CNWRA *A center of excellence in earth sciences and engineering*

A Division of Southwest Research Institute
6220 Culebra Road • San Antonio, Texas, U.S.A. 78228-5166
(210) 522-5160 • Fax (210) 522-5155

December 27, 2000
Contract No. NRC–02–97–009
Account No. 20.01402.471

U.S. Nuclear Regulatory Commission
ATTN: Dr Philip Justus
Division of Waste Management
TWFN (Mail Stop 7–C6)
Washington, DC 20555

Dear Dr. Justus,

Enclosed is the Center for Nuclear Waste Regulatory Analysis deliverable AI 1402.471.131 - Review of AMR entitled "Fracture Geometry Analysis for the Stratigraphic Units of the Repository Host Horizon." This deliverable is in response to the commitment made by NRC at the October 11-12, 2000 Technical Exchange and Management Meeting on Structural Deformation and Seismicity (SDS). At that meeting NRC agreed to provide DOE with comments on the Fracture Geometry Analysis for the Stratigraphic Units of the Repository Host Horizon AMR (ANL-EBS-GE-000006 REV 00). This review identified several areas of concern related to assumptions made by DOE in the analysis of fracture data from the Experimental Studies Facility and the Cross Block Drift, methodology of data analysis, and resulting fracture parameters. The assessment of these concerns with regards to performance is not discussed, as they need to be addressed by the appropriate KTIs.

If you have any questions please contact Dr. David A. Ferrill at 210 522 6082 or me at 210 522 5183.

Sincerely yours,

H. Lawrence McKague
GLGP Manager

HLM/cw

cc:
J. Greeves
J. Holonich
W. Reamer
D. DeMarco
B. Meehan
J. Linehan (w/o enclosure)
N. Stablein
D. Brooks
T. Essig
S. Wastler
B. Leslie
W. Patrick
CNWRA Directors
CNWRA Element Managers
J. Stamatakos
A. Morris
W. Dunne
S. Hsiung
G. Ofoegbu
D. Sims
T. Nagy (SwRI Contracts)
P. Maldonado

Washington Office • Twinbrook Metro Plaza #210
12300 Twinbrook Parkway • Rockville, Maryland 20852-1606

REVIEW OF AMR ENTITLED "FRACTURE GEOMETRY ANALYSIS FOR THE STRATIGRAPHIC UNITS OF THE REPOSITORY HOST HORIZON"

Prepared for

Nuclear Regulatory Commission
Contract NRC–02–97–009

Prepared by

D. Ferrill[1]
W. Dunne[2]
S. Hsiung[1]
A. Morris[3]

[1] Center for Nuclear Waste Regulatory Analyses
San Antonio, Texas

[2] Department of Geological Sciences
The University of Tennessee, Knoxville, Tennessee

[3] Department of Earth and Physical Sciences
The University of Texas at San Antonio, San Antonio, Texas

December 2000

CONTENTS

Section Page

ACKNOWLEDGMENTS

This review was prepared as the result of work performed at the Center for Nuclear Waste Regulatory Analyses (CNWRA) for the U.S. Nuclear Regulatory Commission (NRC) under contract number NRC-02-97-009. This report is an independent product of the CNWRA and does not necessarily reflect the views and regulatory position of the NRC. We thank Rebecca Emmot and Christina Weaver for assistance in report preparation. We thank John Stamatakos, Larry McKague, and Budhi Sagar for technical reviews that greatly improved the report.

1 GENERAL COMMENTS

The purpose of the analysis model report (AMR), entitled Fracture Geometry Analysis for the Stratigraphic Units of the Repository Host Horizon (CRWMS M&O, 2000b), is to evaluate fracture orientations, spacings, and trace lengths in the four lithostratigraphic units that comprise the repository host horizon for the proposed high-level radioactive waste repository at Yucca Mountain, Nevada. Specifically, the analysis is intended to constrain input parameters for key block analysis included in the drift degradation analysis report. This report provides the most complete analysis to date of these input parameters and represents a significant advance in analysis of fracture data from the Exploratory Studies Facility (ESF) and the Cross-Block Drift (CBD).

As part of the agreement between the NRC and DOE resulting from the NRC/DOE Technical Exchange and management meeting on Structural Deformation and Seismicity (October 11–12, 2000), we were tasked with providing the NRC and DOE a review of the AMR. Our review identified several points in need of clarification or elaboration. Section 5 of the AMR asserts that "No assumptions were made as part of this AMR," however we have identified seven implicit or explicit assumptions that lack proof or sound technical bases in the document or elsewhere. These are:

(i) Volume sample from Full-Periphery Geologic Mapping (FPGM) eliminates "directional bias."

(ii) Fractures in the ESF and CBD are representative of fracturing throughout the proposed emplacement volume at Yucca Mountain.

(iii) Lithology is the sole influence on "fracture set" characteristics.

(iv) Consideration of only fractures over 1 m in length is representative or perhaps conservative with respect to rockfall.

(v) Orientation variation within fracture sets is not important in tunnel stability analysis.

(vi) Curvilinear trace length measured along the tunnel walls is a representative measure of fracture size (length).

(vii) Strike (dip direction) of shallowly dipping (<30°) fractures is not important to tunnel stability.

In light of these unsupported assumptions, the conclusion that the resulting parameters represent fracture characteristics throughout the proposed emplacement volume are insufficient for issue closure.

The following specific comments detail our concerns. They provide suggestions for more thorough analysis and elaboration in future revisions of this AMR or that should be addressed in other documents.

2 SPECIFIC COMMENTS

1. In section 6.2.3 (second and third paragraphs) on page 18, the report states that "fracture orientation measurements collected in a 3D volume (i.e., FPGM) do not have this inherent [directional] bias because fractures in every possible orientation are measured." This statement is not correct. The size and shape of the sampling volume relative to fracture network characteristics such as fracture size, spacing, and orientation has an important influence on sampling bias. If characterization of only the most abundant and small fractures is the purpose of the study, then the FPGM approach may be sufficient. This type of characterization actually seems to be the point of the whole AMR, although it is not explicitly stated anywhere.

Specifically, the assumption that the volume sample from FPGM eliminates directional bias (p. 16, last paragraph, bottom of page) is incorrect because of the combined effect of two sampling biases with respect to the cylindrical sampling geometry. Although three-dimensional sampling along a cylinder is advantageous over scanlines, the cylinder is an inequant shape of finite size. Consequently, orientation and length biases persist:

(i) Orientation bias—the relative orientation of fractures with respect to the cylinder axis biases the sample. Specifically, fractures normal to the axis are sampled more than fractures parallel to the axis.

(ii) Length bias—the relative length of fractures biases the sample. Specifically, a long fracture is more likely to be sampled than a short fracture in the same orientation.

To focus this line of thought, let us consider a 100m × 100m × 100m cube centered on the tunnel axis (ESF) with two sides vertical and parallel to the tunnel, two sides vertical and perpendicular to the tunnel, and two sides horizontal. Simplify the tunnel geometry by assuming a horizontal tunnel with a diameter of 8 meters. Consequently, in the cube, the tunnel samples a 100m × 8m (diameter) region. Consider two cases (Case 1: maximum bias for 100m length of tunnel, and Case 2: minimum bias for 100m length of tunnel). For both cases, let us assume that two orthogonal sets of vertical joints are present, and that each set has 100 joints. One joint set is perpendicular to the tunnel axis, and the other set is parallel to the tunnel axis.

Case 1: fracture size = 100m × 100m for each set, fracture spacing is 1m, and all joints are fully contained in the 100m × 100m × 100m cube. The tunnel would sample 100 of the axis-perpendicular traces vs. 8 or 9 of the axis-parallel traces. This sampling bias produces an error of more than an order of magnitude in the relative abundances of the two sets. Comparing fractures parallel and perpendicular to cylinder axis maximizes the effect of orientation bias, and this bias is sensitive to fracture size (bias increases with increasing fracture size).

Case 2: fracture size = 1m × 1m and all joint centers are fully contained in the cube. Assuming an independent Poisson distribution for fracture centers, portions of the fractures normal to the tunnel axis are more likely to be sampled than fractures parallel to the axis. The error is less than an order of magnitude because the fractures are noticeably smaller (both in absolute size and with respect to the tunnel diameter than in Case 1), but the bias remains. The significance of the combined orientation and length bias for samples from the tunnel wall cannot be assessed until the mathematical relationship describing their effect is derived.

2. The report does not address the representativeness of the fracture parameters provided in this AMR with respect to the entire proposed emplacement area at Yucca Mountain. The report states that the fracture data collected by the USGS/USBR as part of the FPGM and DLS programs is the best available subsurface data for analyzing the orientation, frequency, and trace lengths of fractures in the rock mass at Yucca Mountain (p. 14). It seems that this report implicitly equates "best available" with "representative" by not discussing representativeness of data in the report.

For example, consider the statement in section 7 (first paragraph) on page 35 that "...this AMR provides input for selecting the orientation of the emplacement drifts used in the design of the potential repository." How? Does the sampled volume coincide with the proposed repository volume? If not, how will this data be extrapolated to the proposed repository volume in order that it can be used as valid input for repository design? In connection with this question there are a number of issues that need additional documentation and technical support:

(i) Are fracture data presented in this AMR homogeneous with respect to geographic position? For example what percentage of the orientation data for the Tptpmn is from the "intensely fractured zone" of the ESF with its NW mode? If this percentage is large, is it possible that this orientation mode is related to position and fracture origin (tectonic or volcanogenic) rather than lithostratigraphy. If fracture characteristics arise from origin as much as lithology, then the existing data cannot be used to develop a distinctive modal orientation signature for the Tptpmn. Rather the data reflect a mode related to a particular origin in a particular rock volume within the mountain.

What percentage of the orientation data for each lithostratigraphic unit comes from locations where orientation modes are at a large angle to a tunnel axis? If this percentage is large, why are the modes not an artifact of orientation biases, particularly given the above discussion that the cylinder samples, while being 3D, do not eliminate the combined effect of orientation and length bias.

(ii) Has any attempt been made to discriminate between variations that result simply from stratigraphic position and those that arise because data were acquired from different geographic locations? What efforts have been made to use the data sets to demonstrate that localized but significant changes do not occur as a function of ancient topography and bed (or cooling unit) thickness, volcanogenic effects (e.g. presence/absence of fumarolic pathways), or structural effects (e.g., presence/absence or proximity of faults). The *a priori* assumption is that stratigraphic position is the sole influence on "fracture set" characteristics.

3. From a statistical standpoint, the amount of data presented in Figures IV-11, IV-12, and IV-15 for fracture spacing; and Figure V-6, V-16, and V-18 for fracture trace length (and potentially others) is so small that it raises the concern of data representativeness, even with respect to the volume of rock sampled by the ESF and CBD.

4. This AMR study (section 6.4.1 and attachment III) relies on the assumption that fracture mode sets may be defined statistically without reference to origin or timing of fracture formation. The AMR ignores the more appropriate criteria that fracture sets are more importantly defined by common origin and have similar characteristics, of which parallelism may be one characteristic (but not always!). A common problem with statistically defined orientation modes is that these so-called sets may include fractures from different true fracture sets of different origins, which will have different characteristics such as size or abundance. An

example of the effects of this limitation is evident in the discussion at the bottom of page 14 and the top of page 15 about relative trace length magnitudes in lithophysal vs. nonlithophysal units. Previous workers (Sweetkind and Williams-Stroud, 1996) reach conclusions opposite those in the AMR regarding fracture size distributions. They are both correct when fracture origin is considered. Cooling-related fractures that have a prelithophysal age can be quite long because lithophysae did not exist to terminate them, yet volcanic gases existed to drive fracture propagation. In contrast, postlithophysal fractures in lithophysae-bearing units are likely to be short because fracture propagation is terminated by lithophysae. In this way, lithophysal units may contain both the longest and shortest fractures. Averaging these two modes to compare to mean fracture size in nonlithophysal units has little meaning, and in fact, could suppress a key size characteristic (such as a strongly bimodal size distribution) of the fracture population in the lithophysal units.

5. Fractures with trace length less than 1 m were collected at six locations in Tptpmn, Tptpll, and Tptpln units. However, the analysis in this AMR excluded these data because they are not a representative data set. In the Drift Degradation Analysis AMR (CRWMS M&O, 2000a), fractures with trace lengths smaller than 1 m were not considered in assessing rock blocks because the limited available data were not considered representative. Also, this AMR states that "The effect of small trace length fractures on block development, if any, would be to either decrease the maximum block size, or decrease the probability of occurrence of the maximum block. The impact of not considering this data is that the block size distributions presented in this analysis could potentially be more conservative." These statements are in general true for rock units with small fracture spacings. However, for a rock unit such as Tptpll, it may not be correct. By including fractures with trace length smaller than 1 m for the Tptpll, more blocks and relatively larger size of key blocks may develop. To be complete and technically defensibie, fractures with trace length smaller than 1 m should be included in assessing rock blocks for Tptpll.

6. Orientation variation within joint sets is critically important in assessing tunnel stability under both thermal and seismic loading conditions. Recent dynamic analysis indicated that a tunnel in fractured rock tends to be less stable if orientation variation is included, than if fractures within a set are assumed to be parallel (Chen, 2000). Information on fracture orientation distributions within sets is needed for realistic simulation of rockfall and tunnel stability. In section 6.4.1 (Determining Joint Set Orientations; also attachment III) on page 29, it is stated that "The orientation of major planes representing the mean orientation of the joint sets were selected based on the pole-vector concentration observed in the contour plots." What technique was used to determine the mean orientations (strike and dip)? Were they eyeballed, were they averaged giving unit weight to each measurement, or was some other technique used? What selection process was used to identify subpopulations of orientations for the determination of particular orientation modes for each lithostratigraphic unit? What is the "spread" on the orientation modes and how is this "spread," variation, or deviation defined? For example, what are the Fisher (in the case of circular distributions of poles) or Bingham (in the case of elliptical distributions of poles) statistics that define the orientation modes (e.g., Fisher 1953, Onstott 1980, Watson 1983).

7. Page 33—Trace length analysis—The curvilinear trace lengths measured from FPGMs overestimate the size of larger fractures. A better measure of fracture size, that would permit comparison across the size spectrum, is chord length. In addition, a cylindrical sample will underestimate the trace lengths (regardless of the measure) of large fractures at a high angle to the tunnel axis. Neither of these effects has been addressed in the trace length analysis in this AMR. Also, no attempt was made in the AMR to infer overall fracture shapes (are they penny-shaped, blade-shaped, or what?). Such an attempt would be speculative, but could be of interest to model applications. This shape effect may be of particular importance for fractures

that span the entire thickness of a lithostratigraphic unit. For drift degradation analysis, circular fractures were assumed for key block analysis. This assumption lacks technical justification.

8. In section 6.4.2 on page 30, it is stated that "strike was not considered since it is of little interest to tunnel stability when examining subhorizontal fractures." This statement is not true, because the subhorizontal fractures along with subvertical fractures form rock blocks. The strike orientation and variation may greatly affect tunnel stability. Under the thermal and seismic loading conditions, their influence may become more significant. Strong perturbation of the local stress field around emplacement drifts due to thermal expansion may produce shear displacement on subhorizontal (<30° dip) fractures, thus influencing flow patterns in areas surrounding the emplacement drifts and pillars (Ofoegbu, 2000). The pattern of displacement on gently dipping fractures under these thermally perturbed conditions may be very sensitive to fracture strike and dip direction.

3 SUMMARY

Our review of the AMR entitled "Fracture Geometry Analysis for the Stratigraphic Units of the Repository Host Horizon" (CRWMS M&O 2000b) identified several points in need of clarification or elaboration. Although this report provides the most complete analysis to date of these input parameters and represents a significant advance in analysis of fracture data from the Exploratory Studies Facility (ESF) and the Cross-Block Drift (CBD), the claim that the ESF and CBD data provide a directionally unbiased fracture population is not demonstrated in the AMR. Furthermore, the assertion that "No assumptions were made as part of this AMR" is incorrect, and we have identified seven implicit or explicit assumptions that lack proof or sound technical bases in the document or elsewhere. In light of these unsupported assumptions, we find that several technical issues, including the fundamental issue of whether or not the resulting parameters are representative of fracture characteristics throughout the proposed emplacement volume, are called into question.

The path to resolution that we propose for these concerns is to directly address them in a future revision of this AMR, and/or address them in one or more other documents as appropriate. Specifically, the seven assumptions listed in this review need to be explicitly expressed. The claim that the ESF and CBD data provide a directionally unbiased fracture population, and the implicit assumption that this population is representative of the proposed emplacement volume need to be supported (e.g., with confidence limits) or demonstrated to be correct. Additional details are needed on: (i) methodology used in defining fracture sets and mean set orientations, (ii) variation of fracture orientation within sets, and (iii) variation of strike and dip direction of subhorizontal fractures.

4 REFERENCES

Chen, R. Drift Stability and Ground Support Performance Under Thermal and Dynamic Load in Fractured Rock Mass at Yucca Mountain, Nevada. CNWRA 2000–04, Center for Nuclear Waste Regulatory Analyses, San Antonio, Texas. 2000.

CRWMS M&O (Civilian Radioactive Waste Management System Management and Operating Contractor). Drift Degradation Analysis. ANL-EBS-MD-000027 REV 00. Las Vegas, Nevada. 2000a.

CRWMS M&O (Civilian Radioactive Waste Management System Management and Operating Contractor). Fracture Geometry Analysis for the Stratigraphic Units of the Repository Host Horizon. ANL-EBS-GE-000006 REV 00. Las Vegas, Nevada. 2000b.

Fisher, R.A. Dispersion on a sphere. Proceedings of the royal Society of London. v. A217, p. 295–305. 1953.

Ofoegbu, G.I. Thermal-Mechanical Effects of Long-Term Hydrological Properties at the Proposed Yucca Mountain Nuclear Waste Repository. CNWRA 2000–03, San Antonio, Texas. 2000.

Onstott, T.C. Application of Bingham distribution function in paleomagnetic studies. Journal of Geophysical Research. v. 85, p. 1500–1510. 1980.

Sweetkind, D.S., and Williams-Stroud, S.C. Characteristics of Fractures at Yucca Mountain, Nevada: Synthesis Report. Administrative Report. ACC: MOL.19961213.0181. Denver Colorado: U.S. Geological Survey. 1996.

Watson, G.S. Statistics of spheres. University of Arkansas Lecture Notes in mathematical Sciences. Wiley, New York. 238pp. 1983.