

# **Appendix A to Part 100 -- Seismic and Geologic Siting Criteria for Nuclear Power Plants**

## **I. Purpose**

General Design Criterion 2 of Appendix A to part 50 of this chapter requires that nuclear power plant structures, systems, and components important to safety be designed to withstand the effects of natural phenomena such as earthquakes, tornadoes, hurricanes, floods, tsunamis, and seiches without loss of capability to perform their safety functions. It is the purpose of these criteria to set forth the principal seismic and geologic considerations which guide the Commission in its evaluation of the suitability of proposed sites for nuclear power plants and the suitability of the plant design bases established in consideration of the seismic and geologic characteristics of the proposed sites.

These criteria are based on the limited geophysical and geological information available to date concerning faults and earthquake occurrence and effect. They will be revised as necessary when more complete information becomes available.

## **II. Scope**

These criteria, which apply to nuclear power plants, describe the nature of the investigations required to obtain the geologic and seismic data necessary to determine site suitability and provide reasonable assurance that a nuclear power plant can be constructed and operated at a proposed site without undue risk to the health and safety of the public. They describe procedures for determining the quantitative vibratory ground motion design basis at a site due to earthquakes and describe information needed to determine whether and to what extent a nuclear power plant need be designed to withstand the effects of surface faulting. Other geologic and seismic factors required to be taken into account in the siting and design of nuclear power plants are identified.

The investigations described in this appendix are within the scope of investigations permitted by §50.10(c)(1) of this chapter.

Each applicant for a construction permit shall investigate all seismic and geologic factors that may affect the design and operation of the proposed nuclear power plant irrespective of whether such factors are explicitly included in these criteria. Additional investigations and/or more conservative determinations than those included in these criteria may be required for sites located in areas having complex geology or in areas of high seismicity. If an applicant believes that the particular seismology and geology of a site indicate that some of these criteria, or portions thereof, need not be satisfied, the specific sections of these criteria should be identified in the license application, and supporting data to justify clearly such departures should be presented.

These criteria do not address investigations of volcanic phenomena required for sites located in areas of volcanic activity. Investigations of the volcanic aspects of such sites will be determined on a case-by-case basis.

### III. Definitions

As used in these criteria:

(a) The *magnitude* of an earthquake is a measure of the size of an earthquake and is related to the energy released in the form of seismic waves. *Magnitude* means the numerical value on a Richter scale.

(b) The *intensity* of an earthquake is a measure of its effects on man, on man-built structures, and on the earth's surface at a particular location. Intensity means the numerical value on the Modified Mercalli scale.

(c) The *Safe Shutdown Earthquake*<sup>(1)</sup> is that earthquake which is based upon an evaluation of the maximum earthquake potential considering the regional and local geology and seismology and specific characteristics of local subsurface material. It is that earthquake which produces the maximum vibratory ground motion for which certain structures, systems, and components are designed to remain functional. These structures, systems, and components are those necessary to assure:

(1) The integrity of the reactor coolant pressure boundary,

(2) The capability to shut down the reactor and maintain it in a safe shutdown condition,  
or

(3) The capability to prevent or mitigate the consequences of accidents which could result in potential offsite exposures comparable to the guideline exposures of this part.

(d) The *Operating Basis Earthquake* is that earthquake which, considering the regional and local geology and seismology and specific characteristics of local subsurface material, could reasonably be expected to affect the plant site during the operating life of the plant; it is that earthquake which produces the vibratory ground motion for which those features of the nuclear power plant necessary for continued operation without undue risk to the health and safety of the public are designed to remain functional.

(e) A *fault* is a tectonic structure along which differential slippage of the adjacent earth materials has occurred parallel to the fracture plane. It is distinct from other types of ground disruptions such as landslides, fissures, and craters. A fault may have gouge or breccia between its two walls and includes any associated monoclinial flexure or other similar geologic structural feature.

(f) *Surface faulting* is differential ground displacement at or near the surface caused directly by fault movement and is distinct from nontectonic types of ground disruptions, such as landslides, fissures, and craters.

(g) A *capable fault* is a fault which has exhibited one or more of the following characteristics:

- (1) Movement at or near the ground surface at least once within the past 35,000 years or movement of a recurring nature within the past 500,000 years.
- (2) Macro-seismicity instrumentally determined with records of sufficient precision to demonstrate a direct relationship with the fault.
- (3) A structural relationship to a capable fault according to characteristics (1) or (2) of this paragraph such that movement on one could be reasonably expected to be accompanied by movement on the other.

In some cases, the geologic evidence of past activity at or near the ground surface along a particular fault 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 fault from which an evaluation of its characteristics in the vicinity of the site can be reasonably based. Such evidence shall be used in determining whether the fault is a capable fault within this definition.

Notwithstanding the foregoing paragraphs III(g) (1), (2) and (3), structural association of a fault with geologic structural features which are geologically old (at least pre-Quaternary) such as many of those found in the Eastern region of the United States shall, in the absence of conflicting evidence, demonstrate that the fault is not a capable fault within this definition.

(h) A *tectonic province* is a region of the North American continent characterized by a relative consistency of the geologic structural features contained therein.

(i) A *tectonic structure* is a large scale dislocation or distortion within the earth's crust. Its extent is measured in miles.

(j) A *zone requiring detailed faulting investigation* is a zone within which a nuclear power reactor may not be located unless a detailed investigation of the regional and local geologic and seismic characteristics of the site demonstrates that the need to design for surface faulting has been properly determined.

(k) The *control width* of a fault is the maximum width of the zone containing mapped fault traces, including all faults which can be reasonably inferred to have experienced differential movement during Quaternary times and which join or can reasonably be inferred to join the main fault trace, measured within 10 miles along the fault's trend in both directions from the point of nearest approach to the site. (See Figure 1 of this appendix.)

(l) A *response spectrum* is a plot of the maximum responses (acceleration, velocity or displacement) of a family of idealized single-degree-of-freedom damped oscillators against natural frequencies (or periods) of the oscillators to a specified vibratory motion input at their supports.

#### IV. Required Investigations

The geologic, seismic and engineering characteristics of a site and its environs shall be investigated in sufficient scope and detail to provide reasonable assurance that they are sufficiently well understood to permit an adequate evaluation of the proposed site, and to provide sufficient information to support the determinations required by these criteria and to permit adequate engineering solutions to actual or potential geologic and seismic effects at the proposed site. The size of the region to be investigated and the type of data pertinent to the investigations shall be determined by the nature of the region surrounding the proposed site. The investigations shall be carried out by a review of the pertinent literature and field investigations and shall include the steps outlined in paragraphs (a) through (c) of this section.

(a) *Required Investigation for Vibratory Ground Motion.* The purpose of the investigations required by this paragraph is to obtain information needed to describe the vibratory ground motion produced by the Safe Shutdown Earthquake. All of the steps in paragraphs (a)(5) through (a)(8) of this section need not be carried out if the Safe Shutdown Earthquake can be clearly established by investigations and determinations of a lesser scope. The investigations required by this paragraph provide an adequate basis for selection of an Operating Basis Earthquake. The investigations shall include the following:

- (1) Determination of the lithologic, stratigraphic, hydrologic, and structural geologic conditions of the site and the region surrounding the site, including its geologic history;
- (2) Identification and evaluation of tectonic structures underlying the site and the region surrounding the site, whether buried or expressed at the surface. The evaluation should consider the possible effects caused by man's activities such as withdrawal of fluid from or addition of fluid to the subsurface, extraction of minerals, or the loading effects of dams or reservoirs;
- (3) Evaluation of physical evidence concerning the behavior during prior earthquakes of the surficial geologic materials and the substrata underlying the site from the lithologic, stratigraphic, and structural geologic studies;
- (4) Determination of the static and dynamic engineering properties of the materials underlying the site. Included should be properties needed to determine the behavior of the underlying material during earthquakes and the characteristics of the underlying material in transmitting earthquake-induced motions to the foundations of the plant, such as seismic wave velocities, density, water content, porosity, and strength;
- (5) Listing of all historically reported earthquakes which have affected or which could reasonably be expected to have affected the site, including the date of occurrence and the following measured or estimated data: magnitude or highest intensity, and a plot of the epicenter or location of highest intensity. Where historically reported earthquakes could have caused a maximum ground acceleration of at least one-tenth the acceleration of gravity (0.1g) at the foundations of the proposed nuclear power plant structures, the acceleration or intensity and duration of ground shaking at these foundations shall also be

estimated. Since earthquakes have been reported in terms of various parameters such as magnitude, intensity at a given location, and effect on ground, structures, and people at a specific location, some of these data may have to be estimated by use of appropriate empirical relationships. The comparative characteristics of the material underlying the epicentral location or region of highest intensity and of the material underlying the site in transmitting earthquake vibratory motion shall be considered;

(6) Correlation of epicenters or locations of highest intensity of historically reported earthquakes, where possible, with tectonic structures any part of which is located within 200 miles of the site. Epicenters or locations of highest intensity which cannot be reasonably correlated with tectonic structures shall be identified with tectonic provinces any part of which is located within 200 miles of the site;

(7) For faults, any part of which is within 200 miles<sup>(2)</sup> of the site and which may be of significance in establishing the Safe Shutdown Earthquake, determination of whether these faults are to be considered as capable faults.<sup>(3), (4)</sup> This determination is required in order to permit appropriate consideration of the geologic history of such faults in establishing the Safe Shutdown Earthquake. For guidance in determining which faults may be of significance in determining the Safe Shutdown Earthquake, table 1 of this appendix presents the minimum length of fault to be considered versus distance from site. Capable faults of lesser length than those indicated in table 1 and faults which are not capable faults need not be considered in determining the Safe Shutdown Earthquake, except where unusual circumstances indicate such consideration is appropriate;

**Table 1**

<b>Distance from the site (miles):</b>	<b>Minimum length<sup>(1)</sup></b>
0 to 20	1
Greater than 20 to 50	5
Greater than 50 to 100	10
Greater than 100 to 150	20
Greater than 150 to 200	40

1. Minimum length of fault (miles) which shall be considered in establishing Safe Shutdown Earthquake.

(8) For capable faults, any part of which is within 200 miles<sup>(2)</sup> of the site and which may be of significance in establishing the Safe Shutdown Earthquake, determination of:

- (i) The length of the fault;
- (ii) The relationship of the fault to regional tectonic structures; and
- (iii) The nature, amount, and geologic history of displacements along the fault, including particularly the estimated amount of the maximum Quaternary displacement related to any one earthquake along the fault.

(b) *Required Investigation for Surface Faulting.* The purpose of the investigations required by this paragraph is to obtain information to determine whether and to what extent the nuclear power plant need be designed for surface faulting. If the design basis for surface faulting can be clearly established by investigations of a lesser scope, not all of the steps in paragraphs (b)(4) through (b)(7) of this section need be carried out. The investigations shall include the following:

- (1) Determination of the lithologic, stratigraphic, hydrologic, and structural geologic conditions of the site and the area surrounding the site, including its geologic history;
- (2) Evaluation of tectonic structures underlying the site, whether buried or expressed at the surface, with regard to their potential for causing surface displacement at or near the site. The evaluation shall consider the possible effects caused by man's activities such as withdrawal of fluid from or addition of fluid to the subsurface, extraction of minerals, or the loading effects of dams or reservoirs;
- (3) Determination of geologic evidence of fault offset at or near the ground surface at or near the site;
- (4) For faults greater than 1000 feet long, any part of which is within 5 miles<sup>(5)</sup> of the site, determination of whether these faults are to be considered as capable faults;<sup>(6) (7)</sup>
- (5) Listing of all historically reported earthquakes which can reasonably be associated with capable faults greater than 1000 feet long, any part of which is within 5 miles<sup>(5)</sup> of the site, including the date of occurrence and the following measured or estimated data: magnitude or highest intensity, and a plot of the epicenter or region of highest intensity;
- (6) Correlation of epicenters or locations of highest intensity of historically reported earthquakes with capable faults greater than 1000 feet long, any part of which is located within 5 miles<sup>(5)</sup> of the site;
- (7) For capable faults greater than 1000 feet long, any part of which is within 5 miles<sup>(5)</sup> of the site, determination of:
  - (i) The length of the fault;
  - (ii) The relationship of the fault to regional tectonic structures;
  - (iii) The nature, amount, and geologic history of displacements along the fault, including particularly the estimated amount of the maximum Quaternary displacement related to any one earthquake along the fault; and
  - (iv) The outer limits of the fault established by mapping Quaternary fault traces for 10 miles along its trend in both directions from the point of its nearest approach to the site.

(c) *Required Investigation for Seismically Induced Floods and Water Waves.*

(1) For coastal sites, the investigations shall include the determination of:

(i) Information regarding distantly and locally generated waves or tsunamis which have affected or could have affected the site. Available evidence regarding the runup and drawdown associated with historic tsunamis in the same coastal region as the site shall also be included;

(ii) Local features of coastal topography which might tend to modify tsunami runup or drawdown. Appropriate available evidence regarding historic local modifications in tsunami runup or drawdown at coastal locations having topography similar to that of the site shall also be obtained; and

(iii) Appropriate geologic and seismic evidence to provide information for establishing the design basis for seismically induced floods or water waves from a local offshore earthquake, from local offshore effects of an onshore earthquake, or from coastal subsidence. This evidence shall be determined, to the extent practical, by a procedure similar to that required in paragraphs (a) and (b) of this section. The probable slip characteristics of offshore faults shall also be considered as well as the potential for offshore slides in submarine material.

(2) For sites located near lakes and rivers, investigations similar to those required in paragraph (c)(1) of this section shall be carried out, as appropriate, to determine the potential for the nuclear power plant to be exposed to seismically induced floods and water waves as, for example, from the failure during an earthquake of an upstream dam or from slides of earth or debris into a nearby lake.

## V. Seismic and Geologic Design Bases

(a) *Determination of Design Basis for Vibratory Ground Motion.* The design of each nuclear power plant shall take into account the potential effects of vibratory ground motion caused by earthquakes. The design basis for the maximum vibratory ground motion and the expected vibratory ground motion should be determined through evaluation of the seismology, geology, and the seismic and geologic history of the site and the surrounding region. The most severe earthquakes associated with tectonic structures or tectonic provinces in the region surrounding the site should be identified, considering those historically reported earthquakes that can be associated with these structures or provinces and other relevant factors. If faults in the region surrounding the site are capable faults, the most severe earthquakes associated with these faults should be determined by also considering their geologic history. The vibratory ground motion at the site should be then determined by assuming that the epicenters or locations of highest intensity of the earthquakes are situated at the point on the tectonic structures or tectonic provinces nearest to the site. The earthquake which could cause the maximum vibratory ground motion at the site should be designated the Safe Shutdown Earthquake. The specific procedures for determining the design basis for vibratory ground motion are given in the following paragraphs.

(1) *Determination of Safe Shutdown Earthquake.* The Safe Shutdown Earthquake shall be identified through evaluation of seismic and geologic information developed pursuant to the requirements of paragraph IV(a), as follows:

(i) The historic earthquakes of greatest magnitude or intensity which have been correlated with tectonic structures pursuant to the requirements of paragraph (a)(6) of section IV shall be determined. In addition, for capable faults, the information required by paragraph (a)(8) of section IV shall also be taken into account in determining the earthquakes of greatest magnitude related to the faults. The magnitude or intensity of earthquakes based on geologic evidence may be larger than that of the maximum earthquakes historically recorded. The accelerations at the site shall be determined assuming that the epicenters of the earthquakes of greatest magnitude or the locations of highest intensity related to the tectonic structures are situated at the point on the structures closest to the site;

(ii) Where epicenters or locations of highest intensity of historically reported earthquakes cannot be reasonably related to tectonic structures but are identified pursuant to the requirements of paragraph (a)(6) of section IV with tectonic provinces in which the site is located, the accelerations at the site shall be determined assuming that these earthquakes occur at the site;

(iii) Where epicenters or locations of the highest intensity of historically reported earthquakes cannot be reasonably related to tectonic structures but are identified pursuant to the requirements of paragraph (a)(6) of section IV with tectonic provinces in which the site is not located, the accelerations at the site shall be determined assuming that the epicenters or locations of highest intensity of these earthquakes are at the closest point to the site on the boundary of the tectonic province;

(iv) The earthquake producing the maximum vibratory acceleration at the site, as determined from paragraph (a)(1)(i) through (iii) of this section shall be designated the Safe Shutdown Earthquake for vibratory ground motion, except as noted in paragraph (a)(1)(v) of this section. The characteristics of the Safe Shutdown Earthquake shall be derived from more than one earthquake determined from paragraph (a)(1)(i) through (iii) of this section, where necessary to assure that the maximum vibratory acceleration at the site throughout the frequency range of interest is included. In the case where a causative fault is near the site, the effect of proximity of an earthquake on the spectral characteristics of the Safe Shutdown Earthquake shall be taken into account. The procedures in paragraphs (a)(1)(i) through (a)(1)(iii) of this section shall be applied in a conservative manner. The determinations carried out in accordance with paragraphs (a)(1)(ii) and (a)(1)(iii) shall assure that the safe shutdown earthquake intensity is, as a minimum, equal to the maximum historic earthquake intensity experienced within the tectonic province in which the site is located. In the event that geological and seismological data warrant, the Safe Shutdown Earthquake shall be larger than that derived by use of the procedures set forth in section IV and V of the

appendix. The maximum vibratory accelerations of the Safe Shutdown Earthquake at each of the various foundation locations of the nuclear power plant structures at a given site shall be determined taking into account the characteristics of the underlying soil material in transmitting the earthquake-induced motions, obtained pursuant to paragraphs (a)(1), (3), and (4) of section IV. The Safe Shutdown Earthquake shall be defined by response spectra corresponding to the maximum vibratory accelerations as outlined in paragraph (a) of section VI; and

(v) Where the maximum vibratory accelerations of the Safe Shutdown Earthquake at the foundations of the nuclear power plant structures are determined to be less than one-tenth the acceleration of gravity (0.1 g) as a result of the steps required in paragraphs (a)(1)(i) through (iv) of this section, it shall be assumed that the maximum vibratory accelerations of the Safe Shutdown Earthquake at these foundations are at least 0.1 g.

(2) *Determination of Operating Basis Earthquake.* The Operating Basis Earthquake shall be specified by the applicant after considering the seismology and geology of the region surrounding the site. If vibratory ground motion exceeding that of the Operating Basis Earthquake occurs, shutdown of the nuclear power plant will be required. Prior to resuming operations, the licensee will be required to demonstrate to the Commission that no functional damage has occurred to those features necessary for continued operation without undue risk to the health and safety of the public.

The maximum vibratory ground acceleration of the Operating Basis Earthquake shall be at least one-half the maximum vibratory ground acceleration of the Safe Shutdown Earthquake.

(b) *Determination of Need to Design for Surface Faulting.* In order to determine whether a nuclear power plant is required to be designed to withstand the effects of surface faulting, the location of the nuclear power plant with respect to capable faults shall be considered. The area over which each of these faults has caused surface faulting in the past is identified by mapping its fault traces in the vicinity of the site. The fault traces are mapped along the trend of the fault for 10 miles in both directions from the point of its nearest approach to the nuclear power plant because, for example, traces may be obscured along portions of the fault. The maximum width of the mapped fault traces, called the control width, is then determined from this map. Because surface faulting has sometimes occurred beyond the limit of mapped fault traces or where fault traces have not been previously recognized, the control width of the fault is increased by a factor which is dependent upon the largest potential earthquake related to the fault. This larger width delineates a zone, called the zone requiring detailed faulting investigation, in which the possibility of surface faulting is to be determined. The following paragraphs outline the specific procedures for determining the zone requiring detailed faulting investigation for a capable fault.

(1) *Determination of Zone Requiring Detailed Faulting Investigation.* The zone requiring detailed faulting investigation for a capable fault which was investigated pursuant to the requirement of paragraph

<b>Magnitude of earthquake</b>	<b>Width of zone requiring detailed faulting investigation (see fig. 1)</b>
Less than 5.5	1 x control width.
5.5-6.4	2 x control width.
6.5-7.5	3 x control width.
Greater than 7.5	4 x control width.

The largest magnitude earthquake related to the fault shall be used in table 2. This earthquake shall be determined from the information developed pursuant to the requirements of paragraph (b) of Section IV for the fault, taking into account the information required by paragraph (b)(7) of section IV. The control width used in table 2 is determined by mapping the outer limits of the fault traces from information developed pursuant to paragraph (b)(7)(iv) of section IV. The control width shall be used in table 2 unless the characteristics of the fault are obscured for a significant portion of the 10 miles on either side of the point of nearest approach to the nuclear power plant. In this event, the use in table 2 of the width of mapped fault traces more than 10 miles from the point of nearest approach to the nuclear power plant may be appropriate.

The zone requiring detailed faulting investigation, as determined from table 2, shall be used for the fault except where:

- (i) The zone requiring detailed faulting investigation from table 2 is less than one-half mile in width. In this case the zone shall be at least one-half mile in width; or
- (ii) Definitive evidence concerning the regional and local characteristics of the fault justifies use of a different value. For example, thrust or bedding-plane faults may require an increase in width of the zone to account for the projected dip of the fault plane; or
- (iii) More detailed three-dimensional information, such as that obtained from precise investigative techniques, may justify the use of a narrower zone. Possible examples of such techniques are the use of accurate records from closely spaced drill holes or from closely spaced, high-resolution offshore geophysical surveys.

In delineating the zone requiring detailed faulting investigation for a fault, the center of the zone shall coincide with the center of the fault at the point of nearest approach of the fault to the nuclear power plant as illustrated in figure 1.

(c) *Determination of Design Bases for Seismically Induced Floods and Water Waves.* The size of seismically induced floods and water waves which could affect a site from either locally or distantly generated seismic activity shall be determined, taking into consideration the results of

the investigation required by paragraph (c) of section IV. Local topographic characteristics which might tend to modify the possible runup and drawdown at the site shall be considered. Adverse tide conditions shall also be taken into account in determining the effect of the floods and waves on the site. The characteristics of the earthquake to be used in evaluating the offshore effects of local earthquakes shall be determined by a procedure similar to that used to determine the characteristics of the Safe Shutdown Earthquake in paragraph V(a).

(d) *Determination of Other Design Conditions* –

(1) *Soil Stability.* Vibratory ground motion associated with the Safe Shutdown Earthquake can cause soil instability due to ground disruption such as fissuring, differential consolidation, liquefaction, and cratering which is not directly related to surface faulting. The following geologic features which could affect the foundations of the proposed nuclear power plant structures shall be evaluated, taking into account the information concerning the physical properties of materials underlying the site developed pursuant to paragraphs (a)(1), (3), and (4) of section IV and the effects of the Safe Shutdown Earthquake:

(i) Areas of actual or potential surface or subsurface subsidence, uplift, or collapse resulting from:

(a) Natural features such as tectonic depressions and cavernous or karst terrains, particularly those underlain by calcareous or other soluble deposits;

(b) Man's activities such as withdrawal of fluid from or addition of fluid to the subsurface, extraction of minerals, or the loading effects of dams or reservoirs; and

(c) Regional deformation.

(ii) Deformational zones such as shears, joints, fractures, folds, or combinations of these features.

(iii) Zones of alteration or irregular weathering profiles and zones of structural weakness composed of crushed or disturbed materials.

(iv) Unrelieved residual stresses in bedrock.

(v) Rocks or soils that might be unstable because of their mineralogy, lack of consolidation, water content, or potentially undesirable response to seismic or other events. Seismic response characteristics to be considered shall include liquefaction, thixotropy, differential consolidation, cratering, and fissuring.

(2) *Slope stability.* Stability of all slopes, both natural and artificial, the failure of which could adversely affect the nuclear power plant, shall be considered. An assessment shall

be made of the potential effects of erosion or deposition and of combinations of erosion or deposition with seismic activity, taking into account information concerning the physical property of the materials underlying the site developed pursuant to paragraph (a)(1), (3), and (4) of section IV and the effects of the Safe Shutdown Earthquake.

(3) *Cooling water supply.* Assurance of adequate cooling water supply for emergency and long-term shutdown decay heat removal shall be considered in the design of the nuclear power plant, taking in to account information concerning the physical properties of the materials underlying the site developed pursuant to paragraphs (a)(1), (3), and (4) of section IV and the effects of the Safe Shutdown Earthquake and the design basis for surface faulting. Consideration of river blockage or diversion or other failures which may block the flow of cooling water, coastal uplift or subsidence, or tsunami runup and drawdown, and failure of dams and intake structures shall be included in the evaluation, where appropriate.

(4) *Distant structures.* Those structures which are not located in the immediate vicinity of the site but which are safety related shall be designed to withstand the effect of the Safe Shutdown Earthquake and the design basis for surface faulting determined on a comparable basis to that of the nuclear power plant, taking into account the material underlying the structures and the different location with respect to that of the site.

## VI. Application to Engineering Design

### (a) *Vibratory ground motion* –

(1) *Safe Shutdown Earthquake.* The vibratory ground motion produced by the Safe Shutdown Earthquake shall be defined by response spectra corresponding to the maximum vibratory accelerations at the elevations of the foundations of the nuclear power plant structures determine pursuant to paragraph (a)(1) of section V. The response spectra shall relate the response of the foundations of the nuclear power plant structures to the vibratory ground motion, considering such foundations to be single-degree-of-freedom damped oscillators and neglecting soil-structure interaction effects. In view of the limited data available on vibratory ground motions of strong earthquakes, it usually will be appropriate that the response spectra be smoothed design spectra developed from a series of response spectra related to the vibratory motions caused by more than one earthquake.

The nuclear power plant shall be designed so that, if the Safe Shutdown Earthquake occurs, certain structures, systems, and components will remain functional. These structures, systems, and components are those necessary to assure (i) the integrity of the reactor coolant pressure boundary, (ii) the capability to shut down the reactor and maintain it in a safe condition, or (iii) the capability to prevent or mitigate the consequences of accidents which could result in potential offsite exposures comparable to the guideline exposures of this part. In addition to seismic loads, including aftershocks, applicable concurrent functional and accident-induced loads shall be taken into account in the design of these safety-related structures, systems, and components. The design of

the nuclear power plant shall also take into account the possible effects of the Safe Shutdown Earthquake on the facility foundations by ground disruption, such as fissuring, differential consolidation, cratering, liquefaction, and landsliding, as required in paragraph (d) of section V.

The engineering method used to insure that the required safety functions are maintained during and after the vibratory ground motion associated with the Safe Shutdown Earthquake shall involve the use of either a suitable dynamic analysis or a suitable qualification test to demonstrate that structures, systems and components can withstand the seismic and other concurrent loads, except where it can be demonstrated that the use of an equivalent static load method provides adequate conservatism.

The analysis or test shall take into account soil-structure interaction effects and the expected duration of vibratory motion. It is permissible to design for strain limits in excess of yield strain in some of these safety-related structures, systems, and components during the Safe Shutdown Earthquake and under the postulated concurrent conditions, provided that the necessary safety functions are maintained.

(2) *Operating Basis Earthquake.* The Operating Basis Earthquake shall be defined by response spectra. All structures, systems, and components of the nuclear power plant necessary for continued operation without undue risk to the health and safety of the public shall be designed to remain functional and within applicable stress and deformation limits when subjected to the effects of the vibratory motion of the Operating Basis Earthquake in combination with normal operating loads. The engineering method used to insure that these structures, systems, and components are capable of withstanding the effects of the Operating Basis Earthquake shall involve the use of either a suitable dynamic analysis or a suitable qualification test to demonstrate that the structures, systems and components can withstand the seismic and other concurrent loads, except where it can be demonstrated that the use of an equivalent static load method provides adequate conservatism. The analysis or test shall take into account soil-structure interaction effects and the expected duration of vibratory motion.

(3) *Required Seismic instrumentation.* Suitable instrumentation shall be provided so that the seismic response of nuclear power plant features important to safety can be determined promptly to permit comparison of such response with that used as the design basis. Such a comparison is needed to decide whether the plant can continue to be operated safely and to permit such timely action as may be appropriate.

These criteria do not address the need for instrumentation that would automatically shut down a nuclear power plant when an earthquake occurs which exceeds a predetermined intensity. The need for such instrumentation is under consideration.

(b) *Surface Faulting.*

(1) If the nuclear power plant is to be located within the zone requiring detailed faulting investigation, a detailed investigation of the regional and local geologic and seismic

characteristics of the site shall be carried out to determine the need to take into account surface faulting in the design of the nuclear power plant. Where it is determined that surface faulting need not be taken into account, sufficient data to clearly justify the determination shall be presented in the license application.

(2) Where it is determined that surface faulting must be taken into account, the applicant shall, in establishing the design basis for surface faulting on a site take into account evidence concerning the regional and local geologic and seismic characteristics of the site and from any other relevant data.

(3) The design basis for surface faulting shall be taken into account in the design of the nuclear power plant by providing reasonable assurance that in the event of such displacement during faulting certain structures, systems, and components will remain functional. These structures, systems, and components are those necessary to assure (i) the integrity of the reactor coolant pressure boundary, (ii) the capability to shut down the reactor and maintain it in a safe shutdown condition, or (iii) the capability to prevent or mitigate the consequences of accidents which could result in potential offsite exposures comparable to the guideline exposures of this part. In addition to seismic loads, including aftershocks, applicable concurrent functional and accident-induced loads shall be taken into account in the design of such safety features. The design provisions shall be based on an assumption that the design basis for surface faulting can occur in any direction and azimuth and under any part of the nuclear power plant unless evidence indicates this assumption is not appropriate, and shall take into account the estimated rate at which the surface faulting may occur.

(c) *Seismically Induced Floods and Water Waves and Other Design Conditions.* The design basis for seismically induced floods and water waves from either locally or distantly generated seismic activity and other design conditions determined pursuant to paragraphs (c) and (d) of section V, shall be taken into account in the design of the nuclear power plant so as to prevent undue risk to the health and safety of the public.

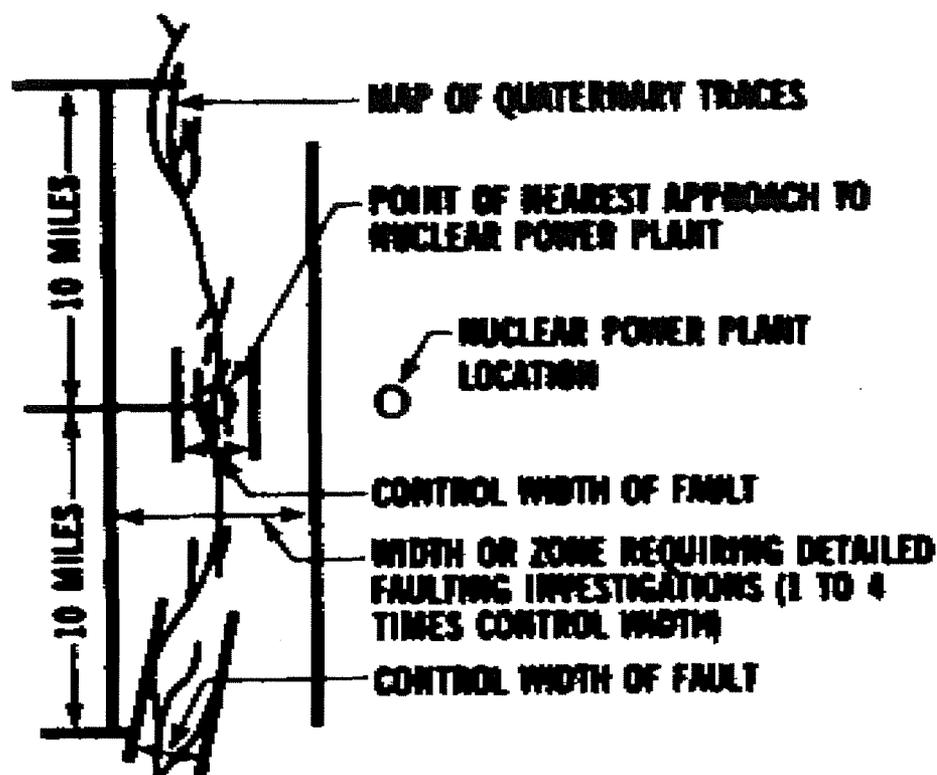


Figure 1 -- Diagrammatic Illustration of Delineation of Width of Zone Requiring Detailed Faulting Investigations For Specific Nuclear Power Plant Location.

(Sec. 201, Pub. L. 93 - 438, 88 Stat. 1243 (42 U.S.C. 5841))

[38 FR 31281, Nov. 13, 1973, as amended at 38 FR 32575, Nov. 27, 1973; 42 FR 2052, Jan. 10, 1977]

<sup>1</sup> The Safe Shutdown Earthquake defines that earthquake which has commonly been referred to as the Design Basis Earthquake.

<sup>2</sup> If the Safe Shutdown Earthquake can be associated with a fault closer than 200 miles to the site, the procedures of paragraphs (a)(7) and (a)(8) of this section need not be carried out for successively more remote faults.

<sup>3</sup> In the absence of absolute dating, evidence of recency of movement may be obtained by applying relative dating technique to ruptured, offset, warped or otherwise structurally disturbed surface or near surface materials or geomorphic features.

<sup>4</sup> The applicant shall evaluate whether or not a fault is a capable fault with respect to the characteristics outlined in paragraphs III(g)(1), (2), and (3) by conducting a reasonable investigation using suitable geologic and geophysical techniques.

<sup>5</sup> If the design basis for surface faulting can be determined from a fault closer than 5 miles to the site, the procedures of paragraphs (b)(4) through (b)(7) of this section need not be carried out for successively more remote faults.

<sup>6</sup> In the absence of absolute dating, evidence of recency of movement may be obtained by applying relative dating techniques to ruptured, offset, warped or otherwise structurally disturbed surface of near-surface materials or geomorphic features.

<sup>7</sup> The applicant shall evaluate whether or not a fault is a capable fault with respect to the characteristics outlined in paragraphs III(g)(1), (2), and (3) by conducting a reasonable investigation using suitable geological and geophysical techniques.



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

July 2002  
Division 3  
DG-3021

**DRAFT REGULATORY GUIDE**

Contact: M. Shah (301)415-8537

**DRAFT REGULATORY GUIDE DG-3021**

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

**A. INTRODUCTION**

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

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

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

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

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

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

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

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

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

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

## B. DISCUSSION

### BACKGROUND

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

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

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

### APPROACH

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

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

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

### CENTRAL AND EASTERN UNITED STATES

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

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

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

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

113 **WESTERN UNITED STATES**

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

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

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

134 Continental U.S. subduction zones are located in the Pacific Northwest and Alaska.  
135 Seismic sources associated with subduction zones are sources within the overriding plate, on the  
136 interface between the subducting and overriding lithospheric plates, and in the interior of the  
137 downgoing oceanic slab. The characterization of subduction zone seismic sources includes  
138 consideration of the three-dimensional geometry of the subducting plate, rupture segmentation of

139 subduction zones, geometry of historical ruptures, constraints on the up-dip and down-dip extent  
140 of rupture, and comparisons with other subduction zones worldwide.

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

## 148 C. REGULATORY POSITION

### 149 1. GEOLOGICAL, GEOPHYSICAL, SEISMOLOGICAL, AND GEOTECHNICAL 150 INVESTIGATIONS

151 **1.1** Comprehensive geological, seismological, geophysical, and geotechnical investigations of  
152 the site area and region should be performed. For ISFSIs co-located with existing nuclear power  
153 plants, the existing technical information should be used along with all other available information  
154 to plan and determine the scope of additional investigations. The investigations described in this  
155 regulatory guide are performed primarily to gather data pertinent to the safe design and  
156 construction of the ISFSI or MRS. Appropriate geological, seismological, and geophysical  
157 investigations are described in Appendix D to this guide. Geotechnical investigations are  
158 described in Regulatory Guide 1.132, "Site Investigations for Foundations of Nuclear Power  
159 Plants" (Ref. 11), and NUREG/CR-5738 (Ref. 12). Another important purpose for the site-  
160 specific investigations is to determine whether there are any new data or interpretations that are  
161 not adequately incorporated into the existing PSHA data bases. Appendix E describes a method  
162 for evaluating new information derived from the site-specific investigations in the context of the  
163 PSHA.

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

170 **1.1.1** Regional geological and seismological investigations are not expected to be extensive nor  
171 in great detail, but should include literature reviews, the study of maps and remote  
172 sensing data, and, if necessary, ground truth reconnaissances conducted within a radius  
173 of 320 km (200 miles) of the site to identify seismic sources (seismogenic and capable  
174 tectonic sources).

175 **1.1.2** Geological, seismological, and geophysical investigations should be carried out within a  
176 radius of 40 km (25 miles) in greater detail than the regional investigations to identify and  
177 characterize the seismic and surface deformation potential of any capable tectonic  
178 sources and the seismic potential of seismogenic sources, or to demonstrate that such  
179 structures are not present. Sites with capable tectonic or seismogenic sources within a  
180 radius of 40 km (25 miles) may require more extensive geological and seismological

181 investigations and analyses (similar in detail to investigations and analysis usually  
182 preferred within an 8-km (5-mile) radius).

183 **1.1.3** Detailed geologic, seismological, geophysical, and geotechnical investigations should be  
184 conducted within a radius of 8 km (5 miles) of the site, as appropriate, to evaluate the  
185 potential for tectonic deformation at or near the ground surface and to assess the  
186 transmission characteristics of soils and rocks in the site vicinity. Sites in the CEUS  
187 where geologically young or recent tectonic activity is not present may be investigated in  
188 less detail. Methods for evaluating the seismogenic potential of tectonic structures and  
189 geological features developed in Reference 13 should be followed.

190 **1.1.4** Very detailed geological, geophysical, and geotechnical engineering investigations should  
191 be conducted within the site [radius of approximately 1 km (0.5 miles)] to assess specific  
192 soil and rock characteristics as described in Reference 11, updated with NUREG/CR-  
193 5738 (Ref. 12).

194 **1.2** The areas of investigation may be expanded beyond those specified above in regions that  
195 include capable tectonic sources, relatively high seismicity, or complex geology, or in regions that  
196 have experienced a large, geologically recent earthquake.

197 **1.3** Data sufficient to clearly justify all assumptions and conclusions should be presented.  
198 Because engineering solutions cannot always be satisfactorily demonstrated for the effects of  
199 permanent ground displacement, it is prudent to avoid a site that has a potential for surface or  
200 near-surface deformation. Such sites normally will require extensive additional investigations.

201 **1.4** For the site and for the area surrounding the site, lithologic, stratigraphic, hydrologic, and  
202 structural geologic conditions should be characterized. The investigations should include the  
203 measurement of the static and dynamic engineering properties of the materials underlying the  
204 site and an evaluation of the physical evidence concerning the behavior during prior earthquakes  
205 of the surficial materials and the substrata underlying the site. The properties needed to assess  
206 the behavior of the underlying material during earthquakes, including the potential for  
207 liquefaction, and the characteristics of the underlying material in transmitting earthquake ground  
208 motions to the foundations of the facility (such as seismic wave velocities, density, water content,  
209 porosity, elastic moduli, and strength) should be measured.

## 210 **2. SEISMIC SOURCES SIGNIFICANT TO THE SITE SEISMIC HAZARD**

211 **2.1** For sites in the CEUS, when the EPRI or LLNL probabilistic seismic hazard analysis  
212 methodologies and data bases are used to determine the design earthquake, it still may be  
213 necessary to investigate and characterize potential seismic sources that were unknown or  
214 uncharacterized and to perform sensitivity analyses to assess their significance to the seismic  
215 hazard estimate. The results of the investigation discussed in Regulatory Position 1 should be  
216 used, in accordance with Appendix E, to determine whether the LLNL or EPRI seismic sources  
217 and their characterization should be updated. The guidance in Regulatory Positions 2.2 and 2.3  
218 below and in Appendix D of this guide may be used if additional seismic sources are to be  
219 developed as a result of investigations.

220 **2.2** When the LLNL or EPRI methods are not used or are not applicable, the guidance in  
221 Regulatory Position 2.3 should be used for identification and characterization of seismic sources.  
222 The uncertainties in the characterization of seismic sources should be addressed as appropriate.  
223 Seismic sources is a general term referring to both seismogenic sources and capable tectonic

224 sources. The main distinction between these two types of seismic sources is that a seismogenic  
225 source would not cause surface displacement, but a capable tectonic source causes surface or  
226 near-surface displacement.

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

233 **2.3** As part of the seismic source characterization, the seismic potential for each source  
234 should be evaluated. Typically, characterization of the seismic potential consists of four equally  
235 important elements:

- 236 1. Selection of a model for the spatial distribution of earthquakes in a source.
- 237 2. Selection of a model for the temporal distribution of earthquakes in a source.
- 238 3. Selection of a model for the relative frequency of earthquakes of various  
239 magnitudes, including an estimate for the largest earthquake that could occur in  
240 the source under the current tectonic regime.
- 241 4. A complete description of the uncertainty.

242 For example, in the LLNL study a truncated exponential model was used for the  
243 distribution of magnitudes given that an earthquake has occurred in a source. A stationary  
244 Poisson process is used to model the spatial and temporal occurrences of earthquakes in a  
245 source.  
246

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

249 **2.3.1** For sites in the CEUS, when the LLNL or EPRI method is not used or not  
250 applicable (such as in the New Madrid, MO; Charleston, SC; Attica, NY, Seismic Zones), it is  
251 necessary to evaluate the seismic potential for each source. The seismic sources and data that  
252 have been accepted by the NRC in past licensing decisions may be used, along with the data  
253 gathered from the investigations carried out as described in Regulatory Position 1.

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

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

275 **2.3.2** For sites located within the WUS, earthquakes can often be associated with  
276 known tectonic structures. For faults, the earthquake potential is related to the characteristics of  
277 the estimated future rupture, such as the total rupture area, the length, or the amount of fault  
278 displacement. The following empirical relations can be used to estimate the earthquake potential  
279 from fault behavior data and also to estimate the amount of displacement that might be expected  
280 for a given magnitude. It is prudent to use several of the following different relations to obtain an  
281 estimate of the earthquake magnitude.

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

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

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

296 **2.3.3** For sites near subduction zones, such as in the Pacific Northwest and Alaska, the  
297 maximum magnitude must be assessed for subduction zone seismic sources. Worldwide  
298 observations indicate that the largest known earthquakes are associated with the plate interface,  
299 although intraslab earthquakes may also have large magnitudes. The assessment of plate  
300 interface earthquakes can be based on estimates of the expected dimensions of rupture or  
301 analogies to other subduction zones worldwide.

### 302 **3. PROBABILISTIC SEISMIC HAZARD ANALYSIS PROCEDURES**

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

308 sensitivity of the hazard to the uncertainties in the significant parameters and to identify the  
309 relative contribution of each seismic source to the hazard.

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

312 **3.1** Perform regional and site geological, seismological, and geophysical investigations in  
313 accordance with Regulatory Position 1 and Appendix D.

314 **3.2** For CEUS sites, perform an evaluation of LLNL or EPRI seismic sources in accordance  
315 with Appendix E to determine whether they are consistent with the site-specific data gathered in  
316 Regulatory Position 1 or require updating. The PSHA should only be updated if the new  
317 information indicates that the current version significantly underestimates the hazard and there is  
318 a strong technical basis that supports such a revision. It may be possible to justify a lower  
319 hazard estimate with an exceptionally strong technical basis. However, it is expected that large  
320 uncertainties in estimating seismic hazard in the CEUS will continue to exist in the future, and  
321 substantial delays in the licensing process will result in trying to justify a lower value with respect  
322 to a specific site. For these reasons the NRC staff discourages efforts to justify a lower hazard  
323 estimate. In most cases, limited-scope sensitivity studies should be sufficient to demonstrate  
324 that the existing data base in the PSHA envelops the findings from site-specific investigations. In  
325 general, significant revisions to the LLNL and EPRI data base are to be undertaken only  
326 periodically (every 10 years), or when there is an important new finding or occurrence. An overall  
327 revision of the data base would also require a reexamination of the acceptability of the reference  
328 probability discussed in Appendix B and used in Regulatory Position 4 below. Any significant  
329 update should follow the guidance of Reference 5.

330 **3.3** For CEUS sites only, perform the LLNL or EPRI PSHA using original or updated sources  
331 as determined in Regulatory Position 2. For sites in WUS, perform a site-specific PSHA (Ref. 5).  
332 The ground motion estimates should be made for rock conditions in the free-field or by assuming  
333 hypothetical rock conditions for a non-rock site to develop the seismic hazard information base  
334 discussed in Appendix C.

335 **3.4** Using the mean reference probability (5E-4/yr) described in Appendix B, determine the 5  
336 percent of critically damped mean spectral ground motion levels for 1 Hz ( $S_{a,1}$ ) and 10 Hz ( $S_{a,10}$ )  
337 (Ref. 2). The use of an alternative reference probability will be reviewed and accepted on a  
338 case-by-case basis.

339 **3.5** Deaggregate the mean probabilistic hazard characterization in accordance with Appendix  
340 C to determine the controlling earthquakes (i.e., magnitudes and distances), and document the  
341 hazard information base, as described in Appendix C.

342 **3.6** As an alternative method, instead of the controlling earthquakes approach described in  
343 Appendix C and Regulatory Position 4 below, determine the ground motions at a sufficient  
344 number of frequencies significant to the ISFSI or MRS design, and then envelope the ground  
345 motions to determine the DE.

#### 346 **4. PROCEDURES FOR DETERMINING THE DESIGN EARTHQUAKE GROUND MOTION**

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

350 **4.1** With the controlling earthquakes determined as described in Regulatory Position 3 and by  
351 using the procedures in Revision 3 of Reference 21 (which may include the use of ground motion  
352 models not included in the PSHA but that are more appropriate for the source, region, and site  
353 under consideration or that represent the latest scientific development), develop 5 percent of  
354 critical damping response spectral shapes for the actual or assumed rock conditions. The same  
355 controlling earthquakes are also used to derive vertical response spectral shapes.

356 **4.2** Use  $S_{a,10}$  to scale the response spectrum shape corresponding to the controlling  
357 earthquake. If there is a controlling earthquake for  $S_{a,1}$ , determine that the  $S_{a,10}$  scaled response  
358 spectrum also envelopes the ground motion spectrum for the controlling earthquake for  $S_{a,1}$ .  
359 Otherwise, modify the shape to envelope the low-frequency spectrum or use two spectra in the  
360 following steps. For a rock site, go to Regulatory Position 4.4.

361 **4.3** For non-rock sites, perform a site-specific soil amplification analysis considering  
362 uncertainties in site-specific geotechnical properties and parameters to determine response  
363 spectra at the free ground surface in the free-field for the actual site conditions. Procedures  
364 described in Appendix D of this guide and Reference 21 can be used to perform soil-amplification  
365 analyses.

366 **4.4** Compare the smooth DE spectrum or spectra used in design at the free-field with the  
367 spectrum or spectra determined in Regulatory Position 2 for rock sites or determined in  
368 Regulatory Position 3 for the non-rock sites to assess the adequacy of the DE spectrum or  
369 spectra.

370 **4.5** To obtain an adequate DE based on the site-specific response spectrum or spectra,  
371 develop a smooth spectrum or spectra or use a standard broad band shape that envelopes the  
372 spectra of Regulatory Position 2 or 3.

## 373 D. IMPLEMENTATION

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

376 This draft guide has been released to encourage public participation in its development.  
377 Except in those cases in which an applicant or licensee proposes an acceptable alternative  
378 method for complying with the specified portions of the NRC's regulations, the methods to be  
379 described in the active guide reflecting public comments will be used in the evaluation of  
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<sup>1</sup> Copies are available at current rates from the U.S. Government Printing Office, P.O. Box 37082, Washington, DC 20402-9328 (telephone (202)512-1800); or from the National Technical Information Service by writing NTIS at 5285 Port Royal Road, Springfield, VA 22161; (telephone (703)487-4650; <<http://www.ntis.gov/ordernow>>. Copies are available for inspection or copying for a fee from the NRC Public Document Room at 11555 Rockville Pike, Rockville, MD; the PDR's mailing address is USNRC PDR, Washington, DC 20555; telephone (301)415-4737 or (800)397-4209; fax (301)415-3548; email is PDR@NRC.GOV.

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

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## APPENDIX A DEFINITIONS

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

499 **Reference Probability** — The reference probability of occurrence of an earthquake event is the  
500 mean annual probability of exceeding the design earthquake.

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

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

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

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

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

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

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

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

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

540 **APPENDIX B**  
541 **REFERENCE PROBABILITY FOR THE EXCEEDANCE LEVEL OF THE**  
542 **DESIGN EARTHQUAKE GROUND MOTION**

543 **B.1 INTRODUCTION**

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

548 **B.2 QUESTION ON REFERENCE PROBABILITY FOR DESIGN EARTHQUAKE**

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

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

556 The present mean annual probability of exceedance value for determining the DE for an  
557 ISFSI or MRS is approximately  $1.0E-04$  (i.e., in any one year, the probability is 1 in 10,000, which  
558 is the reciprocal of  $1.0E-04$ , that the DE established for the site will be exceeded). This value is  
559 based on requirements for nuclear plants. The NRC is considering allowing for the use of a  
560 mean annual probability of exceedance value in the range of  $5.0E-04$  (i.e., in any one year, the  
561 probability is 1 in 2,000 that the DE established for the site will be exceeded) to  $1.0E-04$  for ISFSI  
562 or MRS applications. This Draft Regulatory Guide DG-3021, "Site Evaluations and Determination  
563 of Design Earthquake Ground Motion for Seismic Design of Independent Spent Fuel Storage  
564 Installations and Monitored Retrievable Storage Installations," is being developed to provide  
565 guidelines that are acceptable to the NRC staff for determining the DE for an ISFSI or MRS. DG-  
566 3021 proposes to recommend a mean annual probability of exceedance value of  $5.0E-04$  as an  
567 appropriate risk-informed value for the design of a dry storage ISFSI or MRS. However, the NRC  
568 staff is undertaking further analysis to support a specific value. An ISFSI or MRS license  
569 applicant would have to demonstrate that the use of a higher probability of exceedance value  
570 would not impose any undue radiological risk to public health and safety. In view of this  
571 discussion, the NRC staff is requesting comments on the appropriate mean annual probability of  
572 exceedance value to be used for the seismic design of an ISFSI or MRS and a justification for  
573 this probability.

574 **B.3 RATIONALE FOR THE REFERENCE PROBABILITY**

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

580 **B.3.1 Part 72 Approach**

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

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

### 595 **B.3.2 Reference Probability**

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

- 609  
610 ● In comparison with a nuclear power plant, an operating ISFSI or MRS is a relatively  
611 simple facility in which the primary activities are waste receipt, handling, and storage. An  
612 ISFSI or MRS does not have the variety and complexity of active systems necessary to  
613 support an operating nuclear power plant. After the spent fuel is in place, an ISFSI or  
614 MRS is essentially a static operation.
- 615 ● During normal operations, the conditions required for the release and dispersal of  
616 significant quantities of radioactive materials are not present. There are no high  
617 temperatures or pressures present during normal operations or under design basis  
618 accident conditions to cause the release and dispersal of radioactive materials. This is  
619 primarily due to the low heat-generation rate of spent fuel that has undergone more than  
620 1 year of decay before storage in an ISFSI or MRS, and to the low inventory of volatile  
621 radioactive materials readily available for release to the environment.
- 622 ● The long-lived nuclides present in spent fuel are tightly bound in the fuel materials and  
623 are not readily dispersible. Short-lived volatile nuclides, such as I-131, are no longer  
624 present in aged spent fuel. Furthermore, even if the short-lived nuclides were present  
625 during a fuel assembly rupture, the canister surrounding the fuel assemblies would  
626 confine these nuclides. Therefore, the Commission believes that the seismically induced

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radiological risk associated with an ISFSI or MRS is significantly less than the risk associated with a nuclear power plant. Also, it is NRC policy to use risk-informed regulation as appropriate.

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

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

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

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

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

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

- 664 ● The determination of a DE for an ISFSI or MRS is consistent with the design approach  
665 used in DOE Standard DOE-STD-1020, "Natural Phenomena Hazards Design Evaluation  
666 Criteria for Department of Energy Facilities,"<sup>1</sup> for similar type facilities.

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

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

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

### 673 C.1 INTRODUCTION

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

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

### 686 C.2 PROCEDURE TO DETERMINE CONTROLLING EARTHQUAKES

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

#### 692 Step 2-1

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

#### 700 Step 2-2

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

#### 704 Step 2-3

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

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**Table C.1 Recommended Magnitude and Distance Bins**

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

720

**Step 2-4**

721

722

723

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

724

725

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

726

727

$$P(m,d)_1 = H_{m_{df}1} / (\sum_m \sum_d H_{m_{df}1}) \quad (\text{Equation 1})$$

728

729

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

730

731

732

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

**Step 2-5**

733

734

735

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

736

737

738

739

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

740

741

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

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

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

#### 747 **Step 2-6**

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

$$751 \quad M_c = \sum_d m \sum_m P(m, d)_{10} \quad (\text{Equation 4})$$

752 where  $m$  is the central magnitude value for each magnitude bin.  
753

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

$$756 \quad \text{Ln} \{ D_c (10 \text{ Hz}) \} = \sum_d \text{Ln} (d) \sum_m P(m, d)_{10} \quad (\text{Equation 5})$$

757 where  $d$  is the centroid distance value for each distance bin.  
758  
759

#### 760 **Step 2-7**

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

$$767 \quad M_c (1\text{Hz}) = \sum_m m \sum_{d>100} P(m, d)_1 \quad (\text{Equation 6})$$

768 where  $m$  is the central magnitude value for each magnitude bin.  
769

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

$$772 \quad \text{Ln} \{ D_c (1 \text{ Hz}) \} = \sum_{d>100} \text{Ln} (d) \sum_m P(m, d)_{10} \quad (\text{Equation 7})$$

773 where  $d$  is the centroid distance value for each distance bin.  
774

#### 775 **Step 2-8**

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

778 **C.3 EXAMPLE FOR A CEUS SITE**

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

787 **Step 3-1**

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

792 **Step 3-2**

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

796 **Table C.2 Ground Motion Levels**

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

799 **Step 3-3**

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

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

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

815

816  
817

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

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

826  
827

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

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

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

837 **Step 3-4**

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

841 **Step 3-5**

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

846

847  
848

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

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

857  
858 Figures C.3 to C.5 show the above information in terms of the relative percentage contribution.

859  
860

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

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

869  
870

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

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

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

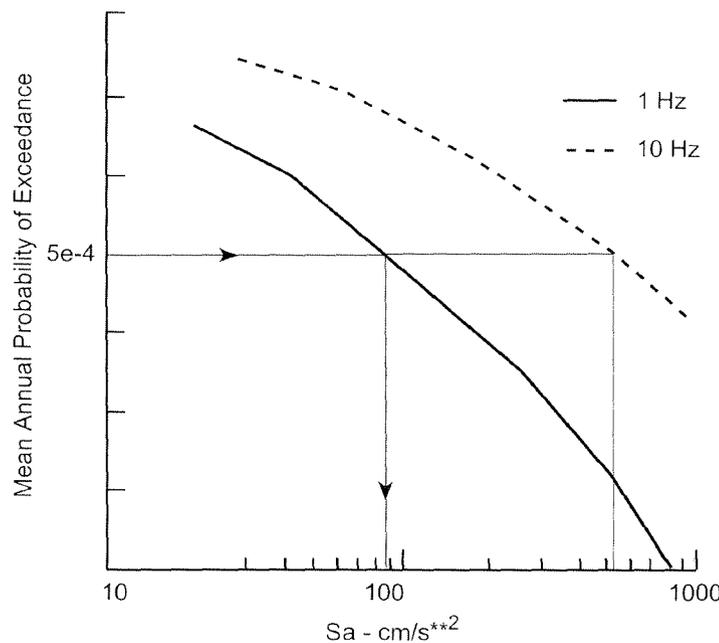
876 **Steps 3-6 and 3-7**

877 To compute the controlling magnitudes and distances at 1 Hz and 10 Hz for the example  
878 site, the values of  $P>100(m,d)_1$  and  $P(m,d)_{10}$  are used with m and d values corresponding to the  
879 mid-point of the magnitude of the bin (5.25, 5.75, 6.25, 6.75, 7.3) and centroid of the ring area  
880 (10, 20.4, 38.9, 77.8, 155.6, 253.3, and somewhat arbitrarily 350 km). Note that the mid-point of

881 the last magnitude bin may change because this value is dependent on the maximum magnitudes  
 882 used in the hazard analysis. For this example site, the controlling earthquake characteristics  
 883 (magnitudes and distances) are given in Table C.8.

884 **Step 3-8**

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



886 Figure C.1  
 887 Curves

888 **C.4 SITE**

889 The  
 890 controlling  
 891 seismic

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

Total Mean Hazard

**S NOT IN THE CEUS**

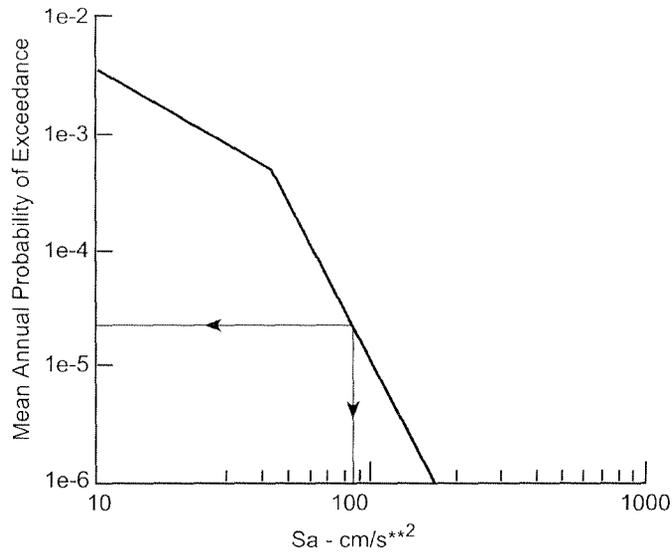
determination of the  
 earthquakes and the  
 hazard information base

897  
898

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

899  
900  
901

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



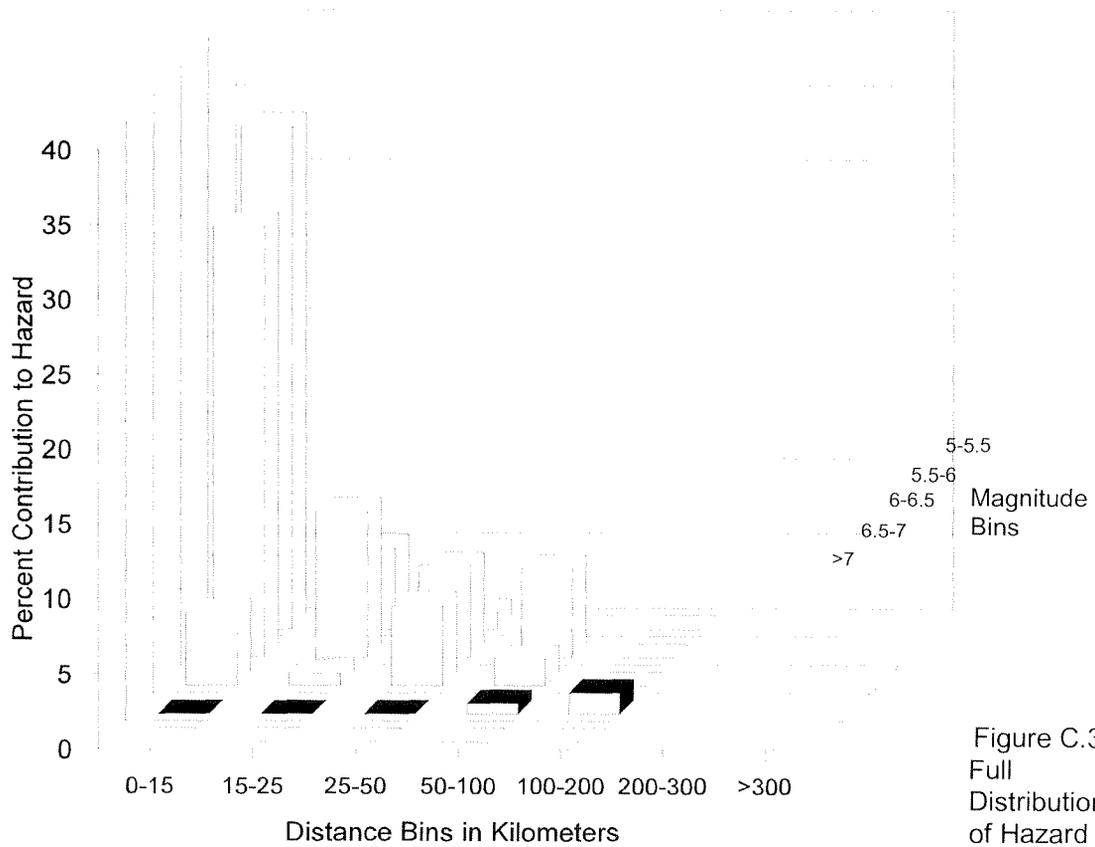
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Figure C.2 1 Hz Mean Hazard Curve for  
Distance Bin 25-50 km and Magnitude Bin 6-6.5

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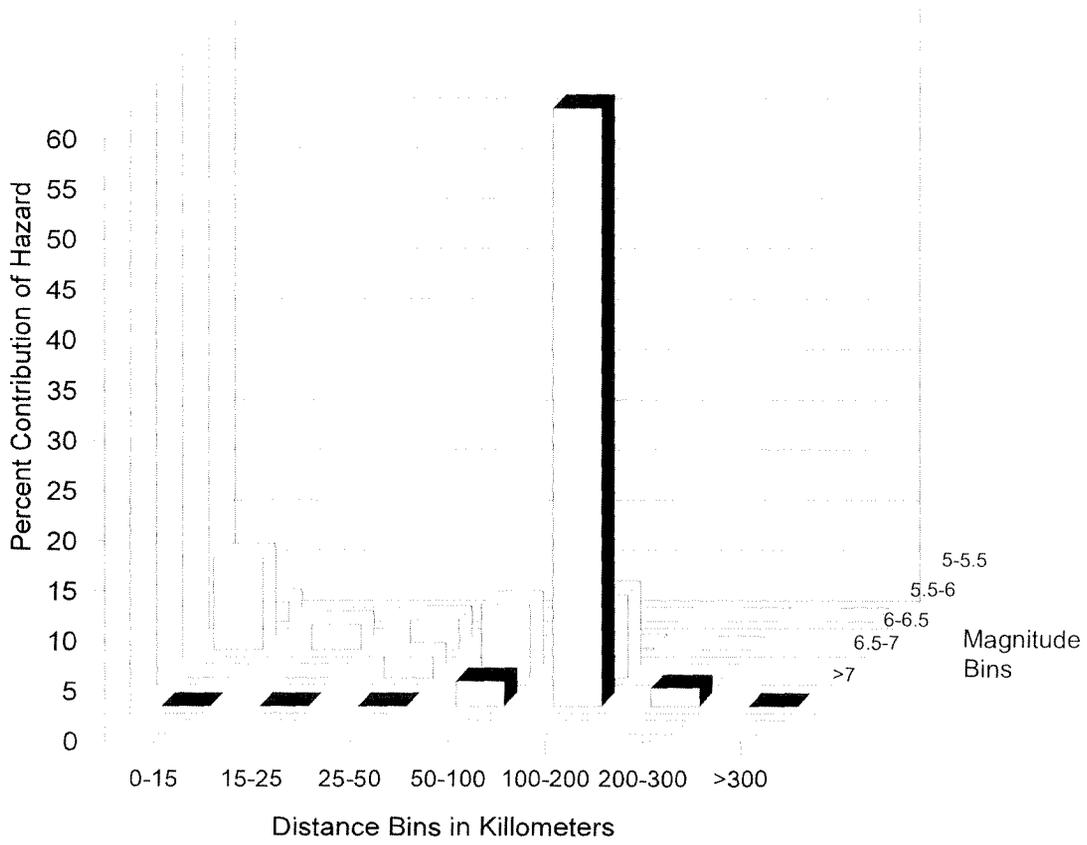
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Figure C.3  
Full  
Distribution  
of Hazard  
for 10 Hz

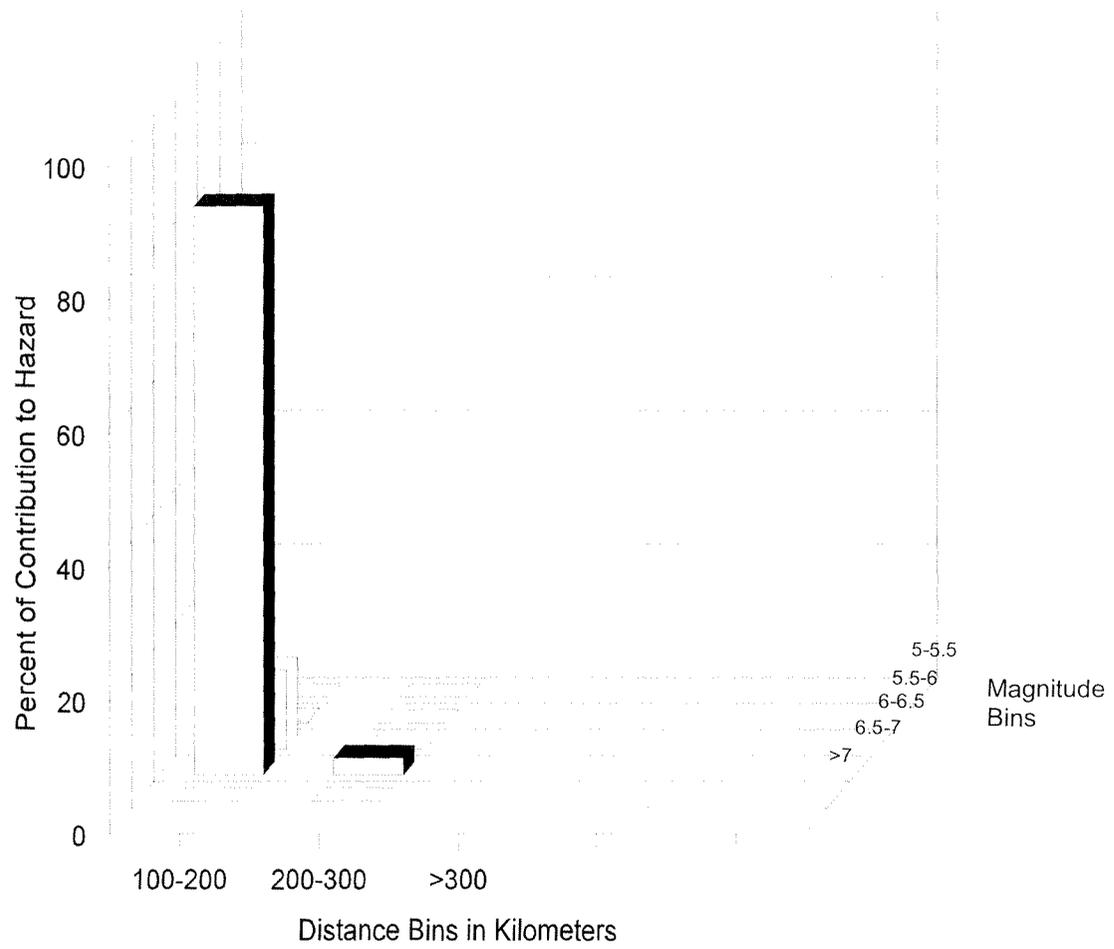
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923

Distribution of Hazard for 1 Hz

Figure C.4  
Full



924  
925  
926

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

Figure C.5