U.S. NUCLEAR REGULATORY COMMISSION
OFFICE OF NUCLEAR REGULATORY RESEARCH

July 2002
Division 3
DG-3021

DRAFT REGULATORY GUIDE

Contact: M. Shah (301)415-8537

DRAFT REGULATORY GUIDE DG-3021

SITE EVALUATIONS AND DETERMINATION OF DESIGN EARTHQUAKE GROUND MOTION FOR SEISMIC DESIGN OF INDEPENDENT SPENT FUEL STORAGE INSTALLATIONS AND MONITORED RETRIEVABLE STORAGE INSTALLATIONS

A. INTRODUCTION

The NRC has recently published proposed amendments to 10 CFR Part 72, “Licensing Requirements for the Independent Storage of Spent Nuclear Fuel and High-Level Radioactive Waste, and Reactor-Related Greater Than Class C Waste.” The Proposed Section 72.103, “Geological and Seismological Characteristics for Applications for Dry Modes of Storage on or after [insert effective date of Final Rule],” in paragraph (f)(1), would require that the geological, seismological, and engineering characteristics of a site and its environs be investigated in sufficient scope and detail to permit an adequate evaluation of the proposed site. The investigation must provide sufficient information to support evaluations performed to arrive at estimates of the design earthquake ground motion (DE) and to permit adequate engineering solutions to actual or potential geologic and seismic effects at the proposed site. In the Proposed Section 72.103, paragraph (f)(2) would require that the geologic and seismic siting factors considered for design include a determination of the DE for the site, the potential for surface tectonic and nontectonic deformations, the design bases for seismically induced floods and

---

This regulatory guide is being issued in draft form to involve the public in the early stages of the development of a regulatory position in this area. It has not received complete staff review or approval and does not represent an official NRC staff position.

Public comments are being solicited on this draft guide (including any implementation schedule) and its associated regulatory analysis or value/impact statement. Comments should be accompanied by appropriate supporting data. Written comments may be submitted to the Rules and Directives Branch, Office of Administration, U.S. Nuclear Regulatory Commission, Washington, DC 20555-0001. Comments may be submitted electronically or downloaded through the NRC’s interactive web site at <WWW.NRC.GOV> through Rulemaking. Copies of comments received may be examined at the NRC Public Document Room, 11555 Rockville Pike, Rockville, MD. Comments will be most helpful if received by **October 7, 2002.**

Requests for single copies of draft or active regulatory guides (which may be reproduced) or for placement on an automatic distribution list for single copies of future draft guides in specific divisions should be made to the U.S. Nuclear Regulatory Commission, Washington, DC 20555, Attention: Reproduction and Distribution Services Section, or by fax to (301)415-2289; or by email to DISTRIBUTION@NRC.GOV. Electronic copies of this draft guide are available through NRC’s interactive web site (see above), or the NRC’s web site <WWW.NRC.GOV> through the Electronic Reading Room under Accession Number ML021710092.

water waves, and other design conditions. In the Proposed Section 72.103, Paragraph (f)(2)(i) would require that uncertainties inherent in estimates of the DE be addressed through an appropriate analysis, such as a probabilistic seismic hazard analysis (PSHA) or suitable sensitivity analyses.

This guide is being developed to provide general guidance on procedures acceptable to the NRC staff for (1) conducting a detailed evaluation of site area geology and foundation stability, (2) conducting investigations to identify and characterize uncertainty in seismic sources in the site region important for the PSHA, (3) evaluating and characterizing uncertainty in the parameters of seismic sources, (4) conducting PSHA for the site, and (5) determining the DE to satisfy the requirements of 10 CFR Part 72.

This guide contains several appendices that address the objectives stated above. Appendix A contains definitions of pertinent terms. Appendix B describes the rationale used to determine the reference probability for the DE exceedance level that is acceptable to the staff. Appendix C discusses determination of the probabilistic ground motion level and controlling earthquakes and the development of a seismic hazard information base, Appendix D discusses site-specific geological, seismological, and geophysical investigations. Appendix E describes a method to confirm the adequacy of existing seismic sources and source parameters as the basis for determining the DE for a site. Appendix F describes procedures for determination of the DE.

This guide applies to the design basis of both dry cask storage Independent Spent Fuel Storage Installations (ISFSIs) and U.S. Department of Energy monitored retrievable storage installations (MRS), because these facilities are similar in design. The reference probability in Regulatory Position 3.4 and Appendix B does not apply to wet storage because applications for this means of storage are not expected, and it is not cost-effective to allocate resources to develop the technical bases for such an expansion of the proposed revision of Part 72.

This guide is consistent with Regulatory Guide 1.165 (Ref. 1), but it has been modified to reflect ISFSI and MRS applications, experience in the use of the dry cask storage methodology, and advancements in the state of knowledge in ground motion modeling (for example, see NUREG/CR-6728 (Ref. 2)).

Regulatory guides are issued to describe and make available to the public such information as methods acceptable to the NRC staff for implementing specific parts of the NRC's regulations, techniques used by the staff in evaluating specific problems or postulated accidents, and guidance to applicants. Regulatory guides are not substitutes for regulations, and compliance with regulatory guides is not required. Regulatory guides are issued in draft form for public comment to involve the public in the early stages of developing the regulatory positions. Draft regulatory guides have not received complete staff review and do not represent official NRC staff positions.

The information collections contained in this draft regulatory guide are covered by the requirements of 10 CFR Part 72, which were approved by the Office of Management and Budget (OMB), approval number 3150-0132. If a means used to impose an information collection does not display a currently valid OMB control number, the NRC may not conduct or sponsor, and a person is not required to respond to, the information collection.

B. DISCUSSION

BACKGROUND

A PSHA has been identified in the proposed Section 72.103 as a means to determine the DE for seismic design of an ISFSI or MRS facility. The proposed rule further recognizes that the nature of uncertainty and the appropriate approach to account for it depends on the tectonic environment of the site and on properly characterizing parameters input to the PSHA, such as seismic sources, the recurrence of earthquakes within a seismic source, the maximum magnitude of earthquakes within a seismic source, engineering estimation of earthquake ground motion, and the level of understanding of the tectonics. Therefore, methods other than probabilistic methods such as sensitivity analyses may be adequate to account for uncertainties.

Every site and storage facility is unique, and therefore requirements for analysis and investigations vary. It is not possible to provide procedures for addressing all situations. In cases that are not specifically addressed in this guide, prudent and sound engineering judgment should be exercised.

PSHA methodology and procedures were developed during the past 20 to 25 years specifically for evaluation of seismic safety of nuclear facilities. Significant experience has been gained by applying this methodology at nuclear facility sites, both reactor and non-reactor sites, throughout the United States. The Western United States (WUS) (west of approximately 104^{o} west longitude) and the Central and Eastern United States (CEUS) (Refs. 3, 4) have fundamentally different tectonic environments and histories of tectonic deformation. Results of the PSHA methodology applications identified the need to vary the fundamental PSHA methodology application depending on the tectonic environment of a site. The experience with these applications also served as the basis for the Senior Seismic Hazard Analysis Committee guidelines for conducting a PSHA for nuclear facilities (Ref. 5).

APPROACH

The general process to determine the DE at a new ISFSI or MRS site includes:

1. Site- and region-specific geological, seismological, geophysical, and geotechnical investigations, and

2. A PSHA.

For ISFSI sites that are co-located with existing nuclear power generating stations, the level of effort will depend on the availability and quality of existing evaluations. In performing this evaluation, the applicant should evaluate whether new data require re-evaluation of previously accepted seismic sources and potential adverse impact on the existing seismic design bases of the nuclear power plant.

CENTRAL AND EASTERN UNITED STATES

The CEUS is considered to be that part of the United States east of the Rocky Mountain front, or east of longitude 104^{o} west (Refs. 6, 7). To determine the DE in the CEUS, an accepted PSHA methodology with a range of credible alternative input interpretations should be used. For sites in the CEUS, the seismic hazard methods, the data developed, and seismic sources identified by Lawrence Livermore National Laboratory (LLNL) (Refs. 3, 4, 6) and the Electric

Power Research Institute (EPRI) (Ref. 7) have been reviewed and are acceptable to the staff. The LLNL and EPRI studies developed data bases and scientific interpretations of available information and determined seismic sources and source characterizations for the CEUS (e.g., earthquake occurrence rates, estimates of maximum magnitude).

In the CEUS, characterization of seismic sources is more problematic than in the active plate-margin region because there is generally no clear association between seismicity and known tectonic structures or near-surface geology. In general, the observed geologic structures were generated in response to tectonic forces that no longer exist and have little or no correlation with current tectonic forces. Therefore, it is important to account for this uncertainty by the use of multiple alternative models.

The identification of seismic sources and reasonable alternatives in the CEUS considers hypotheses presently advocated for the occurrence of earthquakes in the CEUS (e.g., the reactivation of favorably oriented zones of weakness or the local amplification and release of stresses concentrated around a geologic structure). In tectonically active areas of the CEUS, such as the New Madrid Seismic Zone, where geological, seismological, and geophysical evidence suggest the nature of the sources that generate the earthquakes, it may be more appropriate to evaluate those seismic sources by using procedures similar to those normally applied in the WUS.

WESTERN UNITED STATES

The WUS is considered to be that part of the United States that lies west of the Rocky Mountain front, or west of approximately 104° west longitude. For the WUS, an information base of earth science data and scientific interpretations of seismic sources and source characterizations (e.g., geometry, seismicity parameters) comparable to the CEUS as documented in the LLNL and EPRI studies (Refs. 3, 4, 6-8) does not exist. For this region, specific interpretations on a site-by-site basis should be applied (Ref. 9, 10).

The active plate-margin regions include, for example, coastal California, Oregon, Washington, and Alaska. For the active plate-margin regions, where earthquakes can often be correlated with known tectonic structures, structures should be assessed for their earthquake and surface deformation potential. In these regions, at least three types of sources may exist: (1) faults that are known to be at or near the surface, (2) buried (blind) sources that may often be manifested as folds at the earth's surface, and (3) subduction zone sources, such as those in the Pacific Northwest. The nature of surface faults can be evaluated by conventional surface and near-surface investigation techniques to assess orientation, geometry, sense of displacements, length of rupture, quaternary history, etc.

Buried (blind) faults are often associated with surficial deformation such as folding, uplift, or subsidence. The surface expression of blind faulting can be detected by mapping the uplifted or down-dropped geomorphological features or stratigraphy, survey leveling, and geodetic methods. The nature of the structure at depth can often be evaluated by deep core borings and geophysical techniques.

Continental U.S. subduction zones are located in the Pacific Northwest and Alaska. Seismic sources associated with subduction zones are sources within the overriding plate, on the interface between the subducting and overriding lithospheric plates, and in the interior of the downgoing oceanic slab. The characterization of subduction zone seismic sources includes consideration of the three-dimensional geometry of the subducting plate, rupture segmentation of subduction zones, geometry of historical ruptures, constraints on the up-dip and down-dip extent of rupture, and comparisons with other subduction zones worldwide.

The Basin and Range region of the WUS, and to a lesser extent the Pacific Northwest and the Central United States, exhibit temporal clustering of earthquakes. Temporal clustering is best exemplified by the rupture histories within the Wasatch fault zone in Utah and the Meers fault in central Oklahoma, where several large late Holocene coseismic faulting events occurred at relatively close intervals (hundreds to thousands of years) that were preceded by long periods of quiescence that lasted thousands to tens of thousands of years. Temporal clustering should be considered in these regions or wherever paleoseismic evidence indicates that it has occurred.

C. REGULATORY POSITION

1. GEOLOGICAL, GEOPHYSICAL, SEISMOLOGICAL, AND GEOTECHNICAL INVESTIGATIONS

1.1 Comprehensive geological, seismological, geophysical, and geotechnical investigations of the site area and region should be performed. For ISFSIs co-located with existing nuclear power plants, the existing technical information should be used along with all other available information to plan and determine the scope of additional investigations. The investigations described in this regulatory guide are performed primarily to gather data pertinent to the safe design and construction of the ISFSI or MRS. Appropriate geological, seismological, and geophysical investigations are described in Appendix D to this guide. Geotechnical investigations are described in Regulatory Guide 1.132, “Site Investigations for Foundations of Nuclear Power Plants” (Ref. 11), and NUREG/CR-5738 (Ref. 12). Another important purpose for the site-specific investigations is to determine whether there are any new data or interpretations that are not adequately incorporated into the existing PSHA data bases. Appendix E describes a method for evaluating new information derived from the site-specific investigations in the context of the PSHA.

Investigations should be performed at four levels, with the degree of detail based on distance from the site, the nature of the Quaternary tectonic regime, the geological complexity of the site and region, the existence of potential seismic sources, the potential for surface deformation, etc. A more detailed discussion of the areas and levels of investigations and the bases for them are presented in Appendix D to this regulatory guide. General guidelines for the levels of investigation are as follows.

1.1.1 Regional geological and seismological investigations are not expected to be extensive nor in great detail, but should include literature reviews, the study of maps and remote sensing data, and, if necessary, ground truth reconnaissances conducted within a radius of 320 km (200 miles) of the site to identify seismic sources (seismogenic and capable tectonic sources).

1.1.2 Geological, seismological, and geophysical investigations should be carried out within a radius of 40 km (25 miles) in greater detail than the regional investigations to identify and characterize the seismic and surface deformation potential of any capable tectonic sources and the seismic potential of seismogenic sources, or to demonstrate that such structures are not present. Sites with capable tectonic or seismogenic sources within a radius of 40 km (25 miles) may require more extensive geological and seismological investigations and analyses (similar in detail to investigations and analysis usually preferred within an 8-km (5-mile) radius).

1.1.3 Detailed geologic, seismological, geophysical, and geotechnical investigations should be conducted within a radius of 8 km (5 miles) of the site, as appropriate, to evaluate the potential for tectonic deformation at or near the ground surface and to assess the transmission characteristics of soils and rocks in the site vicinity. Sites in the CEUS where geologically young or recent tectonic activity is not present may be investigated in less detail. Methods for evaluating the seismogenic potential of tectonic structures and geological features developed in Reference 13 should be followed.

1.1.4 Very detailed geological, geophysical, and geotechnical engineering investigations should be conducted within the site [radius of approximately 1 km (0.5 miles)] to assess specific soil and rock characteristics as described in Reference 11, updated with NUREG/CR-5738 (Ref. 12).

1.2 The areas of investigation may be expanded beyond those specified above in regions that include capable tectonic sources, relatively high seismicity, or complex geology, or in regions that have experienced a large, geologically recent earthquake.

1.3 Data sufficient to clearly justify all assumptions and conclusions should be presented. Because engineering solutions cannot always be satisfactorily demonstrated for the effects of permanent ground displacement, it is prudent to avoid a site that has a potential for surface or near-surface deformation. Such sites normally will require extensive additional investigations.

1.4 For the site and for the area surrounding the site, lithologic, stratigraphic, hydrologic, and structural geologic conditions should be characterized. The investigations should include the measurement of the static and dynamic engineering properties of the materials underlying the site and an evaluation of the physical evidence concerning the behavior during prior earthquakes of the surficial materials and the substrata underlying the site. The properties needed to assess the behavior of the underlying material during earthquakes, including the potential for liquefaction, and the characteristics of the underlying material in transmitting earthquake ground motions to the foundations of the facility (such as seismic wave velocities, density, water content, porosity, elastic moduli, and strength) should be measured.

2. SEISMIC SOURCES SIGNIFICANT TO THE SITE SEISMIC HAZARD

2.1 For sites in the CEUS, when the EPRI or LLNL probabilistic seismic hazard analysis methodologies and data bases are used to determine the design earthquake, it still may be necessary to investigate and characterize potential seismic sources that were unknown or uncharacterized and to perform sensitivity analyses to assess their significance to the seismic hazard estimate. The results of the investigation discussed in Regulatory Position 1 should be used, in accordance with Appendix E, to determine whether the LLNL or EPRI seismic sources and their characterization should be updated. The guidance in Regulatory Positions 2.2 and 2.3 below and in Appendix D of this guide may be used if additional seismic sources are to be developed as a result of investigations.

2.2 When the LLNL or EPRI methods are not used or are not applicable, the guidance in Regulatory Position 2.3 should be used for identification and characterization of seismic sources. The uncertainties in the characterization of seismic sources should be addressed as appropriate. Seismic sources is a general term referring to both seismogenic sources and capable tectonic sources. The main distinction between these two types of seismic sources is that a seismogenic source would not cause surface displacement, but a capable tectonic source causes surface or near-surface displacement.

Identification and characterization of seismic sources should be based on regional and site geological and geophysical data, historical and instrumental seismicity data, the regional stress field, and geological evidence of prehistoric earthquakes. Investigations to identify seismic sources are described in Appendix D. The bases for the identification of seismic sources should be identified. A general list of characteristics to be evaluated for seismic sources is presented in Appendix D.

2.3 As part of the seismic source characterization, the seismic potential for each source should be evaluated. Typically, characterization of the seismic potential consists of four equally important elements:

1. Selection of a model for the spatial distribution of earthquakes in a source.

2. Selection of a model for the temporal distribution of earthquakes in a source.

3. Selection of a model for the relative frequency of earthquakes of various magnitudes, including an estimate for the largest earthquake that could occur in the source under the current tectonic regime.

4. A complete description of the uncertainty.

For example, in the LLNL study a truncated exponential model was used for the distribution of magnitudes given that an earthquake has occurred in a source. A stationary Poisson process is used to model the spatial and temporal occurrences of earthquakes in a source.

For a general discussion of evaluating the earthquake potential and characterizing the uncertainty, refer to Reference 5.

2.3.1 For sites in the CEUS, when the LLNL or EPRI method is not used or not applicable (such as in the New Madrid, MO; Charleston, SC; Attica, NY, Seismic Zones), it is necessary to evaluate the seismic potential for each source. The seismic sources and data that have been accepted by the NRC in past licensing decisions may be used, along with the data gathered from the investigations carried out as described in Regulatory Position 1.

Generally, the seismic sources for the CEUS are area sources because there is uncertainty about the underlying causes of earthquakes. This uncertainty is due to a lack of active surface faulting, a low rate of seismic activity, or a short historical record. The assessment of earthquake recurrence for CEUS area sources commonly relies heavily on catalogs of observed seismicity. Because these catalogs are incomplete and cover a relatively short period of time, it is difficult to obtain reliable estimates of the rate of activity. Considerable care must be taken to correct for incompleteness and to model the uncertainty in the rate of earthquake recurrence. To completely characterize the seismic potential for a source, it is also necessary to estimate the largest earthquake magnitude that a seismic source is capable of generating under the current tectonic regime. This estimated magnitude defines the upper bound of the earthquake recurrence relationship.

The assessment of earthquake potential for area sources is particularly difficult because one of the physical constraints most important to the assessment, the dimensions of the fault rupture, is not known. As a result, the primary methods for assessing maximum earthquakes for area sources usually include a consideration of the historical seismicity record, the pattern and rate of seismic activity, the Quaternary (2 million years and younger) characteristics of the source, the current stress regime (and how it aligns with known tectonic structures), paleoseismic data, and analogs to sources in other regions considered tectonically similar to the CEUS. Because of the shortness of the historical catalog and low rate of seismic activity, considerable judgment is needed. It is important to characterize the large uncertainties in the assessment of the earthquake potential.

2.3.2 For sites located within the WUS, earthquakes can often be associated with known tectonic structures. For faults, the earthquake potential is related to the characteristics of the estimated future rupture, such as the total rupture area, the length, or the amount of fault displacement. The following empirical relations can be used to estimate the earthquake potential from fault behavior data and also to estimate the amount of displacement that might be expected for a given magnitude. It is prudent to use several of the following different relations to obtain an estimate of the earthquake magnitude.

- Surface rupture length versus magnitude (Refs. 14-17),
- Subsurface rupture length versus magnitude (Ref. 18),
- Rupture area versus magnitude (Ref. 19),
- Maximum and average displacement versus magnitude (Ref. 18), and
- Slip rate versus magnitude (Ref. 20).

When such correlations as in References 14-20 are used, the earthquake potential is often evaluated as the mean of the distribution. The difficult issue is the evaluation of the appropriate rupture dimension to be used. This is a judgmental process based on geological data for the fault in question and the behavior of other regional fault systems of the same type.

In addition to maximum magnitude, the other elements of the recurrence model are generally obtained using catalogs of seismicity, fault slip rate, and other data. In some cases, it may be appropriate to use recurrence models with memory. All the sources of uncertainty must be appropriately modeled. Additionally, the phenomenon of temporal clustering should be considered when there is geological evidence of its past occurrence.

2.3.3 For sites near subduction zones, such as in the Pacific Northwest and Alaska, the maximum magnitude must be assessed for subduction zone seismic sources. Worldwide observations indicate that the largest known earthquakes are associated with the plate interface, although intraslab earthquakes may also have large magnitudes. The assessment of plate interface earthquakes can be based on estimates of the expected dimensions of rupture or analogies to other subduction zones worldwide.

3. PROBABILISTIC SEISMIC HAZARD ANALYSIS PROCEDURES

A PSHA should be performed for the site as it allows the use of multiple models to estimate the likelihood of earthquake ground motions occurring at a site and systematically takes into account uncertainties that exist in various parameters (such as seismic sources, maximum earthquakes, and ground motion attenuation). Alternative hypotheses are considered in a quantitative fashion in a PSHA. Alternative hypotheses can also be used to evaluate the sensitivity of the hazard to the uncertainties in the significant parameters and to identify the relative contribution of each seismic source to the hazard.

The following steps describe a procedure that is acceptable to the NRC staff for performing a PSHA.

3.1 Perform regional and site geological, seismological, and geophysical investigations in accordance with Regulatory Position 1 and Appendix D.

3.2 For CEUS sites, perform an evaluation of LLNL or EPRI seismic sources in accordance with Appendix E to determine whether they are consistent with the site-specific data gathered in Regulatory Position 1 or require updating. The PSHA should only be updated if the new information indicates that the current version significantly underestimates the hazard and there is a strong technical basis that supports such a revision. It may be possible to justify a lower hazard estimate with an exceptionally strong technical basis. However, it is expected that large uncertainties in estimating seismic hazard in the CEUS will continue to exist in the future, and substantial delays in the licensing process will result in trying to justify a lower value with respect to a specific site. For these reasons the NRC staff discourages efforts to justify a lower hazard estimate. In most cases, limited-scope sensitivity studies should be sufficient to demonstrate that the existing data base in the PSHA envelops the findings from site-specific investigations. In general, significant revisions to the LLNL and EPRI data base are to be undertaken only periodically (every 10 years), or when there is an important new finding or occurrence. An overall revision of the data base would also require a reexamination of the acceptability of the reference probability discussed in Appendix B and used in Regulatory Position 4 below. Any significant update should follow the guidance of Reference 5.

3.3 For CEUS sites only, perform the LLNL or EPRI PSHA using original or updated sources as determined in Regulatory Position 2. For sites in WUS, perform a site-specific PSHA (Ref. 5). The ground motion estimates should be made for rock conditions in the free-field or by assuming hypothetical rock conditions for a non-rock site to develop the seismic hazard information base discussed in Appendix C.

3.4 Using the mean reference probability (5E-4/yr) described in Appendix B, determine the 5 percent of critically damped mean spectral ground motion levels for 1 Hz ($S_{a,1}$) and 10 Hz ($S_{a,10}$) (Ref. 2). The use of an alternative reference probability will be reviewed and accepted on a case-by-case basis.

3.5 Deaggregate the mean probabilistic hazard characterization in accordance with Appendix C to determine the controlling earthquakes (i.e., magnitudes and distances), and document the hazard information base, as described in Appendix C.

3.6 As an alternative method, instead of the controlling earthquakes approach described in Appendix C and Regulatory Position 4 below, determine the ground motions at a sufficient number of frequencies significant to the ISFSI or MRS design, and then envelope the ground motions to determine the DE.

4. PROCEDURES FOR DETERMINING THE DESIGN EARTHQUAKE GROUND MOTION

After completing the PSHA (see Regulatory Position 3) and determining the controlling earthquakes, the following procedures should be used to determine the DE. Appendix F contains an additional discussion of some of the characteristics of the DE.

4.1 With the controlling earthquakes determined as described in Regulatory Position 3 and by using the procedures in Revision 3 of Reference 21 (which may include the use of ground motion models not included in the PSHA but that are more appropriate for the source, region, and site under consideration or that represent the latest scientific development), develop 5 percent of critical damping response spectral shapes for the actual or assumed rock conditions. The same controlling earthquakes are also used to derive vertical response spectral shapes.

4.2 Use $S_{a,10}$ to scale the response spectrum shape corresponding to the controlling earthquake. If there is a controlling earthquake for $S_{a,1}$, determine that the $S_{a,10}$ scaled response spectrum also envelopes the ground motion spectrum for the controlling earthquake for $S_{a,1}$. Otherwise, modify the shape to envelope the low-frequency spectrum or use two spectra in the following steps. For a rock site, go to Regulatory Position 4.4.

4.3 For non-rock sites, perform a site-specific soil amplification analysis considering uncertainties in site-specific geotechnical properties and parameters to determine response spectra at the free ground surface in the free-field for the actual site conditions. Procedures described in Appendix D of this guide and Reference 21 can be used to perform soil-amplification analyses.

4.4 Compare the smooth DE spectrum or spectra used in design at the free-field with the spectrum or spectra determined in Regulatory Position 2 for rock sites or determined in Regulatory Position 3 for the non-rock sites to assess the adequacy of the DE spectrum or spectra.

4.5 To obtain an adequate DE based on the site-specific response spectrum or spectra, develop a smooth spectrum or spectra or use a standard broad band shape that envelopes the spectra of Regulatory Position 2 or 3.

D. IMPLEMENTATION

The purpose of this section is to provide information to applicants and licensees regarding the NRC staff's plans for using this draft regulatory guide.

This draft guide has been released to encourage public participation in its development. Except in those cases in which an applicant or licensee proposes an acceptable alternative method for complying with the specified portions of the NRC's regulations, the methods to be described in the active guide reflecting public comments will be used in the evaluation of applications for new dry cask ISFSI and MRS facilities.

REFERENCES

1. USNRC, “Identification and Characterization of Seismic Sources and Determination of Safe Shutdown Earthquake Ground Motion,” Regulatory Guide 1.165, March 1997.[3]

2. R.K. McGuire, W.J. Silva, and C.J. Constantino, “Technical Basis for Revision of Regulatory Guidance on Design Ground Motions: Hazard- and Risk-Consistent Ground Motion Spectra Guidelines,” NUREG/CR-6728, October 2001.

3. D.L. Bernreuter et al., "Seismic Hazard Characterization of 69 Nuclear Plant Sites East of the Rocky Mountains," NUREG/CR-5250, Volumes 1-8, 1989.[1]

4. P. Sobel, "Revised Livermore Seismic Hazard Estimates for Sixty-Nine Nuclear Power Plant Sites East of the Rocky Mountains," NUREG-1488, USNRC, April 1994.[1]

5. R.J. Budnitz et al., "Recommendations for Probabilistic Seismic Hazard Analysis: Guidance on Uncertainty and Use of Experts," NUREG/CR- 6372, Volumes 1 and 2, USNRC, April 1997.[1]

6. J.B. Savy et al., "Eastern Seismic Hazard Characterization Update," UCRL-ID-115111, Lawrence Livermore National Laboratory, June 1993.[2] (Accession number 9310190318 in NRC's Public Document Room)

7. Electric Power Research Institute (EPRI), "Probabilistic Seismic Hazard Evaluations at Nuclear Power Plant Sites in the Central and Eastern United States," NP-4726, All Volumes, 1989-1991.

8. Electric Power Research Institute (EPRI), “The Earthquakes of Stable Continental Regions,” Volume 1: *Assessment of Large Earthquake Potential,* EPRI TR-102261-V1, 1994.

9. Pacific Gas and Electric Company, "Final Report of the Diablo Canyon Long Term Seismic Program; Diablo Canyon Power Plant," Docket Nos. 50-275 and 50-323, 1988.[2]

10. H. Rood et al., "Safety Evaluation Report Related to the Operation of Diablo Canyon Nuclear Power Plant, Units 1 and 2," NUREG-0675, Supplement No. 34, USNRC, June 1991.[1]

---

[1] Copies are available at current rates from the U.S. Government Printing Office, P.O. Box 37082, Washington, DC 20402-9328 (telephone (202)512-1800); or from the National Technical Information Service by writing NTIS at 5285 Port Royal Road, Springfield, VA 22161; (telephone (703)487-4650; <http://www.ntis.gov/ordernow>. Copies are available for inspection or copying for a fee from the NRC Public Document Room at 11555 Rockville Pike, Rockville, MD; the PDR’s mailing address is USNRC PDR, Washington, DC 20555; telephone (301)415-4737 or (800)397-4209; fax (301)415-3548; email is PDR@NRC.GOV.

[2] Copies are available for inspection or copying for a fee from the NRC Public Document Room at 11555 Rockville Pike (first floor), Rockville, MD; the PDR’s mailing address is USNRC PDR, Washington, DC 20555; telephone (301)415-4737 or 1-(800)397-4209; fax (301)415-3548; e-mail <PDR@NRC.GOV>.

11. USNRC, "Site Investigations for Foundations of Nuclear Power Plants," Regulatory Guide 1.132, March 1979. (See also DG-1101, the proposed Revision 2 of Regulatory Guide 1.132, February 2001.)[3]

12. N. Torres et al., “Field Investigations for Foundations of Nuclear Power Facilities,” NUREG/CR-5738, USNRC, 1999.[1]

13. K.L. Hanson et al., “Techniques for Identifying Faults and Determining Their Origins,” NUREG/CR-5503, USNRC, July 1999.[1]

14. D.B. Slemmons, “Faults and Earthquake Magnitude,” U.S. Army Corps of Engineers, Waterways Experiment Station, Misc. Papers S-7-1, Report 6, 1997.

15. D.B. Slemmons, “Determination of Design Earthquake Magnitudes for Microzonation,” *Proceedings of the Third International Microzonation Conference*, University of Washington, Seattle, Volume 1, pp. 119-130, 1982.

16. M.G. Bonilla, H.A. Villalobos, and R.E. Wallace, “Exploratory Trench Across the Pleasant Valley Fault, Nevada,” Professional Paper 1274-B, U.S. Geological Survey, pp. B1-B14, 1984.[2]

17. S.G. Wesnousky, “Relationship Between Total Affect, Degree of Fault Trace Complexibility, and Earthquake Size on Major Strike-Slip Faults in California,” (Abs), *Seismological Research Letters*, Volume 59, No. 1, p.3, 1988.

18. D.L. Wells and K.J. Coppersmith, “New Empirical Relationships Among Magnitude, Rupture Length, Rupture Width, Rupture Area, and Surface Displacement,” *Bulletin of the Seisomological Society of America*, Volume 84, 1994.

19. M. Wyss, “Estimating Maximum Expectable Magnitude of Earthquakes from Fault Dimensions,” *Geology*, Volume 7 (7), pp. 336-340, 1979.

20. D.P. Schwartz and K.J. Coppersmith, “Seismic Hazards: New Trends in Analysis Using Geologic Data,” *Active Tectonics*, National Academy Press, Washington, DC, pp. 215-230, 1986.

21. USNRC, “Standard Review Plan for the Review of Safety Analysis Reports for Nuclear Power Plants,” NUREG-0800, Section 2.5.2, Revision 3, 1997.[3]

APPENDIX A
DEFINITIONS

---

[3] Requests for single copies of draft or active regulatory guides (which may be reproduced) or for placement on an automatic distribution list for single copies of future draft guides in specific divisions should be made in writing to the U.S. Nuclear Regulatory Commission, Washington, DC 20555, Attention: Reproduction and Distribution Services Section, or by fax to (301)415-2289; email <DISTRIBUTION@NRC.GOV>. Copies are available for inspection or copying for a fee from the NRC Public Document Room at 11555 Rockville Pike (first floor), Rockville, MD; the PDR’s mailing address is USNRC PDR, Washington, DC 20555; telephone (301)415-4737 or 1-(800)397-4209; fax (301)415-3548; e-mail <PDR@NRC.GOV>.

Capable Tectonic Source — A capable tectonic source is a tectonic structure that can generate both vibratory ground motion and tectonic surface deformation such as faulting or folding at or near the earth's surface in the present seismotectonic regime. It is described by at least one of the following characteristics:

a. Presence of surface or near-surface deformation of landforms or geologic deposits of a recurring nature within the last approximately 500,000 years or at least once in the last approximately 50,000 years.

b. A reasonable association with one or more moderate to large earthquakes or sustained earthquake activity, usually accompanied by significant surface deformation.

c. A structural association with a capable tectonic source that has characteristics of either a or b above such that movement on one could be reasonably expected to be accompanied by movement on the other.

In some cases, the geological evidence of past activity at or near the ground surface along a potential capable tectonic source may be obscured at a particular site. This might occur, for example, at a site having a deep overburden. For these cases, evidence may exist elsewhere along the structure from which an evaluation of its characteristics in the vicinity of the site can be reasonably based. Such evidence is to be used in determining whether the structure is a capable tectonic source within this definition.

Notwithstanding the foregoing paragraphs, the association of a structure with geological structures that are at least pre-Quaternary, such as many of those found in the Central and Eastern regions of the United States, in the absence of conflicting evidence, will demonstrate that the structure is not a capable tectonic source within this definition.

Controlling Earthquakes — Controlling earthquakes are the earthquakes used to determine spectral shapes or to estimate ground motions at the site. There may be several controlling earthquakes for a site. As a result of the probabilistic seismic hazard analysis (PSHA), controlling earthquakes are characterized as mean magnitudes and distances derived from a deaggregation analysis of the mean estimate of the PSHA.

Design Earthquake Ground Motion (DE) — The DE is the vibratory ground motion for which certain structures, systems, and components, classified as important to safety, are designed, pursuant to Part 72. The DE for the site is characterized by both horizontal and vertical free-field ground motion response spectra at the free ground surface.

Earthquake Recurrence — Earthquake recurrence is the frequency of occurrence of earthquakes having various magnitudes. Recurrence relationships or curves are developed for each seismic source, and they reflect the frequency of occurrence (usually expressed on an annual basis) of magnitudes up to the maximum, including measures of uncertainty.

Intensity — The intensity of an earthquake is a qualitative description of the effects of the earthquake at a particular location, as evidenced by observed effects on humans, on human-built structures, and on the earth's surface at a particular location. Commonly used scales to specify intensity are the Rossi-Forel, Mercalli, and Modified Mercalli. The Modified Mercalli Intensity (MMI) scale describes intensities with values ranging from I to XII in the order of severity. MMI of

I indicates an event that was not felt except by a very few, while MMI of XII indicates total damage of all works of construction, either partially or completely.

Magnitude — An earthquake’s magnitude is a measure of the strength of an earthquake as determined from seismographic observations and is an objective, quantitative measure of the size of an earthquake. The magnitude is expressed in various ways based on the seismograph record, e.g., Richter Local Magnitude, Surface Wave Magnitude, Body Wave Magnitude, and Moment Magnitude. The most commonly used magnitude measurement is the Moment Magnitude, M_w , which is based on the seismic moment computed as the rupture force along the fault multiplied by the average amount of slip, and thus is a direct measure of the energy released during an earthquake event. The Moment Magnitude of an earthquake event (M_w or M) varies from 2.0 and higher values, and since magnitude scales are logarithmic, a unit change in magnitude corresponds to a 32-fold change in the energy released during an earthquake event.

Maximum Magnitude — The maximum magnitude is the upper bound to recurrence curves.

Mean Annual Probability of Exceedance — Mean annual probability of exceedance of an earthquake event of a given magnitude or an acceleration level is the probability that the given magnitude or acceleration level may exceed in a year. The mean annual probability of exceedance of an earthquake event is a reciprocal of the return period of the event.

Nontectonic Deformation — Nontectonic deformation is distortion of surface or near-surface soils or rocks that is not directly attributable to tectonic activity. Such deformation includes features associated with subsidence, karst terrain, glaciation or deglaciation, and growth faulting.

Reference Probability – The reference probability of occurrence of an earthquake event is the mean annual probability of exceeding the design earthquake.

Response Spectrum — A plot of the maximum values of responses (acceleration, velocity, or displacement) of a family of idealized single-degree-of-freedom damped oscillators as a function of its natural frequencies (or periods) to a specified vibratory motion input at their supports.

Return Period — The return period of an earthquake event is an inverse of the mean annual probability of exceedance of the earthquake event.

Safe Shutdown Earthquake (SSE) — The SSE is the vibratory ground motion for which certain structures, systems, and components in a nuclear power plant are designed, pursuant to Appendix S to 10 CFR Part 50, to remain functional. The SSE for the site is characterized by both horizontal and vertical free-field ground motion response spectra at the free ground surface.

Seismic Potential — A model giving a complete description of the future earthquake activity in a seismic source zone. The model includes a relation giving the frequency (rate) of earthquakes of any magnitude, an estimate of the largest earthquake that could occur under the current tectonic regime, and a complete description of the uncertainty. A typical model used for PSHA is the use of a truncated exponential model for the magnitude distribution and a stationary Poisson process for the temporal and spatial occurrence of earthquakes.

Seismic Source — Seismic source is a general term referring to both seismogenic sources and capable tectonic sources.

Seismogenic Source — A seismogenic source is a portion of the earth that is assumed to have a uniform earthquake potential (same expected maximum earthquake and recurrence frequency), distinct from the seismicity of the surrounding regions. A seismogenic source will generate vibratory ground motion but is assumed not to cause surface displacement. Seismogenic sources cover a wide range of possibilities, from a well-defined tectonic structure to simply a large region of diffuse seismicity (seismotectonic province) thought to be characterized by the same earthquake recurrence model. A seismogenic source is also characterized by its involvement in the current tectonic regime (the Quaternary, or approximately the last 2 million years).

Stable Continental Region (SCR) — A stable continental region is composed of continental crust, including continental shelves, slopes, and attenuated continental crust, and excludes active plate boundaries and zones of currently active tectonics directly influenced by plate margin processes. It exhibits no significant deformation associated with the major Mesozoic-to-Cenozoic (last 240 million years) orogenic belts. It excludes major zones of Neogene (last 25 million years) rifting, volcanism, or suturing.

Stationary Poisson Process — A probabilistic model of the occurrence of an event over time (or space) that has the following characteristics: (1) the occurrence of the event in small intervals is constant over time (or space), (2) the occurrence of two (or more) events in a small interval is negligible, and (3) the occurrence of the event in non-overlapping intervals is independent.

Tectonic Structure — A tectonic structure is a large-scale dislocation or distortion, usually within the earth’s crust. Its extent may be on the order of tens of meters (yards) to hundreds of kilometers (miles).

APPENDIX B
REFERENCE PROBABILITY FOR THE EXCEEDANCE LEVEL OF THE DESIGN EARTHQUAKE GROUND MOTION

B.1 INTRODUCTION

This appendix provides a rationale for a reference probability that is acceptable to the NRC staff. The reference probability is used in conjunction with the probabilistic seismic hazard analysis (PSHA) for determining the Design Earthquake Ground Motion (DE) for ISFSI or MRS designs.

B.2 QUESTION ON REFERENCE PROBABILITY FOR DESIGN EARTHQUAKE

The reference probability is the mean annual probability of exceeding the DE. It is the reciprocal of the return period for the design earthquake.

The NRC staff welcomes comments on all aspects of this draft regulatory guide, but is especially interested in receiving comments on the appropriate mean annual probability of exceedance value to be used for the seismic design of an ISFSI or MRS. Please note the following considerations and include a justification for the appropriate mean annual probability of exceedance value.

The present mean annual probability of exceedance value for determining the DE for an ISFSI or MRS is approximately 1.0E-04 (i.e., in any one year, the probability is 1 in 10,000, which is the reciprocal of 1.0E-04, that the DE established for the site will be exceeded). This value is based on requirements for nuclear plants. The NRC is considering allowing for the use of a mean annual probability of exceedance value in the range of 5.0E-04 (i.e., in any one year, the probability is 1 in 2,000 that the DE established for the site will be exceeded) to 1.0E-04 for ISFSI or MRS applications. This Draft Regulatory Guide DG-3021, “Site Evaluations and Determination of Design Earthquake Ground Motion for Seismic Design of Independent Spent Fuel Storage Installations and Monitored Retrievable Storage Installations,” is being developed to provide guidelines that are acceptable to the NRC staff for determining the DE for an ISFSI or MRS. DG-3021 proposes to recommend a mean annual probability of exceedance value of 5.0E-04 as an appropriate risk-informed value for the design of a dry storage ISFSI or MRS. However, the NRC staff is undertaking further analysis to support a specific value. An ISFSI or MRS license applicant would have to demonstrate that the use of a higher probability of exceedance value would not impose any undue radiological risk to public health and safety. In view of this discussion, the NRC staff is requesting comments on the appropriate mean annual probability of exceedance value to be used for the seismic design of an ISFSI or MRS and a justification for this probability.

B.3 RATIONALE FOR THE REFERENCE PROBABILITY

The following describes the rationale for determining the reference probability for use in the PSHA for a dry cask storage system (DCSS) during a seismic event. The mean reference probability of exceedance of 5.0E-4/yr for a seismic event is considered appropriate for the design of a DCSS. The use of a higher reference probability will be reviewed and accepted on a case-by-case basis.

B.3.1 Part 72 Approach

Part 72 regulations classify the structures, systems, and components (SSC) in an ISFSI or MRS facility based on their importance to safety. SSCs are classified as important to safety if they have the function of protecting public health and safety from undue risk and preventing damage to the spent fuel during handling and storage. These SSCs are evaluated for a single level of DE as an accident condition event only (section 72.106). For normal operations and anticipated occurrences (section 72.104), earthquake events are not included.

The DCSSs for ISFSIs or MRSs are typically self-contained massive concrete or steel structures, weighing approximately 40 to 100 tons when fully loaded. There are very few, if any, moving parts. They are set on a concrete support pad. Several limitations have been set on the maximum height to which the casks can be lifted, based on the drop accident analysis. There is a minimum center-to-center spacing requirement for casks stored in an array on a common support pad. The most conservative estimates of structural thresholds of seismic inertia deceleration from a drop accident event, before the confinement is breached so as to exceed the permissible radiation levels, is in the range of 30 g to 40 g.

B.3.2 Reference Probability

The present DE is based on the requirements contained in 10 CFR Part 100 for nuclear power plants. In the Statement of Considerations accompanying the initial Part 72 rulemaking, the NRC recognized that the design peak horizontal acceleration for structures, systems, and components (SSCs) need not be as high as for a nuclear power reactor and should be determined on a “case-by-case” basis until “more experience is gained with licensing of these types of units” (45 FR 74697; November 12, 1980). With over 10 years of experience in licensing dry cask storage and with analyses that demonstrate robust behavior of dry cask storage systems (DCSSs) in accident scenarios (10 specific licenses have been issued and 9 locations use the general license provisions), the NRC now has a reasonable basis to consider lower and more appropriate DE parameters for a dry cask ISFSI or MRS. Therefore, the NRC proposes to reduce the DE for new ISFSI or MRS license applicants to be commensurate with the lower risk associated with these facilities. Factors that result in lower radiological risk at an ISFSI or MRS compared to a nuclear power plant include the following:

- In comparison with a nuclear power plant, an operating ISFSI or MRS is a relatively simple facility in which the primary activities are waste receipt, handling, and storage. An ISFSI or MRS does not have the variety and complexity of active systems necessary to support an operating nuclear power plant. After the spent fuel is in place, an ISFSI or MRS is essentially a static operation.

- During normal operations, the conditions required for the release and dispersal of significant quantities of radioactive materials are not present. There are no high temperatures or pressures present during normal operations or under design basis accident conditions to cause the release and dispersal of radioactive materials. This is primarily due to the low heat-generation rate of spent fuel that has undergone more than 1 year of decay before storage in an ISFSI or MRS, and to the low inventory of volatile radioactive materials readily available for release to the environment.

- The long-lived nuclides present in spent fuel are tightly bound in the fuel materials and are not readily dispersible. Short-lived volatile nuclides, such as I-131, are no longer present in aged spent fuel. Furthermore, even if the short-lived nuclides were present during a fuel assembly rupture, the canister surrounding the fuel assemblies would confine these nuclides. Therefore, the Commission believes that the seismically induced radiological risk associated with an ISFSI or MRS is significantly less than the risk associated with a nuclear power plant. Also, it is NRC policy to use risk-informed regulation as appropriate.

- The critical element for protection against radiation release is the sealed cask containing the spent fuel assemblies. The standards in Part 72 in Subparts E, “Siting Evaluation Factors,” and F, ”General Design Criteria,” ensure that the dry cask storage designs are very rugged and robust. The casks must maintain structural integrity during a variety of postulated non-seismic events, including cask drops, tip-overs, and wind-driven missile impacts. These non-seismic events challenge cask integrity significantly more than seismic events. Therefore, the casks are expected to have substantial design margins to withstand forces from a seismic event greater than the design earthquake.

- During a seismic event at an ISFSI or MRS, a cask may slide if lateral seismic forces are greater than the frictional resistance between the cask and the concrete pad. The sliding and resulting displacements are computed by the applicant to demonstrate that the casks, which are spaced to satisfy the thermal criteria in Subpart F of Part 72, are precluded from impacting other adjacent casks. Furthermore, the NRC staff guidance in reviewing cask designs is to show that public health and safety is maintained during a postulated DE. This can be demonstrated by showing that either casks are designed to prevent sliding or tip over during a seismic event, or the consequences of the calculated cask movements are acceptable. Even if the casks slide or tip over and then impact other casks or the pad during a seismic event significantly greater than the proposed DE, there are adequate design margins to ensure that the casks maintain their structural integrity.

- The combined probability of the occurrence of a seismic event and operational failure that leads to a radiological release is much smaller than the individual probabilities of either of these events. This is because the handling building and crane are used for only a fraction of the licensed period of an ISFSI or MRS and for only a few casks at a time. Additionally, dry cask ISFSIs are expected to handle only sealed casks and not individual fuel assemblies. Therefore, the potential risk of a release of radioactivity caused by failure of the cask handling or crane during a seismic event is small.

Additional factors for reducing the DE for new ISFSI or MRS license applicants include:

- Because the DE is a smooth broad-band spectrum that envelops the controlling earthquake responses, the vibratory ground motion specified is conservative.

- The crane used for lifting the casks in the building is designed using the same industry codes as for a nuclear power plant, and has a safety factor of 5 or greater for lifted loads using the ultimate strength of the materials. Therefore, the crane would perform satisfactorily during an earthquake much larger than the design earthquake.

- The determination of a DE for an ISFSI or MRS is consistent with the design approach used in DOE Standard DOE-STD-1020, “Natural Phenomena Hazards Design Evaluation Criteria for Department of Energy Facilities,”[1] for similar type facilities.

Based on the preceding analysis, the NRC staff concludes that there is a reasonable basis to design ISFSI or MRS SSCs for a single design earthquake, using a mean annual probability of exceedance 5.0E-04, and adequately protect public health and safety.

---

[1] U.S. Department of Energy, “Natural Phenomena Hazards Design Evaluation Criteria for Department of Energy Facilities, DOE-STD-1020-2002, January 2002.   Copies are available at current rates from the U.S. Government Printing Office, P.O. Box 37082, Washington, DC 20402-9328 (telephone (202)512-1800); or from the National Technical Information Service by writing NTIS at 5285 Port Royal Road, Springfield, VA 22161; (telephone (703)487-4650; <http://www.ntis.gov/ordernow>. Copies are available for inspection or copying for a fee from the NRC Public Document Room at 11555 Rockville Pike, Rockville, MD; the PDR’s mailing address is USNRC PDR, Washington, DC 20555; telephone (301)415-4737 or (800)397-4209; fax (301)415-3548; email is PDR@NRC.GOV.

APPENDIX C
DETERMINATION OF CONTROLLING EARTHQUAKES AND DEVELOPMENT OF SEISMIC HAZARD INFORMATION BASE

C.1 INTRODUCTION

This appendix elaborates on the steps described in Regulatory Position 3 of this regulatory guide to determine the controlling earthquakes used to define the Design Earthquake Ground Motion (DE) at the site and to develop a seismic hazard information base. The information base summarizes the contribution of individual magnitude and distance ranges to the seismic hazard and the magnitude and distance values of the controlling earthquakes at 1 and 10 Hz. The controlling earthquakes are developed for the ground motion level corresponding to the reference probability as defined in Appendix B to this regulatory guide.

The spectral ground motion levels, as determined from a probabilistic seismic hazard analysis (PSHA), are used to scale a response spectrum shape. A site-specific response spectrum shape is determined for the controlling earthquakes and local site conditions. Regulatory Position 4 and Appendix F to this regulatory guide describe a procedure to determine the DE using the controlling earthquakes and results from the PSHA.

C.2 PROCEDURE TO DETERMINE CONTROLLING EARTHQUAKES

The following approach is acceptable to the NRC staff for determining the controlling earthquakes and developing a seismic hazard information base. This procedure is based on a de-aggregation of the probabilistic seismic hazard in terms of earthquake magnitudes and distances. When the controlling earthquakes have been obtained, the DE response spectrum can be determined according to the procedure described in Appendix F to this regulatory guide.

Step 2-1

Perform a site-specific PSHA using the Lawrence Livermore National Laboratory (LLNL) or Electric Power Research Institute (EPRI) methodologies (Refs. 1-3) for CEUS sites or perform a site-specific PSHA for sites not in the CEUS or for sites for which LLNL or EPRI methods and data are not applicable, for actual or assumed rock conditions. The hazard assessment (mean, median, 85th percentile, and 15th percentile) should be performed for spectral accelerations at 1, Hz, 10 Hz, and the peak ground acceleration. A lower-bound earthquake moment magnitude, M, of 5.0 is recommended.

Step 2-2

Using the reference probability (5E-4/yr) as defined in Appendix B to this regulatory guide, determine the ground motion levels for the spectral accelerations at 1 and 10 Hz from the total mean hazard obtained in Step 2-1.

Step 2-3

Perform a complete PSHA for each of the magnitude-distance bins illustrated in Table C.1. (These magnitude-distance bins are to be used in conjunction with the LLNL or EPRI methods. For other situations, other binning schemes may be necessary.)

Table C.1 Recommended Magnitude and Distance Bins

Distance Range of Bin (km)	Moment Magnitude Range of Bins				
	5 - 5.5	5.5 - 6	6 - 6.5	6.5 - 7	>7
0 - 15					
15 - 25					
25 - 50					
50 - 100					
100 - 200					
200 - 300					
>300					

Step 2-4

From the de-aggregated results of Step 2-3, the mean annual probability of exceeding the ground motion levels of Step 2-2 (spectral accelerations at 1 and 10 Hz) are determined for each magnitude-distance bin. These values are denoted by H_{mdf1} for 1 Hz, and H_{mdf10} for 10 Hz.

Using H_{mdf} values, the fractional contribution of each magnitude and distance bin to the total hazard for the 1 Hz, $P(m,d)_1$, is computed according to:

$$P(m,d)_1 = H_{mdf1}/(\sum_m \sum_d H_{mdf1}) \qquad \text{(Equation 1)}$$

The fractional contribution of each magnitude and distance bin to the total hazard for the 10 Hz, $P(m,d)_{10}$, is computed according to:

$$P(m,d)_{10} = H_{mdf10}/(\sum_m \sum_d H_{mdf10}) \qquad \text{(Equation 2)}$$

Step 2-5

Review the magnitude-distance distribution for the 1 Hz frequency to determine whether the contribution to the hazard for distances of 100 km (63 mi) or greater is substantial (on the order of 5 percent or greater).

If the contribution to the hazard for distances of 100 km (63 mi) or greater exceeds 5 percent, additional calculations are needed to determine the controlling earthquakes using the magnitude-distance distribution for distances greater than 100 km (63 mi). This distribution, $P{>}100(m,d)_1$, is defined by:

$$P{>}100(m,d)_1 = P(m,d)_1 / \sum_m \sum_{d>100} P(m,d)_1 \qquad \text{(Equation 3)}$$

The purpose of this calculation is to identify a distant, larger event that may control low-frequency content of a response spectrum.

The distance of 100 km (63 mi) is chosen for CEUS sites. However, for all sites the results of full magnitude-distance distribution should be carefully examined to ensure that proper controlling earthquakes are clearly identified.

Step 2-6

Calculate the mean magnitude and distance of the controlling earthquake associated with the ground motions determined in Step 2 for the 10 Hz frequency. The following relation is used to calculate the mean magnitude using results of the entire magnitude-distance bins matrix:

$$M_c = \sum_{d} m \sum_{m} P(m, d)_{10} \qquad \text{(Equation 4)}$$

where m is the central magnitude value for each magnitude bin.

The mean distance of the controlling earthquake is determined using results of the entire magnitude-distance bins matrix:

$$\mathrm{Ln}\ \{ Dc\ (10\ \mathrm{Hz})\} = \sum_{d} \mathrm{Ln}\ (d) \sum_{m} P(m, d)_{10} \qquad \text{(Equation 5)}$$

where d is the centroid distance value for each distance bin.

Step 2-7

If the contribution to the hazard calculated in Step 2-5 for distances of 100 km (63 mi) or greater exceeds 5 percent for the 1 Hz frequency, calculate the mean magnitude and distance of the controlling earthquakes associated with the ground motions determined in Step 2-2 for the average of 1 Hz. The following relation is used to calculate the mean magnitude using calculations based on magnitude-distance bins greater than distances of 100 km (63 mi) as discussed in Step 2-5:

$$Mc\ (1\mathrm{Hz}) = \sum_{m} m \sum_{d>100} P > 100\ (m, d)_{1} \qquad \text{(Equation 6)}$$

where m is the central magnitude value for each magnitude bin.

The mean distance of the controlling earthquake is based on magnitude-distance bins greater than distances of 100 km as discussed in Step 2-5 and determined according to:

$$\mathrm{Ln}\ \{ Dc\ (1\ \mathrm{Hz})\} = \sum_{d>100} \mathrm{Ln}\ (d) \sum_{m} P(m, d)_{10} \qquad \text{(Equation 7)}$$

where d is the centroid distance value for each distance bin.

Step 2-8

Determine the DE response spectrum using the procedure described in Appendix F of this regulatory guide.

C.3 EXAMPLE FOR A CEUS SITE

To illustrate the procedure in Section C.2, calculations are shown here for a CEUS site using the 1993 LLNL hazard results (Refs. C.1, C.2). It must be emphasized that the recommended magnitude and distance bins and procedure used to establish controlling earthquakes were developed for application in the CEUS where the nearby earthquakes generally control the response in the 10 Hz frequency range, and larger but distant events can control the lower frequency range. For other situations, alternative binning schemes as well as a study of contributions from various bins will be necessary to identify controlling earthquakes consistent with the distribution of the seismicity.

Step 3-1

The 1993 LLNL seismic hazard methodology (Refs. C.1, C.2) was used to determine the hazard at the site. A lower bound earthquake moment magnitude, M, of 5.0 was used in this analysis. The analysis was performed for spectral acceleration at 1 and 10 Hz. The resultant hazard curves are plotted in Figure C.1.

Step 3-2

The hazard curves at 1 and 10 Hz obtained in Step 1 are assessed at the reference probability value of 5E-4/yr, as defined in Appendix B to this regulatory guide. The corresponding ground motion level values are given in Table C.2. See Figure C.1.

Table C.2 Ground Motion Levels

Frequency (Hz)	1	10
Spectral Acc. (cm/s/s)	88	551

Step 3-3

The mean seismic hazard is de-aggregated for the matrix of magnitude and distance bins as given in Table C.1.

A complete probabilistic hazard analysis was performed for each bin to determine the contribution to the hazard from all earthquakes within the bin, i.e., all earthquakes with earthquake moment magnitudes greater than 5.0 and distance from 0 km to greater than 300 km. See Figure C.2 where the mean 1 Hz hazard curve is plotted for distance bin 25 - 50 km and magnitude bin 6 - 6.5.

The hazard values corresponding to the ground motion levels, found in Step 2-2, and listed in Table C.2, are then determined from the hazard curve for each bin for spectral accelerations at 1 Hz and 10 Hz. This process is illustrated in Figure C.2. The vertical line corresponds to the value 88 cm/s/s listed in Table C.2 for the 1 Hz hazard curve and intersects the hazard curve for the 25 - 50 km distance bin, 6 - 6.5 magnitude bin, at a hazard value (probability of exceedance) of 1.07E-06 per year. Tables C.3 and C.4 list the appropriate hazard value for each bin for 1 Hz and 10 Hz frequencies respectively. It should be noted that if the mean hazard in each of the 35 bins is added up it equals the reference probability of 5.0E-04.

Table C.3 Mean Exceeding Probability Values for Spectral Accelerations at 1 Hz (88 cm/s/s)

	Moment Magnitude Range of Bins				
Distance Range of Bin (km)	5 - 5.5	5.5 - 6	6 - 6.5	6.5 - 7	>7
0 - 15	9.68E-06	4.61E-05	0.0	0.0	0.0
15 - 25	0.0	1.26E-05	0.0	0.0	0.0
25 - 50	0.0	1.49E-05	1.05E-05	0.0	0.0
50 - 100	0.0	7.48E-06	3.65E-05	1.24E-05	0.0
100 - 200	0.0	1.15E-06	4.17E-05	2.98E-04	0.0
200 - 300	0.0	0.0	0.0	8.99E-06	0.0
> 300	0.0	0.0	0.0	0.0	0.0

Table C.4 Mean Exceeding Probability Values for Spectral Accelerations at 10 Hz (551 cm/s/s)

	Moment Magnitude Range of Bins				
Distance Range of Bin (km)	5 - 5.5	5.5 - 6	6 - 6.5	6.5 - 7	>7
0 - 15	1.68E-04	1.44E-04	2.39E-05	0.0	0.0
15 - 25	2.68E-05	4.87E-05	4.02E-06	0.0	0.0
25 - 50	5.30E-06	3.04E-05	2.65E-05	0.0	0.0
50 - 100	0.0	2.96E-06	8.84E-06	3.50E-06	0.0
100 - 200	0.0	0.0	0.0	7.08E-06	0.0
200 - 300	0.0	0.0	0.0	0.0	0.0
> 300	0.0	0.0	0.0	0.0	0.0

Note: The values of probabilities ≤1.0E-07 are shown as 0.0 in Tables C.3 and C.4.

Step 3-4

Using de-aggregated mean hazard results, the fractional contribution of each magnitude-distance pair to the total hazard is determined. Tables C.5 and C.6 show $P(m,d)_1$ and $P(m,d)_{10}$ for the 1 Hz and 10 Hz, respectively.

Step 3-5

Because the contribution of the distance bins greater than 100 km in Table C.5 contains more than 5 percent of the total hazard for 1 Hz, the controlling earthquake for the 1 Hz frequency will be calculated using magnitude-distance bins for distance greater than 100 km. Table C.7 shows $P>100\ (m,d)_1$ for the 1 Hz frequency.

Table C.5 $P(m,d)_1$ for Spectral Accelerations at 1 Hz
Corresponding to the Reference Probability

	Moment Magnitude Range of Bins				
Distance Range of Bin (km)	5 - 5.5	5.5 - 6	6 - 6.5	6.5 - 7	>7
0 - 15	0.019	0.092	0.0	0.0	0.0
15 - 25	0.0	0.025	0.0	0.0	0.0
25 - 50	0.0	0.030	0.021	0.0	0.0
50 - 100	0.0	0.015	0.073	0.025	0.0
100 - 200	0.0	0.002	0.083	0.596	0.0
200 - 300	0.0	0.0	0.0	0.018	0.0
> 300	0.0	0.0	0.0	0.0	0.0

Figures C.3 to C.5 show the above information in terms of the relative percentage contribution.

Table C.6 $P(m,d)_{10}$ for Spectral Accelerations at 10 Hz
Corresponding to the Reference Probability

	Moment Magnitude Range of Bins				
Distance Range of Bin (km)	5 - 5.5	5.5 - 6	6 - 6.5	6.5 - 7	>7
0 - 15	0.336	0.288	0.048	0.0	0.0
15 - 25	0.054	0.097	0.008	0.0	0.0
25 - 50	0.011	0.061	0.053	0.0	0.0
50 - 100	0.0	0.059	0.018	0.007	0.0
100 - 200	0.0	0.0	0.0	0.014	0.0
200 - 300	0.0	0.0	0.0	0.0	0.0
> 300	0.0	0.0	0.0	0.0	0.0

Table C.7 $P>100\,(m,d)_1$ for Spectral Acceleration at 1 Hz
Corresponding to the Reference Probability

	Moment Magnitude Range of Bins				
Distance Range of Bin (km)	5 - 5.5	5.5 - 6	6 - 6.5	6.5 - 7	>7
100 - 200	0.0	0.003	0.119	0.852	0.0
200 - 300	0.0	0.0	0.0	0.026	0.0
>300	0.0	0.0	0.0	0.0	0.0

Note: The values of probabilities $\leq$1.0E-07 are shown as 0.0 in Tables C.5, C.6, and C.7.

Steps 3-6 and 3-7

To compute the controlling magnitudes and distances at 1 Hz and 10 Hz for the example site, the values of $P>100\,(m,d)_1$ and $P(m,d)_{10}$ are used with m and d values corresponding to the mid-point of the magnitude of the bin (5.25, 5.75, 6.25, 6.75, 7.3) and centroid of the ring area (10, 20.4, 38.9, 77.8, 155.6, 253.3, and somewhat arbitrarily 350 km). Note that the mid-point of the last magnitude bin may change because this value is dependent on the maximum magnitudes used in the hazard analysis. For this example site, the controlling earthquake characteristics (magnitudes and distances) are given in Table C.8.

Step 3-8

The DE response spectrum is determined by the procedures described in Appendix F.

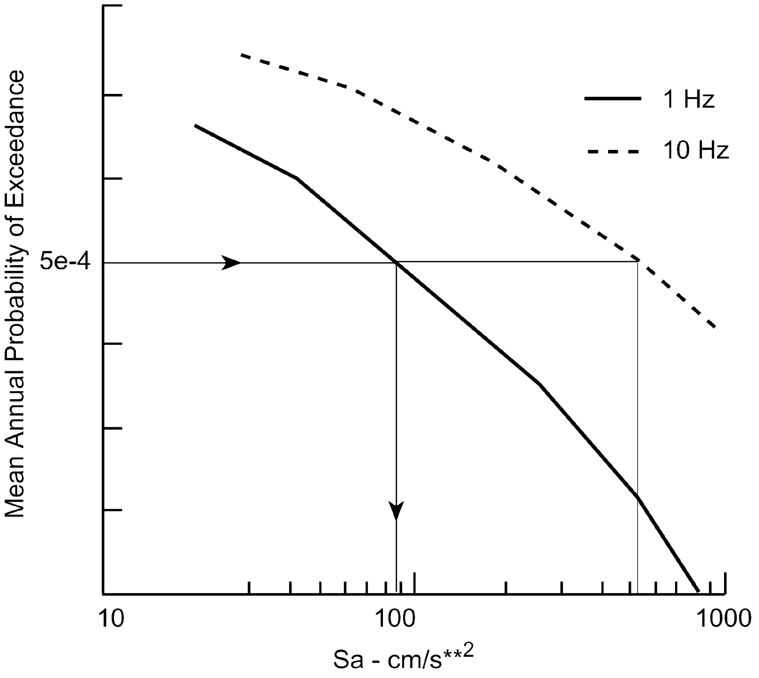

Figure C.1 Total Mean Hazard Curves

C.4 SITES NOT IN THE CEUS

The determination of the controlling earthquakes and the seismic hazard information base for sites not in the CEUS is also carried out using the procedure described in Section C.2 of this appendix. However, because of differences in seismicity rates and ground motion attenuation at these sites, alternative magnitude-distance bins may have to be used. An alternative reference probability may also have to be developed, particularly for sites in the active plate margin region and for sites at which a known tectonic structure dominates the hazard.

Table C.8 Magnitudes and Distances of Controlling Earthquakes from the LLNL Probabilistic Analysis

1 Hz	10 Hz
Mc and Dc > 100 km	Mc and Dc
6.7 and 157 km	5.9 and 18 km

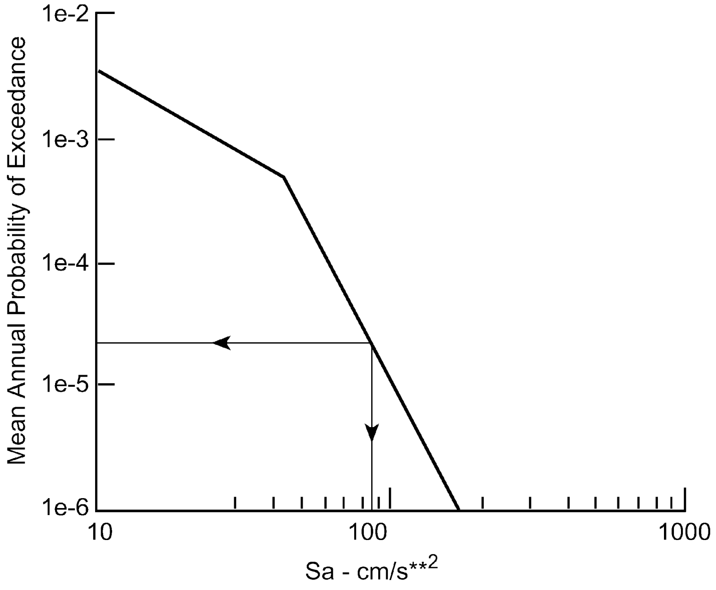

Figure C.2 1 Hz Mean Hazard Curve for Distance Bin 25-50 km and Magnitude Bin 6-6.5

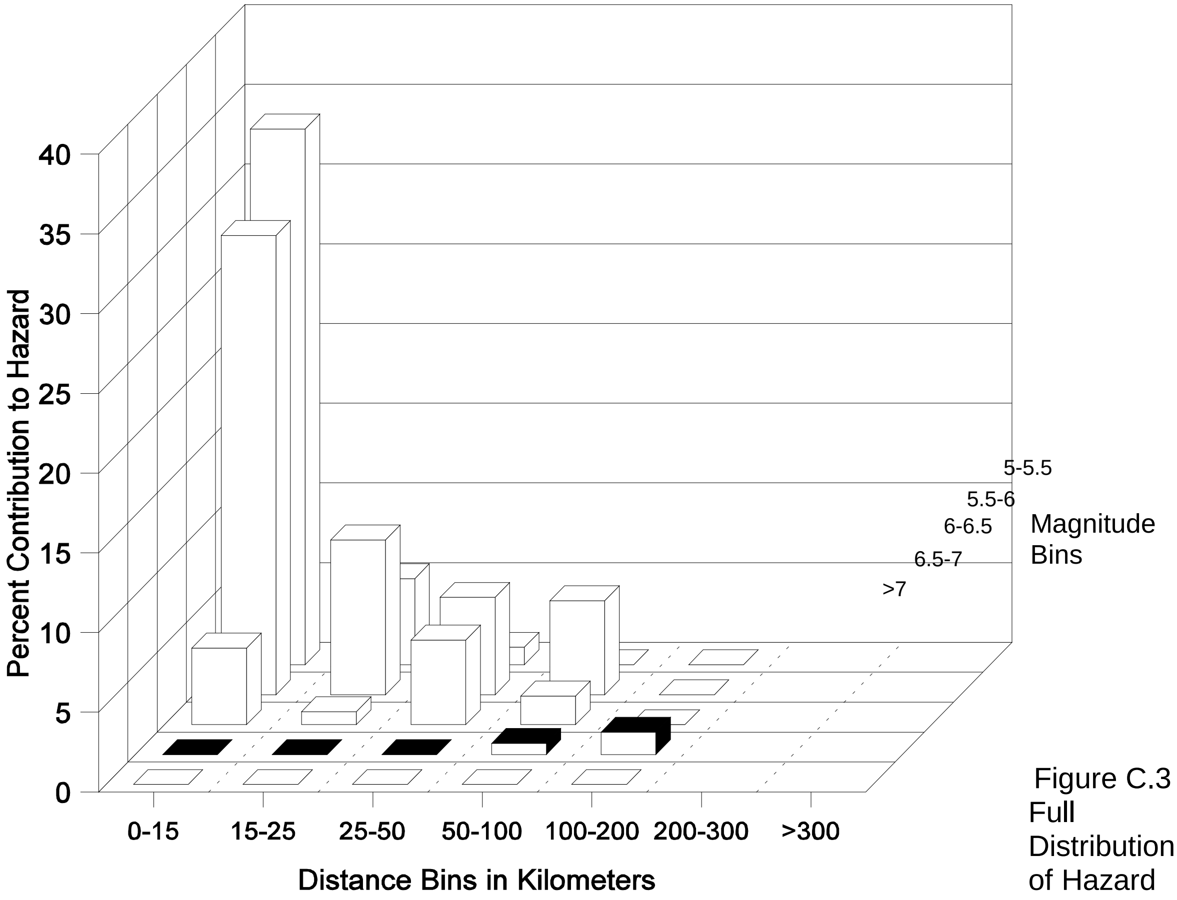

Figure C.3
Full
Distribution
of Hazard
for 10 Hz

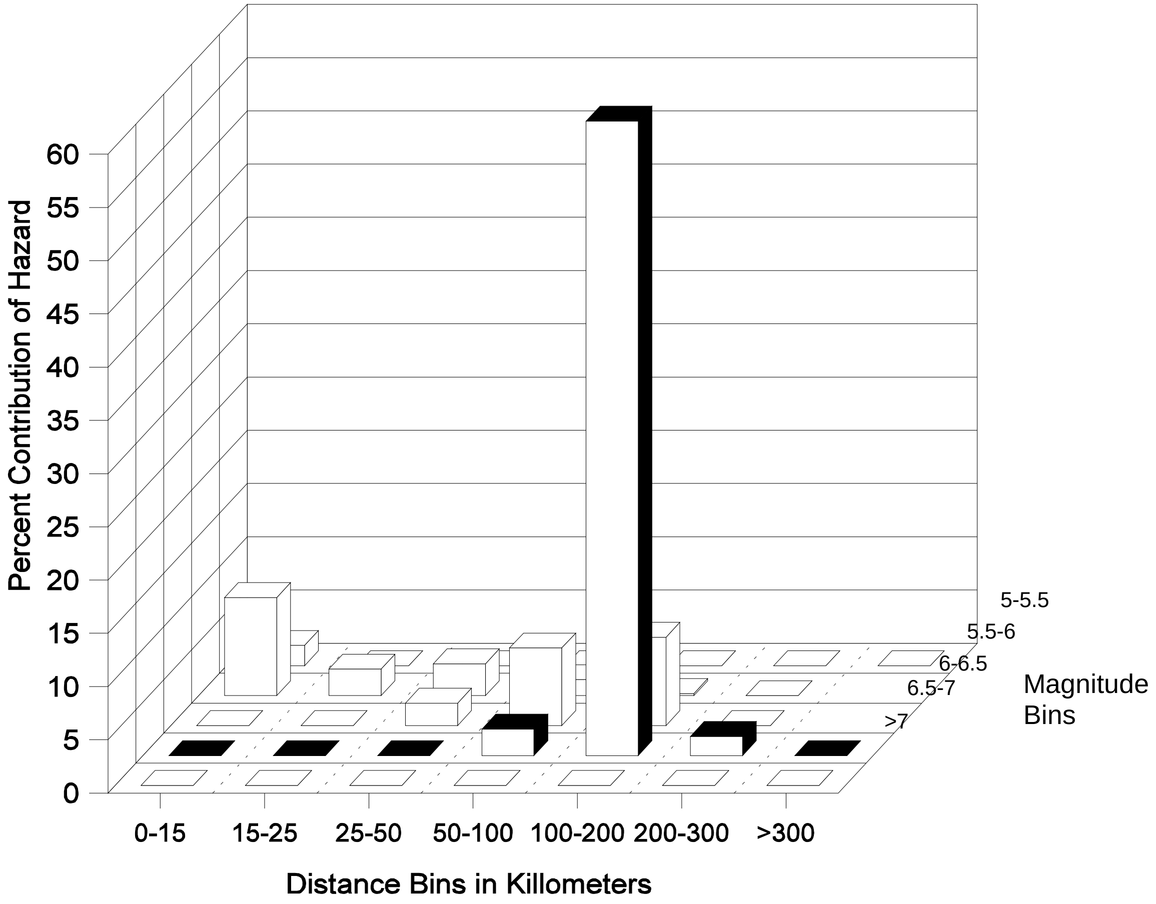

Figure C.4
Full
Distribution of Hazard for 1 Hz

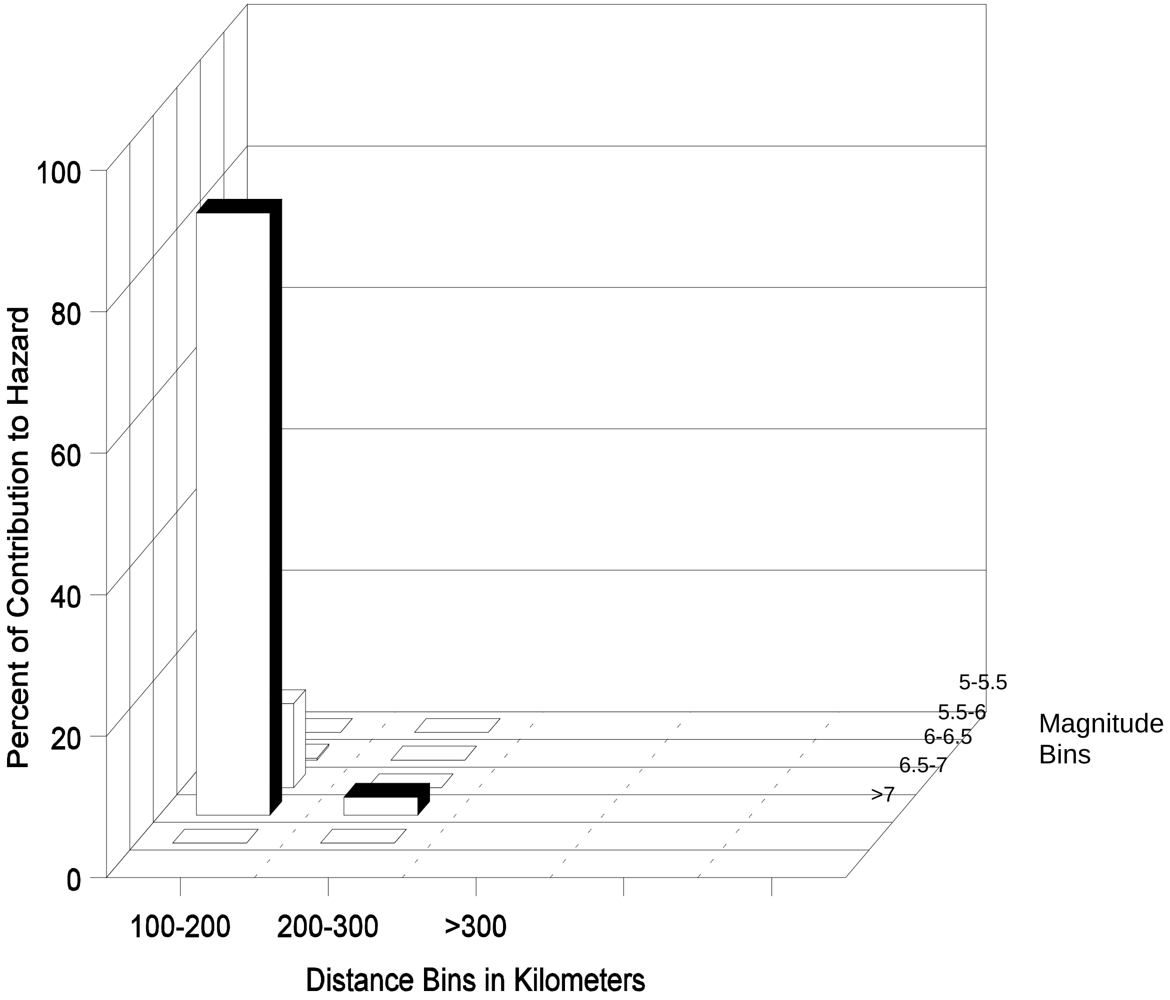

Figure C.5

Renormalized Hazard Distribution for
Distances Greater than 100 km for 1 Hz

REFERENCES

C.1 P. Sobel, "Revised Livermore Seismic Hazard Estimates for Sixty-Nine Nuclear Power Plant Sites East of the Rocky Mountains," NUREG-1488, USNRC, April 1994.[1]

C.2 J.B. Savy et al., "Eastern Seismic Hazard Characterization Update," UCRL-ID-115111, Lawrence Livermore National Laboratory, June 1993. (Accession number 9310190318 in NRC's Public Document Room)[2]

C.3 Electric Power Research Institute (EPRI), "Probabilistic Seismic Hazard Evaluations at Nuclear Power Plant Sites in the Central and Eastern United States," NP-4726, All Volumes, 1989-1991.

---

[1] Copies are available at current rates from the U.S. Government Printing Office, P.O. Box 37082, Washington, DC 20402-9328 (telephone (202)512-1800); or from the National Technical Information Service by writing NTIS at 5285 Port Royal Road, Springfield, VA 22161; <http://www.ntis.gov/ordernow>; telephone (703)487-4650. Copies are available for inspection or copying for a fee from the NRC Public Document Room at 11555 Rockville Pike, Rockville, MD; the PDR's mailing address is USNRC PDR, Washington, DC 20555; telephone (301)415-4737 or (800)397-4209; fax (301)415-3548; email is PDR@NRC.GOV.

[2] Copies are available for inspection or copying for a fee from the NRC Public Document Room at 11555 Rockville Pike (first floor), Rockville, MD; the PDR's mailing address is USNRC PDR, Washington, DC 20555; telephone (301)415-4737 or 1-(800)397-4209; fax (301)415-3548; e-mail <PDR@NRC.GOV>.

APPENDIX D
GEOLOGICAL, SEISMOLOGICAL, AND GEOPHYSICAL INVESTIGATIONS TO CHARACTERIZE SEISMIC SOURCES

D.1 INTRODUCTION

As characterized for use in probabilistic seismic hazard analyses (PSHA), seismic sources are zones within which future earthquakes are likely to occur at the same recurrence rates. Geological, seismological, and geophysical investigations provide the information needed to identify and characterize source parameters, such as size and geometry, and to estimate earthquake recurrence rates and maximum magnitudes. The amount of data available about earthquakes and their causative sources varies substantially between the WUS (west of the Rocky Mountain front) and the Central and Eastern United States (CEUS), or stable continental region (SCR) (east of the Rocky Mountain front). Furthermore, there are variations in the amount and quality of data within these regions.

In active tectonic regions there are both capable tectonic sources and seismogenic sources, and because of their relatively high activity rate they may be more readily identified. In the CEUS, identifying seismic sources is less certain because of the difficulty in correlating earthquake activity with known tectonic structures, the lack of adequate knowledge about earthquake causes, and the relatively lower activity rate. However, several significant tectonic structures exist and some of these have been interpreted as potential seismogenic sources (e.g., the New Madrid fault zone, Nemaha Ridge, and Meers fault).

In the CEUS, there is no single recommended procedure to follow to characterize maximum magnitudes associated with such candidate seismogenic sources; therefore, it is most likely that the determination of the properties of the seismogenic source, whether it is a tectonic structure or a seismotectonic province, will be inferred rather than demonstrated by strong correlations with seismicity or geologic data. Moreover, it is not generally known what relationships exist between observed tectonic structures in a seismic source within the CEUS and the current earthquake activity that may be associated with that source. Generally, the observed tectonic structure resulted from ancient tectonic forces that are no longer present. The historical seismicity record, the results of regional and site studies, and judgment play key roles. If, on the other hand, strong correlations and data exist suggesting a relationship between seismicity and seismic sources, approaches used for more active tectonic regions can be applied.

The primary objective of geological, seismological, and geophysical investigations is to develop an up-to-date, site-specific earth science data base that supplements existing information (Ref. D.1). In the CEUS, the results of these investigations will also be used to assess whether new data and their interpretation are consistent with the information used as the basis for accepted probabilistic seismic hazard studies. If the new data are consistent with the existing earth science data base, modification of the hazard analysis is not required. For sites in the CEUS where there is significant new information (see Appendix E) provided by the site investigation, and for sites in the WUS, site-specific seismic sources are to be determined. It is anticipated that for most sites in the CEUS, new information will have been adequately bounded by existing seismic source interpretations.

The following are to be evaluated for a seismic source for site-specific source interpretations:

- Seismic source location and geometry (location and extent, both surface and subsurface). This evaluation will normally require interpretations of available geological, geophysical, and seismological data in the source region by multiple experts or a team of experts. The evaluation should include interpretations of the seismic potential of each source and relationships among seismic sources in the region in order to express uncertainty in the evaluations. Seismic source evaluations generally develop four types of sources: (1) fault-specific sources, (2) area sources representing concentrated historic seismicity not associated with known tectonic structure, (3) area sources representing geographic regions with similar tectonic histories, type of crust, and structural features, and (4) background sources. Background sources are generally used to express uncertainty in the overall seismic source configuration interpreted for the site region. Acceptable approaches for evaluating and characterizing uncertainties for input to a seismic hazard calculation are contained in NUREG/CR-6372 (Ref. D.2).

- Evaluations of earthquake recurrence for each seismic source, including recurrence rate and recurrence model. These evaluations normally draw most heavily on historical and instrumental seismicity associated with each source and paleoearthquake information. Preferred methods and approaches for evaluating and characterizing uncertainty in earthquake recurrence generally will depend on the type of source. Acceptable methods are described in NUREG/CR-6372 (Ref. D.2).

- Evaluations of the maximum earthquake magnitude for each seismic source. These evaluations will draw on a broad range of source-specific tectonic characteristics, including tectonic history and available seismicity data. Uncertainty in this evaluation should normally be expressed as a maximum magnitude distribution. Preferred methods and information for evaluating and characterizing maximum earthquakes for seismic sources vary with the type of source. Acceptable methods are contained in NUREG/CR-6372 (Ref. D.2).

- Other evaluations, depending on the geologic setting of a site, such as local faults that have a history of Quaternary (last 2 million years) displacements, sense of slip on faults, fault length and width, area of faults, age of displacements, estimated displacement per event, estimated earthquake magnitude per offset event, orientations of regional tectonic stresses with respect to faults, and the possibility of seismogenic folds. Capable tectonic sources are not always exposed at the ground surface in the WUS as demonstrated by the buried reverse causative faults of the 1983 Coalinga, 1988 Whittier Narrows, l989 Loma Prieta, and 1994 Northridge earthquakes. These examples emphasize the need to conduct thorough investigations not only at the ground surface but also in the subsurface to identify structures at seismogenic depths. Whenever faults or other structures are encountered at a site (including sites in the CEUS) in either outcrop or excavations, it is necessary to perform adequately detailed specific investigations to determine whether or not they are seismogenic or may cause surface deformation at the site. Acceptable methods for performing these investigations are contained in NUREG/CR-5503 (Ref. D.3).

- Effects of human activities such as withdrawal of fluid from or addition of fluid to the subsurface associated with mining or the construction of dams and reservoirs.

- Volcanic hazard is not addressed in this regulatory guide and will be considered on a case-by-case basis in regions where a potential for this hazard exists. For sites where volcanic hazard is evaluated, earthquake sources associated with volcanism should be evaluated and included in the seismic source interpretations input to the hazard calculation.

D.2. INVESTIGATIONS TO EVALUATE SEISMIC SOURCES

D.2.1 General

Investigations of the site and region around the site are necessary to identify both seismogenic sources and capable tectonic sources and to determine their potential for generating earthquakes and causing surface deformation. If it is determined that surface deformation need not be taken into account at the site, sufficient data to clearly justify the determination should be presented in the application for an early site permit, construction permit, operating license, or combined license. Generally, any tectonic deformation at the earth's surface within 40 km (25 miles) of the site will require detailed examination to determine its significance. Potentially active tectonic deformation within the seismogenic zone beneath a site will have to be assessed using geophysical and seismological methods to determine its significance.

Engineering solutions are generally available to mitigate the potential vibratory effects of earthquakes through design. However, engineering solutions cannot always be demonstrated to be adequate for mitigation of the effects of permanent ground displacement phenomena such as surface faulting or folding, subsidence, or ground collapse. For this reason, it is prudent to select an alternative site when the potential for permanent ground displacement exists at the proposed site (Ref. D.4).

In most of the CEUS, instrumentally located earthquakes seldom bear any relationship to geologic structures exposed at the ground surface. Possible geologically young fault displacements either do not extend to the ground surface or there is insufficient geologic material of the appropriate age available to date the faults. Capable tectonic sources are not always exposed at the ground surface in the WUS, as demonstrated by the buried (blind) reverse causative faults of the 1983 Coalinga, 1988 Whittier Narrows, 1989 Loma Prieta, and 1994 Northridge earthquakes. These factors emphasize the need to conduct thorough investigations not only at the ground surface but also in the subsurface to identify structures at seismogenic depths.

The level of detail for investigations should be governed by knowledge of the current and late Quaternary tectonic regime and the geological complexity of the site and region. The investigations should be based on increasing the amount of detailed information as they proceed from the regional level down to the site area [e.g., 320 km (200 mi) to 8 km (5 mi) distance from the site]. Whenever faults or other structures are encountered at a site (including sites in the CEUS) in either outcrop or excavations, it is necessary to perform many of the investigations described below to determine whether or not they are capable tectonic sources.

The investigations for determining seismic sources should be carried out at three levels, with areas described by radii of 320 km (200 mi), 40 km (25 mi), and 8 km (5 mi) from the site. The level of detail increases closer to the site. The specific site, to a distance of at least 1 km (0.6 mi), should be investigated in more detail than the other levels.

The regional investigations [within a radius of 320 km (200 mi) of the site] should be planned to identify seismic sources and describe the Quaternary tectonic regime. The data should be presented at a scale of 1:500,000 or smaller. The investigations are not expected to be extensive or in detail, but should include a comprehensive literature review supplemented by focused geological reconnaissances based on the results of the literature study (including topographic, geologic, aeromagnetic, and gravity maps and airphotos). Some detailed investigations at specific locations within the region may be necessary if potential capable tectonic sources or seismogenic sources that may be significant for determining the safe shutdown earthquake ground motion are identified.

The large size of the area for the regional investigations is recommended because of the possibility that all significant seismic sources, or alternative configurations, may not have been enveloped by the LLNL/EPRI data base. Thus, it will increase the chances of (1) identifying evidence for unknown seismic sources that might extend close enough for earthquake ground motions generated by that source to affect the site and (2) confirming the PSHA's data base. Furthermore, because of the relatively aseismic nature of the CEUS, the area should be large enough to include as many historical and instrumentally recorded earthquakes for analysis as reasonably possible. The specified area of study is expected to be large enough to incorporate any previously identified sources that could be analogous to sources that may underlie or be relatively close to the site. In past licensing activities for sites in the CEUS, it has often been necessary, because of the absence of datable horizons overlying bedrock, to extend investigations out many tens or hundreds of kilometers from the site along a structure or to an outlying analogous structure in order to locate overlying datable strata or unconformities so that geochronological methods could be applied. This procedure has also been used to estimate the age of an undatable seismic source in the site vicinity by relating its time of last activity to that of a similar, previously evaluated structure, or a known tectonic episode, the evidence of which may be many tens or hundreds of miles away.

In the WUS it is often necessary to extend the investigations to great distances (up to hundreds of kilometers) to characterize a major tectonic structure, such as the San Gregorio-Hosgri Fault Zone and the Juan de Fuca Subduction Zone. On the other hand, in the WUS it is not usually necessary to extend the regional investigations that far in all directions. For example, for a site such as Diablo Canyon, which is near the San Gregorio-Hosgri Fault, it would not be necessary to extend the regional investigations farther east than the dominant San Andreas Fault, which is about 75 km (45 mi) from the site; nor west beyond the Santa Lucia Banks Fault, which is about 45 km (27 mi). Justification for using lesser distances should be provided.

Reconnaissance-level investigations, which may need to be supplemented at specific locations by more detailed explorations such as geologic mapping, geophysical surveying, borings, and trenching, should be conducted to a distance of 40 km (25 mi) from the site; the data should be presented at a scale of 1:50,000 or smaller.

Detailed investigations should be carried out within a radius of 8 km (5 mi) from the site, and the resulting data should be presented at a scale of 1:5,000 or smaller. The level of investigations should be in sufficient detail to delineate the geology and the potential for tectonic deformation at or near the ground surface. The investigations should use the methods described in subsections D.2.2 and D.2.3 that are appropriate for the tectonic regime to characterize seismic sources.

The areas of investigations may be asymmetrical and may cover larger areas than those described above in regions of late Quaternary activity, regions with high rates of historical seismic activity (felt or instrumentally recorded data), or sites that are located near a capable tectonic source such as a fault zone.

Data from investigations at the site (approximately 1 km^2) should be presented at a scale of 1:500 or smaller. Important aspects of the site investigations are the excavation and logging of exploratory trenches and the mapping of the excavations for the plant structures, particularly plant structures that are characterized as Seismic Category I. In addition to geological, geophysical, and seismological investigations, detailed geotechnical engineering investigations, as described in Regulatory Guide 1.132 (Ref. D.5) and NUREG/CR-5738 (Ref. D.6), should be conducted at the site.

The investigations needed to assess the suitability of the site with respect to effects of potential ground motions and surface deformation should include determination of (1) the lithologic, stratigraphic, geomorphic, hydrologic, geotechnical, and structural geologic characteristics of the site and the area surrounding the site, including its seismicity and geological history, (2) geological evidence of fault offset or other distortion such as folding at or near ground surface within the site area (8 km radius), and (3) whether or not any faults or other tectonic structures, any part of which are within a radius of 8 km (5 mi) from the site, are capable tectonic sources. This information will be used to evaluate tectonic structures underlying the site area, whether buried or expressed at the surface, with regard to their potential for generating earthquakes and for causing surface deformation at or near the site. This part of the evaluation should also consider the possible effects caused by human activities such as withdrawal of fluid from or addition of fluid to the subsurface, extraction of minerals, or the loading effects of dams and reservoirs.

D.2.2 Reconnaissance Investigations, Literature Review, and Other Sources of Preliminary Information

Regional literature and reconnaissance-level investigations should be planned based on reviews of available documents and the results of previous investigations. Possible sources of information, in addition to refereed papers published in technical journals, include universities, consulting firms, and government agencies. The following guidance is provided but it is not considered all-inclusive. Some investigations and evaluations will not be applicable to every site, and situations may occur that require investigations that are not included in the following discussion. In addition, it is anticipated that new technologies will be available in the future that will be applicable to these investigations.

D.2.3 Detailed Site Vicinity and Site Area Investigations

The following methods are suggested but they are not all-inclusive and investigations should not be limited to them. Some procedures will not be applicable to every site, and situations will occur that require investigations that are not included in the following discussion. It is anticipated that new technologies will be available in the future that will be applicable to these investigations.

D.2.3.1 Surface Investigations

Surface exploration to assess the geology and geologic structure of the site area is dependent on the site location and may be carried out with the use of any appropriate combination of the geological, geophysical, and seismological techniques summarized in the following paragraphs. However, not all of these methods must be carried out at a given site.

D.2.3.1.1. Geological interpretations should be performed of aerial photographs and other remote-sensing as appropriate for the particular site conditions, to assist in identifying rock outcrops, faults and other tectonic features, fracture traces, geologic contacts, lineaments, soil conditions, and evidence of landslides or soil liquefaction.

D.2.3.1.2. Mapping topographic, geomorphic, and hydrologic features should be performed at scales and with contour intervals suitable for analysis and descriptions of stratigraphy (particularly Quaternary), surface tectonic structures such as fault zones, and Quaternary geomorphic features. For coastal sites or sites located near lakes or rivers, this includes topography, geomorphology (particularly mapping marine and fluvial terraces), bathymetry, geophysics (such as seismic reflection), and hydrographic surveys to the extent needed to describe the site area features.

D.2.3.1.3. Vertical crustal movements should be evaluated using: (1) geodetic land surveying and (2) geological analyses (such as analysis of regional dissection and degradation patterns), marine and lacustrine terraces and shorelines, fluvial adjustments (such as changes in stream longitudinal profiles or terraces), and other long-term changes (such as elevation changes across lava flows).

D.2.3.1.4. Analysis should be performed to determine the tectonic significance of offset, displaced, or anomalous landforms such as displaced stream channels or changes in stream profiles or the upstream migration of knick-points; abrupt changes in fluvial deposits or terraces; changes in paleo-channels across a fault; or uplifted, down-dropped, or laterally displaced marine terraces.

D.2.3.1.5. Analysis should be performed to determine the tectonic significance of Quaternary sedimentary deposits within or near tectonic zones such as fault zones, including (1) fault-related or fault-controlled deposits such as sag ponds, graben fill deposits, and colluvial wedges formed by the erosion of a fault paleo-scarp, and (2) non-fault-related, but offset, deposits such as alluvial fans, debris cones, fluvial terrace, and lake shoreline deposits.

D.2.3.1.6. Identification and analysis should be performed of deformation features caused by vibratory ground motions, including seismically induced liquefaction features (sand boils, explosion craters, lateral spreads, settlement, soil flows), mud volcanoes, landslides, rockfalls, deformed lake deposits or soil horizons, shear zones, cracks or fissures.

D.2.3.1.7. Analysis should be performed of fault displacements, including the interpretation of the morphology of topographic fault scarps associated with or produced by surface rupture. Fault scarp morphology is useful for estimating the age of last displacement (in conjunction with the appropriate geochronological methods described NUREG/CR-5562 (Ref. D.6), approximate magnitude of the associated earthquake, recurrence intervals, slip rate, and the nature of the causative fault at depth.

D.2.3.2 Subsurface Investigations at the Site [within 1 km (0.5 mi)]

Subsurface investigations at the site to identify and describe potential seismogenic sources or capable tectonic sources and to obtain required geotechnical information are described in Regulatory Guide 1.132 (Ref. D.5) and updated in NUREG/CR-5738 (Ref. D.7). The investigations include, but may not be confined to, the following:

D.2.3.2.1. Geophysical investigations that have been useful in the past include magnetic and gravity surveys, seismic reflection and seismic refraction surveys, bore-hole geophysics, electrical surveys, and ground-penetrating radar surveys.

D.2.3.2.2. Core borings to map subsurface geology and obtain samples for testing such as determining the properties of the subsurface soils and rocks and geochronological analysis;

D.2.3.2.3. Excavation and logging of trenches across geological features to obtain samples for the geochronological analysis of those features.

D.2.3.2.4. At some sites, deep unconsolidated material/soil, bodies of water, or other material may obscure geologic evidence of past activity along a tectonic structure. In such cases, the analysis of evidence elsewhere along the structure can be used to evaluate its characteristics in the vicinity of the site.

In the CEUS it may not be possible to reasonably demonstrate the age of youngest activity on a tectonic structure with adequate deterministic certainty. In such cases the uncertainty should be quantified; the NRC staff will accept evaluations using the methods described in NUREG/CR-5503 (Ref. D.3). A demonstrated tectonic association of such structures with geologic structural features or tectonic processes that are geologically old (at least pre-Quaternary) should be acceptable as an age indicator in the absence of conflicting evidence.

D.2.3.3 Surface-Fault Rupture and Associated Deformation at the Site

A site that has a potential for fault rupture at or near the ground surface and associated deformation should be avoided. Where it is determined that surface deformation need not be taken into account, sufficient data or detailed studies to reasonably support the determination should be presented. Requirements for setback distance from active faults for hazardous waste treatment, storage and disposal facilities can be found in U.S. Environmental Protection Agency regulations (40 CFR Part 264).

The presence or absence of Quaternary faulting at the site needs to be evaluated to determine whether there is a potential hazard that is due to surface faulting. The potential for surface fault rupture should be characterized by evaluating (1) the location and geometry of faults relative to the site, (2) nature and amount of displacement (sense of slip, cumulative slip, slip per event, and nature and extent of related folding and/or secondary faulting), and (3) the likelihood of displacement during some future period of concern (recurrence interval, slip rate, and elapsed time since the most recent displacement). Acceptable methods and approaches for conducting these evaluations are described in NUREG/CR-5503 (Ref. D.3); acceptable geochronology dating methods are described in NUREG/CR-5562 (Ref. D.7).

For assessing the potential for fault displacement, the details of the spatial pattern of the fault zone (e.g., the complexity of fault traces, branches, and en echelon patterns) may be important as they may define the particular locations where fault displacement may be expected in the future. The amount of slip that might be expected to occur can be evaluated directly based on paleoseismic investigations or it can be estimated indirectly based on the magnitude of the earthquake that the fault can generate.

Both non-tectonic and tectonic deformation can pose a substantial hazard to an ISFSI or MRS, but there are likely to be differences in the approaches used to resolve the issues raised by the two types of phenomena. Therefore, non-tectonic deformation should be distinguished from tectonic deformation at a site. In past nuclear power plant licensing activities, surface displacements caused by phenomena other than tectonic phenomena have been confused with tectonically induced faulting. Such structures, such as found in karst terrain; and growth faulting, occurring in the Gulf Coastal Plain or in other deep soil regions, cause extensive subsurface fluid withdrawal.

Glacially induced faults generally do not represent a deep-seated seismic or fault displacement hazard because the conditions that created them are no longer present. However, residual stresses from Pleistocene glaciation may still be present in glaciated regions, although they are of less concern than active tectonically induced stresses. These features should be investigated with respect to their relationship to current in situ stresses.

The nature of faults related to collapse features can usually be defined through geotechnical investigations and can either be avoided or, if feasible, adequate engineering fixes can be provided.

Large, naturally occurring growth faults as found in the coastal plain of Texas and Louisiana can pose a surface displacement hazard, even though offset most likely occurs at a much less rapid rate than that of tectonic faults. They are not regarded as having the capacity to generate damaging vibratory ground motion, can often be identified and avoided in siting, and their displacements can be monitored. Some growth faults and antithetic faults related to growth faults and fault zones should be applied in regions where growth faults are known to be present. Local human-induced growth faulting can be monitored and controlled or avoided.

If questionable features cannot be demonstrated to be of non-tectonic origin, they should be treated as tectonic deformation.

D.2.4 Site Geotechnical Investigations and Evaluations

D.2.4.1 Geotechnical Investigations

The geotechnical investigations should include, but not necessarily be limited to, (1) defining site soil and near-surface geologic strata properties as may be required for hazard evaluations, engineering analyses, and seismic design, (2) evaluating the effects of local soil and site geologic strata on ground motion at the ground surface, (3) evaluating dynamic properties of the near-surface soils and geologic strata, (4) conducting soil-structure interaction analyses, and (5) assessing the potential for soil failure or deformation induced by ground shaking (liquefaction, differential compaction, land sliding).

The extent of investigation to determine the geotechnical characteristics of a site depends on the site geology and subsurface conditions. By working with experienced geotechnical engineers and geologists, an appropriate scope of investigations can be developed for a particular facility following the guidance contained in Regulatory Guide 1.132 (Ref. D.5) updated with NUREG/CR-5738 (Ref. D.6). The extent of subsurface investigations is dictated by the foundation requirements and by the complexity of the anticipated subsurface conditions. The locations and spacing of borings, soundings, and exploratory excavations should be chosen to adequately define subsurface conditions. Subsurface explorations should be chosen to adequately define subsurface conditions; exploration sampling points should be located to permit the construction of geological cross sections and soil profiles through foundations of safety-related structures and other important locations at the site.

Sufficient geophysical and geotechnical data should be obtained to allow for reasonable assessments of representative soil profile and soil parameters and to reasonably quantify variability. The guidance found in Regulatory Guide 1.132 (Ref. D.5) and NUREG/CR-5738 (Ref. D.6) is acceptable. In general, this guidance should be adapted to the requirements of the site to establish the scope of geotechnical investigations for the site as well as the appropriate methods that will be used.

For ISFSIs co-located with existing nuclear plants, site investigations should be conducted if the existing site information is not available or insufficient. Soil/rock profiles (cross-sections) at the locations of the facilities should be provided based on the results of site investigations. The properties required are intimately linked to the designs and evaluations to be conducted. For example, for analyses of soil response effects, assessment of strain dependent-soil-dynamic modulus and damping characteristics are required. An appropriate site investigation program should be developed in consultation with the geotechnical engineering representative of the project team.

Subsurface conditions should be investigated by means of borings, soundings, well logs, exploratory excavations, sampling, geophysical methods (e.g., cross-hole, down-hole, and geophysical logging) that adequately assess soil and ground water conditions and other methods described in NUREG/CR-5738 (Ref. D.6). Appropriate investigations should be made to determine the contribution of the subsurface soils and rocks to the loads imposed on the structures.

A laboratory testing program should be carried out to identify and classify the subsurface soils and rocks and to determine their physical and engineering properties. Laboratory tests for both static and dynamic properties (e.g., shear modulus, damping, liquefaction resistance, etc.) are generally required. The dynamic property tests should include, as appropriate, cyclic triaxial tests, cyclic simple shear tests, cyclic torsional shear tests, and resonant column tests. Both static and dynamic tests should be conducted as recommended in American Society for Testing and Materials (ASTM) standards or test procedures acceptable to the staff. The ASTM specification numbers for static and dynamic laboratory tests can be found in the annual books of ASTM Standards, Volume 04.08. Examples of soil dynamic property and strength tests are shown in Table D.1. Sufficient laboratory test data should be obtained to allow for reasonable assessments of mean values of soil properties and their potential variability.

For coarse geological materials such as coarse gravels and sand-gravel mixtures, special testing equipment and testing facility should be used. Larger sample size is required for laboratory tests on this type of materials (e.g., samples with 12-inch diameter were used in the Rockfalls Testing Facility). It is generally difficult to obtain in situ undisturbed samples of unconsolidated gravelly soils for laboratory tests. If it is not feasible to collect test samples and, thus, no laboratory test results are available, the dynamic properties should be estimated from the published data of similar gravelly soils.

Table D.1 Examples of Soil Dynamic Property and Strength Tests

D 3999-91 (Ref. D.8)	Standard Test Method for the Determination of the Modulus and Damping Properties of Soils Using the Cyclic Triaxial Apparatus
D 4015-92 (Ref. D.9)	Standard Test Methods for Modulus and Damping of Soils by the Resonant-Column Method
D 5311-92 (Ref. D10)	Standard Test Method for Load-Controlled Cyclic Triaxial Strength of Soil

D.2.4.2 Seismic Wave Transmission Characteristics of the Site

To be acceptable, the seismic wave transmission characteristics (spectral amplification or deamplification) of the materials overlying bedrock at the site are described as a function of the significant structural frequencies. The following material properties should be determined for each stratum under the site: (1) thickness, seismic compressional and shear wave velocities, (2) bulk densities, (3) soil index properties and classification, (4) shear modulus and damping variations with strain level, and (5) the water table elevation and its variation throughout the site.

Where vertically propagating shear waves may produce the maximum ground motion, a one-dimensional equivalent-linear analysis or nonlinear analysis may be appropriate. Where horizontally propagating shear waves, compressional waves, or surface waves may produce the maximum ground motion, other methods of analysis may be more appropriate. However, since some of the variables are not well defined and investigative techniques are still in the developmental stage, no specific generally agreed-upon procedures can be recommended at this time. Hence, the staff must use discretion in reviewing any method of analysis. To ensure appropriateness, site response characteristics determined from analytical procedures should be compared with historical and instrumental earthquake data, when such data are available.

D.2.4.3 Site Response Analysis for Soil Sites

As part of quantification of earthquake ground motions at an ISFSI or MRS site, an analysis of soil response effects on ground motions should be performed. A specific analysis is not required at a hard rock site. Site response analyses (often referred to as site amplification analyses) are relatively more important when the site surficial soil layer is a soft clay and/or when there is a high stiffness contrast (wave velocity contrast) between a shallow soil layer and underlying bedrock. Such conditions have shown strong local soil effects on ground motion. Site response analyses are always important for sites that have predominant frequencies within the range of interest for the DE ground motions. Thus, the stiffness of the soil and bedrock as well as the depth of soil deposit should be carefully evaluated.

In performing a site response analysis, the ground motions (usually acceleration time histories) defined at bedrock or outcrop are propagated through an analytical model of the site soils to determine the influence of the soils on the ground motions. The required soil parameters for the site response analysis include the depth, soil type, density, shear modulus and damping, and their variations with strain levels for each of the soil layers. Internal friction angle, cohesive strength, and over-consolidation ratio for clay are also needed for non-linear analyses. The strain dependent shear modulus and damping curves should be developed based on site-specific testing results and supplemented as appropriate by published data for similar soils. The effects of confining pressures (that reflect the depths of the soil) on these strain-dependent soil dynamic characteristics should be assessed and considered in site response analysis. The variability in these properties should be accounted in the site response analysis. The results of the site response analysis should show the input motion (rock response spectra), output motion (surface response spectra), and spectra amplification function (site ground motion transfer function).

D.2.4.4 Ground Motion Evaluations

D.2.4.4.1. Liquefaction is a soil behavior phenomenon in which cohesionless soils (sand, silt, or gravel) under saturated conditions lose a substantial part or all of their strength because of high pore water pressures generated in the soils by strong ground motions induced by earthquakes. Potential effects of liquefaction include reduction in foundation bearing capacity, settlements, land sliding and lateral movements, flotation of lightweight structures (such as tanks) embedded in the liquefied soil, and increased lateral pressures on walls retaining liquefied soil. Guidance in Draft Regulatory Guide DG-1105, “Procedures and Criteria for Assessing Seismic Soil Liquefaction at Nuclear Power Plant Sites” (Ref. D.11), is being developed to be used for evaluating the site for liquefaction potential.

Investigations of liquefaction potential typically involve both geological and geotechnical engineering assessments. The parameters controlling liquefaction phenomena are (1) the lithology of the soil at the site, (2) the ground water conditions, (3) the behavior of the soil under dynamic loadings, and (4) the potential severity of the vibratory ground motion. The following site-specific data should be acquired and used along with state-of-the-art evaluation procedures (e.g., Ref. D.12, Ref. D.13).

- Soil grain size distribution, density, static and dynamic strength, stress history, and geologic age of the sediments;
- Ground water conditions;
- Penetration resistance of the soil, e.g., Standard Penetration Test (SPT), Cone Penetration Test (CPT);
- Shear wave velocity of the soil velocity of the soil;
- Evidence of past liquefaction; and
- Ground motion characteristics.

A soil behavior phenomenon similar to liquefaction is strength reduction in sensitive clays. Although this behavior phenomenon is relatively rare in comparison to liquefaction, it should not be overlooked as a potential cause for land sliding and lateral movements. Therefore, the existence of sensitive clays at the site should be identified.

D.2.4.4.2. Ground settlement during and after an earthquake that is due to dynamic loads, change of ground water conditions, soil expansion, soil collapse, erosion, and other causes must be considered. Ground settlement that is due to the ground shaking induced by an earthquake can be caused by two factors: (1) compaction of dry sands by ground shaking and (2) settlement caused by dissipation of dynamically induced pore water in saturated sands. Differential settlement would cause more damage to facilities than would uniform settlement. Differential compaction of cohesionless soils and resulting differential ground settlement can accompany liquefaction or may occur in the absence of liquefaction. The same types of geologic information and soil data used in liquefaction potential assessments, such as the SPT value, can also be used in assessing the potential for differential compaction. Ground subsidence has been observed at the surface above relatively shallow cavities formed by mining activities (particularly coal mines) and where large quantities of salt, oil, gas, or ground water have been extracted (Ref. D.14). Where these conditions exist near a site, consideration and investigation must be given to the possibility that surface subsidence will occur.

D.2.4.4.3. The stability of natural and man-made slopes must be evaluated when their failures would affect the safety and operation of an ISFSI or MRS. In addition to land sliding facilitated by liquefaction-induced strength reduction, instability and deformation of hillside and embankment slopes can occur from the ground shaking inertia forces causing a temporary exceedance of the strength of soil or rock. The slip surfaces of previous landslides, weak planes or seams of subsurface materials, mapping and dating paleo-slope failure events, loss of shear strength of the materials caused by the natural phenomena hazards such as liquefaction or reduction of strength due to wetting, hydrological conditions including pore pressure and seepage, and loading conditions imposed by the natural phenomena events must all be considered in determining the potential for instability and deformations. Various possible modes of failure should be considered. Both static and dynamic analyses must be performed for the stability of the slopes.

The following information, at a minimum, is to be collected for the evaluation of slope instability:

- Slope cross sections covering areas that would be affected the slope stability;
- Soil and rock profiles within the slope cross sections;
- Static and dynamic soil and rock properties, including densities, strengths, and deformability;
- Hydrological conditions and their variations; and
- Rock fall events.

D.2.5 Geochronology

An important part of the geologic investigations to identify and define potential seismic sources is the geochronology of geologic materials. An acceptable classification of dating methods is based on the rationale described in Reference D.15. The following techniques, which are presented according to that classification, are useful in dating Quaternary deposits.

D.2.5.1 Sidereal Dating Methods

- Dendrochronology
- Varve chronology
- Schlerochronology

D.2.5.2 Isotopic Dating Methods

- Radiocarbon
- Cosmogenic nuclides - ^{36}Cl, ^{10}Be, ^{21}Pb, and ^{26}Al
- Potassium argon and argon-39-argon-40
- Uranium series - ^{234}U-^{230}Th and ^{235}U- ^{231}Pa
- ^{210}Lead
- Uranium-lead, thorium-lead

D.2.5.3 Radiogenic Dating Methods

- Fission track
- Luminescence

- Electron spin resonance

D.2.5.4 Chemical and Biological Dating Methods

- Amino acid racemization
- Obsidian and tephra hydration
- Lichenometry

D.2.5.6 Geomorphic Dating Methods

- Soil profile development
- Rock and mineral weathering
- Scarp morphology

D.2.5.7 Correlation Dating Methods

- Paleomagnetism (secular variation and reversal stratigraphy)
- Tephrochronology
- Paleontology (marine and terrestrial)
- Global climatic correlations - Quaternary deposits and landforms, marine stable isotope records, etc.

In the CEUS, it may not be possible to reasonably demonstrate the age of last activity of a tectonic structure. In such cases the NRC staff will accept association of such structures with geologic structural features or tectonic processes that are geologically old (at least pre-Quaternary) as an age indicator in the absence of conflicting evidence.

These investigative procedures should also be applied, where possible, to characterize offshore structures (faults or fault zones, and folds, uplift, or subsidence related to faulting at depth) for coastal sites or those sites located adjacent to landlocked bodies of water. Investigations of offshore structures will rely heavily on seismicity, geophysics, and bathymetry rather than conventional geologic mapping methods that normally can be used effectively onshore. However, it is often useful to investigate similar features onshore to learn more about the significant offshore features.

REFERENCES

D.1 Electric Power Research Institute, "Seismic Hazard Methodology for the Central and Eastern United States," EPRI NP-4726, All Volumes, 1988 through 1991.

D.2 Senior Seismic Hazard Analysis Committee (SSHAC), "Recommendations for Probabilistic Seismic Hazard Analysis: Guidance on Uncertainty and Use of Experts," NUREG/CR-6372, USNRC, 1997.[1]

D.3 K.L. Hanson et al., Techniques for Identifying Faults and Determining Their Origins," NUREG/CR-5503, USNRC,[1]1999.

D.4 International Atomic Energy Agency, "Earthquakes and Associated Topics in Relation to Nuclear Power Plant Siting," Safety Series No. 50-SG-S1, Revision 1, 1991.

D.5 USNRC, "Site Investigations for Foundation of Nuclear Power Plants," Regulatory Guide 1.132, March 1979.[2] (Proposed Revision 2, DG-1101, was issued for public comment in February 2001.)

D.6 N. Torres et al.,"Field Investigations for Foundations of Nuclear Power Facilities," NUREG/CR-5738, USNRC, 1999.[1]

D.7 J.M. Sowers et al., "Dating and Earthquakes: Review of Quaternary Geochronology and Its Application to Paleoseismology," NUREG/CR-5562, USNRC, 1998..[1]

D.8 American Society of Testing and Materials, "Standard Test Method for the Determination of the Modulus and Damping Properties of Soils Using the Cyclic Triaxial Apparatus," D 3999, 1991.

D.9 American Society of Testing and Materials, "Standard Test Methods for Modulus and Damping of Soils by the Resonant-Column Method," D 4015, 2000.

D.10 American Society of Testing and Materials, "Standard Test Method for Load-Controlled Cyclic Triaxial Strength of Soil," D 5311, 1996.

D.11 USNRC, "Procedures and Criteria for Assessing Seismic Soil Liquefaction at Nuclear Power Plant Sites," Draft Regulatory Guide DG-1105, issued for public comment March 2001.

---

[1] Copies are available at current rates from the U.S. Government Printing Office, P.O. Box 37082, Washington, DC 20402-9328 (telephone (202)512-1800); or from the National Technical Information Service by writing NTIS at 5285 Port Royal Road, Springfield, VA 22161; (telephone (703)487-4650; <http://www.ntis.gov/ordernow>. Copies are available for inspection or copying for a fee from the NRC Public Document Room at 11555 Rockville Pike, Rockville, MD; the PDR's mailing address is USNRC PDR, Washington, DC 20555; telephone (301)415-4737 or (800)397-4209; fax (301)415-3548; email is PDR@NRC.GOV.1.

[2] Requests for single copies of draft or active regulatory guides (which may be reproduced) or for placement on an automatic distribution list for single copies of future draft guides in specific divisions should be made in writing to the U.S. Nuclear Regulatory Commission, Washington, DC 20555, Attention: Reproduction and Distribution Services Section, or by fax to (301)415-2289; email <DISTRIBUTION@NRC.GOV>. Copies are available for inspection or copying for a fee from the NRC Public Document Room at 11555 Rockville Pike (first floor), Rockville, MD; the PDR's mailing address is USNRC PDR, Washington, DC 20555; telephone (301)415-4737 or 1-(800)397-4209; fax (301)415-3548; e-mail <PDR@NRC.GOV>.

D.12 H.B. Seed and I.M. Idriss, “Ground Motions and Soil Liquefaction during Earthquakes,” Earthquake Engineering Research Institute, Oakland, California, Monograph Series, 1982.

D.13 H.B. Seed et al., “Influence of SPT Procedures in Soil Liquefaction Resistance Evaluation,” *Journal of the Geotechnical Engineering Division,* ASCE, 111, GT12, 1225-1273, 1985.

D.14 A.W. Hatheway and C.R. McClure, “Geology in the Siting of Nuclear Power Plants,” *Reviews in Engineering Geology,* Geological Society of America, Volume IV, 1979.

D.15 S. M. Colman, K. L. Pierce, and P.W. Birkland, “Suggested Terminology for Quaternary Dating Methods,” *Quaternary Research*, Volume 288, pp. 314-319, 1987.

APPENDIX E
PROCEDURE FOR THE EVALUATION OF NEW GEOSCIENCES INFORMATION OBTAINED FROM THE SITE-SPECIFIC INVESTIGATIONS

E.1 INTRODUCTION

This appendix provides methods acceptable to the NRC staff for assessing the impact of new information obtained during site-specific investigations on the data base used for the probabilistic seismic hazard analyses (PSHA).

Regulatory Position 4 in this guide describes acceptable PSHAs that were developed by the Lawrence Livermore National Laboratory (LLNL) and the Electric Power Research Institute (EPRI) to characterize the seismic hazard for nuclear power plants and to develop the Safe Shutdown Earthquake (SSE). The procedure to determine the design earthquake ground motion (DE) outlined in this guide relies primarily on either the LLNL or EPRI PSHA results for the Central and Eastern United States (CEUS).

It is necessary to evaluate the geological, seismological, and geophysical data obtained from the site-specific investigations to demonstrate that these data are consistent with the PSHA data bases of these two methodologies. If new information identified by the site-specific investigations would result in a significant increase in the hazard estimate for a site, and this new information is validated by a strong technical basis, the PSHA may have to be modified to incorporate the new technical information. Using sensitivity studies, it may also be possible to justify a lower hazard estimate with an exceptionally strong technical basis. However, it is expected that large uncertainties in estimating seismic hazard in the CEUS will continue to exist in the future, and substantial delays in the licensing process will result from trying to justify a lower value with respect to a specific site.

In general, major recomputations of the LLNL and EPRI data base are planned periodically (approximately every 10 years), or when there is an important new finding or occurrence. The overall revision of the data base will also require a reexamination of the reference probability discussed in Appendix B.

E.2 POSSIBLE SOURCES OF NEW INFORMATION THAT COULD AFFECT THE SSE

Types of new data that could affect the PSHA results can be put in three general categories: seismic sources, earthquake recurrence models or rates of deformation, and ground motion models.

E.2.1 Seismic Sources

There are several possible sources of new information from the site-specific investigations that could affect the seismic hazard. Continued recording of small earthquakes, including microearthquakes, may indicate the presence of a localized seismic source. Paleoseismic evidence, such as paleoliquefaction features or displaced Quaternary strata, may indicate the presence of a previously unknown tectonic structure or a larger amount of activity on a known structure than was previously considered. Geophysical studies (aeromagnetic, gravity, and seismic reflection/refraction) may identify crustal structures that suggest the presence of previously unknown seismic sources. In situ stress measurements and the mapping of tectonic structures in the future may indicate potential seismic sources.

Detailed local site investigations often reveal faults or other tectonic structures that were unknown, or reveal additional characteristics of known tectonic structures. Generally, based on past licensing experience in the CEUS, the discovery of such features will not require a modification of the seismic sources provided in the LLNL and EPRI studies. However, initial evidence regarding a newly discovered tectonic structure in the CEUS is often equivocal with respect to activity, and additional detailed investigations are required. By means of these detailed investigations, and based on past licensing activities, previously unidentified tectonic structures can usually be shown to be inactive or otherwise insignificant to the seismic design basis of the facility, and a modification of the seismic sources provided by the LLNL and EPRI studies will not be required. On the other hand, if the newly discovered features are relatively young, possibly associated with earthquakes that were large and could impact the hazard for the proposed facility, a modification may be required.

Of particular concern is the possible existence of previously unknown, potentially active tectonic structures that could have moderately sized, but potentially damaging, near-field earthquakes or could cause surface displacement. Also of concern is the presence of structures that could generate larger earthquakes within the region than previously estimated.

Investigations to determine whether there is a possibility for permanent ground displacement are especially important in view of the provision to allow for a combined licensing procedure under 10 CFR Part 52 as an alternative to the two-step procedure of the past (Construction Permit and Operating License). In the past at numerous nuclear power plant sites, potentially significant faults were identified when excavations were made during the construction phase prior to the issuance of an operating license, and extensive additional investigations of those faults had to be carried out to properly characterize them.

E.2.2 Earthquake Recurrence Models

There are three elements of the source zone’s recurrence models that could be affected by new site-specific data: (1) the rate of occurrence of earthquakes, (2) their maximum magnitude, and (3) the form of the recurrence model (e.g.,a change from truncated exponential to a characteristic earthquake model). Among the new site-specific information that is most likely to have a significant impact on the hazard is the discovery of paleoseismic evidence such as extensive soil liquefaction features, which would indicate with reasonable confidence that much larger estimates of the maximum earthquake than those predicted by the previous studies would ensue. The paleoseismic data could also be significant even if the maximum magnitudes of the previous studies are consistent with the paleo-earthquakes if there are sufficient data to develop return period estimates significantly shorter than those previously used in the probabilistic analysis. The paleoseismic data could also indicate that a characteristic earthquake model would be more applicable than a truncated exponential model.

In the future, expanded earthquake catalogs will become available that will differ from the catalogs used by the previous studies. Generally, these new catalogues have been shown to have only minor impacts on estimates of the parameters of the recurrence models. Cases that might be significant include the discovery of records that indicate earthquakes in a region that had no seismic activity in the previous catalogs, the occurrence of an earthquake larger than the largest historic earthquakes, re-evaluating the largest historic earthquake to a significantly larger magnitude, or the occurrence of one or more moderate to large earthquakes (magnitude 5.0 or greater) in the CEUS.

Geodetic measurements, particularly satellite-based networks, may provide data and interpretations of rates and styles of deformation in the CEUS that can have implications for earthquake recurrence. New hypotheses regarding present-day tectonics based on new data or reinterpretation of old data may be developed that were not considered or given high weight in the EPRI or LLNL PSHA. Any of these cases could have an impact on the estimated maximum earthquake if the result is larger than the values provided by LLNL and EPRI.

E.2.3 Ground Motion Attenuation Models

Alternative ground motion attenuation models may be used to determine the site-specific spectral shape as discussed in Regulatory Position 4 and Appendix F of this regulatory guide. If the ground motion models used are a major departure from the original models used in the hazard analysis and are likely to have impacts on the hazard results of many sites, a re-evaluation of the reference probability may be needed. Otherwise, a periodic (e.g., every 10 years) reexamination of the PSHA and the associated data base is considered appropriate to incorporate new understanding regarding ground motion attenuation models.

E.3 PROCEDURE AND EVALUATION

The EPRI and LLNL studies provide a wide range of interpretations of the possible seismic sources for most regions of the CEUS, as well as a wide range of interpretations for all the key parameters of the seismic hazard model. The first step in comparing the new information with those interpretations is determining whether the new information is consistent with the following LLNL and EPRI parameters: (1) the range of seismogenic sources as interpreted by the seismicity experts or teams involved in the study, (2) the range of seismicity rates for the region around the site as interpreted by the seismicity experts or teams involved in the studies, and (3) the range of maximum magnitudes determined by the seismicity experts or teams. The new information is considered not significant and no further evaluation is needed if it is consistent with the assumptions used in the PSHA, no additional alternative seismic sources or seismic parameters are needed, or it supports maintaining or decreasing the site mean seismic hazard.

An example is a new ISFSI co-located near an existing nuclear power plant site that was recently investigated by state-of-the-art geosciences techniques and evaluated by current hazard methodologies. Detailed geological, seismological, and geophysical site-specific investigations would be required to update existing information regarding the new site, but it is very unlikely that significant new information would be found that would invalidate the previous PSHA.

On the other hand, after evaluating the results of the site-specific investigations, if there is still uncertainty about whether the new information will affect the estimated hazard, it will be necessary to evaluate the potential impact of the new data and interpretations on the mean of the range of the input parameters. Such new information may indicate the addition of a new seismic source, a change in the rate of activity, a change in the spatial patterns of seismicity, an increase in the rate of deformation, or the observation of a relationship between tectonic structures and current seismicity. The new findings should be assessed by comparing them with the specific input of each expert or team that participated in the PSHA. Regarding a new source, for example, the specific seismic source characterizations for each expert or team (such as tectonic feature being modeled, source geometry, probability of being active, maximum earthquake magnitude, or occurrence rates) should be assessed in the context of the significant new data and interpretations.

It is expected that the new information will be within the range of interpretations in the existing data base, and the data will not result in an increase in overall seismicity rate or increase in the range of maximum earthquakes to be used in the probabilistic analysis. It can then be concluded that the current LLNL or EPRI results apply. It is possible that the new data may necessitate a change in some parameter. In this case, appropriate sensitivity analyses should be performed to determine whether the new site-specific data could affect the ground motion estimates at the reference probability level.

An example is a consideration of the seismic hazard near the Wabash River Valley (Ref. E.1). Geological evidence found recently within the Wabash River Valley and several of its tributaries indicated that an earthquake much larger than any historic event had occurred several thousand years ago in the vicinity of Vincennes, Indiana. A review of the inputs by the experts and teams involved in the LLNL and EPRI PSHAs revealed that many of them had made allowance for this possibility in their tectonic models by assuming the extension of the New Madrid Seismic Zone northward into the Wabash Valley. Several experts had given strong weight to the relatively high seismicity of the area, including the number of magnitude five historic earthquakes that have occurred, and thus had assumed the larger event. This analysis of the source characterizations of the experts and teams resulted in the conclusion by the analysts that a new PSHA would not be necessary for this region because an event similar to the prehistoric earthquake had been considered in the existing PSHAs.

A third step would be required if the site-specific geosciences investigations revealed significant new information that would substantially affect the estimated hazard. Modification of the seismic sources would more than likely be required if the results of the detailed local and regional site investigations indicate that a previously unknown seismic source is identified in the vicinity of the site. A hypothetical example would be the recognition of geological evidence of recent activity on a fault near a site in the SCR similar to the evidence found on the Meers Fault in Oklahoma (Ref. E.2). If such a source is identified, the same approach used in the active tectonic regions of the WUS should be used to assess the largest earthquake expected and the rate of activity. If the resulting maximum earthquake and the rate of activity are higher than those provided by the LLNL or EPRI experts or teams regarding seismic sources within the region in which this newly discovered tectonic source is located, it may be necessary to modify the existing interpretations by introducing the new seismic source and developing modified seismic hazard estimates for the site. The same would be true if the current ground motion models are a major departure from the original models. These occurrences would likely require performing a new PSHA using the updated data base, and may require determining the appropriate reference probability.

REFERENCES

E.1 Memorandum from A. Murphy, NRC, to L. Shao, NRC, Subject: Summary of a Public Meeting on the Revision of Appendix A, "Seismic and Geologic Siting Criteria for Nuclear Power Plants," to 10 CFR Part 100; Enclosure (Viewgraphs): NUMARC, "Development and Demonstration of Industry's Integrated Seismic Siting Decision Process," February 23, 1993.[1]

E.2 A.R. Ramelli, D.B. Slemmons, and S.J. Brocoum, "The Meers Fault: Tectonic Activity in Southwestern Oklahoma," NUREG/CR-4852, USNRC, March 1987.[2]

---

[1] Copies are available for inspection or copying for a fee from the NRC Public Document Room (PDR) at 11555 Rockville Pike, Rockville, MD; the PDR's mailing address is USNRC PDR, Washington, DC 20555; telephone (301)415-4737 or (800)397-4205; fax (301)415-3548; email <PDR@NRC.GOV>.

[2] Copies are available at current rates from the U.S. Government Printing Office, P.O. Box 37082, Washington, DC 20402-9328 (telephone (202)512-1800); or from the National Technical Information Service by writing NTIS at 5285 Port Royal Road, Springfield, VA 22161; (telephone (703)487-4650; <http://www.ntis.gov/ordernow>. Copies are available for inspection or copying for a fee from the NRC Public Document Room at 11555 Rockville Pike, Rockville, MD; the PDR's mailing address is USNRC PDR, Washington, DC 20555; telephone (301)415-4737 or (800)397-4209; fax (301)415-3548; email is PDR@NRC.GOV.

APPENDIX F
PROCEDURE TO DETERMINE THE DESIGN EARTHQUAKE GROUND MOTION

F.1 INTRODUCTION

This appendix elaborates on Step 4 of Regulatory Position 4 of this guide, which describes an acceptable procedure to determine the design earthquake ground motion (DE). The DE is defined in terms of the horizontal and vertical free-field ground motion response spectra at the free ground surface. It is developed with consideration of local site effects and site seismic wave transmission effects. The DE response spectrum can be determined by scaling a site-specific spectral shape determined for the controlling earthquakes or by scaling a standard broad-band spectral shape to envelope the ground motion levels for 1 Hz ($S_{a,1}$) and 10 Hz ($S_{a,10}$), as determined in Step C.2-2 of Appendix C to this guide. The standard response spectrum is generally specified at 5 percent critical damping.

It is anticipated that a regulatory guide will be developed that provides guidance on assessing site-specific effects and determining smooth design response spectra, taking into account recent developments in ground motion modeling and site amplification studies (for example, Ref. F.1).

F.2 DISCUSSION

For engineering purposes, it is essential that the design ground motion response spectrum be a broad-band smooth response spectrum with adequate energy in the frequencies of interest. In the past, it was general practice to select a standard broad-band spectrum, such as the spectrum in Regulatory Guide 1.60 (Ref. F.2), and scale it by a peak ground motion parameter [usually peak ground acceleration (PGA)], which is derived based on the size of the controlling earthquake. Past practices to define the DE are still valid and, based on this consideration, the following three possible situations are depicted in Figures F.1 to F.3.

Figure F.1 depicts a situation in which a site is to be used for a certified ISFSI or MRS design (if available) with an established DE. In this example, the certified design DE spectrum compares favorably with the site-specific response spectra determined in Step 2 or 3 of Regulatory Position 4.

Figure F.2 depicts a situation in which a standard broad-band shape is selected and its amplitude is scaled so that the design DE envelopes the site-specific spectra.

Figure F.3 depicts a situation in which a specific smooth shape for the design DE spectrum is developed to envelope the site-specific spectra. In this case, it is particularly important to be sure that the DE contains adequate energy in the frequency range of engineering interest and is sufficiently broad-band.

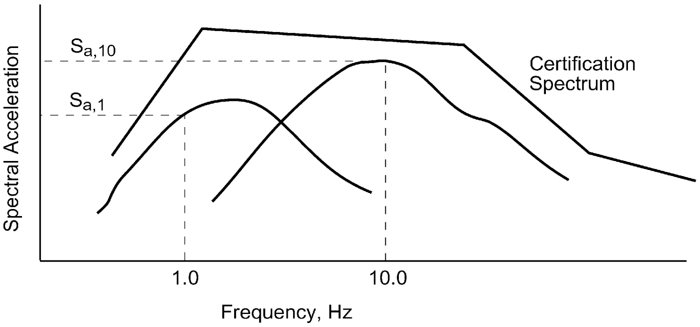

Figure F.1 Use of DE Spectrum of a Certified Design

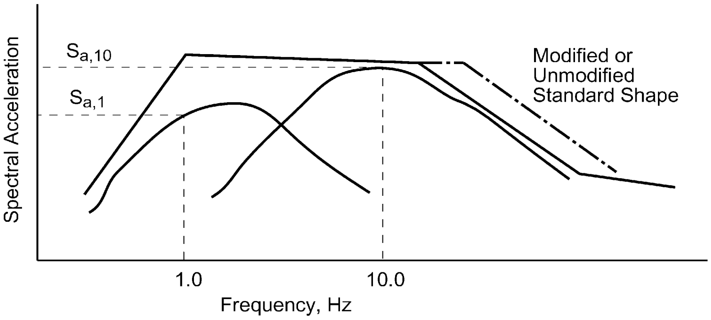

Figure F.2 Use of a Standard Shape for DE

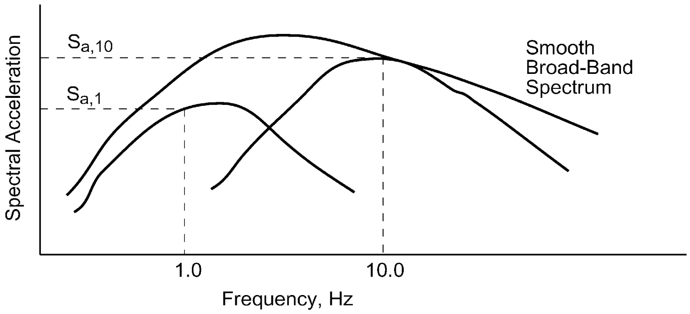

Figure F.3 Development of a Site-Specific DE Spectrum

(Note: The above figures illustrate situations for a rock site. For other site conditions, the DE spectra are compared at free-field after performing site amplification studies as discussed in Step 3 of Regulatory Position 4.)

REFERENCES

F.1 R.K. McGuire, W.J. Silva, and C.J. Constantino, “Technical Basis for Revision of Regulatory Guidance on Design Ground Motions: Hazard- and Risk-Consistent Ground Motion Sp[ectra Guidelines,” NUREG/CR-6728, 2001.[1]

F.2 U.S. NRC, “Design Response Spectra for Seismic Design of Nuclear Power Plants,” Regulatory Guide 1.60, Revision 1, December 1973.[2]

---

[1] Copies are available at current rates from the U.S. Government Printing Office, P.O. Box 37082, Washington, DC 20402-9328 (telephone (202)512-1800); or from the National Technical Information Service by writing NTIS at 5285 Port Royal Road, Springfield, VA 22161; (telephone (703)487-4650; <http://www.ntis.gov/ordernow>. Copies are available for inspection or copying for a fee from the NRC Public Document Room at 11555 Rockville Pike, Rockville, MD; the PDR’s mailing address is USNRC PDR, Washington, DC 20555; telephone (301)415-4737 or (800)397-4209; fax (301)415-3548; email is PDR@NRC.GOV.

[2] Requests for single copies of draft or active regulatory guides (which may be reproduced) or for placement on an automatic distribution list for single copies of future draft guides in specific divisions should be made in writing to the U.S. Nuclear Regulatory Commission, Washington, DC 20555, Attention: Reproduction and Distribution Services Section, or by fax to (301)415-2289; email <DISTRIBUTION@NRC.GOV>. Copies are available for inspection or copying for a fee from the NRC Public Document Room at 11555 Rockville Pike (first floor), Rockville, MD; the PDR’s mailing address is USNRC PDR, Washington, DC 20555; telephone (301)415-4737 or 1-(800)397-4209; fax (301)415-3548; e-mail <PDR@NRC.GOV>.

REGULATORY ANALYSIS

A separate regulatory analysis was not prepared for this draft regulatory guide. The regulatory analysis "Regulatory Analysis of Geological and Seismological Characteristics for and Design of Dry Cask Independent Spent Fuel Storage Installations (10 CFR Part 72)," was prepared for the amendments, and it provides the regulatory basis for this guide and examines the costs and benefits of the rule as implemented by the guide. A copy of the regulatory analysis is available for inspection and copying for a fee at the NRC Public Document Room, as Attachment 3 to SECY-02-0043. The PDR's mailing address is USNRC PDR, Washington, DC 20555; telephone (301)415-4737 or 1-(800)397-4209; fax (301)415-3548; e-mail <PDR@NRC.GOV>.