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May 21, 1996

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for Suitability and Licensing
U.S. Department of Energy
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P. O. Box 98608
Las Vegas, Nevada 89193-8608

Subject: TOPICAL REPORT ON "SEISMIC DESIGN METHODOLOGY FOR A GEOLOGIC REPOSITORY AT YUCCA MOUNTAIN"

Dear Dr. Brocoum:

The U.S. Department of Energy (DOE) submitted the subject report for review by the U.S. Nuclear Regulatory Commission on October 31, 1995. The staff previously had reviewed DOE's annotated outline of the above report (dated August 22, 1994) and provided comments (letter from Bell to Milner, November 3, 1994). Subsequently, the staff reviewed and found acceptable the revised outline submitted by DOE on January 26, 1995. (See NRC letter of February 14, 1995, on the same subject.)

The subject report is the second of three proposed topical reports concerning seismic issues at a proposed geologic repository. The staff has commented on the first of the three topical reports (letter from Bell to Brocoum, dated September 22, 1995). The staff completed its acceptance review of the second topical report using the criteria listed in its topical report review plan (dated February 28, 1994) and concluded that the subject topical report contained sufficient information and initiated its detailed technical review. During the course of this detailed review, the staff requested additional information and sought clarifications during two Appendix 7 meetings held in Las Vegas on March 13-14, 1996, and in San Antonio on April 23, 1996, respectively.

During the first of the above two meetings, DOE made a detailed presentation on its proposed methodology for the surface facilities of the geologic repository operations area. The staff posed a number of detailed questions, and during the resulting discussions it became evident that the contents of the current draft of the topical report would benefit from significant revisions and a change in approach in its proposed methodology. Consequently, during the second Appendix 7 meeting, DOE presented detailed discussions of the proposed design methodology for the underground facility and a revised outline for the topical report to address the concerns raised by the staff.

A summary of the major comments raised by the staff during the two Appendix 7 meetings is enclosed with this letter. Additional questions raised by the staff during the Appendix 7 meetings are not being repeated in the enclosed summary comments either because of the proposed revisions to the topical report or because the staff was satisfied by the explanations given during the presentations.

We believe that the two Appendix 7 meetings served a very useful purpose of streamlining our review of the topical report and saved us time and resources because of the clarification of issues at the staff level. We expect to review DOE's revised topical report using a similar approach and provide early feedback to help resolve this portion of the issue. Another matter of continuing interest to the staff is the scope and timing of the third topical report and how the three reports together address all the aspects of this repository design and performance issue. We understand that due to budgeting constraints, the third topical report is being deferred until FY97. It would be appropriate for the staff to complete its review of the seismic design of the repository in time to be considered by DOE in its viability assessment in 1998. In this regard, the staff is eager to see an early outline of the third report so that the reviewers can keep proper perspective while commenting on the revised version of the second report, as well as give early feedback to DOE on its site-specific design input and approach.

If you have any questions on the contents of this letter or regarding the review of the topical report on the design methodology, please contact Dr. Mysore Nataraja of my staff at (301) 415-6695.

Sincerely,

ORIGINAL SIGNED BY
MICHAEL J. BELL

Michael J. Bell, Chief
Engineering and Geosciences Branch
Division of Waste Management
Office of Nuclear Material Safety
and Safeguards

Enclosure: As stated

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Staff Comments on Topical Report #2

INTRODUCTION

The U.S. Department of Energy (DOE) topical report "Seismic Design Methodology for a Geologic Repository at Yucca Mountain" reviewed herein is the second in a series of three seismic topical reports. Altogether, they will describe the seismic design process the DOE plans to implement for the Yucca Mountain (YM) Geologic Repository Operations Area (GROA). The first topical report which describes the DOE methodology to assess vibratory ground motion and fault displacement hazards has already been reviewed by Nuclear Regulatory Commission (NRC) and comments transmitted to DOE on September 22, 1995. This second topical report describes DOE seismic design methodology and criteria for the YM GROA to meet the NRC preclosure radiological safety requirements. The third topical report, scheduled for preparation after the completion of the second topical report, will describe the DOE assessment of the seismic hazards for the YM GROA and its determination of ground motion and fault displacement values appropriate for design of the GROA structures, systems, and components (SSCs).

This report is based on the (i) review of the second topical report "Seismic Design Methodology for a Geologic Repository at Yucca Mountain," October, 1995, (ii) NRC/DOE Appendix 7 meeting at Las Vegas, Nevada on March 13-14, 1996, and (iii) NRC/DOE Appendix 7 meeting at CNWRA, San Antonio, Texas on April 23, 1996. All the comments that are documented in this review report have been extensively discussed during the above two NRC/DOE Appendix 7 meetings. The recommendations being made here, if accepted by DOE, will resolve the staff comments. The review of the second topical report did not generate any objections. The questions raised by staff during the Appendix 7 meetings to clarify the DOE position with respect to its implementation of seismic design methodology are not being repeated here because the answers provided by DOE staff and consultants were considered adequate. The following eight major comments represent the summary of the staff concerns with the current version of the second seismic topical report.

COMMENTS

SECTION 1.4 Scope

COMMENT 1

The linkages between the proposed preclosure seismic design methodology and the postclosure performance considerations as provided in the Seismic Topical Report #2 are inadequate.

Basis:

In response to NRC comment (Nuclear Regulatory Commission, 1994) on the annotated outline of Seismic Topical Report #2, the DOE (U.S. Department of Energy, 1995) agreed to include in the report a discussion of the linkages between the proposed preclosure seismic design methodology and the postclosure performance considerations. In Section 1.4 of the Seismic Topical Report #2, it is recognized that the postclosure seismic considerations may ultimately impose more stringent limits on some of the SSCs than preclosure seismic considerations alone and it is proposed to implement the more stringent of the two requirements. However, the topical report discusses the postclosure design issues related to seismic hazards in very general terms. The topical report does not provide any mechanism as to how the proposed preclosure seismic design methodology would be modified to include potentially more stringent design requirements imposed by postclosure performance consideration. Furthermore, Figure 1.1 in Section 1.2 of the Seismic Topical Report #2, that provides the DOE steps in seismic hazards assessment and development of a seismic design basis, specifically shows there are no linkages between long-term waste containment and isolation and seismic design. Postclosure concerns potentially impacted by seismic events include activation of existing faults, opening of fractures, seal disruption or failure, and collapse of openings or movement of rock to develop preferential pathways to connect the emplacement area with perched water zones, neighboring steep hydraulic gradient zones, and the condensation area above the emplacement area, which may increase radionuclide release (American Society of Civil Engineers, 1996). This means that seismic events may affect the postclosure performance by causing premature container failure due to instability of emplacement drift, and changing rock permeability including creating preferential pathways. The topical report tried to address the issue of linkages between the proposed preclosure seismic design methodology and postclosure performance objectives through the statement that postclosure requirements, including accommodation of seismic hazards, are captured in the appropriate project requirement documents—the Repository Design Requirements Document (U.S. Department of Energy, 1994a) and the Engineered Barrier System Design Requirements Document (U.S. Department of Energy, 1994b). However, these project requirement documents do not provide any of these linkages. Thus, this statement is not adequate to demonstrate the linkages between the proposed preclosure seismic design methodology and the postclosure performance considerations.

Recommendation:

Seismic Topical Report #2 needs to significantly strengthen its presentation of linkages between the proposed preclosure seismic design methodology and the postclosure performance concerns. This should include discussion of aspects of postclosure performance that are influenced by design, a mechanism to address these issues in design, and revision of Figure 1.1 to specifically show the linkages between the proposed preclosure seismic design methodology and postclosure performance considerations. In revising Figure 1.1, the design logic provided in Figure 2 by Nataraja (1995) may be used as a guideline.

References:

American Society of Civil Engineers. 1996. Seismic and Dynamic Analysis and Design Considerations for Underground Facilities. New York, NY: ASCE. In press.

Nataraja, M.S. 1995. Seismic Design and Performance Considerations: A Regulatory Perspective. *Proceedings of Focus '95*. La Grange Park, IL: American Nuclear Society, Inc.

Nuclear Regulatory Commission. 1994. Letter dated November 3, 1994 from Michael J. Bell of NRC to Ronald A. Milner of DOE. Washington, DC: Nuclear Regulatory Commission.

U.S. Department of Energy. 1995. Letter dated January 25, 1995 from Ronald A. Milner of DOE to Joseph J. Holonich of NRC. Washington, DC: U.S. Department of Energy.

U.S. Department of Energy. 1994a. Repository Design Requirements Document. YMP/CM-0023, Rev. 0, ICN1. Washington, DC: Office of Civilian Radioactive Waste Management.

U.S. Department of Energy. 1994b. Engineered Barrier System Design Requirements Document. YMP/CM-0024, Rev. 0, ICN 1. Washington, DC: Office of Civilian Radioactive Waste Management.

Section 3.2 Outline of the Methodology

COMMENT 2

The relationship between the DOE proposed four seismic performance categories and the NRC Category 1 and Category 2 design basis events in the proposed rule change to 10 CFR Part 60 needs to be established.

Basis:

Although Section 2.1.5 of Seismic Topical Report #2 recognizes the current status of the proposed rule change to 10 CFR Part 60 on design basis events which resulted partially in response to the DOE 1990 petition for rulemaking (55 FR 28771), the topical report has not adopted the SSC categorization proposed by NRC. Instead this topical report has defined four seismic performance categories in terms of quantitative performance goals (i.e., quantitative target annual probability of unacceptable SSC performance) that should not be exceeded. The NRC has proposed two categories of design basis events in 10 CFR Part 60 that are defined in qualitative terms. In order for this topical report to use the proposed seismic design methodology to comply with NRC requirements as proposed in 10 CFR Part 60, it will be necessary for this topical report to categorize SSCs by two seismic performance categories consistent with NRC's Category 1 and Category 2 design basis events.

Recommendation:

Seismic Topical Report #2 needs to categorize SSCs by two seismic performance categories, make appropriate interpretation of the terms Category 1 design basis events, and Category 2 design basis events as proposed in 10 CFR Part 60, and establish design methods and applicable acceptance criteria. This topical report should also enumerate several typical examples of SSCs and their corresponding categorization.

Section 3.2 Outline of the Methodology, and Section B.1 Required Level of Seismic Design Conservatism to Achieve a Specified Seismic Risk Reduction Ratio

COMMENT 3

No rationale is given concerning the choice of uncertainty measures to be used for ground motion and fault offset criteria. It is stated that the mean of probabilistic seismic hazards will be used, but no rationale for this choice is provided.

Basis:

Seismic Topical Report #2 states that it will incorporate uncertainty in interpretations of site characterization data but also mentions that the mean will be used. It does not say why this particular statistical measure, the mean, will be used. The topic of uncertainty, which is inherent in Probabilistic Seismic Hazard Assessment, is of considerable importance for data analyses. Reiter (1990) discusses some of the problems with uncertainty including the generally recognized two types of uncertainty—systematic and random. Reiter illustrates, with examples from the literature, how probabilistic acceleration or seismic hazards increase with various expert opinions concerning variables or when random uncertainty is included. There may be reasons for using the mean, rather than other statistical measures to represent the effects of uncertainty on the ground motion and fault offset criteria. However, given the variety of statistical measures that are considered in the literature (Capen, 1976; Reiter, 1990), a rationale for using the mean should be given.

Recommendation:

Seismic Topical Report #2 should clearly describe why and how the mean of probabilistic seismic hazards or fault displacements will be used to incorporate uncertainty in data and opinions. A rationale for its use compared to other measures such as the median plus a standard deviation or the 85th or other percentile as used, for example, by NRC for nuclear power plant design spectra should be presented. Provide an example calculation showing the increase in conservatism from considering uncertainty in input data and in resulting safety factors.

References:

Capen, E.C. 1976. The difficulty of assessing uncertainty. *Journal of Petroleum Technology*. August. pp. 843-850.

Reiter, L. 1990. *Earthquake Hazard Analysis*. New York, NY: Columbia University Press.

Section 6.1 Safety Performance Requirements

COMMENT 4

The treatment by DOE of repetitive seismic loadings as "low-probability/low-consequence" events is inappropriate.

Basis:

Seismic Topical Report #2 treated repetitive seismic loadings as low-probability/low-consequence events and stated the intent to accommodate possible damage from repetitive seismic loadings through a program of inspection, maintenance, and rehabilitation. The low probability estimate, made by DOE, is based on its analysis of slip rates from dated fault offsets found in trenches. Seismicity implied by DOE slip rates is much lower than historic seismicity. Earthquakes of magnitude 6 to 6.5 produce no surface offset on Basin and Range faults and only a few such faults have higher earthquake magnitude generating capability. Therefore, it is likely that fault-offset dating underestimates fault-offset derived slip rates and directly related earthquake recurrence rates. Studies of the Bare Mountain fault may provide an alternative estimate of fault slip rate. Ferrill et al., (1995) and Stamatakos et al., (1996), who studied faulting in the YM area, indicate that the Bare Mountain slip rate is about 10 times that determined by the DOE paleo fault offset dating method. Gilmore (1992), suggests a Bare Mountain fault slip rate that may be two orders of magnitude higher than that considered by DOE. These studies imply that earthquake occurrence may be much more frequent than predicted by DOE low-probability estimates. The basis for DOE low-probability of earthquake occurrence estimate is questioned. A rationale was not provided in this topical report for DOE treatment of repetitive seismic loadings as low-probability events.

The response and performance of a jointed rock mass are determined by the amount of permanent joint deformation accumulated from a number of episodes of seismic activity (Brown and Hudson, 1974). This aspect has been confirmed at the Lucky Friday Mine field study (Hsiung et al., 1992) and laboratory study (Kana et al., 1995) on rock mass response to repetitive seismicity. A rock mass becomes weaker as joint deformation accumulates, causing large shear displacements including fall of rock blocks from the roof and walls of underground openings. The presence of high thermal loads in the repository environment may have already weakened the rock mass (Management & Operating Contractor, 1995a,b). Thus, the repetitive low-magnitude seismic load under high thermal load may further increase the potential for deleterious rock movements or fracturing of overlying or surrounding rock. Such deleterious rock movements may change hydrological properties of. and flow paths in, the rock mass, and create preferential pathways, and thus have considerable impacts on the postclosure performance, as stated in the "basis" section of Comment #1. Potential changes of hydrological properties and creation of preferential pathways cannot be mitigated through inspection and maintenance, but factoring repetitive seismic loading considerations in ground support design could minimize rock movements and help mitigate some of the potential problems.

While the effects of repetitive episodes of seismic loads are more important to postclosure concerns, they could also potentially impact the stability of drifts during the 100-yr or more operational life of the facility. It is expected that even during the preclosure operation period, a number of seismic events capable of producing cumulative effects could occur at the repository at YM as discussed earlier. However, a rationale was not given in Seismic Topical Report #2 for not considering the effects of repetitive seismic loads for design and the potential postclosure impacts.

Recommendation:

The proposed seismic design methodology should consider the effects of repetitive episodes of seismic loads, as applicable, or discuss why such repetitive episodes do not impact preclosure or postclosure performance.

References:

Brown, E.T., and J.A. Hudson. 1974. Fatigue Failure Characteristics of Some Models of Jointed Rock. *Earthquake Engineering and Structural Dynamics* 2: 379–386.

Ferrill, D.A., G.L. Stirewalt, D.B. Henderson, J.A. Stamatakos, A.P. Morris, B.P. Wernicke, and K.H. Spivey. 1995. *Faulting in the Yucca Mountain Region: Critical Review and Analyses of Tectonic Data From the Central Basin and Range*. CNWRA 95-017. San Antonio, TX: Center for Nuclear Waste Regulatory Analyses.

Gilmore, T.D. 1992. *Geodetic Leveling Data Used to Define Historical Height Changes Between Tonopah Junction and Las Vegas, Nevada*. U.S. Geological Society Open-File Report 92-450. Menlo Park, CA: U.S. Geological Survey.

Hsiung, S.M., W. Blake, A.H. Chowdhury, and T.J. Williams. 1992. Effects of Mining-Induced Seismic Events on a Deep Underground Mine. *Pure and Applied Geophysics* 139: 741–762.

Kana, D.D., D.J. Fox, S.M. Hsiung, and A.H. Chowdhury. 1995. *An Experimental Scale-Model Study of Seismic Response of an Underground Opening in Jointed Rock Mass*. CNWRA 95-012. San Antonio, TX: Center for Nuclear Waste Regulatory Analyses.

Management & Operating Contractor (M&O). 1995a. *Estimation of the Extent of the Disturbed Zone Around a Repository Drift Caused by Excavation and Thermal Loading*. Las Vegas, NV: Management & Operating Contractor.

Management & Operating Contractor (M&O). 1995b. *Total System Performance Assessment—1995: An Evaluation of the Potential Yucca Mountain Repository*. Las Vegas, NV: Management & Operating Contractor.

Stamatakos, J.A., D.A. Ferrill, K.H. Spivey, A.P. Morris, R.A. Donelick, and R.A. Kechum. 1996. New constraints on the Neogene exhumation of Bare Mountain, Nevada from apatite fission-track thermochronomety. *Tectonics* (submitted).

Section 6.2 General Design Criteria and Analysis Considerations and Section 6.5.2 Dynamic Method

COMMENT 5

DOE does not have a verified or generally accepted method (empirical or analytical) for the design of underground openings under the loads and time frame of interest for repository design. This topical report does not provide a logical approach to develop confidence in the design methodology.

Basis:

Seismic Topical Report #2 stated that in seismic design of underground openings, the DOE will use both the empirical and analytical methods, but neither approach has been reasonably verified for the repository environment. The empirical methods are based on tunneling and mining experience and have not been verified for the repository where the seismic motion will take place in the environment of high thermal load and thermally induced phenomena. The dynamic interaction method can, in theory, accommodate most factors influencing design, but requires adequate characterization of dynamic behavior of rock. In recent years, significant progress has been made in understanding the seismic behavior of jointed rock mass and developing rock joint models for cyclic loads (Fishman, 1988; Jing et al., 1992; Wibowo et al., 1993; Hsiung et al., 1992; Huang et al., 1993; Qiu et al., 1993; Hsiung et al., 1994a; Hsiung et al., 1994b; Kana et al., 1995: Souley et al., 1995). It may be possible, with adequate consideration of theories, models, and codes relevant to dynamic analysis of jointed rock mass, to develop a reasonably verified and acceptable numerical dynamic analysis method. Such a verified numerical dynamic analysis method will enable DOE to produce and justify an acceptable design.

Recommendation:

DOE should make use of recently developed techniques relevant to dynamic analysis of jointed rock mass to develop an acceptable numerical dynamic analysis method to design the underground facility. This topical report should also describe the DOE approach to verify the performance of the underground facility during the performance confirmation period.

References:

Fishman, K.L. 1988. *Constitutive Modeling of Idealized Rock Joints Under Quasi-Static and Cyclic Loading*. Ph.D. Dissertation. Tucson, AZ: University of Arizona: 286.

Ghosh, A., S.M. Hsiung, and A.H. Chowdhury. 1995. *Seismic Response of Rock Joints and Jointed Rock Mass*. CNWRA 95-013. San Antonio, TX: Center for Nuclear Waste Regulatory Analyses.

Hsiung, S.M., W. Blake, A.H. Chowdhury, and T.J. Williams. 1992. Effects of mining-induced seismic events on a deep underground mine. *PAGEOPH 139* (3/4): 741–762.

Hsiung, S.M., D.D. Kana, M.P. Ahola, A.H. Chowdhury, and A. Ghosh. 1994a. *Laboratory Characterization of Rock Joints*. NUREG/CR-6178. Washington, DC: Nuclear Regulatory Commission.

Hsiung, S.M., A. Ghosh, A.H. Chowdhury, M.P. Ahola. 1994b. *Evaluation of Rock Joint Models and Computer Code UDEC Against Experimental Results*. NUREG/CR-6216. Washington, DC: Nuclear Regulatory Commission.

Huang, X., B.C. Haimson, M.E. Plesha, and X. Qiu. 1993. An investigation of the mechanics of rock joints, Part I. Laboratory investigation. *International Journal of Rock Mechanics and Mining Sciences & Geomechanics Abstracts* 30(3): 257–269.

Jing, L., E. Nordlund, and O. Stephansson. 1992. An experimental study on the anisotropy and stress-dependency of the strength and deformability of rock joints. *International Journal of Rock Mechanics and Mining Sciences & Geomechanics Abstracts* 29: 535–542.

Kana, D.D., D.J. Fox, S.M. Hsiung, and A.H. Chowdhury. 1995. *An Experimental Model Study of Seismic Response of an Underground Opening in Jointed Rock*. CNWRA 95-012. San Antonio, TX: Center for Nuclear Waste Regulatory Analyses.

Qiu, X., M.E. Plesha, X. Huang, and B.C. Haimson. 1993. An investigation of the mechanics of rock joints Part II. Analytical investigation. *International Journal of Rock Mechanics and Mining Sciences & Geomechanics Abstracts* 30(3): 271–287.

Souley, M., F. Homand, and B. Amadei. 1995. An extension to the Saeb and Amadei constitutive model for rock joints to include cyclic loading paths. *International Journal of Rock Mechanics and Mining Sciences & Geomechanics Abstracts*.

Wibowo, J.B., Amadei, S. Sture, R.H. Price, and A.B. Robertson. 1993. *Effect of Boundary Conditions on the Strength and Deformability of Replicas of Natural Fractures in Welded Tuff: Comparison Between Predicted and Observed Shear Behavior Using a Graphical Method*. SAND92-2247. Albuquerque, NM: Sandia National Laboratories.

SECTION 6.6 Acceptance Criteria

COMMENT 6

The recommended safety factors for design of ground support components as listed in Table 6-2 for combined *in situ*, thermal, and seismic loads may not be conservative with regard to the design method for conventional structural steel and concrete.

Basis:

The recommended factor of safety for concrete/shotcrete ground support components under combined *in situ* and thermal loads is 2.3. However, when the seismic load is combined with *in situ* and thermal loads, the recommended factor of safety is 1.80 for seismic performance categories 3 and 4 (i.e., a reduction of about 22 percent). The corresponding reduction for steel ground support components is about 18 percent. The infrequent nature and short duration of the seismic events are given as the reasons for assigning a lower value when seismic loads are considered with *in situ* and thermal loads. This rationale is acceptable for surface facilities where the probability of occurrence of a seismic event at a time when all other design loads (such as human occupancy) are at their maximum values, is considered to be low.

However, in the underground facility of a repository, the seismic event will take place in the environment of fairly constant *in situ* and thermal loading condition. Thus, the use of infrequent nature and short duration of seismic events as reasons for assigning a lower value of factor of safety when seismic loads are combined with *in situ* and thermal loads is not appropriate.

Recommendations:

Seismic Topical Report #2 should either more completely justify the proposed factors of safety, or select appropriate safety factors for concrete/shotcrete and steel ground support components consistent with the steady nature of *in situ* and thermal loading conditions in the repository environment.

Chapter 9.0 Seismic Safety Design of Repository Structures, Systems, and Components for Fault Displacement

COMMENT 7

Seismic Topical Report #2 does not provide specific details regarding the nature of fault-specific investigations that would be conducted to define the values of set-back distance for fault-avoidance in design.

Basis:

Information provided in this topical report (Section 9.4, for example) indicates that the principal fault-displacement design for PC-3 and PC-4 SSCs will be fault avoidance. Implementation of the fault-avoidance design will be based on a predetermined set-back distance for each Type I fault. For example, it is stated in Section 9.4.1 that "PC-4 and PC-3 SSCs that are spatially extended in a long and narrow configuration...will not be placed coincident with the trace of a Type I fault within its set-back distance." The set-back distance for such a fault is intended to exclude a zone on both sides of the fault within which excessive deformations may occur as a result of a fault-displacement event. Correct implementation of the fault-avoidance design approach depends on the values assigned to set-back distance.

Investigations to evaluate the set-back distance for specific faults may include:

(i) Geologic investigations to define the zone of excessive deformation associated with the existing fault.

(ii) Mechanical analyses of existing faults to define the zone of excessive deformation associated with predetermined magnitudes of fault displacement.

A key uncertainty associated with such investigations is that an assumption has to be made regarding the plane of reactivation of the fault. Such an assumption may be supported by an examination of the distribution of mechanical properties of materials within the current fault zone.

Recommendation:

Seismic Topical Report #2 should present the nature of investigations that DOE intends to conduct to define the set-back distance for Type I faults, to enable an early assessment of the feasibility of the fault-avoidance design approach.

Chapter 9.0 Seismic Safety Design of Repository Structures, Systems, and Components for Fault Displacement

COMMENT 8

The proposed approach for probabilistic fault-displacement design is not likely to ensure adequate consideration of uncertainties in fault-slip history for the Yucca Mountain region from which design parameters can be adequately calculated.

Basis:

Fault slip rates, total displacement, and recurrence rates in the YM Region used by DOE (Wong et al., 1995) are lower than other existing estimates not used by DOE. They do not (i) consider distributed slip in which only a portion of the total displacement may be captured by a trench in alluvium, (ii) identify maximum displacement along faults because of differential displacement and thereby underestimate the slip rate and total displacement (Ferrill, 1995), (iii) incorporate all slip (e.g., horizontal, as well as, vertical) components and thereby underestimate the total displacement (Ferrill, 1995), (iv) include blind seismic sources that do not produce surface rupture and thereby underestimate the recurrence rate, or (v) use other methods of estimating slip rate in order to confirm or modify their estimates (Ferrill et al., 1995; Gilmore, 1992).

Recommendation:

Consider all sources of fault data, not just trenching, to arrive at estimates of faulting parameters and associated uncertainties. Correct all slip rates for geometry and slip vectors to determine maximum slip rate and total displacement.

References:

Ferrill, D.A., G.L. Stirewalt, D.B. Henderson, J.A. Stamatakos, A.P. Morris, B.P. Wernicke, and K.H. Spivey. 1995. *Faulting in the Yucca Mountain Region: Critical Review and Analyses of Tectonic Data From the Central Basin and Range*. CNWRA 95-017. San Antonio, TX: Center for Nuclear Waste Regulatory Analyses.

Gilmore, T.D. 1992. *Geodetic Leveling Data Used to Define Historical Height Changes Between Tonopah Junction and Las Vegas, Nevada*. U.S. Geological Survey Open File Report 92-450. Menlo Park, CA: U.S. Geological Survey.

Wong, I.G., S.K. Pezzopane, M. Mengas, R.K. Green and R.C. Quittmeyer. 1995. Probabilistic seismic hazard analyses of the exploratory facility at Yucca Mountain, Nevada. *Proceedings of Focus '95*. La Grange Park, IL: American Nuclear Society, Inc.