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TOPICAL REPORT, "METHODOLOGY TO ASSESS FAULT DISPLACEMENT AND VIBRATORY GROUND MOTION HAZARDS AT YUCCA MOUNTAIN" (SCPB: N/A)

Reference: Ltr, Bell to Brocoum, dtd 9/22/95

In the referenced letter, the U.S. Nuclear Regulatory Commission (NRC) requested additional information so the staff can complete its review of the subject topical report. The NRC provided four specific comments on the report, supported by several basis points.

The U.S. Department of Energy (DOE) is providing responses to each comment and basis point in Enclosure 1 to this letter. Enclosure 2 summarizes the commitments that are contained in this letter. These responses should provide the additional information on the expert elicitation process that is needed for your review.

If you have additional questions after reviewing this material, DOE suggests that a discussion be held by telephone conference between NRC and DOE technical staffs. Alternatively, an Appendix 7 meeting involving a few NRC and DOE personnel would provide a cost-effective means of resolving any remaining issues. Please contact April V. Gil of my staff at (702) 794-7622 if you wish to initiate such discussions.

Stephan J. Brocoum
Assistant Manager for
Suitability and Licensing

AMSL:RGH-797

Enclosures:
1. Responses to NRC Comments
2. List of Commitments

NH03
102.8
WM-11

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ENCLOSURE 1

U.S. Department of Energy (DOE) Responses to U.S. Nuclear Regulatory Commission (NRC) Comments and Questions on Topical Report YMP/TR-002-NP, "Methodology to Assess Fault Displacement and Vibratory Ground Motion Hazards at Yucca Mountain"

COMMENT 1

DOE needs to clarify and provide technical justification for some statements made in the topical report.

(1a) BASIS: Page 10, Item 3. This section states that the methodology can accommodate such issues as temporal and spatial clustering of earthquake occurrence and simultaneous rupture on multiple faults. No discussion is provided on how this will be accomplished.

RESPONSE: The experts may specify time-dependent earthquake recurrence relationships to reflect interpretations of temporal clustering (see e.g., Cornell and Winterstein, 1988). Spatial clustering and simultaneous rupture on multiple faults are accommodated by specifying dependencies between the activity parameters of seismic source zones. See Cornell and Toro (1989) for a summary of recurrence models and their applications.

(1b) BASIS: Page 17, Section 2.3.2.2. The paragraph states, "If volumetric sources are required to assess fault displacement hazard, their earthquake recurrence relations and maximum magnitudes will be based on available data including seismic, geologic, and tectonic information." Usually, sources are labelled volumetric because there is no known faulting in the area. This is not the case at Yucca Mountain. It is not clear when and how volumetric sources will be used to assess fault displacement hazard.

RESPONSE: The probabilistic seismic hazard analysis (PSHA) methodology permits alternative interpretations of faulting, including volumetric interpretations to represent uncertainty. However, it is expected that the level of detail in fault mapping at the site, both on the surface and underground, will allow the locations and characteristics of Type I faults (McConnell, et al., 1992) to be specified with confidence. Thus, it is expected that volumetric sources will not be needed to represent uncertainty in faulting. Volumetric sources may be used to represent the volumetric extent of a fault zone, determined by detailed mapping.

(1c) *BASIS: Page A-6, the last sentence of the third paragraph states, "Source identification and characterization will be carried out iteratively based on results of the probabilistic seismic hazard...." This implies that probability cutoffs will be used to determine which sources are characterized. If this is the intent of this statement, then it would appear to be taking a course of action recommended against in NUREG-1451 and could result in significant sources being left out.*

RESPONSE: As noted on page 11 of the topical report, the Department intends to use an approach that is consistent with NUREG-1451 (McConnell, et al., 1992) to collect and analyze data for identifying, evaluating, and characterizing seismic sources. The iterative process cited in the text refers to the process employed in the probabilistic seismic hazard methodology whereby comprehensive and documented seismic-source interpretations are provided by the experts, the seismic hazard corresponding to the interpretations is calculated, and the hazard results are provided to the experts to allow them to fully understand the sensitivity of the results to various parameters. The experts may then reevaluate their interpretations considering this feedback and the rest of the information base.

(1d) *BASIS: Page B-4, 2nd to the last paragraph. Define "relatively deterministic behavior."*

RESPONSE: By "relatively deterministic behavior," referring to long-period ground motions, we mean that these ground motions are predicted well using deterministic earthquake-source and path-effect models, in contrast to the case of high-frequency ground motions, the details of which cannot be deterministically predicted, but can be modeled very well as a stochastic process.

(1e) *BASIS: Page B-6, Section B2.4.2, 1st paragraph. Provide the technical basis for the statement, "While theoretical calculations predict that ground motions from normal faulting events should be equivalent to those from reverse faults...."*

RESPONSE: If the only difference between normal and reverse faulting were the direction of slip on the fault surface, then the equivalent double-couple point-source (or distribution of point sources) would differ only in polarization and the resulting ground motions would differ only in polarization. Of course, the ground motions may, in fact, differ because of differences in other faulting parameters, such as stress drop or distribution of slip with depth. As stated in Section B2.4.2, the Department will evaluate whether ground motions from Basin and Range (predominantly normal-faulting) earthquakes differ systematically from those that are predicted by attenuation relationships that have been published for use in the western United States and which are based mostly on strike-slip earthquakes in California.

(1f) BASIS: Page B-7, Section B2.4.3, 1st paragraph. Provide the basis for the statement, "These data indicate at high frequencies, there are no unusual effects observed in the near-fault region." There are references that suggest evidence to the contrary [Boatwright and Boore (1982), and Heaton (1994)]. For example, Heaton (1994) indicates that peak acceleration at a period near 1 second for fault directivity influenced strong motion.

RESPONSE: The staff is correct in pointing out that directivity effects have been observed at high frequency for near-fault ground motions from a few earthquakes, e.g., the magnitude 5.8 and 5.5 Livermore, California earthquakes of January 1980 (Boatwright and Boore, 1982). However, in general, such effects are observed at periods of 1 sec or longer (e.g., Heaton and Helmberger, 1979; Niazi, 1984; Singh, 1981; Niazi, 1982). Bolt (1983) concluded that definitive evidence for directivity effects at high frequencies is limited and somewhat contradictory, and postulated that high frequency ground motions have variations due to scattering, attenuation and source asperities that mask any directivity effects.

In an empirical analysis of rupture directivity effects, Somerville et al. (1995) found that there is no significant difference between fault-normal and fault-parallel response spectral amplitudes at frequencies above 2 Hz. We expect that rupture directivity effects depend in part on the coherency of radiation from the source. The absence of a difference between fault-normal and fault-parallel components above 2 Hz suggests that radiation pattern coherence and, hence, rupture directivity effects are also generally absent at high frequencies.

Rupture directivity effects were analyzed using simulation procedures during the Diablo Canyon Long Term Seismic Program (PG&E, 1989). Those studies showed that, for sites adjacent to strike-slip faults, rupture directivity does not significantly affect peak accelerations, although it does significantly affect peak velocities. Rupture directivity effects were observed in peak accelerations only at sites located off the end of strike-slip fault ruptures. This is believed to be due to the almost uniform radiation pattern that is seen by such sites. Similarly, the observations of directivity in the Livermore earthquakes may reflect the uniformity in radiation pattern that is seen at sites located some distance from small rupture zones. Sites located near large dip-slip faults should see more variability in source radiation and, therefore, less directivity at high frequencies than is observed off the end of strike-slip faults.

The statement by Heaton (1994) that fault directivity influenced peak acceleration is consistent with the observation that directivity effects are very evident in strong motion data recorded adjacent to faults at longer periods (about one second and longer) because he was referring to peak acceleration at a period near 1 second.

To address the staff's concerns, the beginning of Section B2.4.3 will be changed to read:

> "The large accumulation of strong-motion recordings over the past decade includes a substantial number within 10 km of large earthquakes. These data indicate that the principal near-fault effect on high-frequency ground motion is that the amplitudes of the vertical motions become comparable to those of the horizontal motions, whereas they are less than the horizontal motions at greater distances. Rupture directivity effects are not generally observed in high-frequency peak-acceleration data recorded adjacent to the fault rupture, but become more evident when the recording site is located off the end of a strike-slip fault.
>
> "In contrast to the case for high frequencies, at longer periods (about one second and longer), directivity effects are very evident ...."

(1g) BASIS: Pages B-8 and B-9, Section B3.2. First paragraph of this section, second sentence. It would seem that consideration of site responses to vibratory ground motion should be required or substantial justification be provided for not requiring it. If the results of the empirical and numerical analyses are different, what criteria will be used to determine the results that will be used?

RESPONSE: DOE will factor site response into any ground-motion estimates that are used as a basis for the design of safety-related systems, structures, or components (SSCs). The PSHA will provide estimates of ground motion on rock, and these will be modified as appropriate to reflect the ground conditions at specific SSC locations.

Direct measurements of site response will be used to estimate site response empirically and to calibrate numerical models, i.e., the empirical and numerical analyses are complementary. Numerical models will be used to extend the empirical results to different locations and burial depths.

(1h) BASIS: Page B-9, Section B3.3, 1st paragraph. Provide the basis for the statement, "However, if the variance of the site response is derived from small earthquakes, it may not be applicable to larger earthquakes because of the observed tendency of the variance to decrease with increasing magnitude."

RESPONSE: Youngs et al. (1995) documented a statistically significant dependence with magnitude of the standard error of peak horizontal and vertical acceleration data. Specifically, for a large California strong-motion data set for the period 1957 to 1991, the standard error decreases with increasing magnitude.

COMMENT 2

Elicitation of experts, as a means of establishing uncertainty, is proposed but details of how the elicitation will be carried out is not provided.

(2a) BASIS: Page 17, last paragraph. The report mentions both the LLNL (Monte Carlo) and EPRI (Logic Tree) approaches, but it is not clear if both approaches will be used or whether one approach will be chosen over the other. Also, Section 2.3.2.5 lacks information regarding the minimum acceptance criteria for demonstrating that uncertainty propagation was adequately implemented using either approach.

RESPONSE: The Department plans to use the logic tree approach to facilitate peer and regulatory review and evaluation (see Section 2.1.2 of Study Plan 8.3.1.17.3.6; USGS, 1995).
The Department's acceptance criteria for the adequacy of uncertainty propagation are whether the uncertainty estimates have been generated through an open, documented process of

elicitation of qualified experts who have utilized the best available data, whether these interpretations have correctly been parameterized and input to the computer code that is used to calculate ground-motion exceedance probabilities, and whether the computer code has been formally verified in an accepted nuclear quality assurance program.

The Department considers that the propagation of uncertainty in PSHA has been thoroughly examined and is not a technical issue. The logic tree and Monte Carlo approaches produce the same hazard distribution results when applied to the same input interpretations, as was tested during the NRC's review (Bernreuter, et al., 1987) of the EPRI topical report on seismic hazard methodology (EPRI, 1988). The Department's expert elicitation process, modeled after EPRI (1988), is designed to expose the full range of uncertainty in scientific interpretations of seismic source zones and attenuation relationships is captured and documented.

(2b) BASIS: Page B-7, Section B2.5, last paragraph. Many approaches to ground motion evaluation are given. Clarify whether all such approaches will be a part of the elicitation or whether a specific approach will be recommended.

RESPONSE: The Department's panel of ground-motion experts will consider all ground-motion estimation methods that are supported by the data. The weights to be given to the various methods will be determined independently by each ground-motion expert following a thorough evaluation of the methods in workshops.

(2c) BASIS: Clarify how experts will be chosen to ensure that bias is minimized and potential conflicts of interest are identified.

RESPONSE: Experts have been chosen using the following criteria;

- Strong, relevant expertise as demonstrated by academic training, relevant professional reputation, experience, and peer-reviewed publications and reports;
- Willingness to forsake the role of proponent of any model, hypothesis or theory and perform as an impartial expert who considers all hypotheses and theories and evaluates their relative credibility as determined by the data;

- Availability and willingness to commit the time required to perform the evaluations needed to complete the study;

- Specific knowledge of the Yucca Mountain area, the Basin and Range Province, or ground-motion characterization;

- Willingness to participate in a series of open workshops, diligently prepare required evaluations and interpretations, and openly explain and defend technical positions in interactions with other experts participating in the project; and,

- Personal attributes that include strong communications skills, interpersonal skills, flexibility and impartiality, and the ability to simplify and explain the basis for interpretations and technical positions.

Expectations for how experts will be chosen are consistent with DOE's "Principles and Guidelines for Formal Use of Expert Judgement by Yucca Mountain Site Characterization Project" (Rev 0, May 1995). The selection procedure and criteria are consistent with the recommendations provided in NUREG/CR-6372 (Budnitz, et al., 1995). The second and fifth criteria listed above are explicitly designed to minimize the potential for personal bias.

(2d) BASIS: Page C-9, Section C5.1. The disaggregation process proposed for use at Yucca Mountain should be explained in detail.

RESPONSE: PSHA provides an estimate of the integrated probability of exceeding specified levels of a ground-motion parameter (such as peak acceleration) from earthquakes of varying magnitudes, from seismic sources at various distances. Disaggregation identifies the fractional contribution of potential earthquakes in specified magnitude and distance bins, with the intent of identifying the sizes and locations of potential earthquakes that dominate the hazard at the site. If desired, contributing earthquakes can also be sorted into bins that indicate how many standard deviations the target ground motion level is above the median predicted level, for the given magnitude and distance (see, e.g., McGuire, 1995). The Department intends to follow the approach to disaggregation that is described in Draft Regulatory Guide DG-1032 (NRC, 1995). As stated in Study Plan 8.3.1.17.3.6 (USGS, 1995), hazard results will be disaggregated over the range of periods that are significant to facility design.

COMMENT 3

Underground nuclear explosions (UNEs) are proposed as a source of data for determining attenuation with distance or depth, but differences between UNEs and earthquakes do not appear to have been considered.

(3a) BASIS: Page B-10, Section B3.4.2. Explosions which are at depths similar to that of the repository may not be appropriate for determining attenuation because earthquake source energy is released several kilometers deeper than UNEs.

RESPONSE: Because of the differences between UNEs and earthquakes, earthquake recordings will be the primary data source for estimating earthquake ground-motion attenuation, and UNE recordings will be utilized primarily to estimate UNE ground-motion attenuation. However, with due attention to differences in source depths and wavetypes, UNE data can be used to help calibrate seismic velocity and Q models, which are needed for numerical modeling of site and path effects for both earthquakes and UNEs.

COMMENT 4

The topical report discusses in some detail vibratory ground motion hazard, but no detailed discussion on fault displacement hazard is presented.

(4a) BASIS: In regard to long-term or permanent closure, for all Type I faults that transect the repository, the maximum fault displacement determined by paleoseismic analysis should be considered for the design if the results of the probabilistic analysis indicate lower design values. This approach is similar to the one used for the Diablo Canyon Long-Term Seismic Program (LTSP) described in the topical report on p. E-11. The staff regarded the results of the deterministic analysis carried out during the LTSP as being controlling over the results of probabilistic analysis with respect to the Hosgri Fault. Had the probabilistic seismic hazard assessment value been lower than the deterministic

value, the deterministic maximum magnitude would have been the design basis.

RESPONSE: In addition to a probabilistic fault-displacement hazard analysis, the Department intends to conduct a deterministic analysis of fault displacement for Type I faults within 5 km of the repository. The maximum paleoseismic fault displacement and disaggregated results from the probabilistic analysis will both be considered in developing the design-basis fault displacement.

(4b) BASIS: In most cases, it will not be possible to determine an age of last displacement on subsurface faults unless they can be related to faulting at the surface. It is not clear if the state of activity of these faults is being assessed and considered in the topical report.

RESPONSE: The approaches to assessing fault activity that are described in Section A2.1.1 of the topical report are intended to apply to faults encountered in subsurface excavations, or inferred in the subsurface on the basis of geophysical and other data, as well as to faults with mapped surface traces. Because it will likely not be possible to determine the age of last displacement for most subsurface faults, where it is necessary to assess subsurface-fault activity the Department will utilize the same secondary means that are given in the topical report for situations where Quaternary deposits, paleosols, or geomorphic surfaces are not present, e.g., structural relationships and an understanding of the tectonic setting of the site.

(4c) BASIS: Page A-11, Section A4.1. As stated in the topical report, "...the seismicity on an individual fault does not exhibit a typical linear b-value distribution." Further definition of these values is required to determine the probabilistic design ground motions.

RESPONSE: The nature of earthquake recurrence relationships for seismic sources will be the subject of intense discussion in the analysis workshops, and the final interpretations will be developed by the expert teams. The hazard implications of the characteristic-earthquake model vis-a-vis the exponential model and how stability can be achieved in the hazard assessment are discussed on page A-13 of the topical report.

(4d) BASIS: Page A-12, Section A4.3, 4th paragraph. A characteristic slip rate function may be more appropriate than an exponential function for single faults. A thorough

justification will be required if the characteristic earthquake is based upon a segmented fault model and results are predicted for long-time periods, e.g., 10,000 years.

RESPONSE: Earthquake recurrence models and fault-segmentation models will be treated in depth in the PSHA workshops and the experts will be required to thoroughly justify and document all of their interpretations.

(4e) BASIS: Page B-7, Section B2.4.3, 2nd paragraph. Regarding the statement "...the incidence of directivity effects (and the resulting difference between fault-normal and fault-parallel motions) in dip-slip faulting is expected to be less than for strike-slip faulting...." Does this comport with observations reported at the NTS FOC facility in relation to the 1992 Little Skull Mountain earthquake? There is more information about strong motion directivity available now than when the report was prepared, such as the Northridge 1994, and Kobe 1995, earthquakes. These data should be considered in the analysis. In addition, seismic data, orientation, and magnitude of regional tectonic stresses, and their relation to the orientations and attitudes of faults at the repository, should be considered in the ground motion directivity analysis.

RESPONSE: Somerville, et al. (1995) analyzed rupture directivity effects in recorded strong motion data, including data from the 1994 Northridge and 1995 Kobe earthquakes. Their analysis shows that rupture directivity effects for strike-slip faulting are slightly, but not significantly, larger than those from dip-slip faulting.

The finding of Somerville, et al. (1995) that rupture directivity effects are not significantly different for strike-slip and dip-slip faults should simplify the adjustments that need to be made to accommodate these effects. The only parameters that are needed for these adjustments are the strike of the fault and the closest distance to the fault. Other fault parameters, such as the dip of the fault or the rake angle of slip on the fault, do not need to be considered. Similarly, the orientation and magnitude of regional tectonic stresses do not need to be considered. Accordingly, the following text in Section B2.4.3:

> "Differences between fault-normal and fault-parallel motions become significant at periods longer than about one second for strike-slip faulting (Somerville and Graves, 1993), with fault-normal motions as much as 50 percent larger on average

> than the average of the two horizontal components. The incidence of directivity effects (and the resulting difference between the fault-normal and fault-parallel motions) in dip-slip faulting is expected to be less than for strike-slip faulting. If it is concluded that the predominant style of faulting at the site is normal faulting, then it may not be necessary to consider these differences, but it will be important to consider them if there is a significant strike-slip component of faulting on near-site faults.
>
> "The effects of rupture directivity on long period ground motions will be incorporated in empirical attenuation relations, as has been done in part by Sadigh et al. (1993)."

will be replaced by:

> "Somerville et al. (1995) have quantified the difference between fault-normal and fault-parallel response spectral velocities based on an empirical analysis of recorded strong motion data. They show that the ratio between fault-normal and fault-parallel motions becomes larger than unity at a period of 0.5 seconds and increases with increasing period, increasing magnitude, and increasing proximity to the fault.
>
> "The effects of rupture directivity on ground motions having periods longer than 0.5 seconds will be accommodated by making adjustments to response spectral attenuation relations which describe the average of the horizontal components of motion. The adjustments, which are period-, magnitude- and distance-dependent (Somerville et al. 1995), convert the average horizontal component to the fault-normal and fault-parallel components. These ground-motion components can then be combined vectorially, if desired for analytical convenience, to produce ground motions that are oriented in longitudinal and transverse directions with respect to the horizontal axis of repository structures."

The amplitudes and durations of the recorded ground motions from the 1992 Little Skull Mountain earthquake will be examined for directivity effects. The results of this analysis, together with the results of analyses of the 1995 Kobe and 1994 Northridge earthquakes, will be made part of the information base for estimating ground motion at the Yucca Mountain site.

(4f) BASIS: Page C-7, Section C3.4. A fault displacement hazard curve should be constructed and used to encompass fault intersections and faults in the surrounding region.

RESPONSE: The Department intends to construct fault-displacement hazard curves that express the probability of exceeding various amounts of displacement at different surface and subsurface locations at the site, on faults that could affect those locations. These location-specific hazard curves will explicitly incorporate the contribution to faulting hazard from any secondary faulting or dependent faulting. As noted in Section C3.3, identification of expected patterns of primary and secondary faulting will be based on observations of Basin and Range ruptures, including any relationships that can be developed between the width of the zone of secondary deformation and location on the hanging wall or foot wall, sense of slip, and earthquake magnitude.

(4g) BASIS: Page C-10, Table C-1 to C-3. Fault dips and at-depth relationships should be included in one of these tables.

RESPONSE: The Department accepts the staff's comment and will make the requested change.

REFERENCES

Bernreuter, D. L., J. B. Savy, and R. W. Mensing (1987). *Seismic Hazard Characterization of the Eastern United States: Comparative Evaluation of the LLNL and EPRI Studies,* NUREG/CR-4885.

Boatwright, J., and D. M. Boore (1982). "Analysis of the Ground Motion Accelerations Radiated by the 1980 Livermore Valley Earthquakes for Directivity and Dynamic Source Characteristics," *Bulletin of the Seismological Society of America,* Vol 72, pp. 1843-1865.

Bolt, B. A. (1983). *The Contribution of Directivity Focusing to Earthquake Intensities, Report 20: State-of-the-Art for Assessing Earthquake Hazards in the United States,* Miscellaneous Paper s-73-1, U. S. Army Waterways Experiment Station, Vicksburg, Mississippi.

Budnitz, R. J., G. Apostolakis, D. M. Boore, L. S. Cluff, K. J. Coppersmith, C. A. Cornell, and P. A. Morris (1995). *Recommendations for Probabilistic Seismic Hazard Analysis: Guidance on Uncertainty and Use of Experts,* NUREG/CR-6382, U. S. Nuclear Regulatory Commission, Washington, DC.

Cornell, C. A., and G. R. Toro (1989). "Seismic Hazard Assessment," in *Techniques for Determining Probabilities of Events and Processes Affecting the Performance of Geological Repositories: Literature Review,* R. L. Hunter and C. J. Mann, eds., NUREG/CR-3964, SAND86-0196, Vol. 1, U. S. Nuclear Regulatory Commission, Washington, DC.

Cornell, C. A., and S. R. Winterstein (1988). "Temporal and Magnitude Dependence in Earthquake Recurrence Models," *Bulletin of the Seismological Society of America,* Vol. 78, pp. 1522-1537.

Department of Energy (DOE; 1995). *Seismic Design Methodology for a Geologic Repository at Yucca Mountain,* YMP/TR-003-NP.

Electric Power Research Institute (EPRI; 1988). *Seismic Hazard Methodology for the Central and Eastern United States,* Vol. 1-10, Technical Report NP-4726.

Heaton, T. H., and D. V. Helmberger (1979). "Generalized Ray Models of the San Fernando Earthquake," *Bulletin of the Seismological Society of America,* Vol. 69, pp. 1311.1341.

Management & Operating Contractor, Civilian Radioactive Waste Management System (1995). Letter report, dated February 23, 1995, on selection of PSHA experts, from Richard C. Quittmeyer, M&O, to John W. Whitney, U.S. Geological Survey.

McConnell, K. I., M. E. Blackford, and A. K. Ibrahim (1992). *Staff Technical Position on Investigations to Identify Fault Displacement Hazards and Seismic Hazards at a Geologic Repository,* NUREG-1451, U. S. Nuclear Regulatory Commission, Washington, DC.

McGuire, R. (1995). "Probabilistic Seismic Hazard Analysis and Design Earthquakes: Closing the Loop," *Bulletin of the Seismological Society of America,* Vol. 85, pp. 1275-1284.

Niazi, M. (1982). "Source Dynamics of the 1979 Imperial Valley Earthquake from Near-Source Observations (of Ground Motion Acceleration and Velocity)," *Bulletin of the Seismological Society of America,* Vol 72, pp. 1957-1968.

Niazi, M. (1984). "Radiation Asymmetry of the Observed PGA and Question of Focussing in the Near Source Region of April 24, 1984 Morgan Hill Earthquake," in *The 1984 Morgan Hill Earthquake: California Division of Mines and Geology Special Publication 68*, pp. 265-271.

Nuclear Regulatory Commission (NRC; 1995). *Identification and Characterization of Seismic Sources and Determination of Safe Shutdown Earthquake Ground Motion*, Draft Regulatory Guide DG-1032.

Pacific Gas & Electric Company (1989). *Diablo Canyon Long-Term Seismic Program: Response to Questions 6, 8, 9, 15, 17, 18, and 19*. Diablo Canyon Power Plant Docket Nos. 50-275 and 50-323, October, 1989.

Singh, J. P. (1981). *The Influence of Source Directivity on Strong Ground Motions*, Ph.D. Dissertation, University of California at Berkeley.

Somerville, P. G., N. F. Smith, R. W. Graves, and N. A. Abrahamson (1995). "Representation of Near-Fault Rupture Directivity Effects in Design Ground Motions," in *Proceedings of FOCUS '95 Conference*, September 17-21, Las Vegas, Nevada.

Youngs, R. R., N. Abrahamson, F. I. Makdisi, and K. Sadigh. (1995). "Magnitude-Dependent Variance of Peak Ground Acceleration," *Bulletin of the Seismological Society of America*, Vol. 85, pp. 1161-1176.

Youngs, R. R., and K. J. Coppersmith (1985). "Implications of Fault Slip Rates and Earthquake Recurrence Models to Probabilistic Seismic Hazard Estimates," *Bulletin of the Seismological Society of America*, Vol. 75, pp. 939-964.

U. S. Geological Survey (1995). *Probabilistic Analyses of Vibratory Ground Motion and Fault Displacement at Yucca Mountain*, Study Plan No. 8.3.1.17.3.6, Rev. 0, U. S. Department of Energy, Washington, DC.

ENCLOSURE 2

List of Commitments

The following list summarizes the commitments contained in this letter:

1. Section B2.4.3 of the topical report YMP/TR-002-NP, *Methodology to Assess Fault Displacement and Vibratory Ground Motion Hazards at Yucca Mountain*, will be revised as described in the response to Comment 1. [Response to Comment No. 1, Basis Point 1f]

2. Section B2.4.3 of the topical report YMP/TR-002-NP, *Methodology to Assess Fault Displacement and Vibratory Ground Motion Hazards at Yucca Mountain*, will be revised as described in the response to Comment Basis Point. [Response to Comment No. 4, Basis Point 4e]

3. The amplitudes and durations of the recorded ground motions from the 1992 Little Skull Mountain earthquake will be examined for directivity effects. [Response to Comment No. 4, Basis Point 4e]

4. Fault dips and at-depth relationships will be included in one of the Tables C-1 to C-3. [Response to Comment No. 4, Basis Point No. 4g]