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January 30, 1997
Contract No. NRC-02-93-005
Account No. 20-5708-471

U.S. Nuclear Regulatory Commission
ATTN: Mrs. Barbara Meehan
Division of Contracts(DC)
Two White Flint North(T7-12)
Washington, DC 20555

Subject: Submission of Major Milestone 20-5708-471-650, Type I Faults in the Yucca Mountain Region, Revision 1 CNWRA 96-007.

Dear Mrs. Meehan:

This letter transmits revision 1 of Major Milestone 20-5708-471-650, Type I Faults in the Yucca Mountain Region. This revision took longer than usual to complete because additional analysis was done to address the NRC comments (Memorandum Justus to Meehan dated 7/24/96). The accompanying informal memorandum (McKague to Justus) documents the resolution of the NRC comments. Also included is a substitute page 4 for Intermediate Milestone 20-5708-471-620, Identification of Type II Faults (Faults That Are Candidates for Detailed Investigations) in the Yucca Mountain Region. Equation 2 in that milestone contained several typographic errors. It should be noted that the correct formula was used in all calculations of peak acceleration.

Should you have any questions regarding this milestone please contact Dr. H. Lawrence McKague at (210) 522-5183 or me at (210) 522-5158.

Sincerely yours,

E. C. Pearcy for

Wesley C. Patrick
President

HLM/jld
(D:\HLM\C)
Attachment

cc: J. Linehan, S. Fortuna, B. Stiltenpole, J. Greeves, M. Federline, J. Austin, M. Bell, J. Thoma, P. Justus, D. Brooks, J. Trapp, K. McConnell, CNWRA Directors, CNWRA Element Managers, D. Ferrill, J. Stamatakos, R. Chen, S. Rowe (SwRI)

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2.5 FAULT LENGTH ANALYSIS

The peak acceleration at the center of the repository projected to the surface was used as the screening tool for fault length. Peak acceleration is a function of the magnitude of an earthquake and the distance of the rupture from the repository. The empirical relationship between maximum moment magnitude of a potential earthquake and surface rupture length have been most recently refined by Wells and Coppersmith (1994), who developed a median relationship through available observations. Maximum moment magnitude is the size of the largest possible earthquake given the length of the fault and can be estimated using the following equation from Wells and Coppersmith (1994):

$$M = 5.08 + 1.16 * \log L, \qquad \text{(Eq. 1)}$$

where M = magnitude and L is the length of the fault.

In their Probabilistic Seismic Hazard Analysis (PSHA) study of the exploratory studies facility (ESF) (Quittmeyer, 1994; Wong, et al., 1995) the DOE used magnitude $M = 6.25$ as the threshold value for distinguishing between earthquakes that occur on known faults (their fault-source term) and those that occur randomly or on unidentified faults (their area source term). This threshold is based on observations by (Smith and Arabasz, 1991) that $M \leq 6.0 - 6.5$ do not produce surface ruptures in the Basin and Range tectonic province. However, the Basin and Range earthquakes of this magnitude range lie on known faults and fault trends. Smaller-magnitude earthquakes ($M = 5.7 - M = 6.0$) can also produce surface rupture if they happen to have a shallow earthquake focus. Wells and Coppersmith (1994) concluded their regression statistics can be used below $M = 6.0$ and include several well-studied surface rupturing earthquakes of magnitude < 6.0 in their database. Hofmann and Ibrahim (1995) suggest a magnitude $M = 5.7$ as the lower limit to be assigned to individual faults and smaller magnitudes be allowed to occur randomly. Consistent with the preliminary nature of this study, a slightly more conservative value of 5.6 was used for the maximum moment magnitude for faults to be considered for fault-source term. Using the more conservative value and (Eq. 1) magnitude 5.6 earthquakes occur on faults with a mean length of slightly less than 4 km and have displacements of approximately 0.05×10^{-1} m (Wells and Coppersmith, 1994). Therefore, in this study all faults capable of producing $M < 5.6$ earthquakes (i.e., fault < 4 km in length) were excluded from further consideration.

From magnitude (M) and distance to the fault, the median acceleration at the center (surface) of the repository is calculated from the attenuation formula, (Eq. 2) which is based on equation 5 of Campbell (1987). The first term is modified as required by the acceleration in the free field, constrained by far field recording as outlined in Tables 4 and 5 of Campbell (1987).

$$\ln A = -2.893 + (0.85M) - 1.25 \ln((r^2 + 16)^{1/2} + 0.0872 e^{0.678M}) - .0059r \qquad \text{(Eq. 2)}$$

where A is average acceleration, M is magnitude from (Eq. 1), and r is the closest approach of the fault to the center of the repository at the surface. Peak acceleration is A multiplied by 1.12. Distance $((r^2 + 16)^{1/2})$ is modified in this equation to represent distance from the repository to a depth of 4 km on all faults. Four km is the shallowest depth at which peak acceleration can be generated (Campbell, 1987). To perform these calculations a table, for each electronic coverage, containing the fault length and closest approach, was exported into an Excel spreadsheet from the GIS database. After completion of the

CENTER FOR NUCLEAR WASTE REGULATORY ANALYSES

MEMORANDUM

January 30, 1997

To: Phil Justus

From: Larry McKague /H L McK

Subject: Resolution of comments

To aid in the review of the deliverable Type 1 Faults in the Yucca Mountain Region Revision 1, I have documented the resolution of your comments below. The comment resolution is keyed to your memorandum to Barbara Meehan dated July 24, 1996.

General comments

Page 2

- Type 1 faults are identified in Appendix A and Figures 1-1 and 1-2. It was felt that further identification in Appendix B was redundant. Note in Appendix A Type 1, 2 and 3 are placed in appropriate groups.

- The suggestion of incorporating the Amargosa shear and unnamed Crater Flat strike-slip faults was not adopted because they do not meet Type 1 criteria. (see p. 4-8, ¶ 1, sent. 1-2 for explanation and sent. 3 for caveat).

- The Little Skull Mountain earthquake fault was not included for several reasons including (1) The event did not occur on a recognized surface fault. (2) There is some evidence that more than one fault may have been involved (see USGS Seismotectonic Framework and Characterization of Faulting at Yucca Mountain (Tectonic synthesis) Report p. 7-20). (3) The earthquake had a magnitude of 5.8 and would be considered in the background in PSHA analyses for re-evaluation and inclusion of additional faults (p. vii, ¶ 4).

2. - Generally covered in p. 4-8, ¶ 2, sent. 1-2 for explanation and sent. 3 for caveat and p. vii, ¶ 4.

3. - The Yucca Wash, Sever Wash, and Pagany Wash faults generally have weak geologic support for Quaternary movement (See Simond et al. legend on his map and abs. by Dickerson in GSA 1996 Annual Meeting Abs.) These are referenced in the MM (p. 2-4,

¶ 5, also see individual descriptions of faults on p. A-31 and A-32). You are right that these faults, especially the Yucca Wash fault are an important part of the sphenochasm tectonic model, and I think the arguments against their being active are good arguments against that model.

- The orientation of the stress field in the YMR-NTS area is well known from: measurements by Stock et al (1985, 1987) at Yucca Mountain; overcoring and hydrofrac studies in Rainier Mesa (although some show control by topography); natural fractures in playas (notably Yucca Lake)(Carr. Will unnumbered USGS report about 1972 or 1973); borehole elongation in Yucca Flat and on Pahute Mesa; from surface fractures associated with underground nuclear tests (UNTs); and from analysis of seismic moment tensors (Patton and Zant, 1991 JGR p. 18,245-18,259, fig 9). What we don't have a good handle on the magnitude of the *in situ* stress and is variation with depth.

Specific Comments

p. vi, 3rd bullet - Wording changed to indicate seismic hazards. The emphasis of the bullet is on the assessment of the potential for faulting and fault related hazards in light of ... scaling relationships and ... tectonic models. The relative potentials are discussed on: p. 3-10, Sec 3.5, ¶2 (discussion of potential for relative earthquake magnitude between moderate and deep listric models using slip tendency analysis to assess rupture area), p. 4-2, sec 4.1 ¶ 2 (discussion of the assessment of potential by assessing scaling relationship of faults); p. 4.8, ¶ 1 and 2 (discussion of potential for relative earthquake magnitude variation as a function of tectonic model).

p. vi, Fault Classification, ¶ 1 - In NUREG 1451, page 16, sec 4.3 - 0.1g is described as a "... discriminator to determine the scope of investigation to be undertaken... ". The classification of faults into type I, II, and III "... is an approach to the identification and investigation of fault displacement hazards..."(p. 5). It was considered that identification and investigation = discrimination to determine. [Note in USGS Seismotectonic Framework and Characterization of Faulting at Yucca Mountain (Tectonic synthesis) Report, p. 11-1 ¶ 1 NUREG 1451 is referenced as a source of the 0.1g criterion Pezzopane used.]

p. vii, ¶ 1 - Sentence added that indicates sources of faults, i.e., "Only faults included in the coverages of ...study". Also see p. vii, ¶ 4 for caveat on classification of faults.

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p. vii, ¶ 3 - see general comment 1 ¶ 3.

p. vii, ¶ 4 - Assume this reference is to p. vii, ¶ 3, as ¶ 4 does not refer to acceleration in original. Note in Rev 1 this is ¶ 4. The assessment for acceleration is independent of the tectonic models. Acceleration at the repository depends on site-to-source distance and magnitude of the largest credible earthquake. The tectonic models may influence the

maximum magnitude of a given fault. However in this report we simply used Wells and Coppersmith's (1994) equation, which is based on empirical data.

p. viii, ¶ 1 - The magnitudes and associated accelerations refer to hypothetical cross basin faults, not to YWF. See p. 4-8, ¶ 3 and fig. 4-3 for further explanation. Note Fridrich's model includes an active YWF.

p. viii, last ¶ - See new section (2.4) added, specifically p. 2-4, ¶ 1, last sent.

p. 1-1, sec 1.2, ¶ 1 - Accepted.

p. 2-1, sec 2.1, ¶ 1 - New first ¶ added to address comment.

p. 2-3 sec. 2.4, ¶ 1 - (p. 2-4, sec 2.5, ¶ 1 in rev. 1) - McConnell et al., added.

p. 2-3 sec. 2.4, ¶ 1 - (p. 2-4, sec 2.5, ¶ 1 in rev. 1) - Formula has been corrected. Note calculations were done with correct formula. Errors occurred in typing formula into text. The original formula was obtained from R. Hofmann and subsequently verified by K. Smart. Hand calculation were used to check spread sheet results.

p. 2-3 sec. 2.4, ¶ 1 - (p. 2-4, sec 2.4, ¶ 2 in rev. 1) - Justification for using Campbell 1987 was added.

p. 2-3 sec. 2.4, ¶ 1 - (p. 2-4, sec 2.5, ¶ 2 in rev. 1) - Left as Type 2 which leaves it open to additional work. Reference to Harding (1988) was added. Two out of three investigators consider it non seismic. [Note in USGS Seismotectonic Framework and Characterization of Faulting at Yucca Mountain (Tectonic synthesis) Report, Chapter 11, the Beatty scarp does not show up on fig. 11-2 or table 11-1.]

p. 2-4, sec. 2.4, ¶ 3 - (p. 2-4, sec 2.5, ¶ 3 in rev. 1) - Paragraph revised. References added for weak to absent evidence of Quaternary movement. Also see p. 3-10, ¶ 3 and fig. 3-5(a) with caption.

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p. 3-2, sec 3.4, ¶ 1 - Correction made.

p. 3-8 and 3-9, Figs 3-5(a) and 3-5(b) - Comment accepted; captions revised. [Note the figures have been switched in the revision so that fig. 3-5(a) which corresponds with figure 1-1 comes first and fig. 3-5(b) which corresponds with fig. 1-2 comes second.]

p. 3-9, fig. 3-5(b) - fig. 3-5(a) in revision as noted above. Figure changed to include two stress states, one for the YWR and one for the Death Valley region. Explanation added to caption.

p. 3-10, sec 3.4, ¶ 1 - The phrase "when the dome was uplifted" was added to clarify.

p. 3-10, sec 3.5, ¶ 2 - Paragraph revised.

p. 3-10, sec 3.5, ¶ 3 - SW-NE was used by the original author (Zoback).

p. 4-1, sec 4 - Paragraph modified to include some comments others added elsewhere. Recurrence intervals are not discussed since they were not considered part of fault classification. It is a large/important topic that needs to be addressed separately.

p. 4-1, sec 4.1, ¶ 3 - Modified fig. 4-1 accordingly to eliminate work by Scott (1990) and Scott and Bonk (1984).

p. 4-2, sec 4.1, top ¶ - Change made

p. 4-2 (actually p. 4-3), sec 4.1, first full ¶ - Reference to FW fault in section 4.1 corrected.

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p. 4-3, Table 4-1 - Corrections made

p. 4-4 to 4-5 sec 4.2.1, ¶ 2 (p. 4-5, ¶ 1 in rev 1) - References added.

p. 4-5, sec 4.2.1, ¶ 2 - Sentence revised.

p. 4-8, sec 4.2.1, ¶ 1-3 - Material added to clarify.

p. 4-8, sec 4.2.2, ¶ 1 - Deleted (45-70°). Reference added.

p. 4-8, sec 4.2.2, ¶ 1 - Correction made.

p. 4-8, sec 4.2.2, ¶ 2 - Clarified (p. 4-9).

p. 4-8, sec 4.2.2, ¶ 2 - Change made - minimal to reduced.

p. 5-2, sec 5, first bullet - Tip out explained.

p. A-1, Fault Name - Explanation added.

p. A-1, Maximum Displacement - Clarified.

p. A-1, Slip Rate - Clarified.

p. A-1, comment - Splay off the Solitario Canyon fault added. The Abandoned Wash fault is considered part of the Ghost Dance fault. See Abandoned Wash fault that was added to clarify.

p. A-2 Comment - Sentence added for clarification.

Appendices A and B -

- Abandon Wash fault added for clarification.
- Boomerang Point Fault was Simond et al. #13 in McKague (1996). Faults (13-18) are renumbered in rev. 1.
- Cane Spring is correct.
- Drill Hole Wash was not in data bases considered, because it was dropped out by fault length criteria used in Type II study. See p. 2-6 for added explanation.
- Table 4-1 corrected.
- Sun Dance Fault did not meet the criteria to be considered a Type II fault and was therefore not considered in this study.
- West Spring Mountains.
- Change made.