FEB 16 1989

102.1/MB/89/02/04

MEMORANDUM FOR: Cecil O. Thomas, Jr., Chief
Policy Development & Technical Support Branch, NRR

FROM: Ronald L. Ballard, Chief
Geosciences & Systems Performance Branch, HLWM

SUBJECT: OFFICE OF NUCLEAR REACTOR REGULATION SUPPORT FOR ANALYSIS OF CERTAIN STUDIES CONCERNING VIBRATORY GROUND MOTION PRESENTED IN THE YUCCA MOUNTAIN SITE CHARACTERIZATION PLAN

The Geosciences and Systems Performance Branch of the Division of High-Level Waste Management, NMSS, is seeking the support of NRR seismologists in its analysis of the 10,000-year cumulative slip earthquake (10-kyr CSE), which was first presented in the Consultation Draft of the Yucca Mountain, Nevada, Site Characterization Plan (CDSCP). The 10-kyr CSE is a critical characterization parameter related to studies to provide required information on vibratory ground motion that could affect high-level waste geologic repository design or performance.

In its review of the CDSCP for a high-level waste geologic repository, the Geology/Geophysics Section of the Geosciences & Systems Performance Branch commented on the definition of the 10-kyr CSE presented in Section 8.3.1.17.3.1.2 of the CDSCP (see Attachment 1). The primary concern was that the 10-kyr CSE approach to establishing the seismic design basis for repository facilities important to safety may not be adequately conservative.

The DOE responded to this comment in December 1988 with a detailed discussion of the 10-kyr CSE methodology (see Attachment 2). This discussion includes a description of the technical basis for the 10-kyr CSE. It also includes a discussion of the sufficiency of the 10-kyr CSE approach, in conjunction with the planned probabilistic seismic hazard analysis, for the purposes of the SCP. Finally the DOE response concludes with brief remarks on each of the items cited in the NRC comments as a basis for the recommendations.

We would like NRR seismologists to evaluate the concept of the 10-kyr CSE presented in this response in the light of its potential impact on the siting of not only the high-level geologic repository, but also other critical nuclear facilities. We expect that this evaluation would take no more than two to three days and that comments on the 10-kyr CSE could be provided to us by March 16, 1989.

Section 8.3.1.17.3 of the SCP has been included with this memorandum so that NRR reviewers may see how the revisions cited in the comment response have been incorporated into the SCP text (see Attachment 3). If you have any questions

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or require further information, please contact Michael Blackford of the HLGP staff at x20524.

/s/

Ronald L. Ballard, Chief
Geosciences & Systems Performance Branch, HLWM

Enclosures: as stated

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Section 8.3.1.17.3.1.2 Activity: Characterize 10,000-year cumulative slip earthquakes for relevant seismogenic sources (p. 8.3.1.17-63)

COMMENT 52

When the definition of 10,000-year cumulative slip earthquakes for Quaternary faults is applied to the calculation of magnitudes for examples of Yucca Mountain-vicinity faults, the results yield magnitudes that are significantly lower than those derived from accepted fault rupture length-magnitude and displacement-magnitude relationships.

BASIS

- The adverse conditions described in §60.122(c) concerning earthquakes all require an adequate knowledge of the magnitudes of earthquakes that may affect the site.

- The premise that low earthquake recurrence rates could lead to misleading deterministic estimates of magnitude for a given fault, when fault length or displacement are used to develop these estimates, is unsupported. This premise appears to be in conflict with methodologies presented in Section 1.4.2.1 that use fault length or displacement relationships to determine potential maximum earthquake sizes for faults in the Yucca Mountain vicinity. This premise also appears to be in conflict with the initial statement of the following paragraph on page 8.3.1.17-63 that implies that mapped fault lengths and displacement will be used, together with other pertinent geologic data, to evaluate 10,000-year cumulative slip earthquakes.

- If the data for the upper limit of the aggregate fault lengths of the Paintbrush Canyon, Bare Mountain, and Windy Wash faults, which are presented in Table 1-8 of this site characterization plan and on page 78 of materials provided at the DOE/NRC meeting of September 22, 1987 in Las Vegas, Nevada (DOE/NNWSI, 1987), are used in the rupture length-magnitude relationship of Bonilla et al (1984) for western North America, the resultant magnitudes are 7.01, 6.83, and 6.75 respectively.

- If the post-Qta vertical displacement data from the same sources and for the same faults noted above are used to determine the average Quaternary displacements for earthquakes occurring on these faults every 10,000 years (the average Quaternary displacement is determined here by dividing the post-QTa vertical displacement by 100, which is the number of 10,000-year earthquakes in one million years, the conservative estimate of QTa age) and these average Quaternary displacements are used in the displacement-magnitude relationship of Bonilla et al (1984) for western North America, the resultant magnitudes are 5.95, 6.59, and 5.20 respectively.

RECOMMENDATIONS

- The manner in which the rate of earthquake recurrence affects the utility of fault length or displacement in the determination of estimated magnitude for a given fault should be elucidated.

- Preliminary estimates of 10,000-year cumulative slip earthquake magnitudes, based on existing data, for some of the relevant sources in the Yucca Mountain vicinity should be included in the SCP, and an example of how these estimates are determined should also be included. It is recognized that estimates presented in the SCP would be for exemplary purposes only and most likely would be subject to revision during site characterization.

- The technical basis that supports the concept of the 10,000-year cumulative slip earthquake should be established, and that it yields reasonably conservative results/parameters should be demonstrated.

REFERENCES

Bonilla, M.G., Mark, R.K., and Lienkaemper, J.J., 1984, Statistical Relations Among Earthquake Magnitude, Surface Rupture Length, and Surface Fault Displacement: Bulletin of the Seismological Society of America, vol. 74, no. 6, p. 2379-2411.

DOE/NNWSI, 1987, Meeting With the Nuclear Regulatory Commission (NRC) to Summarize the Seismic/Tectonic Strategies Presented in the Consultation Draft of the Nevada Nuclear Waste Storage Investigations (NNWSI) Project Site Characterization Plan (SCP): unpublished material provided to participants of the DOE/NRC meeting of September 22, 1987 in Las Vegas, Nevada.

REVIEW GUIDES

4.3.3, 4.3.4

RESPONSE TO NRC COMMENT #52

COMMENT #52

When the definition of 10,000-year cumulative slip earthquakes for Quaternary faults is applied to the calculation of magnitudes for examples of Yucca Mountain-vicinity faults, the results yield magnitudes that are significantly lower than those derived from accepted fault rupture length-magnitude and displacement-magnitude relationships.

DOE RESPONSE

In response to this comment, the DOE revised Section 8.3.1.17.3.1.2 to clarify the statement that the low recurrence rates for large earthquakes in the southern Great Basin could result in misleading magnitudes if they are estimated using conventional fault length-magnitude or displacement-magnitude relationships. Additionally, new text was inserted to illustrate how 10,000-year cumulative slip earthquake magnitudes would be estimated. A detailed discussion follows of the concept of the 10,000-year cumulative slip earthquake and how this could be used to develop conservative earthquake design. This material is provided to clarify the DOE's position on the subject.

This comment appears to reflect NRC's concern that the 10,000-year cumulative slip earthquake (10-kyr CSE) approach to establishing a seismic design basis for repository facilities that are important to safety, as described in the consultation draft, may not be adequately conservative. The DOE believes that it is important to resolve technical concerns related to licensing as soon as possible, and this response addresses each of the points in NRC Comment #52. Note, however, that the conservatism of the approach should not be an issue with respect to the acceptability of the SCP. The germane issue is, rather, the adequacy of the proposed site-characterization activities for providing the information needed to develop a license-application seismic design. The methodology for developing the license application design may ultimately differ from that which is outlined in the SCP.

The NRC's comment also cites a number of items that are the basis for recommending that the SCP be revised to include (1) a discussion of how earthquake recurrence rates affect the utility of fault length or displacement in estimating magnitudes for a given fault, (2) an illustration of how 10-kyr CSE magnitudes are determined, and (3) an explanation of the technical basis for the concept of the 10-kyr CSE and a demonstration that it leads to reasonably conservative results.

This response addresses each of the above recommendations in turn, starting with the technical basis for the 10-kyr CSE methodology. This is followed by a discussion of the sufficiency of the CSE approach, in conjunction with the planned probabilistic seismic hazard analysis, for the purposes of the SCP. The response concludes with brief remarks on each of the items cited as a basis for the recommendations.

Technical basis

The technical basis of the 10-kyr CSE approach can be established by enumerating the requirements that any approach must meet and then demonstrating that the 10-kyr CSE methodology meets those requirements.

The ultimate objective of any approach to establishing a seismic design basis is a seismic design that is adequate and appropriate. An "adequate" seismic design is defined here as a design that, considering the seismic environment and the nature of the facility being designed, protects the public and workers from any unreasonable risks to health and safety. An "appropriate" design is one that achieves adequacy in a cost-effective manner.

A determination of adequacy must consider the seismic hazard at the site, the probabilities of failure as a function of loading of facility structures and equipment, the consequences of structural and equipment failures, and the uncertainties associated with each of these elements. This consideration can be explicit, as in a probabilistic risk assessment (PRA) which considers seismic initiating events, or it can be implicit, i.e., done by less rigorous methods. One implicit method is to compare proposed seismic design levels with levels that have been found acceptable for other, well-studied facilities and to subjectively modify the design level according to perceived differences between the facilities in the importance of their functions and in potential accident scenarios.

The determination of appropriateness considers, in addition to the factors involved in establishing adequacy, the costs of implementing different design levels versus their efficacy in preventing seismically caused damage and in mitigating the consequences of such damage. Even though any structure or component can always be made safer, at some point the cost of increased protection becomes unacceptable because of competing demands for financial resources.

In addition to the requirement to lead to an adequate and appropriate seismic design, the methodology to establish the design basis is subject to several other constraints, namely, that it lead to reasonably consistent results when applied by different workers and that the results be stable. The requirement for stability means that the design basis provided by the methodology should not be sensitive to any new information other than major changes in the perception of seismic hazard. Stability requires that the design basis be conservative in proportion to the amount of uncertainty in the characterization of the seismic hazard, i.e., the greater the uncertainty, the greater the conservatism required.

Note that a seismic design basis does not have to be a physically realizable description of ground motion or correspond to a physically realizable seismic event to provide a seismic design that will accommodate physically realizable events. This is illustrated by the seismic designs of U.S. nuclear power plants, each of which is based on a smoothed response-spectrum representation of ground motion. This representation has a number of advantages, but it is a mathematical construct that cannot occur in nature. In general, the seismic

RESPONSE TO COMMENT #52 (continued)

Technical basis (continued)

hazard to which a facility is exposed comes from a number of different seismic sources, all of which must be considered in developing the design basis. For nuclear power plants, this has been accomplished by broadening the shape of the design response spectrum in the frequency domain to account for potential ground motion from different sources. The resulting design basis thus does not correspond to a single, realizable seismic event, even though it is referred to as "the safe shutdown earthquake."

Properties of the 10 kyr-CSE methodology

The 10-kyr CSE methodology is expected to provide a design basis that meets all the above requirements, with the possible exception of appropriateness. That is, the resulting design basis could be unnecessarily conservative and not cost-effective.

Preliminary information indicates that the 10-kyr CSE methodology will provide for an adequate seismic design. Specifically, preliminary analysis indicates that the resulting seismic design basis would correspond to a postulated earthquake on the Paintbrush Canyon fault with a magnitude of about 6 to 6.5 and a peak ground acceleration at the site of about 0.5g. A recent analysis of alternative seismic design levels suggests that the accident risks associated with a seismic design level of 0.2g or greater for surface waste-handling facilities would be extremely small. Important factors contributing to this finding are that (1) the surface-facility hot cells are inherently rugged against seismic loading because of shielding requirements and the resulting thick shear-wall construction and (2) the low probability of severe ground motion during the operating life of the facility. Comparison with design levels that have been found to be acceptable for nuclear power plants also indicates that the 10-kyr CSE methodology will provide an adequate design. Reconnaissance probabilistic seismic hazard analyses (cited in the consultation draft) suggest that the annual probability of exceeding 0.5g at the site is between 1×10^{-3} and 1×10^{-4}. A number of accepted nuclear power plant design bases have been found to lie in this same range, and, considering that the risk profile of the waste-handling facilities would be less than that of an operating nuclear power plant, this range appears to be more than adequate for repository facilities.

The appropriateness of the design basis that would result from applying the 10-kyr CSE methodology remains to be determined. The CSE methodology could lead to a design basis more severe than 0.4g, but the preliminary results of a cost-benefit analysis suggest that increasing the 0.4g basis of the current conceptual design cannot be justified in terms of increased safety; the reduction in expected accident costs would be several orders of magnitude less than the cost of increasing the design basis. Nevertheless, the DOE believes that the CSE methodology and the planned adjunct probabilistic seismic hazard analysis provide an appropriate framework for scoping, organizing, and

RESPONSE TO COMMENT #52 (continued)

Properties of the 10 kyr-CSE methodology (continued)

prioritizing seismic-related site characterization activities, as discussed below. The CSE methodology may be revised or a different methodology may be used to actually develop a design basis for the advanced conceptual design and the license application design.

Although differing professional opinions regarding the evaluation of 10-kyr CSE magnitudes can be expected, these differences are expected to be, at worst, no greater than those that would result from the application of alternative methodologies. In particular, reaching consensus on magnitude values for 10-kyr CSEs is expected to be easier than reaching consensus on maximum magnitudes, which are not well defined.

The 10-kyr CSE approach is expected to provide a stable deterministic design basis. Current information suggests that the design basis will correspond to a postulated earthquake on the Paintbrush Canyon fault. The magnitude estimate for this event will depend mostly on geologic information about the Paintbrush Canyon fault itself. Presuming the Paintbrush Canyon fault (and other local faults that may be mechanistically linked to the Paintbrush Canyon fault) have been thoroughly investigated, the design basis should be relatively insensitive to new information about the nature of faulting outside the local area. This would not be true, for example, for a probabilistically defined design basis.

As mentioned above, conservatism is also required for stability. The 10-kyr CSE methodology was crafted to result in a design basis with an exceedance probability in the range of 1×10^{-3} to 1×10^{-4} per year, which, as discussed earlier, is expected to provide strong assurance of adequacy. As described in the consultation draft, an adjunct to the 10-kyr CSE methodology is a probabilistic seismic hazard analysis that will be conducted to confirm, with full consideration of modeling and data uncertainty, that the CSE methodology does, indeed, provide a design basis in the desired probability range. A preliminary cost-benefit analysis suggests that any increase in the current 0.4g conceptual design basis, which would be the likely result of the 10-kyr CSE methodology, would be overly conservative.

That 10-kyr CSE magnitude estimates may be less than "maximum" magnitude estimates derived from published fault length-magnitude and displacement-magnitude relationships does not imply that the CSE approach is not conservative. The likelihood of the design basis being exceeded and the consequences of the exceedance must be evaluated and judged against some measure of acceptable risk to assess the conservatism of the approach. As described above, the 10-kyr CSE methodology is expected to provide a design basis with an annual exceedance probability in the range of 1×10^{-3} to 1×10^{-4}, i.e., the likelihood of exceeding a 10-kyr CSE design basis would be small. Furthermore, an exceedance of the design basis would likely be inconsequential. Preliminary, conservative risk assessments suggest that there is a 95 percent chance that surface waste handling facilities designed to 0.4g would suffer only light damage, with no releases, in the event of 1.0g ground motion. In other words,

RESPONSE TO COMMENT #52 (continued)

Properties of the 10 kyr-CSE methodology (continued)

there would be large margins of safety to accommodate ground motions beyond the design basis. Thus, considering exceedance probabilities and consequences, the 10-kyr CSE approach appears to be conservative.

A 10-kyr CSE may or may not be consistent with expectations based on certain models of fault behavior, but this is not important. Specifically, a 10-kyr CSE may be inconsistent with the characteristic-earthquake model of earthquake recurrence, which holds that faults usually produce earthquakes within a limited range of magnitudes. If fault loading (strain buildup) occurs uniformly over time, the characteristic earthquake model predicts that recurrence times will also fall within a limited range. For example, if the Paintbrush Canyon fault is subject to constant strain buildup and has an average earthquake recurrence time of, say, 75,000 years, the characteristic earthquake model would predict that release of only 10,000-years-worth of accumulated strain in an earthquake would be unlikely. However, as discussed above, physical realizability is not a requirement for an adequate and appropriate design basis.

In summary, the requirements for an adequate and appropriate seismic design basis for repository facilities have been enumerated, and, with the possible exception of appropriateness (cost-effectiveness), current information indicates that the 10-kyr CSE approach would provide a design basis which meets all the requirements.

The effect of recurrence rates on the utility of fault length or displacement for estimating magnitudes

Published fault length-magnitude and displacement-magnitude relationships can and will be used to help characterize maximum-earthquake magnitudes, but such relationships do not consider earthquake recurrence rates and are insufficient for characterizing seismic hazard. Fault length-magnitude and displacement-magnitude relationships will be used to help construct probability distributions on maximum magnitudes to support the planned probabilistic seismic hazard analysis. The earthquake potential of a particular fault is defined by a function that relates frequency (or probability) of earthquake occurrence to earthquake magnitude. The maximum magnitude defines only the large-maximum asymptote of this frequency-magnitude curve and by itself is an incomplete descriptor of earthquake potential. Maximum magnitude cannot, for example, express the difference in hazard posed by a fault which produces magnitude 7 earthquakes every 100 years (e.g., the San Andreas fault) and one that produces magnitude 7 earthquakes every 100,000 years.

Only in special circumstances that do not apply at Yucca Mountain can maximum-magnitude estimators such as fault length-magnitude or displacement-magnitude relationships be sensibly used to provide an appropriate seismic design basis. In areas of very active tectonics where earthquake recurrence times are comparable to typical facility lifetimes, maximum-magnitude estimates may provide appropriate design bases for critical facilities. However, average earthquake recurrence times for faults in the Yucca Mountain region

RESPONSE TO COMMENT #52 (continued)

The effect of recurrence rates on the utility of fault length or displacement for estimating magnitudes (continued)

are several orders of magnitude longer than the planned operating lifetime of the surface waste-handling facilities. The 10-kyr CSE methodology takes this fact into account and, as described in the previous section, may still be too conservative, given the low probability of exceeding the resulting design basis and the low probability of incurring significant damage in the event the design basis is exceeded. The use of a maximum-magnitude estimator to establish the seismic design basis would likely result in a design basis that is even more severe and, thus, cannot be justified.

Example of cumulative-slip-earthquake magnitude determination

The following hypothetical calculation was inserted in Section 8.3.1.17.3.1.2 and is presented here to illustrate how data collected during site characterization studies will be used to estimate the 10-kyr CSE for the ground motion design of surface facilities. (The calculation presented here has slightly more detail than the Section 8.3.1.17.3.1.2 insertion).

Sample Calculation: A fault in the vicinity of the site is identified by the procedures in Activity 8.3.1.17.3.1.1 as a potentially relevant earthquake source. Mapping and trenching studies find that the fault is 30 km long and that it displaces a 740,000-year-old layer 7.5 m vertically and 1.5 m horizontally. Trenching at other localities along the fault indicate that the above values are representative of the behavior of the fault through the Quaternary. The above data are used to calculate a net slip of 7.65 m over 740,000 years and a Quaternary slip rate of 0.01 mm/yr. The average cumulative slip over 10,000 years can then be calculated as 0.1 m. The 10,000 year cumulative slip earthquake assumes that all of this displacement is released as a single event. The magnitude of this event can be estimated using the empirical regression curves such as Bonilla et al. (1984) and Slemmons (1982). The published regression curves use maximum displacement rather than average displacement to estimate magnitude, so a maximum displacement must be estimated for the 10,000 year event. Bonilla (1982) (NUREG/CR-2991, p. 4) found that the maximum displacement is about 3 times the average displacement for most events. Using this value, the maximum displacement for the 10,000 year event is about 0.3 m. When these calculations are conducted for the final evaluations, all published methods will be evaluated and compared. New regression analyses may also be prepared for Basin and Range province comparing displacement with magnitude or moment. For the purposes of this example, if the results of Bonilla et al. (1984) are used, a 0.3 m displacement would indicate an earthquake of M_s 6.6. The rupture length of this event can be estimated using the wna.dl (Western North American; displacement-magnitude) relation of Bonilla et al. (1984) as 18.8 km. The reasonableness of these estimates can be checked by calculating the percentage of the total fault length hypothesized to rupture (63 percent) and comparing the results with historical events in the province or with data on measured scarp lengths along the subject fault. Any data on single event displacements and recurrence intervals can also be compared to the design event to evaluate the results.

RESPONSE TO COMMENT #52 (continued)

Example of cumulative-slip-earthquake magnitude determination

Uncertainty in the estimation of the magnitude of the 10,000 year event can come from the statistical uncertainty associated with the use of regression curves and the uncertainty in the estimate of average displacement rates. The statistical uncertainty in the magnitude estimates can be quantified using the techniques discussed in Bonilla et al. (1984). The uncertainty in the slip rate estimates will be evaluated by reviewing the results from multiple locations along the subject fault and the data on the accuracy of displacement and age dating measurements.

Sufficiency of the cumulative slip earthquake approach for the SCP

The 10-kyr CSE methodology and the planned adjunct probabilistic seismic hazard analysis provide a useful and sufficient framework for scoping, organizing, and prioritizing seismic-hazard-related site characterization activities. Together the CSE methodology and the probabilistic analysis require all types of information that are material to the characterization of seismic hazard, including data on fault lengths and displacements, slip rates, faulting styles, maximum-magnitude estimates, recurrence-rate estimates, attenuation relationships, local and regional tectonic models, historical seismicity data and the uncertainties associated with all of these items.

The planned site characterization activities are designed to provide this information.

DOE Responses to the items cited as a basis for the recommendations

1. Assessment of the magnitudes of earthquakes that may affect the site is an inherent part of a probabilistic seismic hazard analysis and this information will be obtained through the studies described in Section 8.3.1.17.3.

2. Low earthquake recurrence rates are not thought to invalidate estimates of potential earthquake magnitudes made using fault length or displacement. However, when earthquake recurrence rates are low, the use of such estimates alone to characterize seismic hazard can be misleading. Section 8.3.1.17.3.1.2 has been modified to clarify this point.

3. The magnitude values cited in the basis appear to have been calculated assuming that each fault ruptures over 100 percent of its length. More common practice in using rupture length-magnitude relationships is to use a fraction of the total fault length. This would result in smaller magnitude values than the ones cited.

RESPONSE TO COMMENT #52 (continued)

DOE Responses to the items cited as a basis for the recommendations (continued)

4. The magnitude values given in the basis appear to have been derived using average Quaternary displacements and the displacement-magnitude relationship of Bonilla et al. (1984). This is inappropriate because the Bonilla et al. (1984) relationship is for the maximum displacement found in a single event; a correction factor must be applied when using average displacement. This would result in larger magnitude values than the ones cited.

come from Activity 8.3.1.17.4.3.5. The assessment of faulting potential will also consider estimates of slip rates on Quaternary faults in the site area (from Activity 8.3.1.17.4.6.2), the fractal geometry of local fault systems (see description of Activity 8.3.1.17.2.1.1), interpreted tectonic (mechanistic) interrelationships among local faults, and models for the accommodation of regional strain by local faults.

Methods and technical procedures

This activity will only synthesize and compile data collected by other activities. All evaluations and calculations will be documented or verified in conformance with the DOE quality assurance program (Section 8.6).

8.3.1.17.2.2 Application of results

Information on potential fault displacement will be used as follows:

1. In the development and analyses of the repository design (Issue 4.4, preclosure design and technical feasibility, Section 8.3.2.5).

2. In the determination of credible accidents that are applicable to the repository (Issue 2.3, accidental radiological releases, Section 8.3.5.5).

3. In the determination that waste can be accessed and removed from the emplacement boreholes throughout the retrievability period for normal and off-normal conditions (Issue 2.4, waste retrievability, Section 8.3.5.2).

4. In the identification of normal and accident conditions, including disruptive events (Issue 2.7, preclosure radiological design requirements, Section 8.3.2.3).

8.3.1.17.3 Investigation: Studies to provide required information on vibratory ground motion that could affect repository design or performance

Technical basis for obtaining the information need

Link to the technical data chapters and applicable support documents

Sections 1.3, 1.4, and 1.5 of the SCP data chapters provide a technical summary of existing data relevant to this investigation.

Parameters

This investigation will provide the following characterization parameters related to potential vibratory ground motion at the site from natural and man-made seismic sources (Tables 8.3.1.17-5a -5b, -6a, and -6b):

1. Identification of potential earthquake sources in the controlled area.

2. Identification of earthquake sources within 100 km of the site that could be relevant to the site (i.e., that could conceivably control the design-basis ground motions at the site in any frequency band of engineering significance).

3. Magnitudes of 10,000-yr cumulative slip* earthquakes on local earthquake sources.

4. Magnitudes of 10,000-yr cumulative slip* earthquakes on regional earthquake sources.

5. Maximum potential yields of future underground nuclear explosions (UNEs) at the Nevada Test Site (NTS).

6. Closest distance between the site and potential future UNEs at NTS.

7. Ground-motion models/attenuation relationships for the site region (i.e., mathematical models for predicting the values of ground-motion parameters as a function of the distance from and the strength of the earthquake or UNE source).

8. Spectral amplification functions that represent the effects of local site geology on surface seismic motions and the effects of depth on underground seismic motions.

9. Identification of controlling seismic events--those 10,000-yr cumulative slip earthquakes and/or potential largest and closest UNEs that would generate the most severe ground motions at the site in any frequency band of engineering significance, taking into account an local-geologic or depth effects on the ground motion.

10. Time histories and response spectra that are representative of potential ground motion at the site from the controlling seismic event(s).

11. Magnitude-recurrence relationships for all regional earthquake sources that could contribute to the earthquake hazard at the site.

12. Probabilities of exceeding selected ground-motion parameters at the site, developed through probabilistic seismic hazard analysis.

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*10,000-yr cumulative earthquakes are defined here to be earthquakes that, occurring every 10,000 yr, would produce the observed or estimated average Quaternary slip rate on a fault; see discussion in description of Activity 8.3.1.17.3.1.2.

Purpose and objectives of the investigation

The purposes of this investigation are to (1) develop a seismic-design basis for repository facilities that are important to safety and (2) provide other information that will facilitate the assessment of the adequacy of the seismic-design basis and the identification of credible accidents that might be initiated by seismic events and lead to release of radioactive materials. The seismic-design basis will account for both the potential occurrence of earthquakes on nearby faults and potential future underground nuclear explosions at the Nevada Test Site.

The planned methodology for developing the seismic-design basis is, as is discussed in detail below, intended to result in design levels such that the probability of the design level being exceeded is comparable to typical exceedance probabilities for the seismic-design bases of operating nuclear power plants in the United States (i.e., annual probabilities of exceedance on the order of 1×10^{-3} to 1×10^{-4}).

Although this investigation is motivated by the need to develop a seismic-design basis and other information related to the design of facilities important to safety (FITS), the resulting design-basis ground-motion descriptions also may be considered in the design of other repository facilities. (Presently, only the shipping cask and certain components of the waste-handling facilities are considered potentially important to safety (Laub and Jardine, 1987). Current plans call for the FITS seismic-design basis to be considered also in the design of underground facilities (Information Need 4.4.1, site and performance assessment information needed for design, Section 8.3.2.5.1).

The approach that is currently considered appropriate for developing a seismic design basis is deterministic, meaning that the design-basis ground-motion description will correspond to the postulated occurrence of a discrete seismic event or events (e.g., the occurrence of an earthquake of specified magnitude on a particular fault). This type of approach parallels that used to develop the seismic design bases of all nuclear power plants in the United States. In addition, probabilistic estimates of the seismic hazard at the site will be developed that integrate individual contributions to the site's ground-motion potential from earthquake sources at different distances and with different earthquake recurrence characteristics. The probabilistic seismic hazard estimates will be used to evaluate and constrain required technical judgments in the deterministic approach, evaluate the adequacy of the deterministic results, and help identify and focus efforts to refine those parameters that are most important for the deterministic calculations. The probabilistic hazard estimates will also provide input needed to determine credible accidents that are applicable to the repository (Information Need 2.3.1, Section 8.3.5.5.1).

In summary, probabilistic seismic hazard estimates will be an important adjunct to the deterministic estimates that will be developed for consideration in the seismic design of FITS. A discussion of the reasons for using deterministic and probabilistic methodologies in this fashion is given in the Overview section for this investigation.

Technical rationale for investigation

Ten-thousand year cumulative slip earthquakes are defined here to be earthquakes that, occurring every ten-thousand years, would produce the observed or estimated average Quaternary slip rate on a fault (see detailed discussion in description of Activity 8.3.1.17.3.1.2). Controlling seismic events are those exceptional earthquakes and/or potential largest and closest UNEs that would generate the most severe ground motions at the site in any frequency band of engineering significance. The seismic design basis for FITS will be suites of ground-motion time histories and corresponding response spectra that are representative of the controlling seismic events.

A logic diagram for this investigation is presented in Figure 8.3.1.17-5.

Study 8.3.1.17.3.1 will identify and characterize earthquake sources that could potentially be relevant to a deterministic seismic hazard analysis of the site, i.e., sources that could conceivably produce exceptional earthquakes that would control the seismic-design basis in any frequency band of engineering significance. Characterization of earthquake sources for the deterministic hazard assessment will include a determination of each source's location, orientation, depth, likely style of faulting, and an evaluation of the 10,000-yr cumulative slip earthquake magnitude. Here, and elsewhere, uncertainty in the determination of input parameters will be estimated so that the sensitivity of the final results to key assumptions can be estimated.

The identification and characterization of relevant earthquake sources will consider the historical record of regional seismicity; the potential for seismicity to be induced at the site by human activities; the location, nature, and rate of Quaternary faulting in the site area; crustal stresses at seismogenic depths; evidence of neotectonic deformation in the Yucca Mountain area; and the overall tectonic framework of the region.

Study 8.3.1.17.3.2 will determine the potential locations and maximum yields of future UNEs at the NTS, considering constraints such as damage thresholds in Las Vegas. The UNE(s) that would cause the most severe ground motions at the site will then be identified using a predictive model for UNE ground motions.

Models for predicting UNE ground motions and models for predicting earthquake ground motions will be selected or developed in Study 8.3.1.17.3.3. Published ground-motion models for UNEs at NTS will be used where appropriate. If published models are not available for all ground-motion parameters needed, available data will be compiled and the needed models will be developed through regression analyses. Earthquake ground-motion data from the Great Basin and tectonically analogous areas will be tested for statistically significant deviations from published earthquake ground-motion models that have been developed for California and western North America. If the deviations are not statistically significant, a published model will be selected. If needed, new models will be developed through regression analyses.

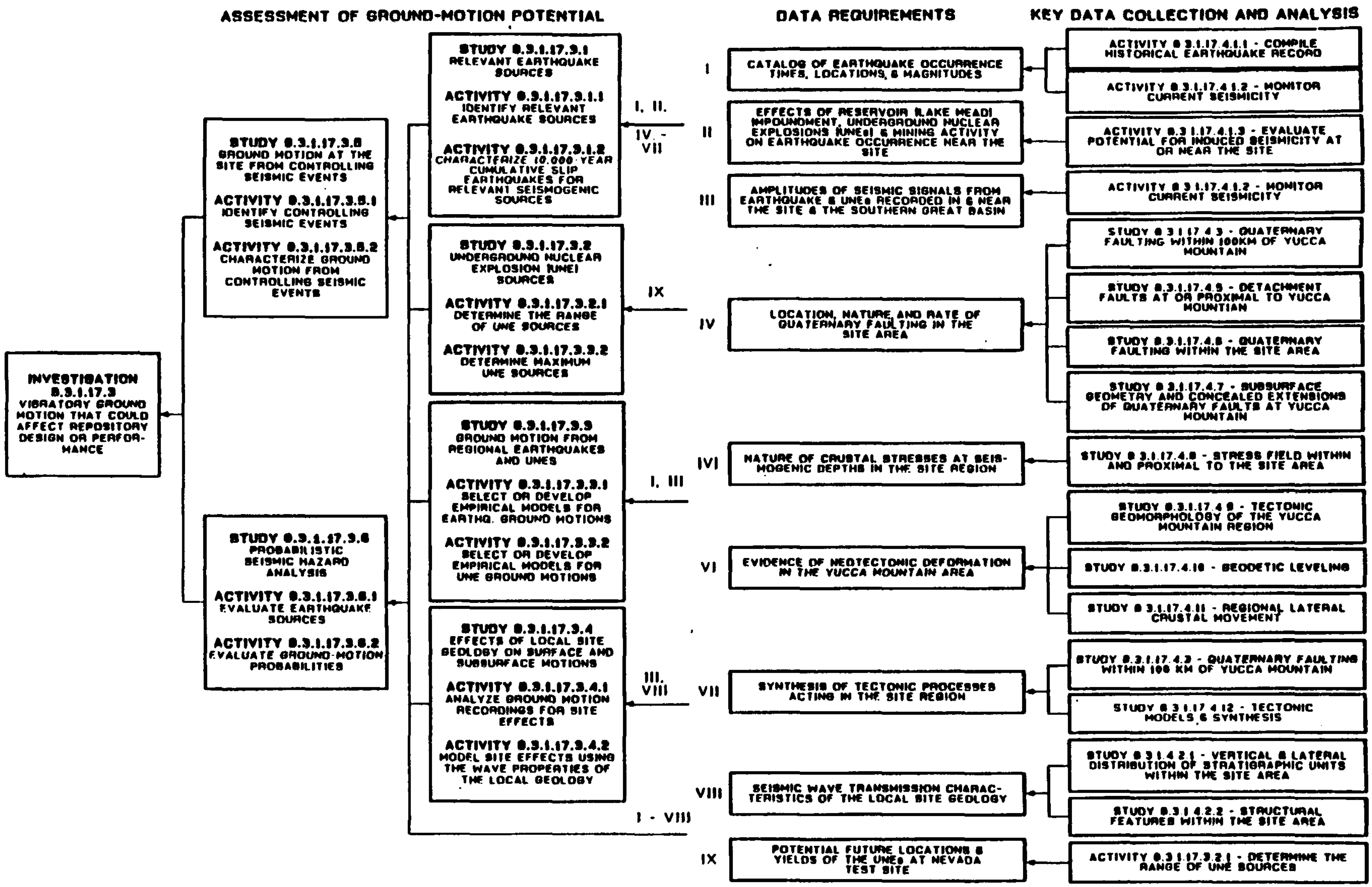

Figure 8.3.1.17-5. Logic diagram for the Investigation 8.3.1.17.3 (preclosure vibratory ground motion). (Roman numerals indicate data flow.)

Systematic effects on surface and subsurface ground motions resulting from the local site geology will be identified and used to correct predictions of the regional ground-motion models developed in Study 8.3.1.17.3.3. These correction factors will be based, to the extent possible, on actual ground-motion recordings obtained in Study 8.3.1.17.4.1. Theoretical models based on the wave properties of the local geology will be developed to the degree necessary to explain the observations to first order and then used to extrapolate the observations to locations and depths where ground motions must be predicted but where recordings are not available.

Identification of controlling seismic events and characterization of the resulting ground motion at the site will be accomplished in Study 8.3.1.17.3.5. Identification of the controlling seismic events will follow directly from the identification of 10,000-year cumulative slip earthquakes on relevant sources in Study 8.3.1.17.3.1, the determination of potential maximum future UNEs in Study 8.3.1.17.3.2, the earthquake and UNE ground-motion models developed in Study 8.3.1.17.3.3, and the local site correction factors developed in Study 8.3.1.17.3.4.

Controlling-event ground motions will be characterized by suites of strong-motion time histories that are representative in terms of expected amplitudes, frequency content, and duration. Methodologies for constructing these time histories will be evaluated. Two different methodologies may be implemented and the results compared to help assess the uncertainty in the final results.

The probabilistic seismic hazard analysis of the site constitutes Study 8.3.1.17.3.6. The first step in the analysis is to identify and characterize earthquake sources that contribute to the hazard (the probability of exceeding different ground-motion levels) at the site. Sources that are more distant and sources with smaller earthquake potential than the "relevant" sources addressed in Study 8.3.1.17.3.1 will be characterized so that exceedance probabilities for ground-motion levels below the design-basis levels can be estimated. (Exceedance probabilities for motions beyond the design-basis will also be estimated.) Each seismic source will be characterized as to location, depth, shape, and magnitude-recurrence characteristics, including maximum-magnitude potential. The considerations in characterizing the contributing earthquake sources in the probabilistic analysis are essentially the same as those in characterizing relevant sources in the deterministic analysis, and so the same types of data are required.

There are different methodologies available for encoding uncertainty in seismic-source-zone interpretations and for aggregating the results of multiple interpretations in a probabilistic seismic hazard analysis. The advantages and disadvantages of available methodologies will be assessed before an approach is chosen.

A probabilistic seismic hazard analysis of the site is expected to be performed concurrently with the deterministic analysis and repeated one or more times, with detail increasing as more data become available. The sensitivity of estimated hazard to various input parameters is easy to assess within the probabilistic framework, and the preliminary analyses will help to identify the parameters of greatest importance to both the probabilistic and deterministic analyses; this information will be used to redirect and focus the characterization activities. The calculated probabilistic hazard levels will also be used to help assess the adequacy of the deterministically derived design-basis ground motions. As was stated earlier, a measure of adequacy that is adopted here is that the annual probability of the design-basis ground motions being exceeded is between 10^{-3} and 10^{-4} per yr, which is the range of probabilities that appears to correspond to seismic-design bases that have been accepted for nuclear power plants in the United States.

8.3.1.17.3.1 Study: Relevant earthquake sources

The objectives of this study are to identify and characterize those earthquake sources that are relevant to a deterministic seismic hazard analysis of the site (i.e., those sources that could be active) and, if active, could cause severe ground shaking at the site. Potential earthquake sources include faults with surface geologic expression as well as concealed faults. Each seismic source will be characterized by its location, depth, orientation, likely style of faulting, and 10,000-yr cumulative slip earthquake magnitude.

8.3.1.17.3.1.1 Activity: Identify relevant earthquake sources

<u>Objectives</u>

The objective of this activity is to identify earthquake sources that could generate severe ground motions at the site.

<u>Parameters</u>

The following types of information will be synthesized in this activity:

1. Maps and cross sections of historical earthquake locations.
2. Maps showing Quaternary faults with lengths greater than about 20 km within 100 km of the site and Quaternary faults with lengths greater than about 1 km within 10 km of the site.
3. Data on the style and rate of Quaternary faulting in the site region.
4. Evidence of neotectonic deformation or stability in the site region.
5. Regional heat-flow anomaly maps and regional and local magnetic-anomaly and gravity-anomaly maps.
6. Regional and local crustal seismic data.
7. Information on local and regional crustal stresses.
8. Local and regional tectonic models.

These information items will be supplied mostly by the data-collection-and-analysis activities in Investigation 8.3.1.17.4 (Figure 8.3.1.17-5).

Description

Relevant earthquake sources will be identified through a synthesis of information of the types listed in the parameter section. Surface evidence of Quaternary faulting and patterns of historical seismicity will be paramount considerations. Magnetic and gravity anomalies, crustal seismic data, and heat-flow will be analyzed for indications of faulting at depth. The assessment of whether a geophysical anomaly corresponds to a fault will consider information on the local structural geology and surface geomorphology. The likelihood of a buried fault being active will be evaluated considering the spatial correlation of the fault with historical seismicity, the orientation of the feature with respect to measured or inferred crustal stress orientations, potential tectonic interrelationships with other local faults, and conceptual models of the regional tectonics.

The assessment of relevance of an identified seismic source requires an assessment of the magnitude capability of the source. Hence, this activity will be performed concurrently and iteratively with the effort to define 10,000-yr cumulative slip earthquakes for relevant earthquake sources in Activity 8.3.1.17.3.1.2.

Relevance to a deterministic seismic hazard analysis of the site of identified earthquake sources will be judged according to a preliminary estimation of the 10,000-yr cumulative slip earthquake magnitude of the source and the distance of the source from the site, using criteria similar to the following:

Source distance (R)	10,000-year cumulative slip earthquake magnitude (M)
$0 \leq R < 3$ km	$M > 5$
$3 \leq R < 100$ km	$M > 4 + 2 \log_{10} R$

Relevance to a deterministic seismic hazard analysis of identified earthquake sources is determined by the potential for such sources to possibly control the severity of ground shaking at any frequency of engineering significance. The determination of relevance involves the determination of the 10,000-yr cumulative slip earthquake for each source and the prediction of potential ground motion in different frequency bands. Attenuation relationships for frequency-specific measures of ground-motion severity (e.g., spectral ordinates of pseudo-relative velocity response) are thus required for the relevancy determination.

The conceptual approach for identifying potentially relevant earthquake sources is illustrated graphically in Figure 8.3.1.17-6. The curve in this figure is based on preliminary professional judgment. No numerical calculations were performed to construct the curve; it is intended to be illustrative only.

The curve drawn in Figure 8.3.1.17-6 reflects the expectation that local faults will control potential high-frequency ground motion and that larger, more distant faults could control lower frequency ground motions. The curve

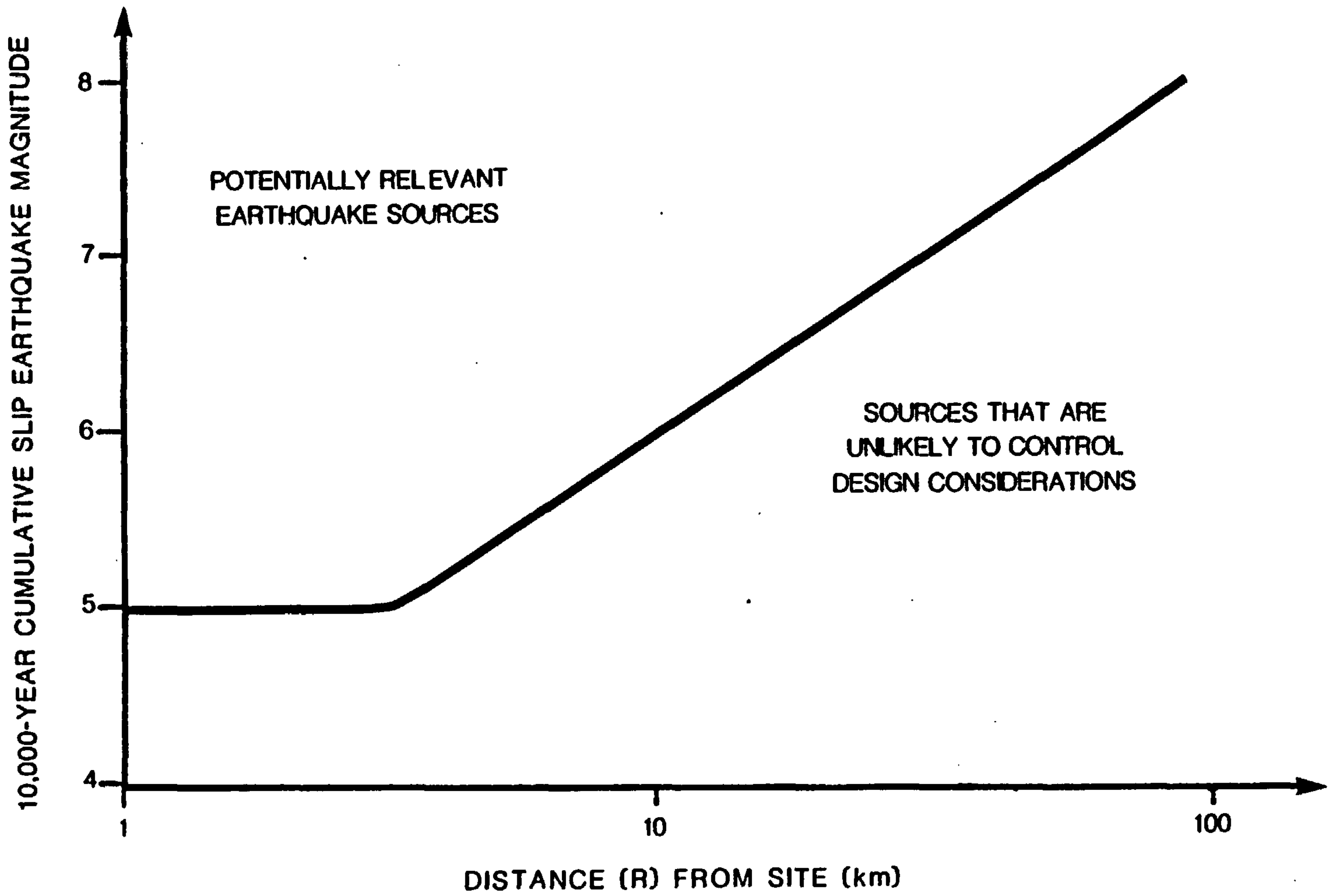

Figure 8.3.1.17-6. Conceptual approach for identifying potentially relevant earthquake sources.

is not permitted to go below magnitude 5 because faults with cumulative-slip earthquake magnitudes less than this value are probably too small to detect with any confidence. (If it is determined that earthquakes smaller than magnitude 5 could impact repository design or performance, their occurrence will be considered to be spatially and temporally random and the associated hazard will be modeled probablistically as part of Study 8.3.1.17.3.6.)

The relevancy criteria will be refined through analysis of the earthquake ground-motion (attenuation) relationships that will be selected or developed in Study 8.3.1.17.3.3 and considering any revisions to the parameters needed for seismic design (Section 8.3.2.5.1) and design analysis (Section 8.3.2.5.7). Given the uncertainty in estimating magnitudes and ground motions, any criteria developed will be applied conservatively to avoid the premature screening of potentially relevant sources.

Methods and technical procedures

This activity will only synthesize and compile data collected by other activities. All evaluations and calculations will be documented or verified in conformance with the DOE quality assurance program (Section 8.6).

8.3.1.17.3.1.2 Activity: Characterize 10,000-yr cumulative slip earthquakes for relevant seismogenic sources

Objectives

The objective of this activity is to characterize 10,000-yr cumulative slip earthquakes for each of the relevant seismogenic sources identified in the previous activity. The nature, size, and location of 10,000-yr cumulative slip earthquakes are to be established based on the seismogenic properties of the potential sources.

Description

The concept of 10,000-yr cumulative slip earthquakes is being established to develop deterministic characterizations of potential severe vibratory ground motion for consideration in the design of repository facilities important to safety. Available data (Section 1.3) for faults in the site region that have moved during the Quaternary suggest that recurrences intervals may be on the order of 1×10^4 to 1×10^5 yr. Such low rates suggest that the use of fault length or displacement to develop deterministic estimates of magnitude for a given fault may be misleading in terms of the hazard posed by the fault. The concept of the 10,000-yr cumulative slip earthquake takes recurrence rates into account, in addition to the fault characteristics, for determining a maximum magnitude for the purpose of estimating potential severe vibratory ground motion at the site. 10,000-yr cumulative slip earthquakes for Quaternary faults are defined as those earthquakes that, occurring every 10,000 yr, would produce the observed or estimated average Quaternary slip rate on a fault. The magnitude of a 10,000-yr cumulative slip earthquake is a best estimate based on the equivalent 10,000-yr displacement and available information on fault dimensions and geometry and possible interactions with other faults. To ensure applicability of the concept in cases where slip rates are such that major strain-releasing earthquakes are expected more often than every 10,000 yr (e.g., the San Andreas fault), the 10,000-yr cumulative slip earthquake magnitude is constrained to not exceed the best-estimate maximum magnitude. Finally, to ensure adequate conservatism of the design vibratory ground motion, an additional constraint on the magnitude is that the resulting design-basis ground motion for facilities important to safety have an annual probability of exceedance between 10^{-3} and 10^{-4} per yr.

Various types of data will be used to evaluate 10,000-yr cumulative slip earthquakes, including estimated slip rates, mapped fault lengths, fault displacement (per event if available), fault type, and other pertinent geologic data. The following hypothetical calculation is presented to illustrate how data collected during site characterization studies will be used to estimate the 10,000-yr cumulative slip earthquake for the ground motion design of surface facilities.

Sample Calculation: A fault in the vicinity of the site is identified by the procedures in Activity 8.3.1.17.3.1.1 as a potentially relevant earthquake source. Mapping and trenching studies find that the fault is 30 km long and that it displaces a 740,000-yr-old layer 7.5 m vertically and 1.5 m horizontally. Trenching at other localities along the fault indicate that the above values are representative of the behavior of the fault through the Quaternary. The above data are used to calculate a net slip of 7.65 m over 740,000 yr and a Quaternary slip rate of 0.01 mm/yr. The average cumulative slip over 10,000 yr can then be calculated as 0.1 m. The 10,000-yr cumulative slip earthquake assumption is that all this displacement is released as a single event. The magnitude of this event can be estimated using empirical regression curves such as Bonilla et al. (1984) and Slemmons (1982). The published regression curves use maximum displacement rather than average displacement to estimate magnitude, so a maximum displacement must be estimated for the 10,000-yr event. Bonilla (1982) found that the maximum displacement is about 3 times the average displacement for most events. Using this value, the maximum displacement for the 10,000-yr event is about 0.3 m. When these calculations are conducted for the final evaluations, all published methods will be evaluated and compared. New regression analyses may also be prepared for the Basin and Range province comparing displacement with magnitude or moment. For the purposes of this example, the results of Bonilla et al. (1984) will be used. Using the wna.dm (western North American; displacement-magnitude) relation of Bonilla et al. (1984), a 0.3 m displacement would indicate an earthquake of M_s 6.6. The rupture length of this event can be estimated using the wna.dl (western North American; displacement-length) relation of Bonilla et al. (1984) as 18.8 km. The reasonableness of these estimates can be checked by calculating the percentage of the total fault length hypothesized to rupture (63 percent) and comparing the results with historical events in the province or with data on measured scarp lengths along the subject fault. Any data on single event displacements and recurrence intervals can also be compared with the design event to evaluate the results.

Uncertainty in the estimation of the magnitude of the 10,000-yr event can come from the statistical uncertainty associated with the use of regression curves and the uncertainty in the estimate of average displacement rates. The statistical uncertainty in the magnitude estimates can be quantified using the techniques discussed in Bonilla et al. (1984). The uncertainty in the slip rate estimates will be evaluated by reviewing the results from multiple locations along the subject fault and the data on the accuracy of displacement and age-dating measurements.

Earthquake magnitude-frequency relationships will be estimated (using available data) considering characteristic-earthquake models or other relationships such as exponentially decaying models or maximum likelihood models. A probability distribution for true maximum magnitude, M_{max}, will be estimated for the probabilistic seismic hazard analysis of the site--Activity 8.3.1.17.3.6.1. The magnitude-frequency relationship will be used to evaluate the recurrence interval associated with M_{max} and will assist in determining whether the 10,000-yr cumulative slip earthquake magnitude should differ from M_{max}.

The 10,000-yr cumulative slip earthquakes for each relevant earthquake source will be characterized by an expected depth or depth-range and earthquake magnitude.

The 10,000-yr cumulative slip earthquake methodology and the planned adjunct probabilistic seismic hazard analysis provide a useful and sufficient framework for scoping, organizing, and prioritizing seismic-hazard-related site-characterization activities. Together the cumulative slip earthquake methodology and the probabilistic analysis require, and the planned site-characterization activities are designed to provide, all types of information that are material to the characterization of seismic hazard, including data on fault lengths and displacements, slip rates, faulting styles, maximum-magnitude estimates, recurrence-rate estimates, attenuation relationships, local and regional tectonic models, historical seismicity, and the uncertainties associated with all these items. The cumulative slip earthquake methodology may be revised or a different methodology may be used to actually develop a design basis for the advanced conceptual design and the license application design. In any instance, the data gathered will be comprehensive and sufficient for application to any methodology.

Methods and technical procedures

This activity will only synthesize and compile data collected by other activities. All evaluations and calculations will be documented or verified in conformance with the DOE quality assurance program (Section 8.6).

8.3.1.17.3.2 Study: Underground nuclear explosion sources

The objective of this study is to characterize the potential future underground nuclear explosions (UNEs) at the Nevada Test Site (NTS) that region would result in the most severe motions at the repository site.

8.3.1.17.3.2.1 Activity: Determine the range of UNE sources

Objectives

The objective of this activity is to determine potential locations and upper limits on the yield of future UNE tests within the NTS.

Description

Previous work on potential UNE ground motions at the site has assumed that a 700-kiloton explosion is detonated in the Buckboard Mesa area of the NTS, at a distance of 23 km from the repository shaft (Vortman, 1986). This activity will review the basis for these assumptions, in particular, the constraints on maximum UNE yields, such as damage thresholds in Las Vegas. (The current test-ban treaty threshold is 150 kiloton.) Factors that could influence the locations of future UNEs, such as terrain and rock types at the NTS, will be reviewed. Information on depth of burial as a function of yield will be compiled. Information available in the open literature is expected to adequately constrain the potential locations, depths, and maximum yields of future UNEs at the NTS.

Methods and technical procedures

This activity will only synthesize and compile data collected by other activities. All evaluations and calculations will be documented or verified in conformance with the DOE quality assurance program (Section 8.6).

8.3.1.17.3.2.2 Activity: Determine maximum underground nuclear explosion source(s)

Objectives

The objective of this activity is to identify the potential future UNE(s) that would generate the most severe ground motions at the site.

Description

UNE ground-motion (attenuation) models (which will be developed or selected in Activity 8.3.1.17.3.3.2) will be used to estimate site ground motions that would result from the largest and/or closest potential future UNEs, as identified in Activity 8.3.1.17.3.2.1. The UNE or UNEs that would generate the most severe ground motions at the site, in any frequency band of engineering significance, will be identified.

Methods and technical procedures

This activity will only synthesize and compile data collected by other activities. All evaluations and calculations will be documented or verified in conformance with the Project quality assurance program (Section 8.6).

8.3.1.17.3.3 Study: Ground motion from regional earthquakes and underground nuclear explosions

Objectives

The objective of this study is to select or develop ground-motion models that are appropriate for estimating ground motion at the site from earthquakes and UNEs. These models will be used to determine the relevancy of seismic sources to a deterministic seismic hazard analysis (Activity 8.3.1.17.3.1.1), identify controlling seismic events (Activity 8.3.1.17.3.5.1), constrain simulated ground motions from controlling seismic events (Activity 8.3.1.17.3.5.2) and estimate the probabilities of exceeding given ground-motion levels at the site (Activity 8.3.1.17.3.6.2).

8.3.1.17.3.3.1 Activity: Select or develop empirical models for earthquake ground motions

Objectives

The objective of this activity is to select or develop empirical ground-motion models that are appropriate for estimating earthquake ground motion at the site. The models will predict ground motion as a function of earthquake magnitude and distance between the earthquake source and the site.

Parameters

Models will be determined for a number of ground-motion parameters, including peak ground acceleration and velocity, duration, and spectral amplitudes at frequencies sampled over the range of engineering significance.

Description

The approach here will be to test available ground-motion data from the Great Basin and areas elsewhere that are tectonically analogous for statistically significant deviations from published models that have been developed for California and western North America. If the deviations are not statistically significant, a published model will be selected. If the deviations are statistically significant or if published models are not available for any of the ground-motion parameters to be modeled, then new models will be developed through regression analyses. Each model selected or developed will include an explicit description of the uncertainty in the model predictions.

Methods and technical procedures

This activity will only synthesize and compile data collected by other activities. All evaluations and calculations will be documented or verified in conformance with the DOE quality assurance program (Section 8.6).

8.3.1.17.3.3.2 Activity: Select or develop empirical models for ground motion from underground nuclear explosions

Objectives

The objective of this activity is to select or develop empirical ground-motion models that are appropriate for estimating ground motion at the site from UNEs at the NTS. The models will predict ground motion as a function of the yield and distance of the UNE.

Parameters

As for earthquakes, models will be determined for a number of ground-motion parameters, including peak ground acceleration and velocity, duration, and spectral amplitudes sampled over the range of engineering significance.

Description

If possible, published ground-motion models for NTS explosions (Vortman, 1986) will be used. If appropriate published models are not available for all ground-motion parameters needed, available data will be compiled and the needed models will be developed through regression analyses.

Methods and technical procedures

This activity will only synthesize and compile data collected by other activities. All evaluations and calculations will be documented or verified in conformance with the DOE quality assurance program (Section 8.6).

8.3.1.17.3.4 Study: Effects of local site geology on surface and subsurface motions

Objectives

The objective of this study is to document systematic effects on surface and subsurface ground motions resulting from the local site geology. Local correction factors will be developed for application to predictions of the regional ground-motion models developed in Study 8.3.1.17.3.3. These correction factors will be based, to the extent possible, on instrumental recordings of ground motion obtained in Study 8.3.1.17.4.1. Theoretical models for the observed site effects will be developed to the extent necessary to explain the observations to first order and then used to extrapolate the observations to locations and depths where ground motions must be predicted but where recordings are not available.

8.3.1.17.3.4.1 Activity: Determine site effects from ground-motion recordings

Objectives

The objectives of this study are to determine, from ground-motion recordings, systematic effects of the local site geology on surface and subsurface motions, and to identify any significant site-wide bias in ground-motion levels, as compared with average levels for the southern Great Basin. These empirical determinations will be used to calibrate theoretical site-effects models in Activity 8.3.1.17.3.4.2.

Parameters

Ground-motion biases in the proximity of proposed locations of surface facilities important to safety, as compared with area averages obtained on rock sites, will be characterized using ratios of Fourier spectra and ratios of peak ground-motion parameters (peak accelerations and peak velocities). Corresponding ratios will be used to characterize reductions in ground motions recorded at the approximate depth of underground facilities as compared to area averages of surface recordings on rock sites.

Description

Recordings of teleseisms, regional earthquakes, local microearthquakes (if any), and UNEs will be obtained at several (3 to 6) surface and two or more borehole sites in Midway Valley, and at the proposed location of surface facilities, as described in Activity 8.3.1.17.4.1.2. The recorded motions will be examined for variation with position to identify any systematic biases, particularly with respect to the depth of the valley sediments. These recorded motions and the spatial variability will be used to help calibrate theoretical models developed in Activity 8.3.1.17.3.4.2 and to determine motion averages representative of proposed locations of surface facilities important to safety.

Spectral amplification functions will be estimated by forming ratios of recorded earthquake spectra at individual locations on Midway Valley to local-array-averaged spectra obtained on nearby rock stations. Amplification factors for peak ground-motion parameters will be similarly determined. The possibility of a site-wide bias in ground-motion levels will be checked by comparing amplitudes recorded at site locations to amplitudes recorded at sites elsewhere in the southern Great Basin, for earthquakes of similar size and at comparable distances.

The spectral amplitudes of subsurface motions will be compared with the spectral amplitudes for the corresponding surface motions and with the area averages for surface motions at rock stations. Previously recorded relevant NTS data will also be considered. These data will be used to quantify spectral reductions in motion with depth as a function of frequency. Instruments will be installed at two or more surface sites on Yucca Mountain, above proposed underground facilities, and at several sites within the exploratory shafts and drifts. The local array stations will be installed during the first phase of a planned upgrade of the current regional seismic network. These stations will digitally record and buffer incoming signals and then telemeter them via a satellite link to Golden, Colorado. In addition, a dense array of portable seismic event recorders will be temporarily deployed at some point for the study of local site effects. This temporary array will likely be deployed to take advantage of announced nuclear tests at the NTS.

Methods and technical procedures

This activity will only synthesize and compile data collected by other activities. All evaluations and calculations will be documented or verified in conformance with the DOE quality assurance program (Section 8.6).

8.3.1.17.3.4.2 Activity: Model site effects using the wave properties of the local geology

Objectives

The objective of this activity is to develop a calibrated theoretical site-effects model for use in extrapolating the observations documented in Activity 8.3.1.17.3.4.1 to locations and depths where ground-motion predictions are needed, but where instrumental recordings are not available.

Parameters

The product of this activity will be theoretical spectral amplification functions. Corresponding amplification factors for peak-ground-motion parameters will be estimated from the spectral amplification functions, if needed.

Description

Theoretical site-effects models will be developed, based on measurements of the wave properties (shear- and compressional-wave velocities, material damping, and densities) as determined in the investigation of soil and bedrock properties (Section 8.3.1.14.2). As part of that investigation, the seismic velocity structure of the site will be determined to a depth of at least 1 km, particularly under Midway Valley.

The approach to modeling will be to construct the simplest model that predicts the first-order features of the observed site-response functions. The initial model will assume a one-dimensional velocity structure, linear soil response, and vertically incident body waves. More complexity (e.g., nonvertically incident body waves, surface waves, equivalent-linear soil response, or two-dimensional velocity structure) will be introduced as necessary.

Methods and technical procedures

This activity will only synthesize and compile data collected by other activities. All evaluations and calculations will be documented or verified in conformance with the DOE quality assurance program (Section 8.6).

8.3.1.17.3.5 Study: Ground motion at the site from controlling seismic events

The objectives of this study are to identify the controlling seismic events and to characterize the resulting controlling ground motions. Controlling seismic events are those UNEs or 10,000-yr cumulative slip earthquakes that would generate the most severe ground motions at the site, at frequencies of engineering significance.

Two activities are included in this study.

8.3.1.17.3.5.1 Activity: Identify controlling seismic events

Objectives

The objective of this activity is to identify those UNEs or 10,000-yr cumulative slip earthquakes that would produce the most severe ground motions at the site at frequencies of engineering significance. There may be more than one controlling seismic event because different events may generate the most severe ground motions in different frequency bands.

Parameters

The controlling earthquake(s) will be characterized by earthquake magnitude and hypocentral location. Controlling earthquakes will be additionally characterized by the fault strike and dip and expected slip direction. The controlling UNE(s), if any, will be characterized by distance, azimuth, depth, and yield.

Description

Identification of the controlling seismic events will follow directly from the identification of 10,000-yr cumulative slip earthquakes on relevant sources in Study 8.3.1.17.3.1, the identification of potential future UNEs in Study 8.3.1.17.3.2, the earthquake and UNE ground-motion models developed in Study 8.3.1.17.3.3, and the local site correction factors developed in Study 8.3.1.17.3.4. Site ground-motion parameters, including peak ground acceleration and velocity, duration, and spectral ordinates at several frequencies, will be calculated for the 10,000-yr cumulative slip earthquakes and for the closest, largest potential UNEs. The seismic sources that produce the most severe ground motions as indicated by the calculated ground-motion parameters will be designated as controlling.

Methods and technical procedures

This activity will only synthesize and compile data collected by other activities. All evaluations and calculations will be documented or verified in conformance with the DOE quality assurance program (Section 8.6).

8.3.1.17.3.5.2 Activity: Characterize ground motion from the controlling seismic events

Objectives

The objective of this activity is to generate suites of strong-motion time histories and corresponding response spectra that are representative in amplitude, frequency content, and duration of site ground motions that could be generated by the controlling seismic events.

Parameters

The parameters for this activity are identified in the previous section on objectives.

Description

A number of methodologies are available for simulating strong ground motions, and the first task in this activity will be to determine which method or methods will be used. At present, two general approaches appear promising.

The first approach is to scale selected instrumental strong-motion records to the sizes (earthquake magnitudes or UNE yields) and distances of the controlling seismic events. The advantage of this approach is that the instrumental records can be chosen to minimize the necessary size and distance scaling. The disadvantage of this approach is that the available strong-motion records come from locations other than Yucca Mountain and therefore reflect different site conditions and, for earthquakes, perhaps different source characteristics.

The second approach is to model motion from a controlling seismic event by a summation of motions recorded at the site for smaller events (i.e., to use the small-event records as Green's functions in the simulation of the larger, controlling event (Hartzell, 1985; Spudich, 1985)). The advantage of the Green's function summation method is that propagation-path and local-geologic effects on site ground motions are inherently accounted for. The disadvantage (for earthquakes) is the uncertainty associated with scaling source characteristics of small events to those of large events.

The feasibility of both approaches described above, and possibly others, will be evaluated for application to Yucca Mountain. It may be appropriate to implement more than one approach and compare the results to help assess the uncertainty in the final results.

The peak ground-motion parameters, durations, and spectral ordinates of the resulting time histories will be checked for consistency with the regional ground-motion models developed in Study 8.3.1.17.3.3 and any necessary corrections will be made. The spectral content of the time histories will be corrected for local site effects, as necessary, using the spectral amplification functions developed in Study 8.3.1.17.3.4.

Methods and technical procedures

This activity will only synthesize and compile data collected by other activities. All evaluations and calculations will be documented or verified in conformance with the DOE quality assurance program (Section 8.6).

8.3.1.17.3.6 Study: Probabilistic seismic hazards analyses

The primary objective of this study is to quantify the probability for experiencing ground motions of varying degrees of severity that might result from earthquakes of varying magnitude and distance from the site. Results from this study will be used to evaluate and constrain required technical judgments in the deterministic evaluation of design-basis ground motions (such as the determination of exceptional earthquake magnitudes), evaluate the adequacy of the deterministic results, and help identify and focus efforts to refine those parameters that are most important for the deterministic calculations. The probabilistic hazard estimates will also provide information needed to assess the credibility of postulated accidents at the repository that might lead to releases of radioactive materials (Information Need 2.3.1, Section 8.3.5.5.1).

8.3.1.17.3.6.1 Activity: Evaluate earthquake sources

Objectives

The objective of this activity is to determine average rates for earthquake recurrence as a function of magnitude for the southern Great Basin to a distance of about 100 km from the site, and then to apportion these rates onto active faults and subregional seismic source zones.

Parameters

Earthquake sources will be characterized by location, shape, depth, and earthquake-recurrence rates as a function of magnitude, including the specification of a maximum magnitude or probability distribution for maximum magnitude.

The following types of information will be synthesized in this activity:

1. Maps and cross sections of historical earthquake locations.

2. Maps showing Quaternary faults with lengths greater than about 20 km within 100 km of the site and Quaternary faults with lengths greater than about 1 km within 10 km of the site.

3. Data on the style and rate of Quaternary faulting in the site region.

4. Evidence of neotectonic deformation or stability in the site region.

5. Regional and local magnetic-anomaly and gravity-anomaly maps.

6. Regional and local crustal seismic data.

7. Information on local and regional crustal stresses.

8. Local and regional tectonic models.

Description

The earthquake catalog developed in Study 8.3.1.17.4.1 will be used to determine the rate that earthquakes have occurred in the region surrounding the site during historical time as a function of magnitude. The completeness of the historical earthquake record in different areas and time intervals will be evaluated considering the number of events reported in the catalog as a function of magnitude and time, past human population distributions, and past distributions of recording instruments. Different types of magnitudes reported in the catalog will be converted to a uniform magnitude measure, possibly M_L, moment-magnitude, or both. (Statistical uncertainty in the conversions will be carried through the hazard analysis.) Additional checks will be made to reconcile the gross rates of crustal deformation for the southern Great Basin with deformation rates implied from observations of seismic-moment release rates. Estimates of the upper-magnitude limits for earthquakes in this area will be required to translate rates of earthquake occurrences to rates of crustal deformations. From these investigations, best estimates, accompanied by estimates of uncertainty, will be developed for characterizing the regional rate of earthquake occurrences.

This regional rate of earthquake occurrences will then be apportioned onto active faults and subregional source zones according to models of the local and regional tectonics. More than one model will likely be required for apportioning the earthquake activity in order to express the uncertainty in current scientific interpretations and to focus efforts to refine those source representations that have the greatest impact on the site.

In this activity, seismologic and geologic data will be used to interpret earthquake sources that contribute to the probability of exceeding given ground-motion levels at the site in essentially the same manner as they will be used in Study 8.3.1.17.3.1 to interpret earthquake sources that might control site ground motions in a deterministic hazard analysis. See the description sections of Activities 8.3.1.17.3.1.1 and 8.3.1.17.3.1.2. The scope of this activity is more comprehensive in that more seismic sources will be characterized, multiple interpretations of seismic sources will most likely be retained and their relative likelihoods judged, any dependencies in the interpreted existence of source zones (e.g., perfect dependence or mutual exclusiveness of some sources) must be specified, and maximum magnitudes must be estimated explicitly.

Source-zone maps will be produced by this activity to indicate the earthquake probability as a function of magnitude and location within the southern Great Basin.

Methods and technical procedures

The methods and technical procedures for Activity 8.3.1.17.3.6.1 are given in the following table.

Method	Technical procedure Number	Title	Date
	(NWM-USGS-)		
Integration of regional seismic and geologic data	SP-02,R0	Procedure for calculating frequency of recurrence curves	14 Sept 81
	SP-03,R0	Seismic zoning procedure	14 Sept 81
	SP-08,R0	Seismic study of the tectonic environment	06 June 83

[a]TBD = to be determined.

8.3.1.17.3.6.2 Activity: Evaluate ground motion probabilities

Objectives

The objectives of this activity are (1) to estimate the probability of exceeding given ground-motion levels at the site and (2) to integrate the contributions to that probability from all identified earthquake sources that could generate potentially damaging ground motion at the site.

Parameters

The basic information items needed for a probabilistic seismic hazard analysis are as follows:

1. Boundaries of seismic source zones, including, if warranted, alternative interpretations and corresponding judgments of the relative likelihood that each interpretation is correct.

2. Earthquake-magnitude recurrence rates for each source zone, including estimates of maximum magnitudes and assessments of uncertainty.

3. Specification of any dependencies in the interpreted existence or activity of source zones (e.g., perfect dependence or mutual exclusiveness of some sources).

4. Ground-motion (attenuation) models for predicting expected values and variances of required ground-motion parameters (e.g., peak velocity) as a function of distance and source size.

Description

There are a number of software packages available for computing probabilistic seismic hazard estimates given the information listed in the parameters section (e.g., codes developed by the Electric Power Research Institute (EPRI, 1986) and Lawrence Livermore National Laboratory (Bernreuter et al., 1986)). Some codes embody different means of propagating uncertainties through the analysis to the final results, and the alternative approaches will be evaluated. It may be appropriate to calculate hazard levels using different codes for comparison.

As stated previously, the probabilistic seismic hazard analysis will be performed iteratively, in parallel with the deterministic hazard analysis. The sensitivity of calculated hazard to different input parameters will be tested to identify what interpretations impact the site the most and may, therefore, warrant refinement. The final hazard estimates will be compared with the deterministically derived design-basis ground motions to verify that they correspond to annual exceedance probabilities of 10^{-3} to 10^{-4} per year.

Methods and technical procedures

The methods and technical procedures for Activity 8.3.1.17.3.6.2 are given in the following table.

Method	Technical procedure		
	Number	Title	Date
Probabilistic hazard calculations	TBD[a]	Probabilistic ground-motion calculations	TBD

[a]TBD = to be determined.

8.3.1.17.3.7 Application of results

Information on vibratory ground motion will be used as follows:

1. In the development and analysis of the repository design (Issue 4.4, technical feasibility, Section 8.3.2.5).

2. In the determination of credible accidents that are applicable to the repository (Issue 2.3, accidental radiological releases, Section 8.3.5.5).

3. In the determination that waste can be accessed and removed from the emplacement boreholes throughout the retrievability period for normal and off-normal conditions (Issue 2.4, waste retrievability, Section 8.3.5.2).

4. In the identification of normal and accident conditions, including disruptive events (Issue 2.7, repository design criteria on radiological safety, Section 8.3.2.3).