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TRANSMITTAL OF REPORT ADDRESSING KEY TECHNICAL ISSUE (KTI) AGREEMENT ITEM STRUCTURAL DEFORMATION AND SEISMICITY (SDS) 3.03

Reference: Ltr, Reamer to Brocoum, dtd 8/3/01

This letter transmits the report entitled, *Fracture Geometry for the Stratigraphic Units of the Repository Host Horizon,* to address the U.S. Nuclear Regulatory Commission (NRC) Request for Additional Information associated with Agreement Item SDS 3.03 sent in the referenced letter. The agreement is as follows:

> "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 U.S. Department of Energy (DOE) considers that the original agreement item has been completed. The NRC reviewed the Analysis and Model Report, *Fracture Geometry Analysis for the Stratigraphic Units of the Repository Host Horizon*, and provided comments and information needs in the referenced letter. The enclosed report addresses each of the information needs identified by the NRC in the referenced letter. The DOE intends to document the results of the additional fracture studies and further address the information needs, as described in Enclosure 1, in a new fracture report to be completed in June 2003. The DOE considers that it would be appropriate to close the original agreement and monitor progress on resolution of the information needs separately from the original agreement.

NMSS07
WM-11

This letter makes no new regulatory commitments. Please direct any questions concerning this letter and the enclosure to J. Timothy Sullivan at (702) 794-5589 or Timothy C. Gunter at (702) 794-1343.

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OL&RC:TCG-1350

Enclosure:
Fracture Geometry for the Stratigraphic Units of the Repository Host Horizon

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FRACTURE GEOMETRY FOR THE STRATIGRAPHIC UNITS OF THE REPOSITORY HOST HORIZON

June 2002

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FRACTURE GEOMETRY FOR THE STRATIGRAPHIC UNITS OF THE REPOSITORY HOST HORIZON

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ACRONYMS AND ABBREVIATIONS

AMR	Analysis/Model Report
DOE	U.S. Department of Energy
DRKBA	Discrete Region Key Block Analysis
ECRB	Enhanced Characterization of Repository Block
ESF	Exploratory Studies Facility
KTI	key technical issue
NRC	U.S. Nuclear Regulatory Commission
pdf	probability density function
Tptpll	Topopah Spring lower lithophysal zone
Tptpmn	Topopah Spring Tuff middle non-lithophysal zone
Tptpul	Topopah Spring Tuff crystal-poor upper lithophysal zone

FRACTURE GEOMETRY FOR THE STRATIGRAPHIC UNITS OF THE REPOSITORY HOST HORIZON

This report describes the basis to resolve and close information needs associated with the Structural Deformation and Seismicity Key Technical Issue (KTI) agreement item SDS 3.03. The agreement item is the U.S. Department of Energy (DOE)-U.S. Nuclear Regulatory Commission (NRC) agreement (Gardner 2000 [DIRS 154287]) that the NRC needs to review the Analysis/Model Report (AMR), Fracture Geometry Analysis for the Stratigraphic Units of the Repository Host Horizon. The NRC was to provide feedback and proposed agreements, if needed, to DOE. The NRC provided feedback in the form of eight information needs (Reamer 2001).

This report addresses each of the information needs and describes a revised approach for rockfall analysis that DOE has implemented.

1. BACKGROUND

The DOE submitted the AMR, Fracture Geometry Analysis for the Stratigraphic Units of the Repository Host Horizon (CRWMS M&O 2000 [DIRS 152286]), to the NRC for review and comment. After reviewing the document, the NRC determined that the information in the AMR was not sufficient for NRC to conduct a licensing review and requested additional information (Reamer 2001). The following summaries are based on descriptions documenting the NRC's information needs (Reamer 2001).

1.1 NRC COMMENTS AND INFORMATION NEEDS

NRC has expressed concerns that some DOE justifications for fracture-related issue closures were based on assertions of conservatism. For example, NRC has suggested that in the absence of direct measurements of fracture characteristics, DOE should provide a technical basis for fracture-related parameters used in process models. For rockfall analysis, the NRC noted that fracture length bias for largest fractures based on tunnel data has not been corrected by the analysis of full-periphery geometric mapping data (Gardner 2000 [DIRS 154287]).

Further, the NRC noted (Reamer 2001, page 4), "The technical bases for the analyses of key blocks to determine rockfall size and locations and the calculations of the angle of intersection of drift alignments with dominant fracture traces used to select the emplacement drift orientation that rely on the key fracture parameters in this AMR [Fracture Geometry Analysis for the Stratigraphic Units of the Repository Host Horizon] would be inadequate for a potential license application review. The NRC identified eight specific topics for which additional information is needed to support a licensing review."

1.1.1 Directional Bias (Reamer 2001, page 5)

The staff indicated that the combined effect of two sampling biases – orientation and length – associated with cylindrical sampling surfaces was not eliminated, and bias remains in the fracture data and derived parameters for the repository host horizon.

Information Need: *DOE needs to provide a technical basis for the conclusion that fracture geometry parameter values for the repository host horizon are correct, or provide a set of data corrected for the sampling biases along with a description of the methodology used for the sampling bias correction, or risk inform its results.*

1.1.2 Representativeness of Fracture Parameters (Reamer 2001, page 5)

The staff position is that DOE has not demonstrated that the causes of variability in fracture orientation, length, and spacing from the sample sites in tunnels and drifts are likely to be present and similarly distributed in the repository area.

Information Need: 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 should be done to 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 AMR.

Alternatively, DOE would need to develop alternative 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.

1.1.3 Misrepresentation of Aggregated Fracture Characteristics (Reamer 2001, page 6)

DOE fracture sets (within each lithologic unit) were defined based on orientation modes, without reference to the origin or timing of fracture formation. In the current DOE approach, joints of the same orientation produced by cooling, tectonic, and excavation processes would all be lumped into the same set. Key differences of fracture characteristics (such as bimodal size distributions and limited volumetric distribution due to origin) will tend to be misrepresented by statistically defining sets based on orientation along and averaging other fracture parameters. Misleading statistical representation of fracture sets can result from DOE's categorization.

Information Need: *DOE needs to provide a technical basis/rationale 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.*

1.1.4 Fractures Over One-Meter in Length (Reamer 2001, page 6)

The staff indicates that there is a limited data set of fracture characteristics for fractures less than one meter trace length since DOE did not include these fractures in the analysis because they were not sufficiently representative. The DOE approach to rockfall analysis (regarding fracture length) appears to be appropriate for rock units with small fracture spacings. However, for a rock unit such as Topopah Spring lower lithophysal (Tptpll), it may be inappropriate. Citing Hsiung et al. (2001), the staff noted that by including fractures with trace length smaller than one meter for the Tptpll, more blocks and relatively larger size key blocks (than for other units) may develop. Therefore, the assumption could cause DOE to underestimate the rockfall potential for the Tptpll rock unit.

Information Need: *DOE needs to provide a technical basis/rationale for using a fracture-length database for various rockfall analyses and other calculations that is truncated at one-meter. This should be done to support DOE key block analyses for the Tptpll unit that are underway. Alternatively, DOE could risk-inform the fracture-length database.*

1.1.5 Orientation Variation Within Fracture Sets (Reamer 2001, page 6)

The staff notes that DOE reported a single mean orientation of all fractures in a set to represent that particular set. The statistics were based on pole-vector concentrations observed in contour plots of stereographic projections of the poles of joint (fracture) planes. Little or no consideration was given to the effect of joints that deviated from the mean in the dominant, or subordinate, joint sets in key block analyses or in the reanalyses of the alignment of emplacement drifts.

Analyses of tunnel stability underestimate rockfall potential when variations in joint orientation are not considered in the analyses. The AMR [Fracture Geometry Analysis for the Stratigraphic Units of the Repository Host Horizon] is the source of joint data for key block and other analyses of tunnel and rift stability, but does not provide a reviewer sufficient details to independently evaluate the DOE conclusion or assumption concerning the variability of orientation within joint sets. Specifically, DOE did not discuss: (i) the method used to determine the mean orientations; (ii) the selection process used to identify subpopulations of orientations for the determination of particular orientation modes for each rock unit; and (iii) the "spread" of the orientation modes and how the spread (variation and deviation from the mean) was defined.

Information Need: *DOE needs to describe the procedure for defining sets, explain the use of single-value orientations to represent fracture set mean orientation, provide statistics that represent the range or variation in orientation distribution within each fracture set, or risk-inform the fracture-orientation variation data-base.*

1.1.6 Fracture Trace Length and Fracture Shape (Reamer 2001, page 7)

The staff noted that DOE measured the trace length of fractures that intersect the cylindrical exploratory studies facility and cross drift tunnel walls (i.e., curvilinear trace length). DOE did not describe its concept of the overall shape of fractures (e.g., circular, rectangular). The staff noted that curvilinear trace length tends to overestimate the size of larger fractures relative to smaller ones, because of the increased absolute effect of tunnel wall curvature on larger fractures. Curvilinear traces of fractures intersecting cylinders vary considerably as the angle of intersection of the fracture plane with the cylinder axis varies from near zero (fractures paralleling tunnel axis) to ninety degrees (fractures perpendicular to tunnel axis), for the same size fractures. Neither of these measurement effects were addressed in the AMR.

The selection of fracture shape as a factor in an analysis has not been justified. The shape effect of fractures that span the entire thickness of a rock unit is of some importance because a particular shape – circular – was assumed for key block analysis.

Information Need: *DOE needs to provide (1) a technical basis for the method it used to measure fracture lengths in tunnels and drifts to support its conclusions; (2) an assessment of the potential fracture shapes and their significance, if any, to performance; or (3) risk-inform the results of its fracture trace length and fracture shape data and assumptions, respectively.*

1.1.7 Strikes of Shallowly-Dipping Fractures (Reamer 2001, page 7)

The staff noted that DOE stated that strike was not considered since it is of little interest to tunnel stability when examining subhorizontal fractures. The staff disputed this position by noting that the pattern of displacement on shallowly-dipping fractures under thermal and seismic perturbations is sensitive to fracture strike and dip directions. Citing Ofoegbu et al. (2001), the staff asserted that subhorizontal fractures are expected to be particularly important contributors to roof collapse.

Information Need: *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.*

1.1.8 Statistical Significance of Fracture Populations in the Exploratory Studies Facility and Enhanced Characterization of Repository Block

The staff noted that DOE's numerical analyses of fracture parameters stated the number of samples used in each analysis and that DOE assumed that the number of samples studied was sufficient to conclude statistical significance or representativeness of the sample populations. However, DOE did not discuss the statistical uncertainty associated with the assumptions that the sample populations are representative or statistically significant.

Information Need: *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.*

1.2 DEFINITION OF TECHNICAL TERMS

Discrete Region Key Block Analysis (DRKRB)–A numerical code for probabilistic key block analysis. This code was used in the Drift Degradation Analysis AMR (BSC 2001 [DIRS 156304]).

Devitrification—A process by which glassy components of rocks are transformed into definite minerals, which are usually minute and are chiefly quartz and feldspar.

Lithophysae—Hollow or partially filled cavities in tuffs that represent former gas pockets.

Topopah Spring Tuff lower lithophysal zone (Tptpll)—Densely welded, devitrified, generally purplish gray to brownish gray tuff with 1-7 percent lithophysae. Varies in thickness from 69 to 104 m.

Topopah Spring Tuff middle non-lithophysal zone (Tptpmn)—Densely welded, devitrified, generally grayish-orange pink to light brown tuff with 0-5 percent lithophysae. Varies in thickness from 29 to 38 m.

Topopah Spring Tuff crystal-poor upper lithophysal zone (Tptpul)—Moderately to densely welded, devitrified, generally light gray to purplish gray tuff with 2 to 40 percent lithophysae. Varies in thickness from 46 to 77 m.

3-Dimensional Distinct Element Code (3DEC)—A numerical code for three-dimensional, dynamic modeling of rockfall.

2. APPLICABLE NUCLEAR SAFETY STANDARDS/REQUIREMENTS/GUIDANCE

Rockfall analyses are expected to be included in analyses that support the repository postclosure performance assessment. The Yucca Mountain disposal regulations include a requirement to provide the technical basis for models used in the performance assessment (10 CFR 63.114(g)).

2.1 APPLICABLE REQUIREMENTS

Overlapping concerns apply to the issue of the geometry of fractures for the stratigraphic units of the repository host horizon. The original provision is in the form of agreement SDS 3.03 associated with subissue 3, Fracturing, of the Structural Deformation and Seismicity Key Technical Issue (Gardner 2000 [DIRS 154287]). This agreement is included in Section 2.2. The other provisions are in the form of the information needs specified in the NRC's request for information (Reamer 2001). These information needs are described in Section 1.1 (items 1.1.1 through 1.1.8).

2.2 KTI AGREEMENT

The following KTI agreement statement is based on the Summary Highlights of the NRC/DOE Technical Exchange and Management Meeting on Structural Deformation and Seismicity that occurred on October 11-12, 2000 (Gardner 2000 [DIRS 154287]).

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.

3. BASIS FOR REGULATORY COMPLIANCE STATEMENT

The primary end-users of the fracture geometry information are structural stability studies of rockfall and long-term drift degradation. Previous studies of rockfall potential (BSC 2001 [DIRS 156304]) were based on the use of a "keyblock" analysis approach in which the fracture geometry (dip, dip direction, spacing, trace length and relative position along the drift axis) were input as probability density functions (pdf's). The pdf's were derived from detailed line mapping and full periphery mapping in the Exploratory Studies Facility [ESF] and the Enhanced Characterization of the Repository Block [ECRB] for fractures with a trace length greater or equal to 1 m. Fractures were grouped into three sets, two with high dip angle (about 80°) and another with shallow dip (less than 30°) combining the vapor phase partings and less-regular flat-lying fractures. Fracture distributions were randomly generated from the geometric pdf's, and blocks formed in a region around the drift. Kinematically removable blocks were then identified from the set of all blocks, and checked for gravitational force-balance equilibrium using friction angle and cohesion for each set. Since the keyblock program is based on a static analysis method assuming gravitational forces only, there is no provision for accounting for either in-situ stresses (which tend to stabilize the tunnel through development of confinement) or dynamic loading. In these analyses, the effects of seismic accelerations were accounted for in an approximate fashion by adjusting the surface strength properties of the fractures.

DOE has now replaced this keyblock approach with numerical approaches in which the fracture structure, in-situ stresses and site-specific ground motions are represented explicitly by the model. These numerical approaches are described in Subsection 3.2.

3.1 BACKGROUND

The current approach to rockfall and drift degradation is to use numerical methods to represent the rock-mass geologic structure and dynamic forces introduced by seismicity. The two predominant rock types that comprise the repository – the middle nonlithophysal unit, and the lower lithophysal unit – are expected to behave in mechanically-distinct fashions. The middle nonlithophysal unit is characterized by hard, intact rock cut by several sets of fractures (Mongano, et al. 1999 [DIRS 149850]). It is expected that failure of this rock will be via movement and fall-out of blocks formed by the fractures rather than stress-related yield of the intact rock itself. The lower lithophysal unit, however, is characterized by abundant lithophysal cavities (averaging approximately 20 percent by volume) and abundant, small-scale fracturing between lithophysae (small-scale fracture study) (GS990908314224.009 [DIRS 146877]). It is expected that failure mode and block-size distribution within the lower lithophysal unit will be controlled by the lithophysal porosity and the small-scale fracturing rather than the less frequent, continuous fractures. Observations in the ESF and ECRB support these ideas. These observations show that occasional keyblocks were formed during original tunneling operations in the nonlithophysal units, whereas yield in the lower lithophysal unit is characterized by loosening of the skin of the opening along the inter-lithophysae fractures. In contrast, therefore, to the middle nonlithophysal unit, it is expected that the yield of the lower lithophysal unit will be stress-controlled rather than a result of keyblock formation on major through-going structures. This behavior may be amenable to description using a more standard two-dimensional approach that combines the effects of the small-scale fractures and lithophysae into an equivalent rock-mass constitutive model. Current, on-going in-situ compression testing will determine the applicability of this approach.

The type of numerical approach required may need to be different for these two basic rock types. In the middle nonlithophysal unit, where failure is controlled by keyblocks, a true three-dimensional, dynamic, discontinuum modeling approach is appropriate. The 3DEC program will be used for the analysis. It is DOE's intention to utilize the fracture geometry statistics from the full-periphery mapping and detailed line surveys (with modifications or verifications as described below) as basic input to utilities that generate block geometries around the tunnel. Additionally, the project is analyzing the existing data to explore the general nature of fracture terminations and their relationship to fracture-trace length. The fractures in the middle nonlithophysal unit generally have relatively short trace lengths, and often terminate either in solid rock or against other fractures. The result is that the fracturing is highly discontinuous in nature, with abundant solid rock "bridges" between fracture traces. Additionally, the fracture surface and large-scale roughness have been described during the mapping. In particular, the large-scale roughness (meter scale) may be of importance in defining strength properties. The amplitude and wavelength of these features, as well as the small-scale (10-20 cm) roughness is also determined.

In the lower lithophysal unit, where the behavior is expected to be more-or-less homogeneous as described above, a two-dimensional approach, based either on a continuum-based constitutive model or on a discontinuum approach are possibilities. Final determination will be made as in-situ and laboratory testing is completed this fiscal year.

The advantages of this approach to rockfall prediction are:

- The modeling proposed is based on dynamic numerical formulations – no assumptions are made regarding application of dynamic loading.
- Properties of fractures are assigned on a set-by-set basis.
- Application of site-specific ground motions.

The disadvantages of this approach are:

- The models are deterministic in nature and require long run times to simulate site specific ground motions.
- To create probabilistic output will require a large number of simulations.

3.2 SAFETY/TECHNICAL BASIS FOR THE COMPLIANCE DEMONSTRATION

DOE intends to address these issues as part of the on-going drift degradation studies, which includes completion of a new report that will describe the fracture and lithophysal characteristics in units of the repository host horizon. DOE expects this report to be available by June 2003. The following discussion addresses each of the information needs previously described in Sections 1.1.1 through 1.1.8.

3.2.1 Directional Bias

The directional bias issue will be addressed in two ways. First, a correction factor will be applied to the detailed line mapping results to examine bias occurring due to the orientation of the drift and its impact on fractures that strike in a sub-parallel fashion. Second, fracture mapping data obtained from the numerous alcoves (driven perpendicular to the main drift) as well as surface outcrop mapping of the units, conducted in Solitario Canyon, will be added to the database. This total data set is being examined to determine if other fracture sets or orientations have been improperly represented in the statistical treatment of the data.

3.2.2 Representativeness of Fracture Parameters

A large data set of fractures has been compiled describing the middle nonlithophysal unit in the Exploratory Studies Facility and the Enhanced Characterization of the Repository Block cross drift. Block formation in this unit is controlled primarily by larger trace length fractures (i.e., those with trace lengths >1m). The ESF facility borders a significant extent of the proposed repository emplacement area and thus provides a database far exceeding most tunneling, and underground civil construction projects. Recent surface mapping of repository unit exposures in Solitario Canyon to the west and WT-11 Wash to the south of the repository block has indicated fracture orientation is consistent with the ESF measurements. DOE intends to develop a new report that would describe the fracture and lithophysal characteristics in units of the repository host horizon and would include these data. DOE expects the report to be available by June 2003. Additionally, fracture interpretation from the ECRB (Mongano et. al. 1999 [DIRS 149850]) would be added to the new report. Description of the short length fractures in the lower lithophysal unit would be discussed as a basis for estimation of potential rockfall block sizes in this unit.

3.2.3 Misrepresentation of Aggregated Fracture Characteristics

Most of the fracturing originated from cooling with some re-mobilization due to tectonism. A detailed understanding of the cooling origins and tectonic re-activation history of the fracturing of the units is not needed in design, or performance calculations or assessments. The hydrologic models used in performance assessment are based on equivalent continuum models that are not based on the detailed history of fracture formation, but on direct field measurements. The fracture characterization used as a basis for the rockfall and drift degradation studies are based on field mapping with subsequent analysis of the variability of dip, dip direction, trace length, spacing, fracture terminations, fracture-surface roughness, large-scale planarity, etc. The particular origin of these fractures is not a requirement for estimation of the blocks formed from these fracture sets. DOE is re-examining how the fractures have been grouped into sets, largely by azimuth and dip, to determine if physical features dictate that a greater number of independent sets should be used in the rockfall studies.

3.2.4 Fractures Over One-Meter in Length

DOE is currently studying the effects of fractures of less than one meter in length, primarily in the lower lithophysal zone (See Section 1.2 for descriptions of units). As stated in Subsection 3.1, DOE agrees that a large population of short length (inter-lithophysae) fractures exist in the lower lithophysal zone, and these fractures could effect drift degradation mode, and rockfall size and amount. DOE intends to develop a new report that would describe the fracture and lithophysal characteristics in units of the repository host horizon and would include information about the abundance and orientations of fractures. DOE expects the report to be available by June 2003. The effect of these fractures on rock-mass mechanical properties and failed block dimensions will be determined through in-situ flatjack compression tests (performed to failure) in areas within the lower lithophysal zone and upper lithophysal zone that have varying short-fracture length content in the groundmass. Field observation clearly indicates that the abundant nature of these short fractures in the lower lithophysal zone will lead to rockfall characterized by relatively more, but smaller blocks (i.e., on the order of cm side lengths) in comparison to the middle non-lithophysal zone. According to the current plan, this observation will be verified in the analyses leading to the revision of the Drift Degradation analysis report, which is expected to be available in the last half of FY 2003.

Additionally, DOE is examining the impact of short fractures on the size of solid rock "bridges" between joint traces. It is possible that short fractures could join together with longer fractures when stressed if the intervening rock bridges should fail. Thus, wedges could possibly form that are a complex combination of longer joints and small, discontinuous joints. This phenomenon has not been observed in the ECRB where only 5 total wedges have actually detached during the tunneling operations. However, DOE is now performing studies to generate a picture of the occurrence of rock bridges and how they might impact the importance or necessity of accounting for them in the middle non-lithophysal zone. DOE intends to document the results of these studies in report describing the fracture and lithophysal characteristics of the units of the repository host horizon. DOE expects the report to be available by June 2003.

3.2.5 Orientation Variation Within Fracture Sets

Orientation variation within a set will be accounted for in the block generation for the 3DEC (e.g., Itasca, 1998) analyses which form the basis for the rockfall calculations in the middle non-lithophysal zone. Fracture orientation will be described, within each set, by a probability density function that will be sampled during block generation. The probability density function is developed directly from the underground mapping. DOE intends to develop a new report that would describe the fracture and lithophysal characteristics in units of the repository host horizon and would include the procedures employed and their impact on block size distribution. DOE expects the report to be available by June 2003.

3.2.6 Fracture Trace Length and Fracture Shape

The large population of fractures sampled in the ESF and ECRB provides a representative sampling of fracture lengths, since the mean fracture length for each set is a fraction of the diameter of intersection of the tunnel. In other words, the tunneling has sampled sufficient fractures that have intersected the tunnel at various locations along the fracture planes that we have a database that represents the range of fracture lengths.

To define the actual distribution of trace lengths, DOE is conducting some simple analytical studies of the impact of assumed fracture radius (for circular disks) and side length (for rectangular fractures) on the intersection length of the fracture and tunnel walls. Using detailed line mapping data, random fractures can be generated from the probability density functions that describe the fracture geometry (i.e., dip, dip direction, spacing, and lateral offset of the fracture centroid along the tunnel wall). Assuming a tunnel of 5.5 m diameter is excavated through this array of fractures, the intersection of fracture and tunnel wall (the curvilinear trace length) can be determined. The fracture radius (disks) and side length (rectangles) can then be varied and the impact on the curvilinear trace length determined. The actual fracture radius or side length can be varied to achieve agreement between field and analytical results. This process identifies the actual trace length (i.e., the disk radius or rectangle side length) that accounts for the field-measured data. Initial studies documented in the Drift Degradation Analysis report (BSC 2001 [DIRS 156304]) estimated fracture disk radius by conducting a parameter study in which the radius was varied until a rough match in the number, size and location of obvious keyblocks formed compared to the DRKBA program was obtained. The results of that work will be compared to the current approach described above. DOE intends to document the results in an update of the Drift Degradation analysis report, which is expected to be available in the last half of FY 2003.

Additionally, the "height" and "width" of each fracture (as determined by the length of perpendicular lines connecting the ends of the trace of the fracture on the tunnel wall) was measured in the field to give an indication of the true size of the fracture. DOE intends to develop a new report that would describe the fracture and lithophysal characteristics in units of the repository host horizon and would also describe the above studies. DOE expects the report to be available by June 2003.

3.2.7 Strikes of Shallowly-Dipping Fractures

DOE recognizes the importance of shallow-dipping discontinuities in analyses of the potential for roof collapse. In analyses reported in *Fracture Geometry Analysis for the Stratigraphic Units of the Repository Host Horizon* (CRWMS M&O 2000 [DIRS 152286]), features with dips less than 30 degrees were combined into one set. The analysis showed that these fractures have a moderately adverse effect on tunnel stability, regardless of the strikes of the fractures. As noted here, the seismic rockfall modeling will be based on use of the 3DEC program – a three dimensional discontinuum numerical approach. The basic input to this model are the histograms of the dip, dip direction, trace length, etc., gained from the full periphery and detailed line mapping of joints in the ESF and ECRB. DOE will consider the full range of strikes of shallowly-dipping fractures used as input to the 3DEC modeling; in other words, no "filtering" of the joint strike is being used when developing input to the model.

3.2.8 Statistical Significance of Fracture Populations in the Exploratory Studies Facility and Enhanced Characterization of the Repository Block

DOE notes that the Yucca Mountain fracture database consists of approximately 35,000 fracture measurements, and that the degree of fracture characterization at Yucca Mountain far exceeds that done in typical tunneling projects. Fracture mapping of the tunnels in the ESF provides a high degree of confidence that the full range of fracture characteristics anticipated in the emplacement drift horizon has been sampled. This database will be supplemented by recent surface mapping of repository unit outcrops observed to the west of the repository block in Solitario Canyon and to the south of the repository block in WT-11 Wash. . DOE intends to develop a new report that would describe the fracture and lithophysal characteristics in units of the repository host horizon and would also document this supplemental data. DOE expects this report to be available by June 2003.

4. SUMMARY

DOE considers that the original agreement item has been completed. DOE provided the AMR, *Fracture Geometry Analysis for the Stratigraphic Units of the Repository Host Horizon* (CRWMS M&O 2000 [DIRS 152286]), to the NRC for review. The NRC reviewed the document and provided comments and requests for information in a letter (Reamer 2001). DOE considers that it would be appropriate to close the original agreement and monitor progress on resolution of the information needs separately from the original agreement.

DOE has developed a new approach for rockfall and drift degradation analyses. Previous studies of rockfall potential (BSC 2001 [DIRS 156304]) were based on the use of a "keyblock" analysis approach in which the fracture geometry (dip, dip direction, spacing, trace length and relative position along the drift axis) were input as probability density functions. The current approach to rockfall and drift degradation is to use numerical methods to represent the rock-mass geologic structure and dynamic forces introduced by seismicity. The two predominant rock types that comprise the repository – the middle nonlithophysal unit, and the lower lithophysal unit – are expected to behave in mechanically-distinct fashions. The middle nonlithophysal unit is characterized by hard, intact rock cut by several sets of fractures (Mongano et al. 1999 [DIRS 149850]). It is expected that failure of this rock will be via movement and fall-out of blocks formed by the fractures rather than stress-related yield of the intact rock itself. The lower lithophysal unit, however, is characterized by abundant lithophysal cavities (averaging approximately 20 percent by volume) and abundant, small-scale fracturing between lithophysae (small-scale fracture study) (GS990908314224.009 [DIRS 146877]). It is expected that failure mode and block-size distribution within the lower lithophysal unit will be controlled by the lithophysal porosity and the small-scale fracturing rather than the less frequent, continuous fractures. Observations in the ESF and ECRB support these ideas. These observations show that occasional keyblocks were formed during original tunneling operations in the nonlithophysal units, whereas yield in the lower lithophysal unit is characterized by loosening of the skin of the opening along the inter-lithophysae fractures. In contrast to the middle nonlithophysal unit, the yield of the lower lithophysal unit is expected to be stress-controlled rather than a result of keyblock formation on major through-going structures.

5. REFERENCES

5.1 DOCUMENTS CITED

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5.2 CODES, STANDARDS, REGULATIONS, AND PROCEDURES

10 CFR 63. Energy: Disposal of High-level Radioactive Wastes in a Geologic Repository at Yucca Mountain, Nevada. Readily available.

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