THE U.S. NUCLEAR REGULATORY COMMISSION OFFICE OF NUCLEAR MATERIAL SAFETY AND SAFEGUARDS REVIEW OF THE U.S. DEPARTMENT OF ENERGY KEY TECHNICAL ISSUE AGREEMENT RESPONSES RELATED TO THE POTENTIAL GEOLOGIC REPOSITORY AT YUCCA MOUNTAIN NEVADA: STRUCTURAL DEFORMATION AND SEISMICITY 3.03

1.0 INTRODUCTION

The U.S. Nuclear Regulatory Commission (NRC) issue resolution goal during this pre-licensing period is to ensure the U.S. Department of Energy (DOE) has assembled enough information on a given issue for NRC to accept a License Application for review. Resolution by the NRC staff during pre-licensing does not prevent anyone from raising any issue for NRC consideration during the licensing proceedings. Also, and just as important, resolution of an issue by NRC during pre-licensing does not prejudge the NRC staff evaluation of the issue during the licensing review. Issues are considered resolved by the NRC staff during pre-licensing when the staff have no further questions or comments about how DOE is addressing an issue. Pertinent new information could raise new questions or comments on a previously resolved issue.

This report summarizes the wording and history of Agreement Structural Deformation and Seismicity (SDS) 3.03, describes the relevance of the agreement to repository performance, and summarizes the current status of the agreement.

2.0 WORDING AND HISTORY OF AGREEMENT SDS.3.03

Agreement SDS.3.03 was reached at a meeting held October 11–12, 2000, to discuss the SDS Key Technical Issue (Schlueter, 2000). The wording of this agreement is as follows.

SDS.3.03. "The NRC needs to review the Fracture Geometry Analysis for the Stratigraphic Units of the Repository Host Horizon AMR. The NRC will provide feedback and proposed agreements to DOE, if needed, by December 2000."

The NRC staff reviewed the document, Fracture Geometry Analysis for the Stratigraphic Units of the Repository Host Horizon Analysis Model Report (CRWMS M&O, 2000), and stated that the information was not sufficient for NRC to conduct a licensing review (Reamer, 2001). The staff considered the relevant fracture data inadequate for a potential License Application without additional information. The results of this review are summarized in a report by Ferrill, et al. (2000) that was included with Reamer (2001), and the report specified eight additional information needed (AIN) items necessary to support a potential licensing review.

The eight AIN items specified for Agreement SDS.3.03 are:

Item 1 DOE needs to: (i) provide a technical basis for DOE's conclusion that fracture geometry parameter values for the repository host horizon are correct; (ii) provide a set of data corrected for these sampling biases along with a description of the methodology used for sampling bias correction; or (iii) risk-inform its results.

Item 2 DOE needs to provide a technical basis or rationale to support its extrapolation of fracture parameters to the repository footprint area that accounts for heterogeneities in the repository host horizon and uncertainties in the fracture characteristics and their distribution. This rationale should support models and calculations used to select the new emplacement drift alignment and for the key block analyses underway. Similarly, rationales should be developed to support the use of the active fracture model and calculations that import or abstract fracture spacing data from the repository host horizon fracture analysis model report. Alternatively, DOE would need to develop other viable fracture models and assess the range of results derived from consideration of the assumptions of variability and uncertainties or otherwise risk-inform its current extrapolation.

Item 3 DOE needs to provide a technical basis or rationale or both for its selection of fracture sets (i.e., sets based on orientation and lithology, rather than on origin) and provide statistics that represent the parameter distributions within each fracture set or risk-inform the aggregated characteristics.

Item 4 DOE needs to provide a technical basis or rationale or both for using a fracture-length database for various rockfall analyses and other calculations that is truncated at 1 m [3.3 ft]. This rationale should be provided to support DOE's key block analyses for the lower lithophysal unit of the Topopah Spring Tuff (Tptpll) that are underway. Alternatively, DOE could risk-inform the fracture-length database.

Item 5 DOE needs to describe the procedure for defining sets, explain the use of single-value orientations to represent fracture set mean orientations, provide statistics that represent the range or variation in orientation distribution within each fracture set, or risk-inform the fracture-orientation variation database.

Item 6 DOE needs to provide: (i) a technical basis for the method it used to measure fracture lengths in tunnels and drifts to support its conclusions; (ii) an assessment of the potential fracture shapes and their significance, if any, to performance; or (iii) risk-inform the results of DOE's fracture trace length and fracture shape data and assumptions.

Item 7 DOE needs to provide, in a transparent format, a distribution of orientations and related population statistics for subhorizontal fractures that it used or assumed for tunnel stability analysis or risk-inform the current uses or assumptions.

Item 8 DOE needs to provide a population statistical analysis—unit by unit, set by set—of the fracture data and results and provide the character statistics or risk-inform the current assumption.

By a letter dated October 30, 2001 (Brocoum, 2001), DOE submitted a table that summarized the eight AIN items requested by NRC, identified the documentation that was expected to address the information needs, and provided an expected submittal date to NRC for the documentation identified. The DOE indicated that the information to address all eight items would be included in a fracture analysis model report, with an expected submittal date of September 2003. In addition, DOE indicated that portions of items 5 and 6 would be addressed in a revision of the "Drift Degradation Analysis" report, ANL–EBS–MD–000027 (Bechtel SAIC Company, LLC, 2004) with an expected submittal date of September 2003.

3.0 RELEVANCE TO REPOSITORY PERFORMANCE

Agreement SDS.3.03 relates to DOE's characterization of fractures in the stratigraphic units of the repository host horizon. Each of the eight AIN items reflects a particular characteristic important to a feature, event, or process significant to waste isolation. Fractures are direct contributors to several integrated subissues, including:

- Mechanical Disruption of Engineered Barriers (ENG2)
- Climate and Infiltration (UZ1)
- Flow Paths in the Unsaturated Zone (UZ2)
- Flow Paths in the Saturated Zone (SZ1)
- Radionuclide Transport in the Saturated Zone (SZ2)

Further, fractures are important to other processes and events (e.g., drift degradation) and are, therefore, indirect contributors to several other integrated subissues:

- Degradation of Engineered Barriers (ENG1)
- Quantity and Chemistry of Water Contacting Waste Packages and Waste Form (ENG3)
- Radionuclide Transport in the Unsaturated Zone (UZ3)

Although fractures are not an explicitly considered feature in the Risk Insights Baseline Report (NRC, 2004), they are contributors to numerous risk significant features, events, and processes (FEPs). In particular, uncertainties in fracture characteristics (e.g., fracture orientations, intensity, size, and aperture distribution) contribute to uncertainties in other FEPs. Examples are shown in Table 1.

Table 1. Examples of Risk Insight Rankings and Their Significance to Waste Isolation for Processes Influenced by Uncertainties in Fracture Characteristics (Modified from NRC, 2004).

Effect of seepage on flow paths in the unsaturated zone	High significance
Effects of accumulated rockfall on mechanical disruption of engineered barriers	Medium significance
Effects of hydrological properties of the unsaturated zone on flow paths in the unsaturated zone	Medium significance
Effects of present-day net infiltration rate on climate and infiltration	Medium significance
Dynamic effects of rockfall on mechanical disruption of engineered barriers	Low significance

Each of the eight AIN items that NRC specified with regard to Agreement SDS.3.03 (Reamer, 2001) is important to one or more areas of waste isolation and overall repository performance.

Item 1 centers on orientation bias introduced by fracture-sampling strategies that employ a linear scanline technique, such as the detailed line survey data collected by DOE and its subcontractors in the Exploratory Studies Facility and the Enhanced Characterization of the Repository Block cross-drift. The DOE maintains that systematic correction is unnecessary (Bechtel SAIC Company, LLC, 2003). In addition, DOE has assumed that the full periphery geologic mapping data collected in the Exploratory Studies Facility and Enhanced Characterization of the Repository Block do not contain a fracture-orientation bias. Ferrill, et al. (2000) show that, while three-dimensional sampling along a cylinder (i.e., tunnel) is better than a simple scanline, the inequant shape and finite size of the cylinder still lead to bias in fracture orientation. As with the detailed line survey data, the full periphery geologic mapping undersamples fractures with orientations approximately parallel to the tunnel axis. The tunnels are nearly horizontal and, therefore, lead to a biased sample of features that are also close to horizontal (i.e., low-angle fractures). Consequently, the number and intensity of shallowly dipping fractures are not accurately represented by the detailed line survey or full periphery geologic mapping data. This error leads to uncertainty in the three-dimensional geometry of fractures in the repository host horizon stratigraphic intervals and fracture connectivity, which in turn, affects conceptual models of preferential flow paths in the unsaturated and saturated zones and the magnitude of drift degradation caused by rockfall.

Item 2 focuses on DOE's presumption that fracture characteristics are essentially homogeneous throughout the planned repository footprint, such that fracture data collected in the Exploratory Studies Facility and Enhanced Characterization of the Repository Block can be directly extrapolated to areas not yet characterized (CRWMS M&O, 2000; Bechtel SAIC Company, LLC, 2003). This assumption is used in repository design and has led DOE to select an emplacement drift orientation of approximately 072E. This drift orientation would provide the most stable tunnel configuration. The selected orientation is based on DOE's assumption that the high percentage of northwest-striking, steeply dipping fractures observed in the detailed line survey and full periphery geologic mapping data is representative of the entire repository footprint. In addition, DOE's analyses have presumed that the dominant control on variations in fracture characteristics is lithological and textural (i.e., presence or absence of lithophysae) (Bechtel SAIC Company, LLC, 2004). This assumption has an inadequate technical basis and, to date, DOE has not explored alternative controls such as geographic location, fault proximity, or volcanic bed thickness variations. This assumption influences conceptual models of the effects of accumulated rockfall on mechanical disruption of engineered barriers.

Item 3 questions DOE's methodology of selecting fracture sets solely on the basis of orientation modes without consideration of other characteristics such as relative timing of formation. The DOE has not formally responded to this item, but the most recently released version of the Drift Degradation Analysis report (Bechtel SAIC Company, LLC, 2004) includes a short discussion of the selection of fracture sets for the lithophysal intervals based on orientation and perceived time of formation. The low-angle fractures are extracted as a set, and the remaining steeply dipping fractures are separated by tracelength {<3 m [9.8 ft] versus >3 m [9.8 ft]} and then further subdivided by orientation. This approach is based on the assumption that the oldest fractures are the longest, because younger fractures are likely to terminate if they encounter a preexisting fracture. The justification, however, for the 3-m [9.8 ft] cutoff value is not fully addressed in the analysis model report. This methodology is not applied to the nonlithophysal intervals, and no explanation is provided. Item 3 is important because it leads to uncertainty in the three-dimensional geometry of fractures in the repository host horizon stratigraphic intervals and fracture connectivity, which in turn, affects conceptual models of preferential flow paths in

the unsaturated and saturated zones and the magnitude of drift degradation caused by rockfall.

Item 4 questions the appropriateness of a lower tracelength cutoff of 1 m [3.3 ft] for measurement (recording) of fractures. Although DOE has collected limited data about small fractures {i.e., tracelengths #1 m [3.3 ft]} via short horizontal {6 m [19.7 ft] long} and vertical {2 m [6.6 ft] high} traverses, DOE's investigators have not incorporated these data into the analyses because these data represent a small sample population. Although NRC acknowledged the inherent limitations of this data set, it suggested that further analyses were warranted because short fractures may be important contributors to rockfall processes in the lithophysal intervals (Ferrill, et al., 2000; Reamer, 2001). Furthermore, small fractures (in terms of both tracelength and aperture) are fundamental to processes such as flow in the unsaturated zone.

Item 5 requests that DOE document the rationale for selection of single values to represent the average orientation of each fracture set that is defined without explicit analysis of the variation in individual fracture orientations within a set. The uncertainty in fracture orientation (i.e., data spread around the average value) is not considered in DOE's analysis for drift degradation. In that analysis, DOE generated synthetic three-dimensional fracture populations using FRACMAN®, but used incorrect dispersion values to describe the variability in fracture orientation within a fracture set. These synthetic fracture populations form the primary input for 3DEC models of rockfall. By not correctly incorporating the natural variability of fracture orientation into the synthetic fracture-generation process, DOE is developing rockfall simulations that do not realistically represent the geologic conditions at the potential repository site. Failure to incorporate the orientation variability leads to underestimation of the number of rock blocks that fall because the number of fracture intersections (and, therefore, discrete rock blocks) is underestimated, which affects conceptual models of both the effects of accumulated rockfall and the dynamic effects of rockfall on mechanical disruption of engineered barriers.

Item 6 centers on the measurement of fracture tracelength and the assessment of fracture shape. The DOE did not characterize fracture shape (e.g., rectangular, circular, and elliptical) during the collection of detailed line survey or full periphery geologic mapping data in the Exploratory Studies Facility or Enhanced Characterization of the Repository Block. Drift degradation analysis calculations, however, were based on synthetic fracture geometries generated with fractures assumed to be circular (Bechtel SAIC Company, LLC, 2004). Fracture size (i.e., radius of the circle) was calculated by assuming that the radius was approximately two-thirds the observed fracture tracelength. The technical basis for this assumption has not been addressed by DOE, and the effect on analyses of related processes is unclear. For example, the FRACMAN®-generated synthetic fractures used as input for the 3DEC rockfall models could be unrealistically small, which might lead to underestimation of the spatial extent and overall volume of rockfall as well as the maximum block size. This error affects conceptual models of both the effects of accumulated rockfall and the dynamic effects of rockfall on mechanical disruption of engineered barriers.

Item 7 concerns DOE's treatment of shallowly dipping fractures. The DOE has assumed that the distribution of strike values for the low-angle fractures does not impact other analyses. These low-angle fractures, however, are important for rockfall analyses because it is the combination of low-angle and steeply dipping fractures that serve to control block formation because the low-angle fractures link to the steeply dipping fractures. The synthetic fracture geometries that DOE generates with FRACMAN® will not be statistically similar to the observed

fracture population unless a representative orientation distribution is employed. This error affects conceptual models of both the effects of accumulated rockfall and the dynamic effects of rockfall on mechanical disruption of engineered barriers.

Item 8 concerns the fracture data collected by detailed line survey and full periphery geologic mapping in the Exploratory Studies Facility and Enhanced Characterization of the Repository Block may not be representative of all parts of the potential repository site. In the absence of fracture data collected across the entire site, NRC requested that DOE provide a detailed statistical analysis of the fracture data according to stratigraphic interval and set so the inherent variability would be documented. Until the existing fracture data are fully understood, using the information in a predictive way for assessing areas not yet excavated is not supported by adequate technical bases.

4.0 SUMMARY

The DOE indicated that its responses to the eight AIN items contained in Agreement SDS.3.03 would be provided to NRC in either a fracture analysis model report (expected submittal September 2003) or a revision of the Drift Degradation Analysis report (expected submittal September 2003). The NRC staff are still awaiting DOE's fracture analysis model report. NRC has reviewed the most-recently released version of the Drift Degradation Analysis report (Bechtel SAIC Company, LLC, 2004), and this analysis model report does not provide responses to the eight AIN items.

5.0 STATUS OF THE AGREEMENT

Based on the staff review, the NRC staff conclude that DOE has not provided the information requested by Agreement SDS.3.03. It is up to DOE to decide how or whether to respond to the staff's feedback. The NRC will make its final determination on any issues relevant to licensing during review of any License Application.

6.0 REFERENCES

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