APPENDIX A

SUMMARY OF RECENT INFORMATION RELEVANT TO THE INTEGRATED SITE MODEL

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1. INTRODUCTION

This white paper contains a summary of recent field work results and other additional information that are relevant to the site characteristics described in the integrated site model used to support the *Yucca Mountain Science and Engineering Report* (YMS&ER) (DOE 2001a) and the *Yucca Mountain Preliminary Site Suitability Evaluation* (YMPSSE) (DOE 2001b). The U.S. Department of Energy (DOE) released these two documents for public review in May and August, respectively, of this year.

The white paper focuses on the results of field work and other additional information that became available after the integrated site model was completed to support the preparation of the YMS&ER and the YMPSSE. The summary of this recent information is being used to conduct an impact review, in accordance with AP-2.14Q, *Review of Technical Products and Data*, to determine if this additional information has any impact on the technical analyses supporting the YMS&ER and the YMPSSE. The documentation of the additional information in this white paper is an interim step and primarily used to support this impact review. This information is expected to be formally documented in subsequent technical reports, as appropriate.

To assist in the impact review, this white paper briefly describes the component models of the integrated site model used to support the YMS&ER and the YMPSSE. This white paper provides a summary of the recent test results and other additional information and discusses the potential implications of this more recent information on our understanding of the integrated site model.

2. SUMMARY DESCRIPTION OF THE COMPONENT MODELS OF THE INTEGRATED SITE MODEL

The purpose of the integrated site model (CRWMS M&O 2000a) is to provide a framework for discussing and illustrating the geological features and properties of Yucca Mountain. The integrated site model is important to the evaluation of the potential repository because it provides three-dimensional static representations of the geology, selected hydrologic and rock properties, and mineralogic-characteristics data. These representations are contained in three separate component models: the geologic framework model (BSC 2001), the rock properties model (CRWMS M&O 2000b), and the mineralogic model (CRWMS M&O 2000c). In fiscal year 2001, *Fracture Geometry Analysis for the Stratigraphic Units of the Repository Host Horizon* (CRWMS M&O 2000d) was included as a component of the integrated site model.

The geologic framework model is a representation of the rock layers and faults that comprise Yucca Mountain. It provides the framework into which the rock properties and mineralogic distributions are placed, and it provides primary input for evaluating and siting a repository as well as inputs and the unsaturated zone and saturated zone flow and transport models. The geologic framework model was constructed using Earthvision software. The geologic framework model is a three dimensional model constructed by adding or subtracting layers of selected geologic unit vertical thicknesses (isochores). The isochores are assembled relative to

three reference horizons (base of the Tiva Canyon Tuff Crystal-Poor Member Vitric Zone Nonwelded Subzone, top of the Calico Hills Formation, and the top of the older Tertiary unit). Faults were included in the geologic framework model based on their measured length, maximum vertical displacement, intersections with the Enhanced Characterization of the Repository Block (ECRB) Cross-Drift and the Exploratory Studies Facility, and, if needed, to reconcile results between the model and the geologic maps.

Inputs to the geologic framework model are borehole lithostratigraphic contacts, maps of geology and topography, underground data from the ECRB Cross-Drift and the Exploratory Studies Facility, and measured stratigraphic sections. A preliminary version of GFM version 3.0 did not include results from two recently drilled boreholes, WT-24 and SD-6, and the ECRB Cross-Drift. The actual stratigraphic contact depths were compared to those predicted by GFM 3.0 and then incorporated into the revised GFM 3.1. The model was validated based on comparisons of predicted and actual observed stratigraphic contacts. These comparisons showed that the majority of contacts fell within the validation criteria. Predictions that fell outside the window of uncertainty were caused by unanticipated geologic variability and were not the result of deficiencies in the model. The current version of GFM version 2000 (in preparation) makes an assessment of the inherent uncertainty caused by data distribution, geologic variability, observed variability, and prediction error.

The rock properties model provides a description of the distributions of the following rock material properties for all four model units (Paintbrush Tuff nonwelded (PTn), Topopah Spring welded (TSw), and Calico Hills (CHn), and Prow Pass Tuff (Tcp)): matrix porosity, whole rock bulk density, and matrix saturated hydraulic conductivity. These model units correspond to the named geologic formations as indicated in Table 10 of *Rock Properties Model Analysis Model Report* (CRWMS M&O 2000b). For the TSw model unit, two additional rock material properties are provided: lithophysal porosity and whole-rock thermal conductivity material. The rock properties model was constructed using selected geostatistical subroutine library modules and software routines to produce the geostatistical models. For the rock properties model an assumption was made that there is a correlation between porosity and other rock properties and that this correlation could be used to derive other input data using porosity as a surrogate property. This assumption was used to model the spatial distribution of bulk density, saturated hydraulic conductivity, and thermal conductivity.

The rock properties model has seven different classes of data used as inputs. The first four of the listed categories involve measurements of rock material properties. The fifth property is derived from in situ geophysical measurements. The final two inputs consist of the stratigraphic contacts bounding the four rock properties modeling units. The seven types of inputs are:

- Laboratory core porosity data
- Calculated petrophysical porosity data
- Laboratory-measured secondary property data
- X-ray diffraction indicators of mineral alteration
- Petrophysical indicators of hydrous-phase mineral alteration
- Observed (measured) lithostratigraphic contacts
- Modeled lithostratigraphic contacts (provided from the geologic framework model).

There are three fundamentally different types of models included within the rock properties model. The first type is a suite of 50 simulated property models generated for each material property using conditional simulation techniques. The second type is the summary expectation (E-type or expected value) model for each rock property. These E-type models provide a single average values (based on the 50 individual simulations) at each node to represent the property values most likely to be encountered at each discretized location. The third model is also a summary-type model and provides the node-by-node standard deviation of the 50 individual simulated property models to provide users with an estimate of the associated geologic uncertainty.

Concerns raised regarding the apparent discrepancies between the expected value hydraulic conductivity model of RPM3.1 and the zeolite content model of MM3.0 lead to the revision in Calico Hills modeling in RPM 2000 (in preparation). The "cutoff" at which a rock is presumed to be altered was changed from 5 to 15 percent because, when hydraulic conductivity versus hydrous-phase mineral content (hpmc) is plotted, a sharp break was observed at approximately 15 percent hpmc. This formed the basis for dividing the hydraulic conductivity data set into two populations: altered (hpmc ≥0.15) and unaltered (hpmc ≤0.15). The other significant change was that the analysis of the core and petrophysical measurements used to indicate mineral alteration are analyzed and evaluated separately. Previously core and petrophysical measurements were combined into a single data set prior to analysis. The result was the creation of a hydrous-phase mineral content for the Calico Hills model layer. This differs from the original hydrous mineral alteration probability. The hydrous-phase mineral content models are based solely on X-ray diffraction mineralogy and are used to test the validity of the hydrous mineral alteration probability models, which are based on data from core, petrophysical, and X-ray diffraction data.

The MM3.0 is a three-dimensional weighted, inverse distance representation of mineralogical abundance. It was developed specifically for incorporation into the integrated site model and enables the prediction of calculated mineral abundances at any position, within any region or stratigraphic unit in the integrated site model area. The mineralogic model was constructed using STRATAMODEL Version 4.1.1, which is a program designed for three-dimensional mineralogic modeling. The stratigraphic framework for the mineralogic model was created from 22 stratigraphic surfaces obtained from GFM 3.1. The 22 sequences were defined to keep the mineralogic model as simple as possible and at the same time to accurately define the zeolitic, vitric, and potential repository host horizon units at Yucca Mountain. Ten mineral groups or classes were modeled:

- Soptive zeolites (the sum of clinoptilolite, heulandite, mordenite, chabazite, erionite, and stellerite)
- Nonsorptive zeolite (analcime)
- Volcanic glass
- Tridymite
- Cristoballite and opal-CT
- Quartz
- Feldspars

- Mica
- Calcite
- Smectite + illite.

The inputs for the mineralogic model consist of stratigraphic surfaces from GFM 3.1 and quantitative X-ray diffraction analyses of mineral abundances. For the mineralogic model the assumption was made that sample collection methods for drill cuttings did not severely affect the mineral abundance data or the mineralogic model predictions base on those data. Therefore, drill cuttings mineral abundance data were used as input for the mineralogic model.

The purpose of *Fracture Geometry Analysis for the Stratigraphic Units of the Repository Host Horizon* (CRWMS M&O 2000d) was to evaluate the geometry of the primary joint sets associated with the lithostratigraphic units of the repository host horizon. For this report the analysis was limited to the following zones of the Topopah Spring Tuff: upper lithophysal (Tptpul), middle nonlithophysal (Tptpmn), lower lithophysal (Tptpll), and lower nonlithophysal (Tptpln). The results of this report support the analysis performed by the *Drift Degradation Analysis* (CRWMS M&O 2000e). Specifically, *Fracture Geometry Analysis for the Stratigraphic Units of the Repository Host Horizon* (CRWMS M&O 2000d) provides the geometric input parameters for the joint sets used as input to the acquired software code DRKBA V3.3. DRKBA V3.3 is used to determine the size and distribution of key blocks in *Drift Degradation Analysis* (CRWMS M&O 2000e). In addition, the results of *Fracture Geometry Analysis for the Stratigraphic Units of the Repository Host Horizon* (CRWMS M&O 2000d) were used as input for determining the orientation of the emplacement drifts used in layout design work for a repository at Yucca Mountain.

Data for the primary joint set orientations were obtained from full-periphery geologic maps of the Exploratory Studies Facility and ECRB Cross-Drift produced by the U.S. Geological Survey/U.S. Bureau of Reclamation. Joint set spacing and trace length distributions were derived from U.S. Geological Survey/U.S. Bureau of Reclamation detailed line surveys from the Exploratory Studies Facility and ECRB Cross-Drift. The data analyzed in *Fracture Geometry Analysis for the Stratigraphic Units of the Repository Host Horizon* (CRWMS M&O 2000d) were limited to fracture lengths greater than 1 m (3 ft). The 1-m (3-ft) length joint set orientation and spacing and trace length distributions were the primary data obtained throughout the entire Exploratory Studies Facility and ECRB Cross-Drift by the U.S. Geological Survey/U.S. Bureau of Reclamation. To segregate the full-periphery-geologic-maps fracture data set into subsets representing the lithostratigraphic units, a volume or solids model (ESF–ECRB Version 1) was constructed using the Vulcan V3.4 software. The results of the fracture geometric analysis are contained in DTN: MO0008SPAFRA06.004.

Fracture orientation data from full-periphery geologic maps obtained in the Exploratory Studies Facility and ECRB Cross-Drift were used to provide a representation of joint set orientations for the repository host horizon. In general, each of the lithostratigraphic units that comprise the repository host horizon displays one primary south to southeast striking, steeply dipping, joint set with one or more secondary steeply dipping sets, and a subhorizontal joint set.

Joint set spacing and trace length distributions obtained from examining the detailed line surveys shows that the majority of the joint spacing distributions are log normal with a higher intensity of

fracturing observed for the nonlithophysal zones (Tptpmn and Tptpln) compared to the lithophysal zones (Tptpul and Tptpll). The log normal distributions suggest a random distribution of fracture intersections with the detailed line surveys. The majority of trace length distributions are log normal, similar to the spacing distributions. In general the trace lengths appear to be slightly longer in the lithophysal zones (Tptpul and Tptpll) than in the nonlithophysal zones (Tptpmn and Tptpln).

3. SUMMARY OF RECENT TEST RESULTS AND OTHER ADDITIONAL INFORMATION

This section summarizes recent results obtained from field work that have provided information relevant to enhancing our understanding of the integrated site model. This additional information consists of underground observations of excavation-induced fractures and *Fracture Geometry Analysis for the Stratigraphic Units of the Repository Host Horizon* (CRWMS M&O 2000d).

In the primary data sets for *Fracture Geometry Analysis for the Stratigraphic Units of the Repository Host Horizon* (CRWMS M&O 2000d), the fractures mapped and recorded in the full-periphery geologic maps and detailed line surveys did not distinguish between natural and excavation-induced fractures. To assess the impacts of excavation-induced fractures, visual observations were conducted in the Exploratory Studies Facility, ECRB Cross-Drift, alcoves (2, 5, 6, 8), and niches (1 through 5). The investigation was confined to the stratigraphic units that comprise the repository host horizon. Three methods of excavation were used during construction: tunnel boring machine, alpine miner, and drill-and-blast. This investigation examined all three methods of excavation. The criteria described in Table 1 were used to distinguish between excavation-induced and natural fractures.

Table 1. Criteria Used to Distinguish between Natural and Excavation-Induced Fractures

Criteria	Natural Fractures	Excavation-Induced Fractures
Surface infillings and coatings	Fracture surfaces are infilled or coated	Fracture surfaces have no infillings or coatings
Surface alterations	Fracture surfaces have vapor phase or other alterations	Fracture surfaces have no alteration on fracture walls
Surface characteristics	Fracture surfaces are planar and/or smooth	Fracture surfaces are generally rough and irregular
Orientation	Fractures occur in sets or groups with an aligned or preferred orientation	Fractures tend to have a random orientation, depending on excavation method
Lengths	Fractures have a range of lengths	Fracture lengths tend to be short and terminate in natural fractures, especially in tunnel boring machine and Alpine-miner sections

For this investigation, fracture length was generally limited to fractures longer than a few centimeters. Shorter fractures were considered to be in the microfracture range and were not analyzed.

In general the impact of excavation-induced fractures was found to be minimal. Tunnel-boring-machine-induced fractures were found to be generally confined to a few centimeters (under normal cutting conditions). Alpine-miner-induced fractures were found to be confined to a few centimeters to possibly a few tens of centimeters in depth. Drill-and-blast was found to influence tens of centimeters adjacent to the excavated surface. The only area that displayed significant excavation-induced fractures was in ECRB Cross-Drift, which was excavated with the tunnel boring machine, from approximately Station 15+50 to 16+50. From Station 15+00 to 17+50 in the ECRB Cross-Drift, there was an apparent increase in fracture density and wall roughness on the left wall of the drift when compared to the right wall. The consistent nature of this feature and other observations suggests that it is caused by the action of the tunnel boring machine cutter head. It is suspected these excavation-induced fractures are caused by the tunnel boring machine cutter head carrying large blocks around and gouging the left wall as the head rotates upward.

4. IMPLICATIONS OF RECENT TEST RESULTS AND OTHER ADDITIONAL INFORMATION

Excavation-induced fractures of significant size were found to be rare in the underground excavations at Yucca Mountain. Inspection of excavation-induced fractures caused by the tunnel boring machine and alpine miner has shown that in general their influence is restricted to a few centimeters to tens of centimeters in depth. Similarly drill-and-blast-induced fractures are limited to a depth of influence of tens of centimeters.

Because of the relatively rare occurrence and overall limited depth of influence observed for excavation-induced fractures their impact to the postclosure analysis performed in *Drift Degradation Analysis* (CRWMS M&O 2000e) is likely to be limited. With proper scaling and support, the excavation-induced fractures will have little or no consequence affecting engineering properties.

5. REFERENCES

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