Data gathered in this Study will provide information about the types, abundances, distributions, compositions, and textural relationships of minerals along potential groundwater pathways. This information will be used in conjunction with data from sorption experiments (SCP Investigation 8.3.1.3.4) to evaluate radionuclide retardation by sorption processes along flow paths to the accessible environment" (p.1).

"The accuracy of input required for transport modeling has not been determined yet, therefore the accuracy of results needed in this activity cannot be defined" (p.15).

If it is determined in the future that greater accuracy is required for transport modeling than proposed in this study plan, work carried out according to this plan may be inadequate.

Recommendation

Determine the degree of accuracy before the work begins or plan for alternative procedures if the requirements for accuracy for transport modeling are not met.

Activity 8.3.1.3.2.1.2 Internal Stratigraphy for the Candidate Host Rock

Question 1

Could the exclusive sampling of core in a vertical sense significantly bias the estimations of types, abundances, distributions, compositions, and textural relationships of minerals along potential groundwater pathways such that calculated radionuclide retardation would be overestimated?

Basis

"The unsaturated zone beneath the Yucca Crest consists of a layered sequence of tuffs deposited from volcanic eruptions ..." (Hoxie, 1989).

Due to contrasts in hydraulic conductivity between horizontal layers, lateral components of flow may be significant. "In aquifer-aquitard systems with permeability contrasts of 2 orders of magnitude or more, flowlines tend to become almost horizontal in the aquifers and almost vertical in the aquitards" (p.173 Freeze and Cherry, 1979). At Yucca Mountain, for example, Tiva Canyon welded tuff has a saturated hydraulic conductivity of 10E-11 m/s, whereas the underlying Paintbrush nonwelded unit has a saturated hydraulic conductivity of 10E-7 m/s (Hoxie,1989).

The plan does not describe work to establish horizontal variability at scales smaller than defined by drill hole distances.

"The assumptions about representativeness of thin sections will be examined in detail during prototype testing" (p.19)

Recommendation

Provide evidence to show that sampling core in orientations other than vertical is not needed for transport modeling.

References

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

Hoxie, D. T., 1989, A conceptual model for the unsaturated-zone hydrologic system, Yucca Mountain, Nevada, in Radioactive Waste Management and the Nuclear Fuel Cycle, 1989, Vol. 13(1-4), pp. 63-75.

Study Plan 8.3.1.3.2.1 Mineralogy, Petrology, and Chemistry of Transport Pathways

Question 2

How do the parameters characterizing rocks and minerals determined in this study correlate with parameters important to sorption to be collected in Study Plan 8.3.1.3.4.1: Batch Sorption Studies?

Basis

"The purpose of this Study is to characterize the mineralogy, petrology, and chemistry along potential groundwater flow paths leading from the repository to the accessible environment. Data gathered in this Study will provide information about the types, abundances, distributions, compositions, and textural relationships of minerals along potential groundwater pathways. This information will be used in conjunction with data from sorption experiments (SCP Investigation 8.3.1.3.4) to evaluate radionuclide retardation by sorption processes along flow paths to the accessible environment" (p.1).

Work planned in Activity 8.3.1.3.4.1.1, Batch sorption measurements as a function of solid phase composition, will determine correlations of sorption coefficients with mineralogy (p.8.3.1.3-70). The solid parameters, which may be important to sorption, such as surface area, site density, cation exchange capacity, etc. will be determined on pure mineral separates in the Sorption Studies.

Recommendation

Explain how the information from this study will be used in the sorption studies.

Activity 8.3.1.3.2.1.1 Quantitative Mineralogy of the Host Rock and Along Transport Pathways

Question 3

What is the method for determining changes in lithology?

Basis

"Analyses will be performed on samples from core and from the exploratory shaft samples whenever changes in lithology are apparent so that complete mineralogical data are available for all lithologies" (p.14).

It is not evident that the method for determining changes in lithology is described in any of the listed detailed procedures.

Recommendation

Provide a description of the method for determining changes in lithology.

Study Plan 8.3.1.3.2.1 Mineralogy, Petrology, and Chemistry of Transport Pathways

Question 4

How does software validation differ from model validation?

Basis

"The software used to support licensing will be verified and validated according to the LANL Software QA plan" (p.13).

The term "model validation" is defined as the method taken to assure that a model is a correct representation of the process or system for which it is intended (Brooks and Coplan, 1987). Concensus on how to achieve assurance does not yet exist.

The meaning of the term "software validation" is unknown by the NRC technical reviewers.

Recommendation

Discuss the difference between software validation used in this study plan and model validation.

Reference

Brooks, P. and S. Coplan, 1987, The role of verification and validation in licensing repositories for disposal of high-level waste, Proceedings of GEOVAL 1987, vol. 1, p. 41.