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DRAFT REGULATORY GUIDE DG-1032
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IDENTIFICATION AND CHARACTERIZATION OF SEISMIC SOURCES AND DETERMINATION OF SAFE SHUTDOWN EARTHQUAKE GROUND MOTION

A. INTRODUCTION

The NRC has recently proposed amendments to 10 CFR Part 100, "Reactor Site Criteria," in the Federal Register on October 17, 1994 (59 FR 52255). In the proposed Section 100.23, "Geologic and Seismic Siting Factors," paragraph (c), "Geological, Seismological, and Engineering Characteristics," 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, to provide sufficient information to support evaluations performed to arrive at estimates of the Safe Shutdown Earthquake Ground Motion (SSE), and to permit adequate engineering solutions to actual or potential geologic and seismic effects at the proposed site. Data on the vibratory ground motion, tectonic surface deformation, nontectonic deformation, earthquake recurrence rates, fault geometry and slip rates, site foundation material, and seismically induced floods, water waves, and other siting factors would be obtained by reviewing pertinent literature and carrying out field investigations.

In the proposed Section 100.23, paragraph (d), "Geologic and Seismic Siting Factors," would require that the geologic and seismic siting factors considered for design include a determination of the SSE for the site, the potential for surface tectonic and nontectonic deformations, the design bases for seismically induced floods and water waves, and other design conditions.

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 and does not represent an official NRC staff position.

Public comments are being solicited on the 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 Review and Directives Branch, DFIPS, Office of Administration, U.S. Nuclear Regulatory Commission, Washington, DC 20555. Copies of comments received may be examined at the NRC Public Document Room, 2120 L Street NW., Washington, DC. Comments will be most helpful if received by May 12, 1995.

Requests for single copies of draft guides (which may be reproduced) or for placement on an automatic distribution list for single copies of future guides in specific divisions should be made in writing to the U.S. Nuclear Regulatory Commission, Washington, DC 20555, Attention: Office of Administration, Distribution and Mail Services Section.

In the proposed Section 100.23, paragraph (d)(1), "Determination of the Safe Shutdown Earthquake Ground Motion," would require that uncertainty inherent in estimates of the SSE be addressed through an appropriate analysis, such as a probabilistic seismic hazard analysis or suitable sensitivity analysis.

This guide is being developed to provide general guidance on procedures acceptable to the NRC staff to (1) conduct geological, geophysical, seismological, and geotechnical investigations, (2) identify and characterize seismic sources, (3) conduct probabilistic seismic hazard analyses, and (4) determine the SSE for satisfying the requirements of the proposed Section 100.23.

This guide contains several appendices that address the objectives stated above. Appendix A contains a list of definitions of pertinent terms. Appendix B describes the procedure used to determine the reference probability for the SSE exceedance level. Appendix C discusses the development of a seismic hazard information base and the determination of the probabilistic ground motion level and controlling earthquakes. 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 SSE for a site. Appendix F describes procedures to determine the SSE.

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 Commission'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.

Any information collection activities mentioned in this regulatory guide are contained as requirements in the proposed amendments to 10 CFR Part 100 that would provide the regulatory basis for this guide. The proposed amendments have been submitted to the Office of Management and Budget for clearance that may be appropriate under the Paperwork Reduction Act. Such clearance, if obtained, would also apply to any information collection activities mentioned in this guide.

B. DISCUSSION

BACKGROUND

A probabilistic seismic hazard analysis (PSHA) has been identified in the proposed Section 100.23 as one of the means to address uncertainties in estimates of the SSE. The proposed rule further recognizes that the nature of uncertainty and the appropriate approach to account for it depend on the tectonic regime and parameters such as the knowledge of seismic sources, the existence of historical and recorded data, and the understanding of tectonics. Therefore, methods other than probabilistic methods such as sensitivity analyses may be adequate for some sites to account for uncertainties.

Appendix A, "Seismic and Geologic Siting Criteria for Nuclear Power Plants," to 10 CFR Part 100 is primarily based on a deterministic methodology. Past licensing experience in applying Appendix A has demonstrated the need to formulate procedures that quantitatively incorporate uncertainty in the evaluation of seismic hazards. A deterministic representation of seismic sources and ground motions at a site does not explicitly provide a quantitative representation of the uncertainties in scientific interpretations of geological, seismological, and geophysical data.

Probabilistic procedures were developed during the past 10-15 years specifically for nuclear power plant seismic hazard assessments in the Central and Eastern United States (CEUS) (the area east of the Rocky Mountains), also referred to as the Stable Continent Region (SCR). These procedures provide a structured approach for decisionmaking with respect to the SSE when performed together with site-specific investigations. A PSHA provides a framework to address the uncertainties associated with the identification and characterization of seismic sources by incorporating multiple interpretations of seismological parameters. Within the framework of a probabilistic analysis, uncertainties in the characterization of seismic sources and ground motions are identified and incorporated in the procedure at each step of the process for estimating the SSE. The role of site-specific regional and site geological, seismological, and geophysical investigations is to develop geosciences information about the site for use in the detailed design of the facility, as well as to ensure that the seismic hazard analysis is based on up-to-date information.

Experience in performing seismic hazard evaluations in active plate margin regions in the Western United States (for example, the San Gregorio-Hosgri fault zone and the Cascadia Subduction Zone) has also identified uncertainties associated with the characterization of seismic sources (Refs. 1, 2, and 3). Sources of uncertainty include fault geometry, rupture segmentation, rupture extent, seismic-activity rate, and earthquake occurrence modeling. As is the case for sites in the CEUS, alternative hypotheses and parameters must be considered to account for these uncertainties.

Uncertainties associated with the identification and characterization of seismic sources in tectonic environments in both the CEUS and the Western United States should be evaluated. Therefore, the same basic approach can be applied to determine the SSE.

APPROACH

The process to determine the SSE at a site should include:

1. Site- and region-specific geological, seismological, geophysical and geotechnical investigations, and
2. A probabilistic seismic hazard assessment.

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 105° West (Refs. 4 and 5). To determine the SSE 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. 4, 5, and 6) and the Electric Power Research Institute (EPRI) (Ref. 7) have been reviewed and accepted by 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 bear little or no correlation with current tectonic forces. Thus, there is greater uncertainty in making judgments about the CEUS than there is for active plate margin regions, and 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 (for example, 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 in that region, it may be more appropriate to evaluate those seismic sources by using procedures similar to those normally applicable in the Western United States.

WESTERN UNITED STATES

The Western United States is considered to be that part of the United States that lies west of the Rocky Mountain front, or west of approximately 105° West Longitude. For the Western United States, 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 does not exist. For this region, specific interpretations on a site-by-site basis should be applied (Ref. 1).

The active plate margin region includes coastal California, Oregon, and Washington. For the active plate margin region, where earthquakes can often be correlated with known tectonic structures, those structures should be assessed for their earthquake and surface deformation potential. In this region, at least three types of sources 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 strike, geometry, sense of displacements, length of rupture, Quaternary history, etc.

Buried (blind) faults are often accompanied by coseismic 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 core borings and geophysical techniques.

United States subduction zones are located in the Pacific Northwest and Alaska. Seismic sources associated with subduction zones are sources within the overriding plate, the interface between the subducting and overriding lithospheric plates, and intraslab sources in the interior of the downgoing oceanic slab. The characterization of subduction zone seismic sources includes consideration of the following: 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 Western United States, and to a lesser extent the Pacific Northwest and the Central United States, include 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 thousand 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 and regions around the site should be performed. These investigations are performed primarily to gather information needed to confirm the suitability of the site and to gather data pertinent to the safe design and construction of the nuclear power plant. Appropriate geological, seismological, and geophysical investigations are described in Appendix D to this draft guide. Geotechnical investigations are described in Regulatory Guide 1.132, "Site Investigations for Foundations of Nuclear Power Plants" (Ref. 8). Another important purpose for the site-specific investigations is to determine whether there are new data or interpretations that are not adequately incorporated in the existing PSHA databases. Appendix E describes a method to evaluate new information derived from the site-specific investigations in the context of the PSHA.

These investigations should be performed at four levels, with the degree of their 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 deformations, etc. The levels of investigation are:

1. Regional geological and seismological investigations such as geological reconnaissances and literature reviews should be conducted within a radius of 320 km (200 miles) of the site to identify seismic sources (seismogenic and capable tectonic sources).

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).

3. Detailed geological, 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 ground motion transmission characteristics of soils and rocks in the site vicinity. Investigations should include monitoring by a network of seismic stations.

4. Very detailed geological, geophysical, and geotechnical engineering investigations should be conducted within the site (radius of approximately 1 km) to assess specific soil and rock characteristics as described in Regulatory Guide 1.132 (Ref. 8).

1.2 The areas of investigations may be expanded beyond those specified above in regions that include capable tectonic sources, relatively high seismicity, or complex geology.

1.3 It should be demonstrated that deformation features discovered during construction, particularly faults, do not have the potential to compromise the safety of the plant. The two-step licensing practice of requiring applicants to acquire a Construction Permit (CP), and then during construction apply for an Operating License (OL), has been expanded to allow for an alternative procedure. The requirements and procedures applicable to NRC's issuance of combined licenses for nuclear power facilities are in 10 CFR 52.71. Applying the combined licensing procedure to a site could result in the award of a license prior to construction. During the construction of nuclear power plants licensed in the past two decades, previously unknown faults were often discovered in site excavations. Before an OL would be issued, it was necessary to demonstrate that the faults in the excavation posed no hazard to the facility. Under the combined license procedure, these kinds of features should be mapped and assessed as to their rupture and ground motion generating potential while the excavations' walls and bases are exposed. Therefore, a commitment should be made, in documents (Safety Analysis Reports) supporting the license application, to notify the NRC staff when excavations are open for inspection and to geologically map all excavations.

1.4 Sufficient data to clearly justify all conclusions should be presented. Because engineering solutions cannot always be 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.

1.5 For the site and the area surrounding the site, the 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 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 plant (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 A seismic source 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 documented. A general list of characteristics to be evaluated for a seismic source is presented in Appendix D.

2.2 As part of the seismic source characterization, the seismic potential (magnitude and recurrence rate) for each source should be determined.

2.2.1 For sites located in the CEUS, the seismic sources and data that have been accepted by the NRC staff in past licensing decisions may be used to estimate seismic potential. It is necessary to use a variety of approaches to estimate the maximum magnitude for a seismic source in the CEUS because there is uncertainty about the underlying causes of earthquakes because of lack of active surface faulting. Also, there is a short historical record and low seismicity rate. The determination of the maximum magnitude for each identified seismic source is based on the maximum historical earthquake, 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 the known tectonic structures in the source), and paleoseismic data. These seismic sources and their parameters should be used to judge the adequacy of seismic sources and parameters used in the LLNL or EPRI PSHA.

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

1. Surface rupture length versus magnitude (Refs. 9-12).

2. Subsurface rupture length versus magnitude (Ref. 13).

3. Rupture area versus magnitude (Ref. 14).

4. Maximum and average displacement versus magnitude (Ref. 13).

5. Slip rate versus magnitude (Ref. 15).

Fault hazard analyses in the Western United States using these and other methods should consider the frequency of occurrence and calculated slip rates on faults based on the geochronology of strata and crosscutting relationships.

Additionally, the phenomenon of temporal clustering should be considered when there is geological evidence of its past occurrence.

2.2.3 For sites 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 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 (PSHA) 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 a PSHA 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. The PSHA can be used to evaluate the sensitivity to the varying significant parameters and to identify the relative contribution of each seismic source to the hazard.

The following steps describe a PSHA procedure that is acceptable to the NRC staff. The details of the calculational aspects of the PSHA are included in Appendix C.

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

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 Step 1 or require updating. The PSHA should only be updated if it will lead to higher hazard estimates.

3. Perform the LLNL or EPRI probabilistic seismic hazard analysis (for CEUS sites only) using original or updated

sources as determined in Step 2 or a site-specific PSHA for sites in other parts of the country. The ground motion estimates should be made for rock conditions in the free-field or by assuming hypothetical rock conditions for a nonrock site to develop the seismic hazard information base discussed in Appendix C.

4. Using the reference probability (1E-5 per yr) described in Appendix B, which is applicable to all sites, determine 5% of critically damped median spectral ground motion levels for the average of 5 and 10 Hz, $S_{a,5-10}$, and for the average of 1 and 2.5 Hz, $S_{a,1-2.5}$. Appendix B discusses situations in which an alternative reference probability may be more appropriate. The alternative reference probability is reviewed and accepted on a case-by-case basis. Appendix B also describes a procedure that should be used when a general revision to the reference probability is needed.

5. Deaggregate the hazard in accordance with Appendix C to determine the controlling earthquakes (i.e., magnitudes and distances). Document the hazard information base as discussed in Appendix C.

4. PROCEDURES FOR DETERMINING THE SSE

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

1. With the controlling earthquakes determined as described in Regulatory Position 3 and by using the procedures in Draft Standard Review Plan (SRP) Section 2.5.2 (which may include the use of ground motion models not included in the probabilistic seismic hazard analysis but that are more appropriate for the source, region, and site under consideration or that represent the latest scientific

development), develop 5% of critical damping response spectral <u>shapes</u> for the actual or assumed rock conditions.

2. Use $S_{a,5\text{-}10}$ to scale the response spectrum shape corresponding to the controlling earthquake. If, as described in Appendix C, there is a controlling earthquake for $S_{a,1\text{-}2.5}$, determine that the $S_{a,5\text{-}10}$ scaled response spectrum also envelopes the ground motion spectrum for the controlling earthquake for $S_{a,1\text{-}2.5}$. Otherwise, modify the shape to envelope the low-frequency spectrum or use two spectra in the following steps. See additional discussion in Appendix F. For the rock site go to Step 4.

3. For the nonrock 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.

4. Compare the smooth SSE spectrum or spectra used in design (e.g., 0.3g, broad-band spectra used in Advanced Light Water Reactor designs) with the spectrum or spectra determined in Step 2 for rock sites or determined in Step 3 for the nonrock sites to assess the adequacy of the SSE spectrum or spectra.

   To obtain an adequate design SSE 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 Step 2 or Step 3.

   Additional discussion of this step is provided in Appendix F.

D. <u>IMPLEMENTATION</u>

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

This proposed revision has been released to encourage public participation in its development. Except in those cases in which the applicant proposes an acceptable alternative method for complying with the specified portions of the Commission's regulations, the method to be described in the active guide reflecting public comments will be used in the evaluation of applications for construction permits, operating licenses, early site permits, or combined licenses submitted after the implementation date to be specified in the active guide. This guide would not be used in the evaluation of an application for an operating license submitted after the implementation date to be specified in the active guide if the construction permit was issued prior to that date.

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[1]Copies are available for inspection or copying for a fee from the NRC Public Document Room at 2120 L Street NW., Washington, DC; the PDR's mailing address is Mail Stop LL-6, Washington, DC 20555; telephone (202)634-3273; fax (202)634-3343.

[2]Copies are available for inspection or copying for a fee from the NRC Public Document Room at 2120 L Street NW., Washington, DC; the PDR's mailing address is Mail Stop LL-6, Washington, DC 20555; telephone (202)634-3273; fax (202)634-3343. Copies may be purchased at current rates from the U.S. Government Printing Office, P.O. Box 37082, Washington, DC 20402-9328 (telephone (202)512-2249); or from the National Technical Information Service by writing NTIS at 5285 Port Royal Road, Springfield, VA 22161.

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APPENDIX A
DEFINITIONS

Controlling Earthquakes -- In the probabilistic seismic hazard analysis (PSHA), the controlling earthquakes are characterized as mean magnitudes and distances derived from a deaggregation analysis of the PSHA. The controlling earthquakes are the earthquakes used to estimate ground motions at the site. There may be several controlling earthquakes for a site.

Intensity -- The intensity of an earthquake is a measure of vibratory ground motion effects on humans, human-built structures, and on the earth's surface at a particular location. Intensity is described by a numerical value on the Modified Mercalli scale.

Magnitude -- An earthquake's magnitude is a measure of the strength of the earthquake as determined from seismographic observations.

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 terrane, glaciation or deglaciation, and growth faulting.

Safe Shutdown Earthquake Ground Motion (SSE) -- The Safe Shutdown Earthquake Ground Motion is the vibratory ground motion for which certain structures, systems, and components would be designed, pursuant to the proposed Appendix S to 10 CFR Part 50, to remain functional.

Seismic Source -- A "seismic source" is a general term referring to both seismogenic sources and capable tectonic sources.

> 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 large earthquakes or sustained earthquake activity that are usually accompanied by significant surface deformation.

c. A structural association with a capable tectonic source having characteristics of section a in this paragraph 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 particular 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, structural association of a structure with geological structural features that are geologically old (at least pre-Quaternary), such as many of those found in the Central and Eastern region of the United States will, in the absence of conflicting evidence, demonstrate that the structure is not a capable tectonic source within this definition.

Seismogenic Source -- A "seismogenic source" is a portion of the earth that has uniform earthquake potential (same expected maximum earthquake and frequency of recurrence) distinct from other 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 -- A "stable continental region" (SCR) 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.

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 kilometers (miles).

APPENDIX B

REFERENCE PROBABILITY FOR THE EXCEEDANCE LEVEL OF THE SAFE SHUTDOWN EARTHQUAKE GROUND MOTION

B.1 INTRODUCTION

This appendix describes the procedure used by the NRC staff to determine the reference probability, an annual probability of exceeding the Safe Shutdown Earthquake Ground Motion (SSE) at future nuclear power plant sites, that is acceptable to the NRC staff. The reference probability is used in Appendix C in conjunction with the probabilistic seismic hazard analysis (PSHA).

B.2 REFERENCE PROBABILITY FOR THE SSE

The reference probability is the annual probability level such that 50% of a set of currently operating plants (selected by the NRC, see Table B.1) has an annual median probability of exceeding the SSE below this level. The reference probability is determined for the annual probability of exceeding the average of the 5 and 10 Hz SSE response spectrum ordinates.

B.3 PROCEDURE TO DETERMINE THE REFERENCE PROBABILITY

The following procedure was used to determine the reference probability and should be used in the future if general revisions to PSHA methods or data bases result in significant changes in hazard predictions for the selected plant sites in Table B.1.

The reference probability is calculated using the Lawrence Livermore National Laboratory (LLNL) methodology and results (Refs. B.1 and B.2) but is also considered applicable for the Electric Power Research Institute (EPRI) study (Refs. B.3 and B.4). This reference probability is also to be used in conjunction with sites not in the Central and Eastern United States (CEUS) and for sites for which LLNL and EPRI methods and data have not been used or are not available.

The final SSE ground motion at a higher reference probability may be more appropriate and acceptable[1] considering the slope characteristics of the site hazard, the overall uncertainty in calculations (i.e., differences between mean and median hazard estimates), and the knowledge of the seismic sources that contribute to the hazard. Reference B.4 includes a procedure to determine an alternative reference probability on the risk-based considerations; its application will also be reviewed on a case-by-case basis.

B.3.1 Selection of Current Plants for Reference Probability Calculations

Table B.1 identifies plants, along with their site characteristics, used in calculating the reference probability. These plants represent relatively recent designs that used Regulatory Guide 1.60, "Design Response Spectra for Seismic Design of Nuclear Power Plants" (Ref. B.5), or similar spectra as their design bases. The use of these plants should ensure an adequate level of conservatism in determining an SSE consistent with recent licensing decisions.

B.3.2 Procedure To Establish Reference Probability

Step 1

Using an accepted methodology, calculate the seismic hazard results for the site for spectral responses at 5 and 10 Hz (as stated earlier, the staff used the LLNL methodology and associated results as documented in Refs. B.1 and B.2).

Step 2

Calculate the median composite annual probability of exceeding the SSE for spectral responses at 5 and 10 Hz using median hazard estimates. The composite annual probability is determined as:

$$\text{Composite probability} = 1/2(a1) + 1/2(a2)$$

---

[1] The use of a higher reference probability will be reviewed and accepted on a case-by-case basis.

where a1 and a2 represent median annual probabilities of exceeding SSE spectral ordinates at 5 and 10 Hz, respectively. The procedure is illustrated in Figure B-1.

Step 3

Figure B-2 illustrates the distribution of median probabilities of exceeding the SSEs for the plants in Table B.1 based on the LLNL methodology (Refs. B.1 and B.2). The reference probability is simply the median probability of this distribution.

For the LLNL methodology, this reference probability is 1E-5/yr and, as stated earlier, is also to be used in conjunction with the current EPRI methodology (Ref. B.3) or for sites not in the CEUS.

Table B.1 Plants/Sites Used in Determining Reference Probability

Plant/Site Name	Soil Condition Primary/Secondary*
Limerick	Rock
Shearon Harris	Sand - S1
Braidwood	Rock
River Bend	Deep Soil
Wolf Creek	Rock
Watts Bar	Rock
Vogtle	Deep Soil
Seabrook	Rock
Three Mile Is.	Rock/Sand - S1
Catawba	Rock/Sand - S1
Hope Creek	Deep Soil
McGuire	Rock
North Anna	Rock/Sand - S1
Summer	Rock/Sand - S1
Beaver Valley	Sand - S1
Byron	Rock
Clinton	Till - T3
Davis Besse	Rock
LaSalle	Till - T2
Perry	Rock
Bellefonte	Rock
Callaway	Rock/Sand - S1
Commanche Peak	Rock
Grand Gulf	Deep Soil
South Texas	Deep Soil
Waterford	Deep Soil
Millstone 3	Rock
Nine Mile Point	Rock/Sand - S1
Brunswick	Sand - S1

* If two soil conditions are listed, the first is the primary and the second is the secondary soil condition. See Ref. B.1 for a discussion of soil conditions.

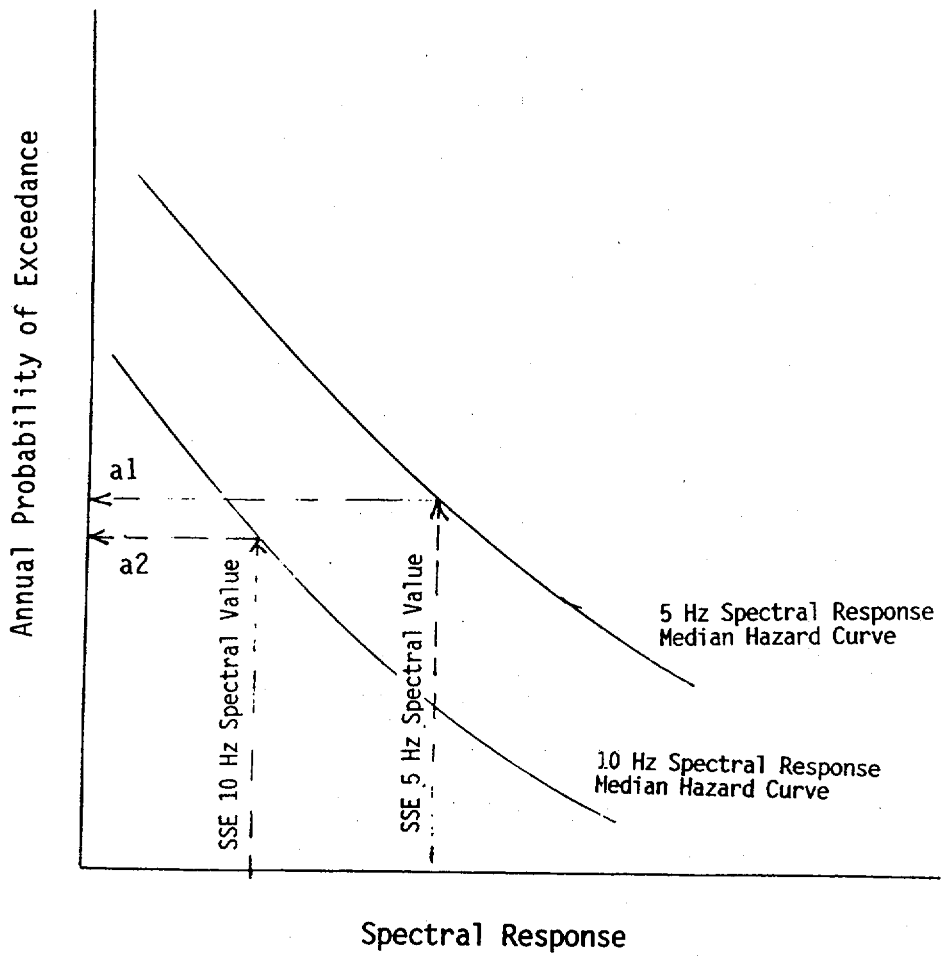
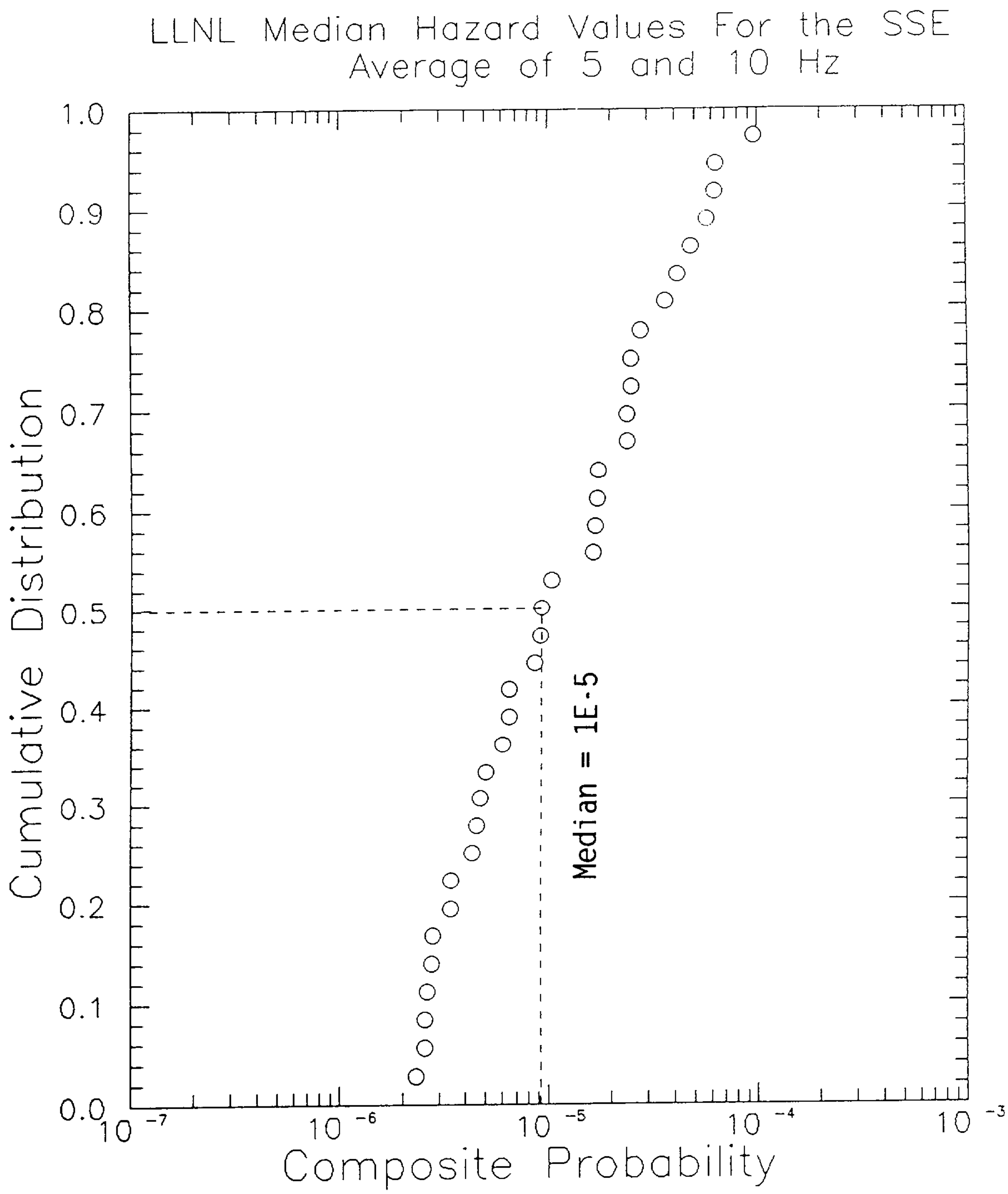


Figure B.1 Procedure to Compute Probability of Exceeding Design Basis

Comp. Prob. = 1/2(a1) + 1/2(a2)



Probability of Exceeding SSE

Figure B.2 Probability of Exceeding SSE using Median LLNL Hazard Estimates

REFERENCES

B.1 D.L. Bernreuter et al., "Seismic Hazard Characterization of 69 Nuclear Plant Sites East of the Rocky Mountains," NUREG/CR-5250, January 1989.[2]

B.2 P. Sobel, "Revised Livermore Seismic Hazard Estimates for Sixty-Nine Nuclear Power Plant Sites East of the Rocky Mountains," NUREG-1488, USNRC, April 1994.[2]

B.3 Electric Power Research Institute, "Probabilistic Seismic Hazard Evaluations at Nuclear Power Plant Sites in the Central and Eastern United States: Resolution of the Charleston Earthquake Issue," Report NP-6395-D, April 1989.

B.4 Attachment to Letter from D. J. Modeen, Nuclear Energy Institute, to A.J. Murphy, USNRC, Subject: Seismic Siting Decision Process, May 25, 1994.[3]

B.5 USNRC, "Design Response Spectra for Seismic Design of Nuclear Power Plants," Regulatory Guide 1.60.[2]

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[2] Copies are available for inspection or copying for a fee from the NRC Public Document Room at 2120 L Street NW., Washington, DC; the PDR's mailing address is Mail Stop LL-6, Washington, DC 20555; telephone (202)634-3273; fax (202)634-3343. Copies may be purchased at current rates from the U.S. Government Printing Office, P.O. Box 37082, Washington, DC 20402-9328 (telephone (202)512-2249); or from the National Technical Information Service by writing NTIS at 5285 Port Royal Road, Springfield, VA 22161.

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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 Draft Regulatory Guide DG-1032 to determine the controlling earthquakes used to define the Safe Shutdown Earthquake Ground Motion (SSE) 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 the average of 1 and 2.5 Hz and the average of and 5 and 10 Hz. They 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 SSE using the controlling earthquakes.

C.2 PROCEDURE TO DETERMINE CONTROLLING EARTHQUAKES

The following is an approach 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. Once the controlling earthquakes have been obtained, the SSE response spectrum can be determined according to the procedure described in Appendix F to this regulatory guide.

Step 1

(a) Perform a site-specific PSHA using the Lawrence Livermore National Laboratory (LLNL) or Electric Power Research Institute (EPRI) methodologies for Central and Eastern United States (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 available, for actual or assumed rock conditions. The hazard assessment should be performed for spectral accelerations at 1, 2.5, 5, 10, and 25 Hz, and the peak ground acceleration. A lower-bound magnitude of 5.0 is recommended. The PSHA should include an uncertainty assessment.

(b) Determine the following parameters as part of the assessment for each ground motion measure:

- Total hazard in terms of the median (50th percentile), mean, 85th, and 15th percentile hazard curves.
- De-aggregated median hazard results for a matrix of magnitude-distance pairs discussed in Step 3. As a part of the information base, de-aggregated results for mean hazard results may also be useful.

These results obtained from the de-aggregation of the median hazard are used to determine the SSE and to develop the seismic hazard information base.

<u>Step 2</u>

(a) Using the reference probability as defined in Appendix B to this regulatory guide, determine the ground motion levels for the spectral accelerations at 1, 2.5, 5, and 10 Hz from the total median hazard obtained in Step 1.

(b) Calculate the average ground motion level for the 1 and 2.5 Hz and the 5 and 10 Hz spectral acceleration pairs.

Steps 3 to 5 describe the procedure to develop the seismic hazard information base for each ground motion level determined in Step 2. This information base will consist of:

- Fractional contribution of each magnitude-distance pair to the total median seismic hazard.
- Magnitudes and distances of the controlling earthquakes.

- The ground motion levels for the spectral accelerations at 1, 2.5, 5, and 10 Hz defined in Step 2.

- The average of the ground motion levels listed above at the 1 and 2.5 Hz, $S_{a1-2.5}$, and 5 and 10 Hz, S_{a5-10}, spectral accelerations corresponding to the reference probability.

Step 3

Using the de-aggregated median hazard results from Step 1, at the ground motion levels obtained from Step 2 calculate the fractional contribution to the total median hazard of earthquakes in a selected set of magnitude and distance bins (Section C.3 provides magnitude and distance bins to be used in conjunction with the LLNL and EPRI methods) for the average of 1 and 2.5 Hz and 5 and 10 Hz. The median annual probability of exceeding the ground motion levels calculated in Step 1 for each magnitude and distance bin and ground motion measure is denoted by H_{mdf}.

The fractional contribution of each magnitude and distance bin to the total hazard for the average of 1 and 2.5 Hz, $P(m,d)_1$, is computed according to:

$$P(m,d)_1 = \frac{\dfrac{(\sum_{f=1,2} H_{mdf})}{2}}{\sum_m \sum_d \dfrac{(\sum_{f=1,2} H_{mdf})}{2}} \qquad (Equation\ 1)$$

where f = 1 and f = 2 represent the ground motion measure at 1 and 2.5 Hz, respectively.

The fractional contribution of each magnitude and distance bin to the total hazard for the average of 5 and 10 Hz, $P(m,d)_2$, is computed according to:

$$P(m,d)_2 = \frac{\dfrac{\left(\sum_{f=1,2} H_{mdf}\right)}{2}}{\sum_m \sum_d \dfrac{\left(\sum_{f=1,2} H_{mdf}\right)}{2}} \qquad \text{(Equation 2)}$$

where f = 1 and f = 2 represent the ground motion measure at 5 and 10 Hz, respectively.

Step 4

Review the magnitude-distance distribution for the average of 1 and 2.5 Hz to determine whether the contribution to the hazard for distances of 100 km or greater is substantial (on the order of 5% or greater).

If the contribution to the hazard for distances of 100 km or greater exceeds 5%, 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:

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

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 is chosen for CEUS sites. However, for CEUS sites and sites not in the CEUS the results of full magnitude-distance distribution should be carefully examined to ensure that proper controlling earthquakes are clearly identified.

Step 5

Calculate the mean magnitude and distance of the controlling earthquake associated with the ground motions determined in Step 2 for the average of 5 and 10 Hz. The following relation is used to calculate the mean magnitude using results of the entire magnitude-distance bins matrix:

$$M_c\ (5\text{-}10\ Hz) = \sum_m m \sum_d P(m,d)_2 \qquad (Equation\ 4)$$

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:

$$Ln\ \{D_c\ (5\text{-}10\ Hz)\} = \sum_d Ln(d) \sum_m P(m,d)_2 \qquad (Equation\ 5)$$

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

Step 6

If the contribution to the hazard calculated in Step 4 for distances of 100 km or greater exceeds 5% for the average of 1 and 2.5 Hz, calculate the mean magnitude and distance of the controlling earthquakes associated with the ground motions determined in Step 2 for the average of 1 and 2.5 Hz. The following relation is used to calculate the mean magnitude using calculations based on magnitude-distance bins greater than distances of 100 km as discussed in Step 4:

$$M_c\ (1\text{-}2.5\ Hz) = \sum_m m \sum_{d>100} P{>}100\,(m,d)_1 \qquad (Equation\ 6)$$

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 4 and determined according to:

$$Ln\ \{D_c\ (1\text{-}2.5\ Hz)\} = \sum_{d>100} Ln(d) \sum_{m} P{>}100(m,d)_2 \qquad (Equation\ 7)$$

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

Step 7

Determine the SSE 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 and 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 5 to 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 1

The 1993 LLNL seismic hazard methodology (Ref. C.1 and C.2) was used to determine the hazard at the site. A lower bound magnitude of 5.0 was used in this analysis. The analysis was performed for spectral acceleration at 1, 2.5, 5, and 10 Hz.

Step 2

The hazard curves at 1, 2.5, 5, and 10 Hz obtained in Step 1 are assessed at the reference probability value of 1E-5/yr, as defined in Appendix B to this regulatory guide. The corresponding ground motion level values are given in Table C.1.

Table C.1

Ground Motion Levels

Frequency (Hz)	1	2.5	5	10
Spectral Acc. (cm/s/s)	139	373	396	374

The average of the ground motion levels at the 1 and 2.5 Hz, $S_{a1-2.5}$, and 5 and 10 Hz, S_{a5-10}, are given in Table C.2.

Table C.2

Average Ground Motion Values

$S_{a1-2.5}$ (cm/s/s)	256
S_{a5-10} (cm/s/s)	385

<u>Step 3</u>

The seismic hazard is de-aggregated for the matrix of magnitude and distance bins as given in Table C.3.

Table C.3

Recommended Magnitude and Distance Bins

Distance Range of Bin (km)	Magnitude Range of Bin				
	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					

A complete probabilistic hazard analysis was performed for each bin to determine the contribution to the hazard from all earthquakes within the bin, e.g., all earthquakes with magnitudes 6 to 6.5 and distance 25 to 50 km from the site. Using de-aggregated median hazard results, the fractional contribution of each magnitude-distance pair to the total hazard is determined.

Tables C.4 and C.5 show $P(m,d)_1$ and $P(m,d)_2$ for the average of 1 and 2.5 Hz and 5 and 10 Hz, respectively.

Table C.4

$P(m,d)_1$ for Average Spectral Accelerations 1 and 2.5 Hz Corresponding to the Reference Probability

Distance Range of Bin (km)	Magnitude Range of Bin				
	5 - 5.5	5.5 - 6	6 - 6.5	6.5 - 7	>7
0-15	0.139	0.043	0.000	0.000	0.000
15-25	0.052	0.032	0.000	0.000	0.000
25-50	0.018	0.016	0.000	0.000	0.000
50-100	0.005	0.021	0.002	0.000	0.000
100-200	0.002	0.031	0.114	0.000	0.000
200-300	0.000	0.012	0.036	0.000	0.000
> 300	0.000	0.000	0.005	0.066	0.406

Table C.5

$P(m,d)_2$ for Average Spectral Accelerations 5 and 10 Hz Corresponding to the Reference Probability

Distance Range of Bin (km)	Magnitude Range of Bin				
	5 - 5.5	5.5 - 6	6 - 6.5	6.5 - 7	>7
0-15	0.417	0.097	0.000	0.000	0.000
15-25	0.220	0.079	0.000	0.000	0.000
25-50	0.080	0.042	0.000	0.000	0.000
50-100	0.004	0.014	0.001	0.000	0.000
100-200	0.000	0.008	0.031	0.000	0.000
200-300	0.000	0.001	0.004	0.000	0.000
> 300	0.000	0.000	0.000	0.000	0.002

Step 4

Because the contribution of the distance bins greater than 100 km in Table C.4 does account for more than 5% of the total hazard for the average of 1 and 2.5 Hz, the controlling earthquake for the spectral average of 1 and 2.5 Hz will be calculated using magnitude-distance bins for distance greater than 100 km. Table C.6 shows $P_{>100}$ (m,d)$_1$ for the average of 1-2.5 Hz.

Table C.6

$P_{>100}$ (m,d)$_1$ for Average Spectral Accelerations 1 and 2.5 Hz
Corresponding to the Reference Probability

Distance Range of Bin (km)	Magnitude Range of Bin				
	5 - 5.5	5.5 - 6	6 - 6.5	6.5 - 7	>7
100-200	0.003	0.046	0.170	0.000	0.000
200-300	0.000	0.018	0.054	0.000	0.000
> 300	0.000	0.000	0.007	0.098	0.604

Figures C.1 to C.3 show the above information in terms of the relative percentage contribution.

Steps 5 and 6

To compute the controlling magnitudes and distances at 1-2.5 Hz and 5-10 Hz for the example site, the values of $P_{>100}$ (m,d)$_1$ and P(m,d)$_2$ 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.7.

Table C.7

Magnitudes and Distances of Controlling Earthquakes from the LLNL Probabilistic Analysis

1-2.5 Hz	5 - 10 Hz
M_c and D_c > 100 km	M_c and D_c
6.9 and 286 km	5.4 and 18 km

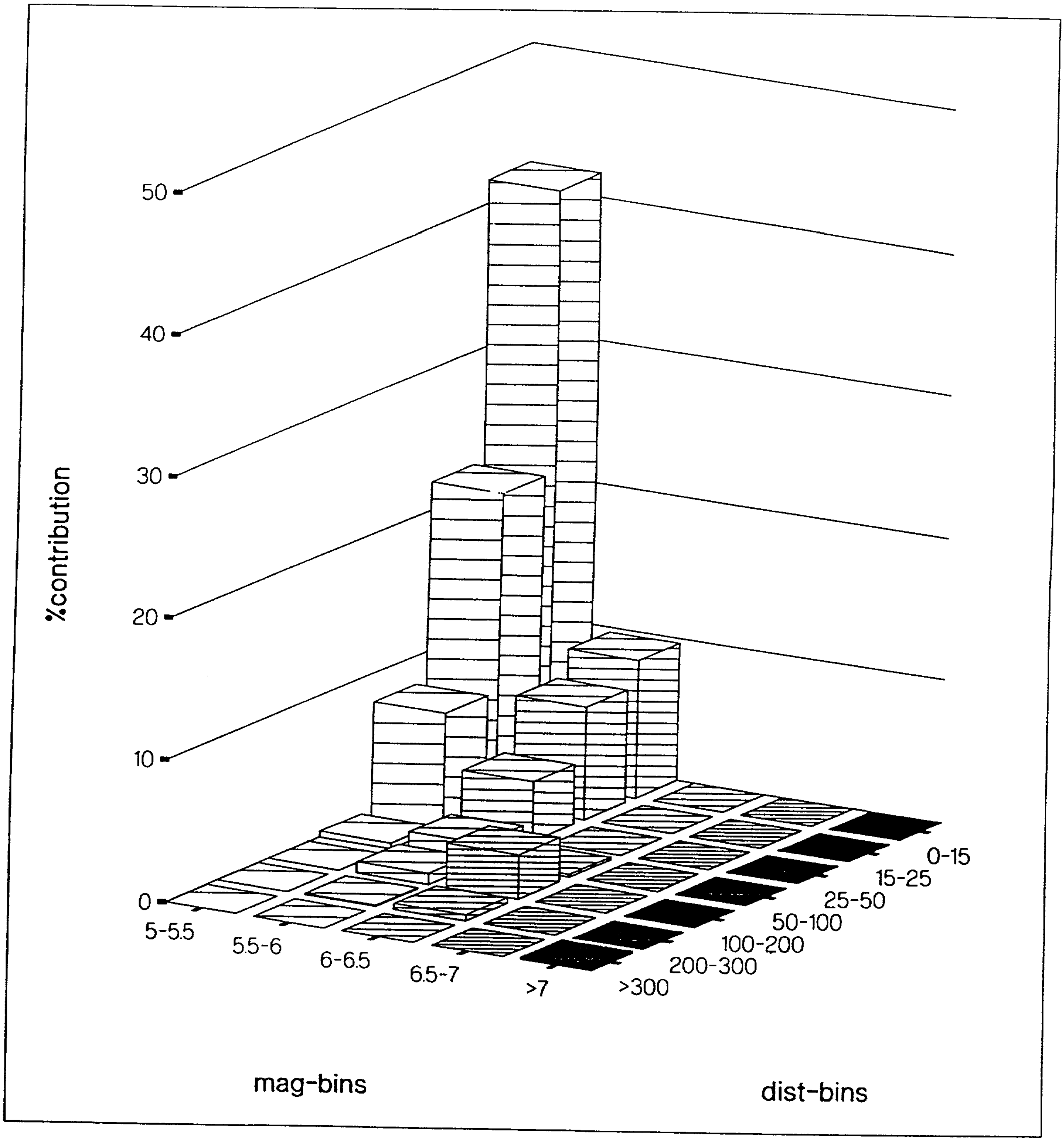
Step 7

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

C.4 SITES NOT IN THE CEUS

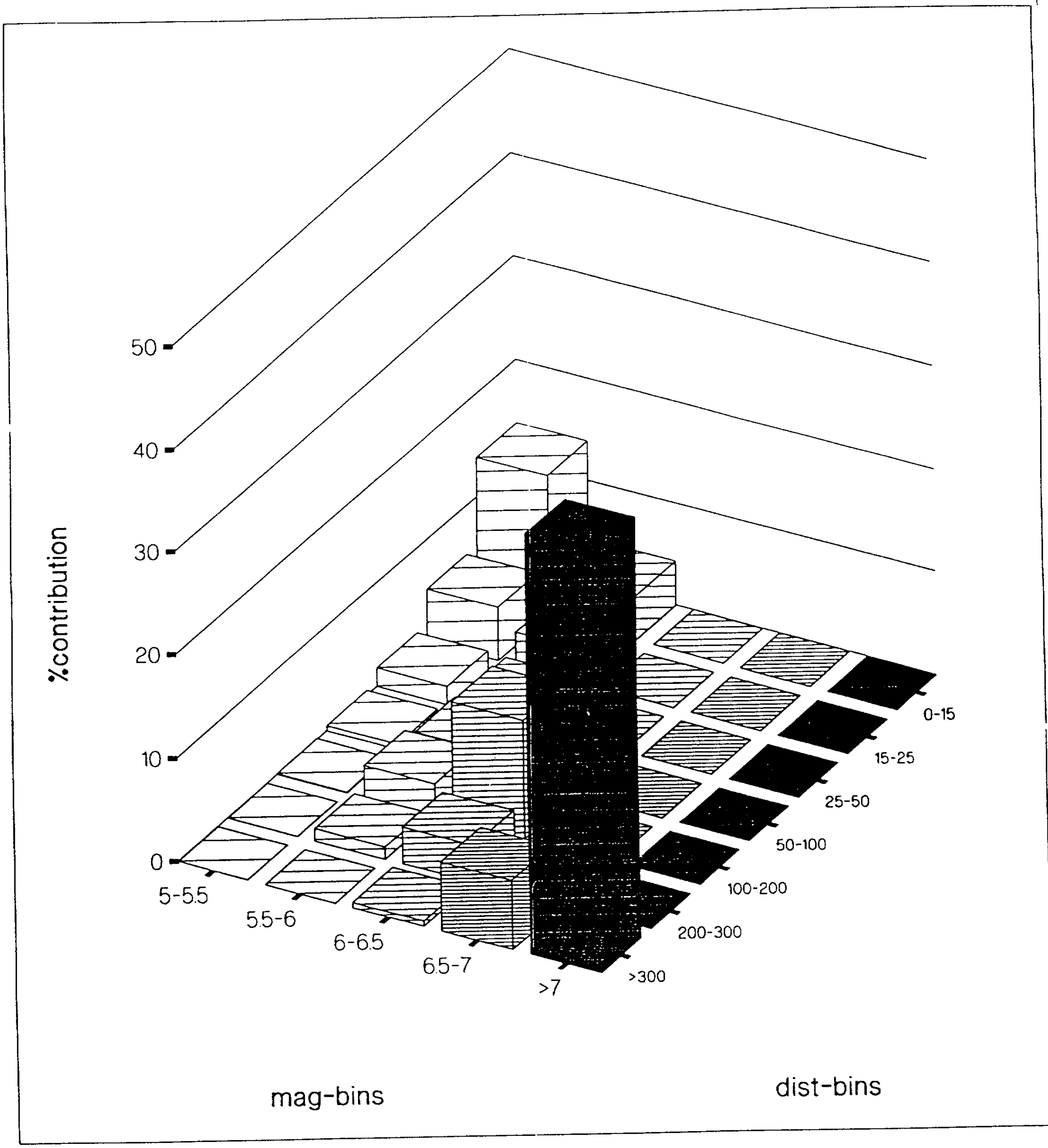
The determination of the controlling earthquakes and the seismic hazard information base for sites not in the CEUS is also carried out using the procedure described in Section C.2 of this appendix. However, because of differences in seismicity rates and ground motion attenuation at these sites, alternative magnitude-distance bins may have to be used. In addition, as discussed in Appendix B, 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.

median



1 Figure C.1 Full Distribution for Average of 5 and 10Hz

median



1 Figure C.2 Full Distribution for Average of 1 and 2.5Hz

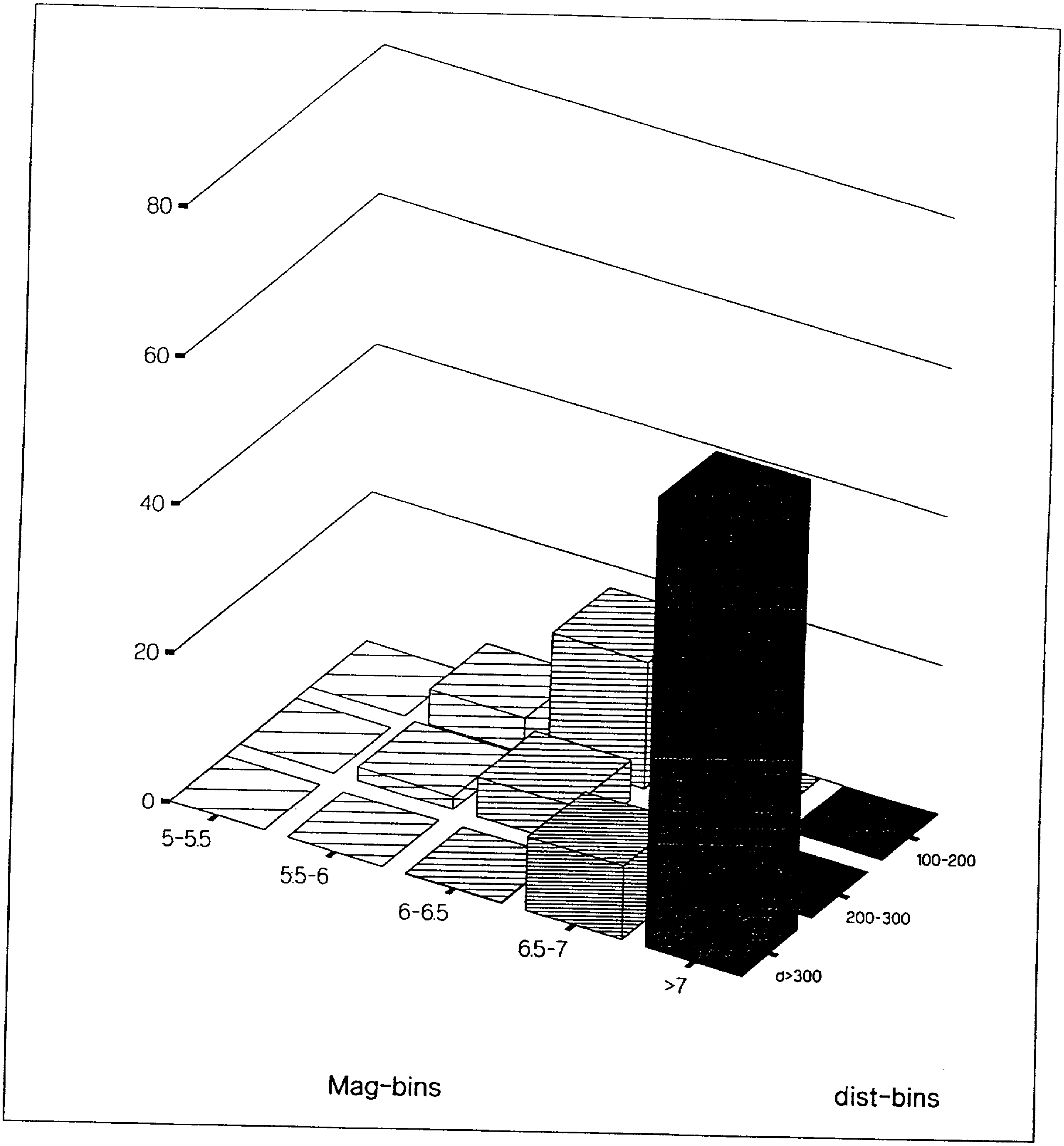


Figure C.3 Renormalized Hazard Distribution for Distances > 100km for average of 1 and 2.5Hz

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).

[1]Copies are available for inspection or copying for a fee from the NRC Public Document Room at 2120 L Street NW., Washington, DC; the PDR's mailing address is Mail Stop LL-6, Washington, DC 20555; telephone (202)634-3273; fax (202)634-3343. Copies may be purchased at current rates from the U.S. Government Printing Office, P.O. Box 37082, Washington, DC 20402-9328 (telephone (202)512-2249); or from the National Technical Information Service by writing NTIS at 5285 Port Royal Road, Springfield, VA 22161.

APPENDIX D

GEOLOGICAL, SEISMOLOGICAL, AND GEOPHYSICAL INVESTIGATIONS TO CHARACTERIZE SEISMIC SOURCES

D.1 INTRODUCTION

Seismic sources are areas within which future earthquakes are likely to occur at similar 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 Western United States (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 the focus will be on the identification of both capable tectonic sources and seismogenic sources. In the CEUS, identifying seismic sources is less certain because of the difficulty in correlating earthquake activity with known tectonic structures and the lack of adequate knowledge about earthquake causes.

In the CEUS, several significant tectonic structures exist and some of these have been interpreted as potential seismogenic sources (e.g., New Madrid fault zone, Nemaha Ridge, and Meers fault). There is no single recommended procedure to follow to characterize maximum magnitude associated with such candidate seismogenic sources; therefore, it is most likely that the determination of the properties of the seismic source 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, thus a structure's extent may not be a very meaningful indicator of the size of future earthquakes associated with the source. 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, development of new seismic sources 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 Western United States, site-specific seismic sources are 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 is a general list of characteristics to be determined for a seismic source for site-specific source interpretations:

- Source zone geometry (location and extent, both surface and subsurface).

- Description of Quaternary (last 2 million years) displacements (sense of slip on the fault, fault length and width, area of the fault plane, age of displacements, estimated displacement per event, estimated magnitude per offset, and displacement history or uplift rates of seismogenic folds).

- Historical and instrumental seismicity associated with each source.

- Paleoseismicity.

- Relationship of the potential seismic source to other potential seismic sources in the region.

- Maximum magnitude earthquake that can be generated by the seismic source, based on the source's known characteristics, including seismicity.

- Recurrence model (Frequency of earthquake occurrence versus magnitude).
- Other factors that will be evaluated, depending on the geologic setting of a site, such as:
    - Effects of human activities such as withdrawal of fluid from or addition of fluid to the subsurface, extraction of minerals, or the construction of dams and reservoirs.
    - Volcanism. Volcanic hazard is not addressed in this regulatory guide. It will be considered on a case-by-case basis in regions where this hazard exists.
    - Other factors that can contribute to characterization of seismic sources such as strike and dip of tectonic structures, orientations of regional and tectonic stresses, fault segmentation (along both strike and downdip), etc.

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 early site review, 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 adequate 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, adequate engineering solutions cannot always be demonstrated 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.2).

In most of the CEUS, as determined from instrumentally determined earthquake hypocenters, tectonic structures at seismogenic depths often bear no 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 ground surface in the Western United States 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 not only conduct thorough investigations 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 to 8 km distance from the site). Whenever faults or other structures are encountered at a site (including sites in the CEUS) either in 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 divided into three levels, Regional, Site Vicinity, and Site Area. Regional investigations should extend to a distance of 320 km (200 mi) from the site, and data should be presented at a scale of 1:500,000 or smaller. The regional investigations should be planned to identify seismic sources and describe the Quaternary tectonic regime. The investigations 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). 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 SSE, are identified.

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 in the site vicinity 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 in the site area within a radius of 8 km (5 mi) from the site, and the resulting data should be presented at a scale of 1:5000 or smaller. The level of investigations in the site vicinity should delineate the geologic regime 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 site vicinity and site area investigations may be asymmetrical and may cover a larger area 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 square kilometer) 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 those that are characterized as Seismic Category I. In addition to geological, geophysical, and seismological investigations, considerable geotechnical engineering investigations as described in Regulatory Guide 1.132 (Ref. D.3) should be conducted at the site.

The investigations needed to assess the integrity 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. The evaluation should 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 can be planned based on reviews of available documents and the results of previous investigations. Possible sources of information may include universities, consulting firms, and government agencies. A detailed list of possible sources of information is given in Regulatory Guide 1.132 (Ref. D.3).

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 needed to assess the neotectonic regime and the geology of the area around the site is dependent on the site location and may be carried out with the use of any appropriate combination of the following geological, geophysical, seismological, and geotechnical engineering techniques, but not all will be carried out at a given site.

D.2.3.1.1. Geological interpretations of aerial photographs and other remote-sensing imagery, 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 of topographic, geologic, geomorphic, and hydrologic features at scales and contour intervals suitable for analysis, stratigraphy (particularly Quaternary), surface tectonic structures such as fault zones, and Quaternary geomorphic features. For offshore sites, 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 for evaluation.

D.2.3.1.3. Identification and evaluation of vertical crustal movements by (1) geodetic land surveying to identify and measure short-term crustal movements (Refs. D.4 and D.5) 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 (Ref. D.6).

D.2.3.1.4. Analysis of offset, displaced, or anomalous landforms such as displaced stream channels or changes in stream profiles or the upstream migration of nickpoints (Refs. D.7 - D.12); abrupt changes in fluvial deposits or terraces; changes in paleochannels across a fault (Refs. D.11 and D.12); or uplifted, downdropped, or laterally displaced marine terraces (Ref. D.12).

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

D.2.3.1.6. Identification and analysis 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 (Refs. D.13 and D.14).

D.2.3.1.7. Estimation of the ages of fault displacements by analysis of the morphology of topographic fault scarps associated with or produced by surface rupture. Fault scarp morphology is useful in estimating age of last displacement, approximate size of the earthquake, recurrence intervals, slip rate, and the nature of the causative fault at depth (Refs. D.15 - D.18).

D.2.3.2 Seismological Investigations

D.2.3.2.1. Listing of all historically reported earthquakes having Modified Mercalli Intensity (MMI) greater than or equal to IV or magnitude greater than or equal to 3.0 that can reasonably be associated with seismic sources, any part of which is within a radius of 320 km (200 miles) of the site (the site region). The earthquake descriptions should include the date of occurrence and measured or estimated data on the highest intensity, magnitude, epicenter, depth, focal mechanism, and stress drop. Historical seismicity includes both historically reported and instrumentally recorded data. For pre-instrumentally recorded data, intensity should be converted to magnitude, the procedure used to convert it to magnitude should be clearly documented, and epicenters should be determined based on intensity distributions. Methods to convert intensity values to magnitudes in the CEUS are described in References D.1, D.19, D.20, and D.21.

D.2.3.2.2. Seismic monitoring in the site area should be established as soon as possible after site selection. For sites in the CEUS, a single large dynamic range, broad-band seismograph may be adequate. For sites in the Western United States, a network of at least five such seismographs would be deployed within 25 km (15 mi) surrounding the site.

The primary purposes of seismic monitoring are to obtain data from distant earthquakes, to determine site response, and provide assurance that there are no significant sources of earthquakes within the site vicinity. For sites in the Western United States seismic monitoring could help locate any ongoing seismicity that may indicate capable faulting within the site vicinity.

Monitoring should be initiated up to five years prior to construction of a nuclear unit at a site and should continue for at least five years following initiation of plant operation.

D.2.3.3 Subsurface Investigations

Subsurface investigations in the site area and within the site vicinity to identify and define seismogenic sources and capable tectonic sources may include the following investigations.

D.2.3.3.1. Geophysical investigations such as air or ground magnetic and gravity surveys, seismic reflection and seismic refraction surveys, borehole geophysics, and ground-penetrating radar.

D.2.3.3.2. Core borings to map subsurface geology and obtain samples for testing such as examining the properties of the subsurface soils and rocks and geochronological analysis.

D.2.3.3.3. Excavating and logging of trenches across geological features as part of the neotectonic investigation and to obtain samples for the geochronological analysis of those features.

At some sites, deep 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 (Refs. D.12 and D.22).

D.2.4 Geochronology

An important part of the geologic investigations to identify and define potential seismic sources is the geochronology of geologic materials. The NRC is currently supporting a research project to develop a data base on which to base a future regulatory guide on geochronological methods. This guide will contain an up-to-date bibliography of state-of-the-art documents on geochronology. The availability of this guide will be published in the *Federal Register*.

An acceptable classification of dating methods is based on the rationale described in Reference D.23. The following techniques, which are presented according to that classification, are useful in dating Quaternary deposits.

D.2.4.1 Sidereal Dating Methods

- Dendrochronology - tree-ring analysis - age range is from modern times to several thousand years (Refs. D.24 and D.25).
- Varve chronology - 0 to 10,000 years (Ref. D.26).

D.2.4.2 Isotopic Dating Methods

- Radiocarbon for dating organic materials - 100 to 40,000 (up to 100,000 years using AMS) (Refs. D.27 and D.28).
- Potassium argon for dating volcanic rocks ranging in age from about 100,000 to 10 million years (Refs. D.27 and D.29).
- Argon 39 - Argon 40, for dating relatively unweathered igneous and metamorphic rocks - 100,000 to unlimited upper limit (Ref. D.30)
- Uranium series uses the relative properties of various decay products of ^{238}U or ^{235}U. Ages range from 10,000 to 350,000 years (Ref. D.27). $^{235}U/^{238}U$ can yield between 40,000 and 1,000,000 years (Ref. D.31).
- Uranium Trend - for relatively undisturbed soils ranging in age from 100,000 to 900,000 years (Ref. D.32).

D.2.4.3 Cosmogenic Isotopes - for dating surficial rocks and soils. Nuclides ^{36}Cl, ^{10}Be, ^{21}Pb, and ^{26}Al - age range varies within the Quaternary according to isotope tested (Refs. D.33 and D.34).

D.2.4.4 Radiogenic Dating Methods

- Thermoluminescence (TL) - for dating fine-grained eolian and lacustrine, and possibly alluvium and colluvium as well - age range is from 1,000 to 1,000,000 years (Refs. D.27 and D.35).
- Electron spin resonance (ESR) is used for sediments, shells, carbonates, bones, and possibly to date quartz that formed in fault gouge during the fault event - age range is from 50,000 to 500,000 years (Ref. D.36).
- Fission Track - for dating minerals such as zircon and apatite, with fissionable uranium in volcanic rocks - 100 to several million years (Refs. D.27 and D.37).

D.2.4.5 Chemical and Biological Dating Methods

- Obsidian and Tephra Hydration - age range is from 200 to several million years (Ref. D.38).
- Amino Acid Racemization - for fossils, shells, and bones - age range is from 100 to 1,000,000 years (Refs. D.39 and D.40).
- Rock varnish chemistry - cation ratio of manganese, iron, and clay coatings on desert stones - age range is 1,000 to 40,000 years (Ref. D.41). The results of this method are controversial and its use is not recommended pending further validation.

D.2.4.6 Geomorphic Dating Methods

- Soil profile development - for analysis of the upper few meters of stable soils - age range is from 1,000 to 1,000,000 years (Refs. D.27, D.42 through D.47).
- Rock and mineral weathering - for measuring the progression of weathering, such as thicknesses of weathering rind development on the margins of clasts, hornblende etching, limestone solutioning, etc. - age range, depending on material - 10 to 1,000,000 (Ref. D.27).
- Geomorphic position - fluvial and marine terraces, and glacial moraines - 1,000 to 1,000,000 years (Ref. D.48).
- Rate of deposition - lacustrine, playa, and sometimes alluvial deposits - tens to millions of years (Ref. D.26)
- Scarp degradation - works best in coarse unconsolidated alluvium - age range is from 2,000 to 20,000 years (Refs. D.15 and D.49).

D.2.4.7 Correlation Dating Methods

- Lithostratigraphy - correlation of distinctive geologic units between sites - age range is from 0 to 4.5 billion years (Ref. D.50)
- Tephrochronology - volcanic ash layers interbedded with sedimentary deposits - age range is from zero to several million years (Refs. D.51 and D.38).

- Paleomagnetism - most igneous and sedimentary rocks containing hematite and magnetite - age range is from 0 to 5,000,000 years (Ref. D.27).
- Archeology - deposits associated with archeological materials (Ref. D.52).
- Paleontology (marine and terrestial) - fossil-bearing rocks or soils - age range is from 0 to 1 billion years (Ref. D.53).
- Lichenometry - used to estimate ages from sizes of lichens growing on gravel or boulders (such as glacial deposits) (Ref. D.54).

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 can normally be used effectively onshore. However, it is often useful to investigate similar features onshore to learn more about the significant offshore features.

D.2.5 Distinction Between Tectonic and Nontectonic Deformation

Nontectonic deformation, like tectonic deformation, at a site can pose a substantial hazard to nuclear power plants, but there are likely to be differences in the approaches used to resolve the issues raised by the two types of phenomena. Therefore, nontectonic 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 features include faults on which the last displacement was induced by glaciation or deglaciation; collapse structures, such as found in karst terrain; and growth faulting, such as occurs in the Gulf Coastal Plain or in other deep soil regions subject to 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 earthquakes, can often be identified and avoided in siting, and their displacements can be monitored. Some growth faults and antithetic faults related to growth faults are not easily identified; therefore, investigations described above with respect to capable 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.

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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 probabilistic seismic hazard analysis (PSHA).

Regulatory Position 4 in this guide describes acceptable PSHA analyses that were developed by Lawrence Livermore National Laboratories (LLNL) and the Electric Power Research Institute (EPRI) to estimate the controlling earthquakes and to develop the Safe Shutdown Earthquake ground motion (SSE). The procedure to determine the SSE outlined in this Draft Regulatory Guide DG-1032 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 significant differences between the investigation results and the PSHA data base are identified and these differences would result in a significant increase in the hazard estimate for a site, the PSHA may have to be modified to incorporate the new information.

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 effect 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. Future geophysical studies (aeromagnetic, gravity, and seismic reflection/refraction) will probably 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 historical earthquakes that were large and close to the proposed facility, a modification may be required.

Of particular concern is the possible existence of previously unknown, potentially active tectonic structures that could localize moderate-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.

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, for example, 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 would ensue than those predicted by the previous studies. The paleoseismic data could also be significant even if the maximum magnitudes of the previous studies are consistent with the paleoseismic 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 place 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 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 models may be used to determine the site-specific spectral shape as discussed in Regulatory Position 4 and Appendix F. 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 reevaluation of the reference probability may be needed using the procedure discussed in Appendix B. Otherwise, a periodic (e.g., every ten years) reexamination of PSHA and the associated data base is considered appropriate to incorporate new understanding regarding ground motion models.

E.3 PROCEDURE AND EVALUATION

The EPRI and LLNL studies provided 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 median seismic hazard.

An example is an additional nuclear unit sited 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 median 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.

Usually 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 PSHA's 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 5 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 nuclear power plant site in the stable continental region (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 Western United States 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 in accordance with the procedure described in Appendix B.

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, US NRC, March 1987.[2]

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[1]Copies are available for inspection or copying for a fee from the NRC Public Document Room at 2120 L Street NW., Washington, DC; the PDR's mailing address is Mail Stop LL-6, Washington, DC 20555; telephone (202)634-3273; fax (202)634-3343.

[2]Copies are available for inspection or copying for a fee from the NRC Public Document Room at 2120 L Street NW., Washington, DC; the PDR's mailing address is Mail Stop LL-6, Washington, DC 20555; telephone (202)634-3273; fax (202)634-3343. Copies may be purchased at current rates from the U.S. Government Printing Office, P.O. Box 37082, Washington, DC 20402-9328 (telephone (202)512-2249); or from the National Technical Information Service by writing NTIS at 5285 Port Royal Road, Springfield, VA 22161.

APPENDIX F

PROCEDURE TO DETERMINE THE SAFE SHUTDOWN EARTHQUAKE GROUND MOTION

F.1 INTRODUCTION

This appendix elaborates on Step 4 of Regulatory Position 4 of Draft Regulatory Guide DG-1032, which describes an acceptable procedure to determine the Safe Shutdown Earthquake Ground Motion (SSE). The SSE 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 SSE response spectrum is determined by scaling a spectral shape determined for the controlling earthquakes to the average ground motion levels for 5 and 10 Hz ($S_{a,5-10}$), and 1 and 2.5 Hz ($S_{a,1-2.5}$) determined in Step C.2 of Appendix C to this guide.

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 (e.g., 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 anchor it to a peak ground motion parameter (usually peak ground acceleration), which is derived based on the size of the controlling earthquake. During the licensing review this spectrum was checked against site-specific spectral estimates derived using Standard Review Plan 2.5.2 procedures to be sure that the SSE design spectrum adequately enveloped the site-specific spectrum. These past practices to define the SSE 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 design with an established SSE (for instance, an Advanced Light Water Reactor with 0.3g PGA SSE). In this example, the certified design SSE 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 SSE envelopes the site-specific spectra.

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

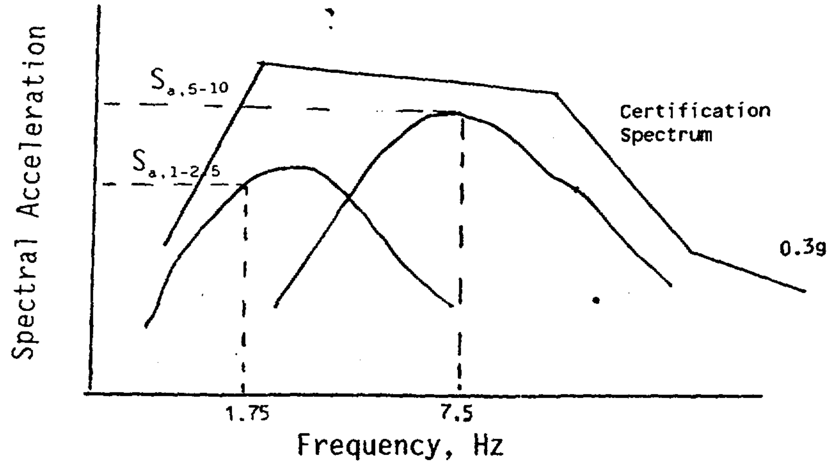

Figure F.1 Use of SSE Spectrum of a Certified Design

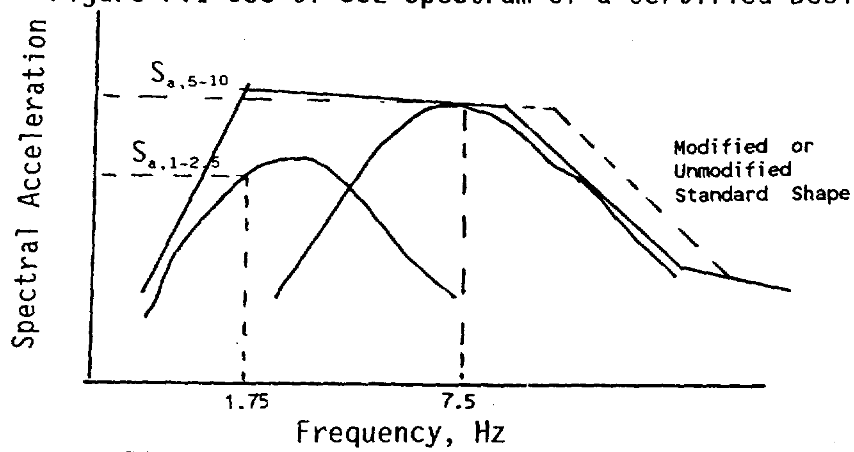

Figure F.2 Use of a Standard Shape for SSE

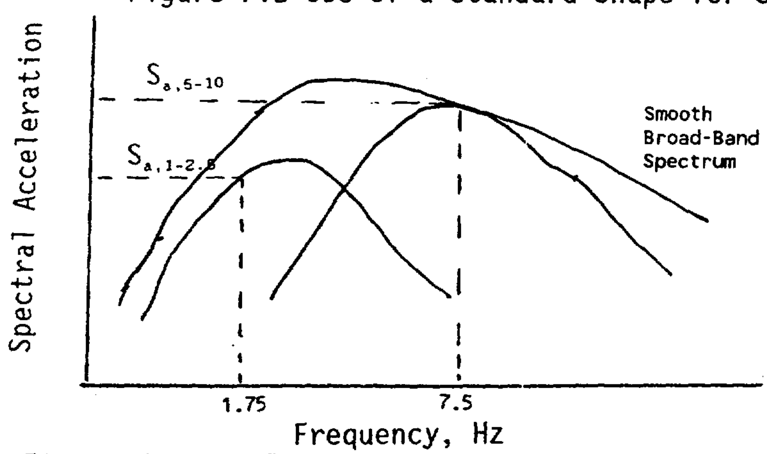

Figure F.3 Development of a Site-Specific SSE Spectrum

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

REFERENCES

F.1 Electric Power Research Institute, "Guidelines for Determining Design Basis Ground Motions," EPRI Report TR-102293, Volumes 1-4, May 1993.

F.2 USNRC, "Design Response Spectra for Seismic Design of Nuclear Power Plants," Regulatory Guide 1.60.[1]

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[1]Copies are available for inspection or copying for a fee from the NRC Public Document Room at 2120 L Street NW., Washington, DC; the PDR's mailing address is Mail Stop LL-6, Washington, DC 20555; telephone (202)634-3273; fax (202)634-3343. Copies may be purchased at current rates from the U.S. Government Printing Office, P.O. Box 37082, Washington, DC 20402-9328 (telephone (202)512-2249); or from the National Technical Information Service by writing NTIS at 5285 Port Royal Road, Springfield, VA 22161.

REGULATORY ANALYSIS

A separate regulatory analysis was not prepared for this regulatory guide. The draft regulatory analysis, "Proposed Revision of 10 CFR Part 100 and 10 CFR Part 50," was prepared for the proposed 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 draft regulatory analysis is available for inspection and copying for a fee at the NRC Public Document Room, 2120 L Street NW. (Lower Level), Washington, DC, as Enclosure 2 to Secy 94-194.

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