UNITED STATES
NUCLEAR REGULATORY COMMISSION
WASHINGTON, D.C. 20555-0001

July 25, 1996

Dr. Stephan Brocoum
Assistant Manager for
Suitability and Licensing
Department of Energy
Office of Civilian Radioactive
Waste Management
Yucca Mountain Site Characterization
Office
P. O. Box 98608
Las Vegas, Nevada 89193-8608

SUBJECT: ISSUE RESOLUTION STATUS REPORT ON "METHODOLOGY TO ASSESS FAULT DISPLACEMENT AND VIBRATORY GROUND MOTION HAZARD AT YUCCA MOUNTAIN"

Dear Dr. Brocoum:

The subject Topical Report (TR 1) is the first of three Department of Energy (DOE) TRs that addresses DOE's seismic hazard assessment methodology for Yucca Mountain. The Nuclear Regulatory Commission staff review of TR 1 has been completed. As a result of our review, we conclude that sufficient information exists in various forms to close all of our comments on TR 1 (see enclosure). Consequently, consistent with the agreement on issue resolution, the staff has no further questions at this time on TR 1.

As you are aware, our approach to the resolution of open issues or comments uses all available information, not just the information provided by DOE in its response to NRC comments (Brocoum to Bell, dated January 29, 1996). With respect to our comments on the Department's use of expert elicitation in this instance, we have relied not only on the DOE response of January 29, 1996, but on DOE's response (Brocoum to NRC, dated May 13, 1996) to NRC's draft staff "Branch Technical Position (BTP) on the Use of Expert Elicitation in the High-Level Radioactive Waste Program," which was published for comment in February 1996.

Because TR 1 is limited to describing the seismological assessment methodology, the staff expects to have further comments on how the methodology will be implemented. Implementation will be assessed in the context of our review of TR 2 and TR 3. Consequently, the staff will not be issuing a prelicensing evaluation report (PER) at this time. In lieu of preparing a PER on TR 1, the staff has completed this Issue Resolution Status Report documenting the basis for its determination that its comments are resolved at this time. As indicated in the enclosure, it is our understanding that TR 1 will be revised in a manner that reflects the resolution of those comments. When DOE provides the final information regarding the seismic design criteria and design inputs that DOE indicated would be contained in TR 2 and TR 3 respectively, we anticipate that a PER will be developed that addresses DOE's seismic design basis.

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If you have any questions concerning this letter or its enclosure, please contact Dr. Bakr Ibrahim of my staff at (301) 415-6651.

Sincerely,

Original Signed By

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

Enclosure: As stated

cc: See attached list

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STATUS OF TOPICAL REPORT
METHODOLOGY TO ASSESS FAULT DISPLACEMENT
AND VIBRATORY GROUND MOTION HAZARDS
AT YUCCA MOUNTAIN

Background and Summary

During the Nuclear Regulatory Commission staff's review of the Topical Report (TR 1) on the seismic hazard analysis methodology submitted by the Department of Energy (DOE) in June 1994, comments were sent to DOE (Bell to Milner, dated 9/7/94, and Bell to Milner, dated 1/12/95). In the letter dated 1/12/95, the staff noted that its decision to proceed with a technical review of TR 1 was contingent on an acceptable DOE response to four concerns. In a letter dated March 16, 1995, DOE responded to the four concerns identified in NRC's acceptance review (Bell to Milner, dated 1/12/95) of TR 1. The staff found DOE's responses to the four concerns to be acceptable and, as a result, conducted a review of TR 1 in accordance with NRC's Division of Waste Management Topical Report Review Plan, dated February 8, 1994.

On September 22, 1995, in a letter from Bell to Brocoum, the staff identified four comments, and DOE responded in a letter from Brocoum to Bell dated January 29, 1996. In that letter, DOE committed to making three specific changes to TR 1. However, the staff suggested to DOE that TR 1 would be enhanced in clarity if changes were made by DOE to TR 1 that reflected the overall content of the DOE responses to the issues raised by NRC. Accordingly, in an E-mail dated June 6, 1996, DOE agreed to make revisions to TR 1 that incorporate DOE's responses to all of NRC's comments and issues. In addition, it should be noted that with respect to Comment 2 on expert elicitation, we have considered not only the January 29, 1996, DOE response, but also DOE's comments (Brocoum to NRC, dated May 13, 1996) on NRC's draft staff "Branch Technical Position (BTP) on the Use of Expert Elicitation in the High-Level Radioactive Waste Program," which was published for comment in February 1996.

Consequently, we conclude that sufficient information exists in various forms to close all of our comments on the TR 1. In-progress work (revision of TR 1 and development of TR 2 and TR 3) being conducted by DOE will be reviewed for consistency with the indicated basis for resolution.

STAFF COMMENT 1

DOE needs to clarify and provide technical justification for some of the statements made in the TR.

BASIS (1a): 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.

DOE 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.

STAFF COMMENT ON DOE RESPONSE:

The staff considers DOE's response to be adequate. As understood by the staff, the TR will be revised to include the above DOE's response. Therefore, this comment is resolved.

BASIS (1b): 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 which is not the case at Yucca Mountain. It is not clear when and how volumetric sources will be used to assess fault displacement hazard.

DOE 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.

STAFF COMMENT ON DOE RESPONSE:

The staff considers DOE's response to be adequate. As understood by the staff, TR 1, when revised, will reflect the content of the DOE response. Therefore, this comment is resolved.

BASIS (1c): 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.

DOE 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.

STAFF COMMENT ON DOE RESPONSE:

The staff considers DOE's response to be adequate. As understood by the staff, TR 1, when revised, will reflect the content of the DOE response which is a better statement than the text in the TR. Therefore, this comment is resolved.

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

DOE 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.

STAFF COMMENT ON DOE RESPONSE:

The staff considers DOE's response to be adequate. As understood by the staff, TR 1, when revised, will reflect the content of the DOE response. Therefore, this comment is resolved.

BASIS (1e): Page B-6, B 2.4.2, first 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... ." McGarr (1984), for example, does not suggest that ground motion from normal faulting should be equivalent to those from reverse faults but does suggest that normal and strike-slip faulting could produce ground motion more similar to each other.

DOE 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.

STAFF COMMENT ON DOE RESPONSE:

The staff considers DOE's response to be adequate. As understood by the staff, TR 1, when revised, will reflect the content of the DOE response. Therefore, this comment is resolved. However, the NRC staff considers that effective stress across normal and reverse faults differs and this difference affects potential stress drops and acceleration produced, e.g., McGarr (1984). Dips of reverse and normal faults are statistically different and can affect near-field ground motion predictions. These aspects of faulting will be reviewed by the staff when it reviews DOE's seismic design input for Yucca Mountain.

BASIS (1f): Page B-7, Section 2.4.3, first 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.

DOE 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 (Pacific Gas and Electric, 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 1 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 B 2.4.3 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 1 second and longer), directivity effects are very evident ...."

STAFF COMMENT ON DOE RESPONSE

The staff considers DOE's response to be adequate. As understood by the staff, TR 1, when revised, will address the potential problem of high-frequency accelerations from breaking asperities, as well as directivity from fault fling. Therefore, this comment is resolved.

BASIS (1g): Pages B-8 and B-9, Section B 3.2. 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?

DOE 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.

STAFF COMMENT ON DOE RESPONSE:

The staff considers DOE's response to be adequate. As understood by the staff, TR 1, when revised, will reflect the content of the DOE response, including a description of the numerical models proposed to extend empirical results to different locations and particularly to different depths. Therefore, this comment is resolved.

BASIS (1h): Page B-9, Section B 3.3, first 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."

DOE 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.

STAFF COMMENT ON DOE RESPONSE:

The staff considers DOE's response to be adequate. Therefore, this comment is resolved. As understood by the staff, TR 1, when revised, will include the addition of the cited reference. However, DOE may need to assess the question of whether this phenomena, "the standard error decreases with increasing magnitude", is caused by the small size of the reduced data set for near-field ground motion from large earthquakes.

STAFF 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.

BASIS (2a): Page 17, last paragraph. The report mentions both the Lawrence Livermore National Laboratory (Monte Carlo) and EPRI (Logic Tree) approaches, but 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.

DOE 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, and is captured and documented.

STAFF COMMENT ON DOE RESPONSE:

The staff considers DOE's response to be adequate. Also, in TR 3, DOE will provide the rationale/justification for the use of the mean hazard rather than the 84th percentile or other measure to accommodate uncertainty. Therefore, this comment is resolved.

BASIS (2b): Page B-7, Section B 2.5, last paragraph. Many approaches to ground motion evaluation are given. It is not clear if all such approaches will be a part of the elicitation or whether a specific approach will be recommended.

DOE 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.

STAFF COMMENT ON DOE RESPONSE:

The staff considers DOE's response to be adequate. As understood by the staff, TR 1, when revised, will reflect the content of the DOE response. Therefore, this comment is resolved.

BASIS (2c): It is not clear how experts will be chosen to ensure that bias is minimized and potential conflicts of interest are identified.

DOE 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 "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.

STAFF COMMENT ON DOE RESPONSE:

The staff raised the following two concerns: (1) how will experts be chosen to ensure that bias is minimized, and (2) how will experts be chosen to ensure that potential conflicts of interest are identified. DOE's response indicates that its selection procedures and criteria for choosing "experts" are consistent with the recommendations provided in NUREG/CR-6372 (Budnitz, et al., 1995). Because these criteria are generally consistent with NRC's draft staff "Branch Technical Position (BTP) on the Use of Expert Elicitation in the High-Level Radioactive Waste Program," (February 1996), the staff considers DOE's response to be adequate to ensure that bias is minimized. However, neither the DOE response nor the supporting references to the response address the issue concerning the identification of potential conflicts of interest. A key aspect of selecting experts, according to NRC's BTP, includes the identification of potential conflicts of interest. The NRC BTP was made available for public comment on February 28, 1996. NRC received DOE's comments on May 13, 1996. In brief, DOE commented that they are "... substantially in agreement..." with the guidance as contained in the BTP. As stated previously, a key criterion to the "expert" selection process is the willingness of the candidate to "... publicly disclose all potential conflicts of interest." Because the BTP is intended as guidance to DOE, and DOE expressed no objections concerning the criterion for selecting "experts," NRC can conclude that the "...conflict of interest..." criterion will be adopted by DOE in future elicitations. Therefore, with respect to the adequacy of the TR, as implied by DOE's agreement with the staff's technical position in the BTP, the second aspect of our comment has been adequately addressed.

Based on the above discussion, the staff considers this comment resolved. Future elicitations conducted by DOE will be reviewed for consistency with NRC's BTP.

BASIS (2d): Page C-9, C 5.1. The disaggregation process proposed for use at Yucca Mountain should be explained in detail.

DOE 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.

STAFF COMMENT ON DOE RESPONSE:

The staff considers DOE's response to be adequate. As understood by the staff, TR 1, when revised, will reflect the content of the DOE response. Therefore, this comment is resolved.

STAFF 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.

BASIS (3a): Page B-10, Section B 3.4.2. 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 kms deeper than UNEs.

DOE 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.

STAFF COMMENT ON DOE RESPONSE

The staff considers DOE's response to be adequate. As understood by the staff, TR 1, when revised, will reflect the content of the DOE response. Therefore, this comment is resolved.

COMMENT 4

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

BASIS (4a): In regard to the long-term or permanent closure, for all 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 TR on p. E-11. The staff regarded the results of the deterministic analyses carried out during the LTSP as being controlling over the results of probabilistic analysis with respect to the Hosgri Fault. Had the PSHA value been lower than the deterministic value, the deterministic maximum magnitude would have been the design basis.

DOE 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.

STAFF COMMENT ON DOE RESPONSE:

The staff considers DOE's response to be adequate. As understood by the staff, TR 1, when revised, will reflect the content of the DOE response, including a discussion of how DOE intends to use the results from the deterministic and probabilistic approaches. Therefore, this comment is resolved.

BASIS (4b): 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 TR.

DOE RESPONSE: The approaches to assessing fault activity that are described in Section A 2.1.1 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.

STAFF COMMENT ON DOE RESPONSE:

The staff considers DOE's response to be adequate. As understood by the staff, TR 1, when revised, will reflect the content of the DOE response, including a discussion about the age-dating methods that will be used. Therefore, this comment is resolved.

BASIS (4c): Page A-11, Section A 4.1. As stated in the TR, "... 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.

DOE 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.

STAFF COMMENT ON DOE RESPONSE:

The staff considers DOE's response to be adequate. As understood by the staff, TR 1, when revised, will reflect the content of the DOE response. Therefore, this comment is resolved.

BASIS (4d): Page A-12, Section A 4.3, fourth 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.

DOE 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.

STAFF COMMENT ON DOE RESPONSE:

The staff considers DOE's response to be adequate. As understood by the staff, TR 1, when revised, will reflect the content of the DOE response. Therefore, this comment is resolved.

BASIS (4e): Page B-7, Section B 2.4.3, second 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 1994 Northridge, and 1995 Kobe, 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.

DOE 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 B 2.4.3:

"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.

STAFF COMMENT ON DOE RESPONSE:

The staff considers DOE's response to be adequate. As understood by the staff, TR 1, when revised, will contain the indicated revised text, committing to consider the directivity effects from Little Skull Mountain, and DOE will use the results of the analysis of the Kobe and the Northridge earthquakes when estimating ground motion at Yucca Mountain. Therefore, this comment is resolved.

BASIS (4f): Page C-7, Section C 3.4. A fault displacement hazard curve should be constructed and used to encompass fault intersections and faults in the surrounding regions. However, as stated earlier, for faults of possible Quaternary activity, it should be assumed that they will rupture during the life of the repository.

DOE RESPONSE: The Department intends to construct fault-displacement hazard curves that express the probability of exceeding various amounts of placement 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.

STAFF COMMENT ON DOE RESPONSE:

The staff considers DOE's response to be adequate. As understood by the staff, TR 1, when revised, will reflect the content of the DOE response, and DOE will use an approach that is consistent with NUREG-1451 (see Comment 1). This comment is resolved.

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

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

STAFF COMMENT ON DOE RESPONSE:

The staff considers DOE's response to be adequate. Therefore, this comment is resolved.

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