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PREPUBLICATION

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

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

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

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

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

30 This guide applies to the design basis of both dry cask storage Independent Spent Fuel
31 Storage Installations (ISFSIs) and U.S. Department of Energy monitored retrievable storage
32 installations (MRS), because these facilities are similar in design. The reference probability in
33 Regulatory Position 3.4 and Appendix B does not apply to wet storage because of the greater
34 consequences associated with the potential accident scenarios for these facilities. This is
35 because wet storage requires active systems, such as systems to remove heat and maintain
36 adequate water levels. These active systems have a higher probability of failure than the passive
37 systems used in dry modes of storage, thus resulting in a greater seismic risk for wet modes of
38 storage.

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

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

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

56 **B. DISCUSSION**

57 **BACKGROUND**

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

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

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

80 **APPROACH**

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

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

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

90 **CENTRAL AND EASTERN UNITED STATES**

91 The CEUS is considered to be that part of the United States east of the Rocky Mountain
92 front, or east of longitude 104° west (Refs. 6, 7). To determine the DE in the CEUS, an accepted
93 PSHA methodology with a range of credible alternative input interpretations should be used. For
94 sites in the CEUS, the seismic hazard methods, the data developed, and seismic sources
95 identified by Lawrence Livermore National Laboratory (LLNL) (Refs. 3, 4, 6) and the Electric
96 Power Research Institute (EPRI) (Ref. 7) have been reviewed and are acceptable to the staff.
97 The LLNL and EPRI studies developed data bases and scientific interpretations of available
98 information and determined seismic sources and source characterizations for the CEUS (e.g.,
99 earthquake occurrence rates, estimates of maximum magnitude).

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

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

114 **WESTERN UNITED STATES**

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

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

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

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

142 The Basin and Range region of the WUS, and to a lesser extent the Pacific Northwest
143 and the Central United States, exhibit temporal clustering of earthquakes. Temporal clustering is

144 best exemplified by the rupture histories within the Wasatch fault zone in Utah and the Meers
145 fault in central Oklahoma, where several large late Holocene coseismic faulting events occurred
146 at relatively close intervals (hundreds to thousands of years) that were preceded by long periods
147 of quiescence that lasted thousands to tens of thousands of years. Temporal clustering should
148 be considered in these regions or wherever paleoseismic evidence indicates that it has occurred.

149

C. REGULATORY POSITION

1. GEOLOGICAL, GEOPHYSICAL, SEISMOLOGICAL, AND GEOTECHNICAL INVESTIGATIONS

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

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

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

176 **1.1.2** Geological, seismological, and geophysical investigations should be carried out within a
177 radius of 40 km (25 miles) in greater detail than the regional investigations to identify and
178 characterize the seismic and surface deformation potential of any capable tectonic
179 sources and the seismic potential of seismogenic sources, or to demonstrate that such
180 structures are not present. Sites with capable tectonic or seismogenic sources within a
181 radius of 40 km (25 miles) may require more extensive geological and seismological
182 investigations and analyses (similar in detail to investigations and analysis usually
183 preferred within an 8-km (5-mile) radius).

184 **1.1.3** Detailed geologic, seismological, geophysical, and geotechnical investigations should be
185 conducted within a radius of 8 km (5 miles) of the site, as appropriate, to evaluate the
186 potential for tectonic deformation at or near the ground surface and to assess the

187 transmission characteristics of soils and rocks in the site vicinity. Sites in the CEUS
188 where geologically young or recent tectonic activity is not present may be investigated in
189 less detail. Methods for evaluating the seismogenic potential of tectonic structures and
190 geological features developed in Reference 13 should be followed.

191 **1.1.4** Very detailed geological, geophysical, and geotechnical engineering investigations should
192 be conducted within the site [radius of approximately 1 km (0.5 miles)] to assess specific
193 soil and rock characteristics as described in Reference 11, updated with NUREG/CR-
194 5738 (Ref. 12).

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

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

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

211 **2. SEISMIC SOURCES SIGNIFICANT TO THE SITE SEISMIC HAZARD**

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

221 **2.2** When the LLNL or EPRI methods are not used or are not applicable, the guidance in
222 Regulatory Position 2.3 should be used for identification and characterization of seismic sources.
223 The uncertainties in the characterization of seismic sources should be addressed as appropriate.
224 Seismic sources is a general term referring to both seismogenic sources and capable tectonic
225 sources. The main distinction between these two types of seismic sources is that a seismogenic
226 source would not cause surface displacement, but a capable tectonic source causes surface or
227 near-surface displacement.

228 Identification and characterization of seismic sources should be based on regional and
229 site geological and geophysical data, historical and instrumental seismicity data, the regional

230 stress field, and geological evidence of prehistoric earthquakes. Investigations to identify seismic
231 sources are described in Appendix D. The bases for the identification of seismic sources should
232 be identified. A general list of characteristics to be evaluated for seismic sources is presented in
233 Appendix D.

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

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

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

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

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

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

266 The assessment of earthquake potential for area sources is particularly difficult because
267 one of the physical constraints most important to the assessment, the dimensions of the fault
268 rupture, is not known. As a result, the primary methods for assessing maximum earthquakes for
269 area sources usually include a consideration of the historical seismicity record, the pattern and
270 rate of seismic activity, the Quaternary (2 million years and younger) characteristics of the
271 source, the current stress regime (and how it aligns with known tectonic structures), paleoseismic

272 data, and analogs to sources in other regions considered tectonically similar to the CEUS.
273 Because of the shortness of the historical catalog and low rate of seismic activity, considerable
274 judgment is needed. It is important to characterize the large uncertainties in the assessment of
275 the earthquake potential.

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

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

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

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

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

303 **3. PROBABILISTIC SEISMIC HAZARD ANALYSIS PROCEDURES**

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

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

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

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

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

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

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

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

347 **4. PROCEDURES FOR DETERMINING THE DESIGN EARTHQUAKE GROUND MOTION**

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

351 **4.1** With the controlling earthquakes determined as described in Regulatory Position 3 and by
352 using the procedures in Revision 3 of Reference 21 (which may include the use of ground motion
353 models not included in the PSHA but that are more appropriate for the source, region, and site
354 under consideration or that represent the latest scientific development), develop 5 percent of

355 critical damping response spectral shapes for the actual or assumed rock conditions. The same
356 controlling earthquakes are also used to derive vertical response spectral shapes.

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

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

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

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

374 **D. IMPLEMENTATION**

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

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

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

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

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437 **APPENDIX A**
438 **DEFINITIONS**

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

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

- 443 a. Presence of surface or near-surface deformation of landforms or geologic
444 deposits of a recurring nature within the last approximately 500,000 years or at
445 least once in the last approximately 50,000 years.
- 446 b. A reasonable association with one or more moderate to large earthquakes or
447 sustained earthquake activity, usually accompanied by significant surface
448 deformation.
- 449 c. A structural association with a capable tectonic source that has characteristics of
450 either a or b above such that movement on one could be reasonably expected to
451 be accompanied by movement on the other.

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

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

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

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

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

475 **Intensity** — The intensity of an earthquake is a qualitative description of the effects of the
476 earthquake at a particular location, as evidenced by observed effects on humans, on human-built
477 structures, and on the earth's surface at a particular location. Commonly used scales to specify
478 intensity are the Rossi-Forel, Mercalli, and Modified Mercalli. The Modified Mercalli Intensity
479 (MMI) scale describes intensities with values ranging from I to XII in the order of severity. MMI of
480 I indicates an event that was not felt except by a very few, while MMI of XII indicates total
481 damage of all works of construction, either partially or completely.

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

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

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

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

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

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

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

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

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

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

519 **Seismogenic Source** — A seismogenic source is a portion of the earth that is assumed to have
520 a uniform earthquake potential (same expected maximum earthquake and recurrence
521 frequency), distinct from the seismicity of the surrounding regions. A seismogenic source will
522 generate vibratory ground motion but is assumed not to cause surface displacement.

523 Seismogenic sources cover a wide range of possibilities, from a well-defined tectonic structure to
524 simply a large region of diffuse seismicity (seismotectonic province) thought to be characterized
525 by the same earthquake recurrence model. A seismogenic source is also characterized by its
526 involvement in the current tectonic regime (the Quaternary, or approximately the last 2 million
527 years).

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

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

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

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

544 **B.1 INTRODUCTION**

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

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

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

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

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

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

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

581 **B.3.1 Part 72 Approach**

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

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

596 **B.3.2 Reference Probability**

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

- 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
- 616 ● During normal operations, the conditions required for the release and dispersal of
617 significant quantities of radioactive materials are not present. There are no high
618 temperatures or pressures present during normal operations or under design basis
619 accident conditions to cause the release and dispersal of radioactive materials. This is
620 primarily due to the low heat-generation rate of spent fuel that has undergone more than
621 1 year of decay before storage in an ISFSI or MRS, and to the low inventory of volatile
622 radioactive materials readily available for release to the environment.
- 623 ● The long-lived nuclides present in spent fuel are tightly bound in the fuel materials and
624 are not readily dispersible. Short-lived volatile nuclides, such as I-131, are no longer
625 present in aged spent fuel. Furthermore, even if the short-lived nuclides were present
626 during a fuel assembly rupture, the canister surrounding the fuel assemblies would
627 confine these nuclides. Therefore, the Commission believes that the seismically induced

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

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

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

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

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

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

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

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

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

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

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673

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

674 **C.1 INTRODUCTION**

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

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

687 **C.2 PROCEDURE TO DETERMINE CONTROLLING EARTHQUAKES**

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

693 **Step 2-1**

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

701 **Step 2-2**

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

705 **Step 2-3**

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

709

Table C.1 Recommended Magnitude and Distance Bins

710

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					

711

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720

Step 2-4

722

723

724

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 $H_{m,df1}$ for 1 Hz, and $H_{m,df10}$ for 10 Hz.

725

726

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:

727

728

$$P(m,d)_1 = H_{m,df1} / (\sum_m \sum_d H_{m,df1}) \quad \text{(Equation 1)}$$

729

730

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:

731

732

$$P(m,d)_{10} = H_{m,df10} / (\sum_m \sum_d H_{m,df10}) \quad \text{(Equation 2)}$$

Step 2-5

734

735

736

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).

737

738

739

740

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:

741

742

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

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

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

748 **Step 2-6**

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

$$752 \quad M_c = \sum_d m \sum_m P(m, d)_{10} \quad \text{(Equation 4)}$$

753 where m is the central magnitude value for each magnitude bin.
754

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

$$757 \quad \text{Ln} \{ D_c (10 \text{ Hz}) \} = \sum_d \text{Ln} (d) \sum_m P(m, d)_{10} \quad \text{(Equation 5)}$$

758 where d is the centroid distance value for each distance bin.
759
760

761 **Step 2-7**

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

$$768 \quad M_c (1\text{Hz}) = \sum_m m \sum_{d>100} P > 100 (m, d)_1 \quad \text{(Equation 6)}$$

769 where m is the central magnitude value for each magnitude bin.
770

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

$$773 \quad \text{Ln} \{ D_c (1 \text{ Hz}) \} = \sum_{d>100} \text{Ln} (d) \sum_m P(m, d)_{10} \quad \text{(Equation 7)}$$

774 where d is the centroid distance value for each distance bin.
775

776 **Step 2-8**

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

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

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

788 **Step 3-1**

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

793 **Step 3-2**

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

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

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

800 **Step 3-3**

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

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

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

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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

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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

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

838 **Step 3-4**

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

842 **Step 3-5**

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

847

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**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

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

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**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

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**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

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

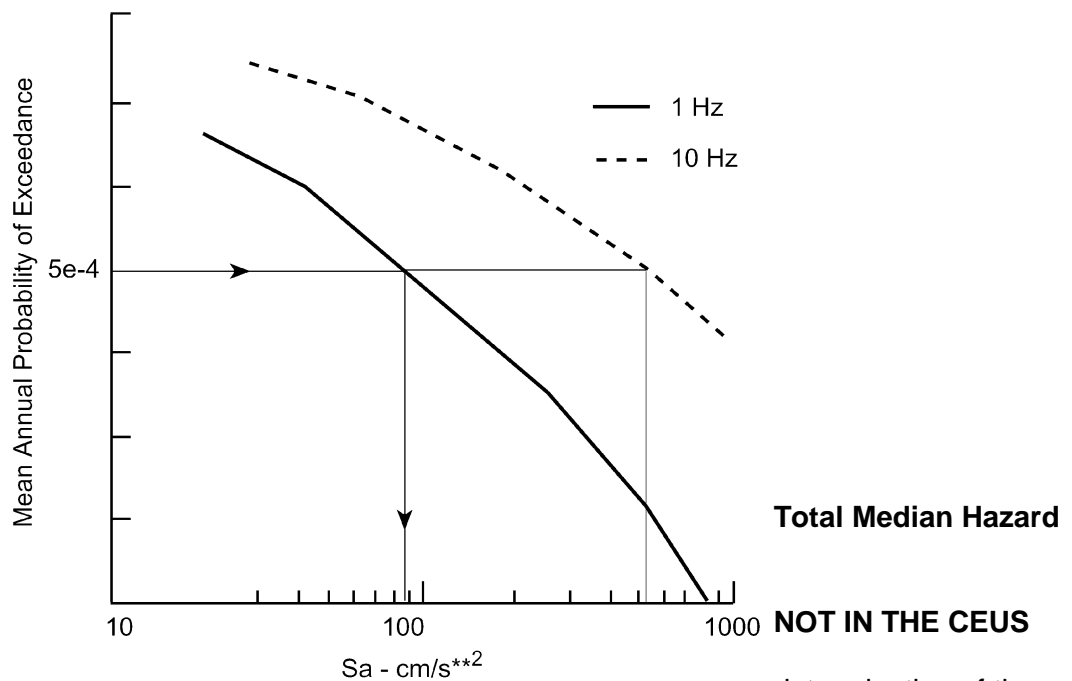
877 **Steps 3-6 and 3-7**

878 To compute the controlling magnitudes and distances at 1 Hz and 10 Hz for the example
879 site, the values of $P>100(m,d)_1$ and $P(m,d)_{10}$ are used with m and d values corresponding to the
880 mid-point of the magnitude of the bin (5.25, 5.75, 6.25, 6.75, 7.3) and centroid of the ring area
881 (10, 20.4, 38.9, 77.8, 155.6, 253.3, and somewhat arbitrarily 350 km). Note that the mid-point of

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

885 **Step 3-8**

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



887 **Figure C.1**
 888 **Curves**

889 **C.4 SITES**

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

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

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

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1 Hz Mean Hazard
Distance Bin 25-50 km
Bin 6-6.5

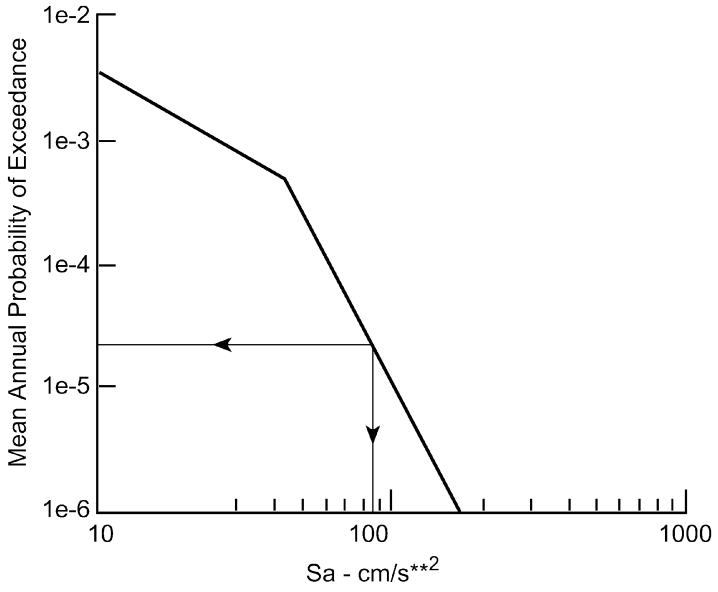
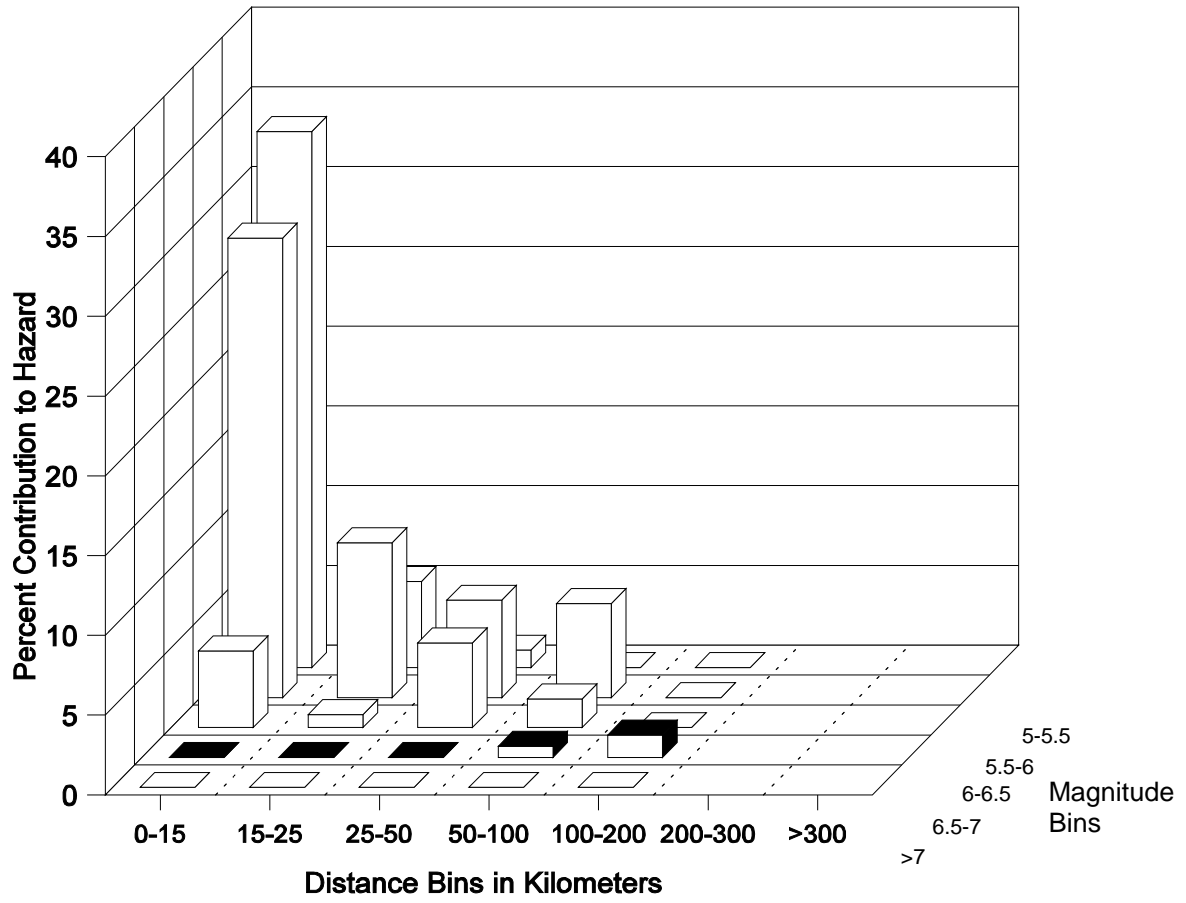


Figure C.2
Curve for
and Magnitude

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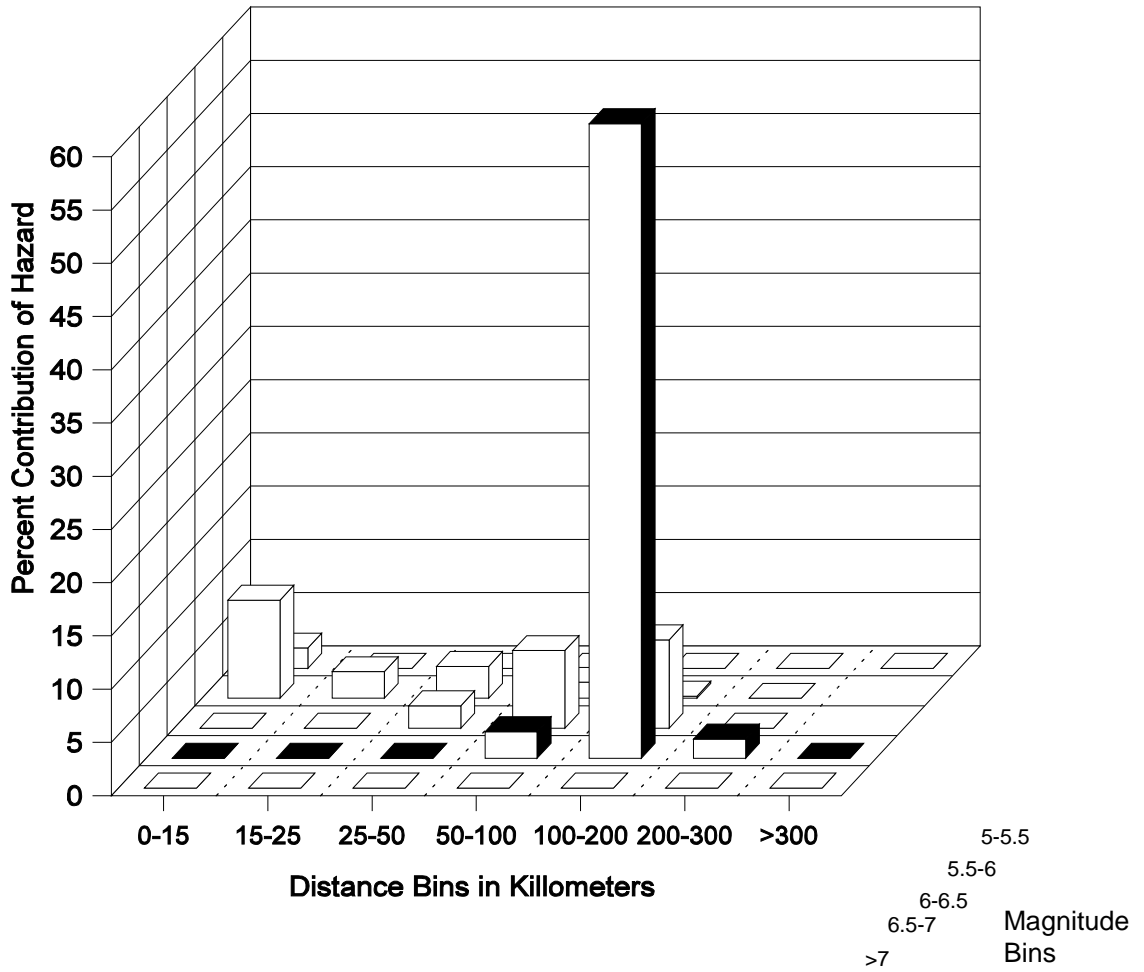


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Figure C.3 Full Distribution of Hazard for 10 Hz

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Figure C.4 Full Distribution of Hazard for 1 Hz

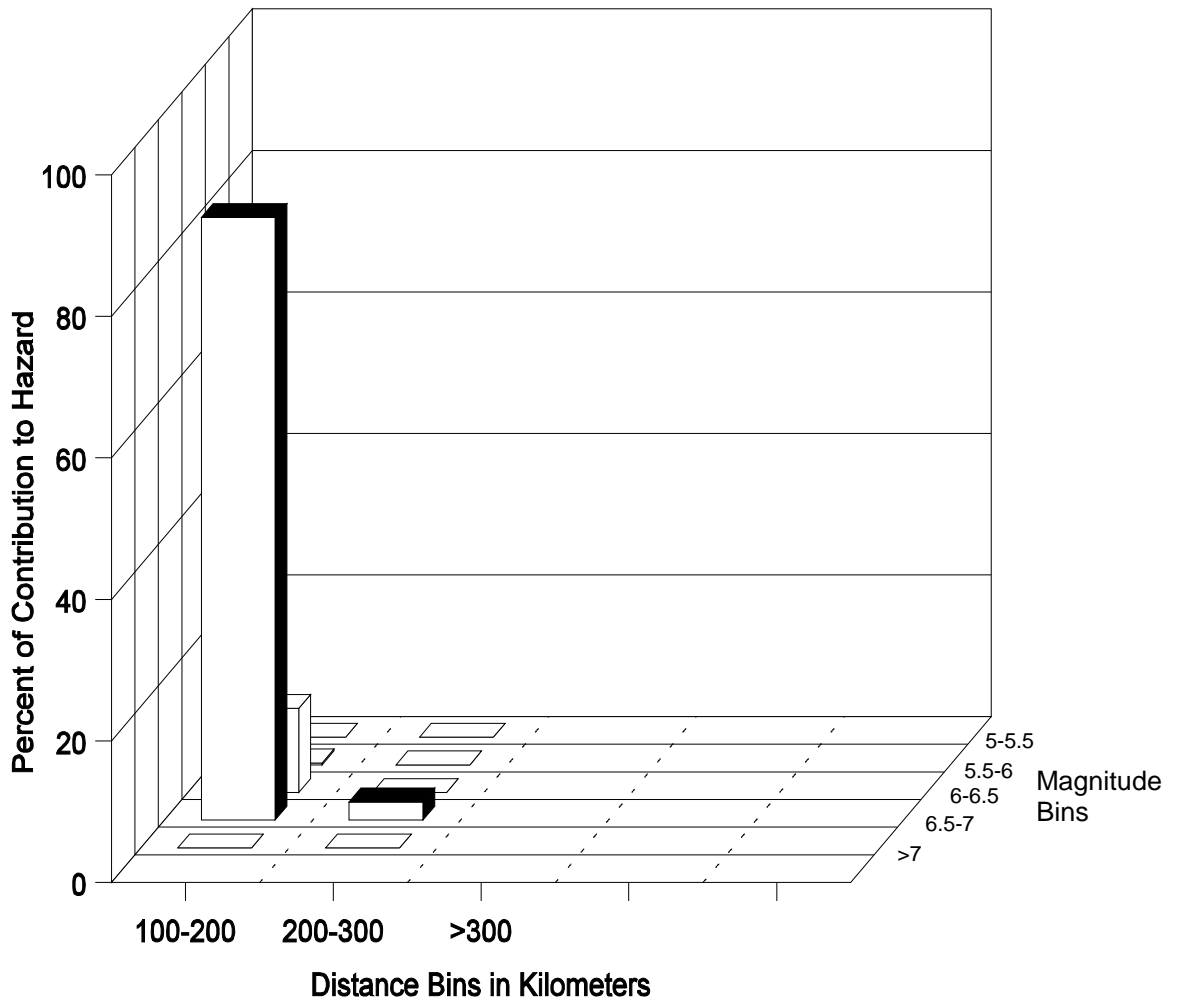


Figure C.5 Renormalized Hazard Distribution for Distances Greater than 100 km for 1 Hz

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922

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928 NRC's Public Document Room)²
- 929 C.3 Electric Power Research Institute (EPRI), "Probabilistic Seismic Hazard Evaluations at
930 Nuclear Power Plant Sites in the Central and Eastern United States," NP-4726, All
931 Volumes, 1989-1991.

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

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

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

935 D.1 INTRODUCTION

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

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

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

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

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

- 975 • Seismic source location and geometry (location and extent, both surface and subsurface).
976 This evaluation will normally require interpretations of available geological, geophysical,
977 and seismological data in the source region by multiple experts or a team of experts. The
978 evaluation should include interpretations of the seismic potential of each source and
979 relationships among seismic sources in the region in order to express uncertainty in the
980 evaluations. Seismic source evaluations generally develop four types of sources: (1)
981 fault-specific sources, (2) area sources representing concentrated historic seismicity not
982 associated with known tectonic structure, (3) area sources representing geographic
983 regions with similar tectonic histories, type of crust, and structural features, and (4)
984 background sources. Background sources are generally used to express uncertainty in
985 the overall seismic source configuration interpreted for the site region. Acceptable
986 approaches for evaluating and characterizing uncertainties for input to a seismic hazard
987 calculation are contained in NUREG/CR-6372 (Ref. D.2).
- 988 • Evaluations of earthquake recurrence for each seismic source, including recurrence rate
989 and recurrence model. These evaluations normally draw most heavily on historical and
990 instrumental seismicity associated with each source and paleoearthquake information.
991 Preferred methods and approaches for evaluating and characterizing uncertainty in
992 earthquake recurrence generally will depend on the type of source. Acceptable methods
993 are described in NUREG/CR-6372 (Ref. D.2).
- 994 • Evaluations of the maximum earthquake magnitude for each seismic source. These
995 evaluations will draw on a broad range of source-specific tectonic characteristics,
996 including tectonic history and available seismicity data. Uncertainty in this evaluation
997 should normally be expressed as a maximum magnitude distribution. Preferred methods
998 and information for evaluating and characterizing maximum earthquakes for seismic
999 sources vary with the type of source. Acceptable methods are contained in NUREG/CR-
1000 6372 (Ref. D.2).
- 1001 • Other evaluations, depending on the geologic setting of a site, such as local faults that
1002 have a history of Quaternary (last 2 million years) displacements, sense of slip on faults,
1003 fault length and width, area of faults, age of displacements, estimated displacement per
1004 event, estimated earthquake magnitude per offset event, orientations of regional tectonic
1005 stresses with respect to faults, and the possibility of seismogenic folds. Capable tectonic
1006 sources are not always exposed at the ground surface in the WUS as demonstrated by
1007 the buried reverse causative faults of the 1983 Coalinga, 1988 Whittier Narrows, 1989
1008 Loma Prieta, and 1994 Northridge earthquakes. These examples emphasize the need to
1009 conduct thorough investigations not only at the ground surface but also in the subsurface
1010 to identify structures at seismogenic depths. Whenever faults or other structures are
1011 encountered at a site (including sites in the CEUS) in either outcrop or excavations, it is
1012 necessary to perform adequately detailed specific investigations to determine whether or
1013 not they are seismogenic or may cause surface deformation at the site. Acceptable
1014 methods for performing these investigations are contained in NUREG/CR-5503 (Ref. D.3).
- 1015 • Effects of human activities such as withdrawal of fluid from or addition of fluid to the
1016 subsurface associated with mining or the construction of dams and reservoirs.
- 1017 • Volcanic hazard is not addressed in this regulatory guide and will be considered on a
1018 case-by-case basis in regions where a potential for this hazard exists. For sites where
1019 volcanic hazard is evaluated, earthquake sources associated with volcanism should be

1020 evaluated and included in the seismic source interpretations input to the hazard
1021 calculation.

1022 **D.2. INVESTIGATIONS TO EVALUATE SEISMIC SOURCES**

1023 **D.2.1 General**

1024
1025 Investigations of the site and region around the site are necessary to identify both
1026 seismogenic sources and capable tectonic sources and to determine their potential for generating
1027 earthquakes and causing surface deformation. If it is determined that surface deformation need
1028 not be taken into account at the site, sufficient data to clearly justify the determination should be
1029 presented in the application for an early site permit, construction permit, operating license, or
1030 combined license. Generally, any tectonic deformation at the earth's surface within 40 km (25
1031 miles) of the site will require detailed examination to determine its significance. Potentially active
1032 tectonic deformation within the seismogenic zone beneath a site will have to be assessed using
1033 geophysical and seismological methods to determine its significance.

1034 Engineering solutions are generally available to mitigate the potential vibratory effects of
1035 earthquakes through design. However, engineering solutions cannot always be demonstrated to
1036 be adequate for mitigation of the effects of permanent ground displacement phenomena such as
1037 surface faulting or folding, subsidence, or ground collapse. For this reason, it is prudent to select
1038 an alternative site when the potential for permanent ground displacement exists at the proposed
1039 site (Ref. D.4).

1040 In most of the CEUS, instrumentally located earthquakes seldom bear any relationship to
1041 geologic structures exposed at the ground surface. Possible geologically young fault
1042 displacements either do not extend to the ground surface or there is insufficient geologic material
1043 of the appropriate age available to date the faults. Capable tectonic sources are not always
1044 exposed at the ground surface in the WUS, as demonstrated by the buried (blind) reverse
1045 causative faults of the 1983 Coalinga, 1988 Whittier Narrows, 1989 Loma Prieta, and 1994
1046 Northridge earthquakes. These factors emphasize the need to conduct thorough investigations
1047 not only at the ground surface but also in the subsurface to identify structures at seismogenic
1048 depths.

1049 The level of detail for investigations should be governed by knowledge of the current and
1050 late Quaternary tectonic regime and the geological complexity of the site and region. The
1051 investigations should be based on increasing the amount of detailed information as they proceed
1052 from the regional level down to the site area [e.g., 320 km (200 mi) to 8 km (5 mi) distance from
1053 the site]. Whenever faults or other structures are encountered at a site (including sites in the
1054 CEUS) in either outcrop or excavations, it is necessary to perform many of the investigations
1055 described below to determine whether or not they are capable tectonic sources.

1056 The investigations for determining seismic sources should be carried out at three levels,
1057 with areas described by radii of 320 km (200 mi), 40 km (25 mi), and 8 km (5 mi) from the site.
1058 The level of detail increases closer to the site. The specific site, to a distance of at least 1 km
1059 (0.6 mi), should be investigated in more detail than the other levels.

1060 The regional investigations [within a radius of 320 km (200 mi) of the site] should be
1061 planned to identify seismic sources and describe the Quaternary tectonic regime. The data
1062 should be presented at a scale of 1:500,000 or smaller. The investigations are not expected to

1063 be extensive or in detail, but should include a comprehensive literature review supplemented by
1064 focused geological reconnaissances based on the results of the literature study (including
1065 topographic, geologic, aeromagnetic, and gravity maps and airphotos). Some detailed
1066 investigations at specific locations within the region may be necessary if potential capable
1067 tectonic sources or seismogenic sources that may be significant for determining the safe
1068 shutdown earthquake ground motion are identified.

1069 The large size of the area for the regional investigations is recommended because of the
1070 possibility that all significant seismic sources, or alternative configurations, may not have been
1071 enveloped by the LLNL/EPRI data base. Thus, it will increase the chances of (1) identifying
1072 evidence for unknown seismic sources that might extend close enough for earthquake ground
1073 motions generated by that source to affect the site and (2) confirming the PSHA's data base.
1074 Furthermore, because of the relatively aseismic nature of the CEUS, the area should be large
1075 enough to include as many historical and instrumentally recorded earthquakes for analysis as
1076 reasonably possible. The specified area of study is expected to be large enough to incorporate
1077 any previously identified sources that could be analogous to sources that may underlie or be
1078 relatively close to the site. In past licensing activities for sites in the CEUS, it has often been
1079 necessary, because of the absence of datable horizons overlying bedrock, to extend
1080 investigations out many tens or hundreds of kilometers from the site along a structure or to an
1081 outlying analogous structure in order to locate overlying datable strata or unconformities so that
1082 geochronological methods could be applied. This procedure has also been used to estimate the
1083 age of an undatable seismic source in the site vicinity by relating its time of last activity to that of
1084 a similar, previously evaluated structure, or a known tectonic episode, the evidence of which may
1085 be many tens or hundreds of miles away.

1086 In the WUS it is often necessary to extend the investigations to great distances (up to
1087 hundreds of kilometers) to characterize a major tectonic structure, such as the San Gregorio-
1088 Hosgri Fault Zone and the Juan de Fuca Subduction Zone. On the other hand, in the WUS it is
1089 not usually necessary to extend the regional investigations that far in all directions. For example,
1090 for a site such as Diablo Canyon, which is near the San Gregorio-Hosgri Fault, it would not be
1091 necessary to extend the regional investigations farther east than the dominant San Andreas
1092 Fault, which is about 75 km (45 mi) from the site; nor west beyond the Santa Lucia Banks Fault,
1093 which is about 45 km (27 mi). Justification for using lesser distances should be provided.

1094 Reconnaissance-level investigations, which may need to be supplemented at specific
1095 locations by more detailed explorations such as geologic mapping, geophysical surveying,
1096 borings, and trenching, should be conducted to a distance of 40 km (25 mi) from the site; the data
1097 should be presented at a scale of 1:50,000 or smaller.

1098 Detailed investigations should be carried out within a radius of 8 km (5 mi) from the site,
1099 and the resulting data should be presented at a scale of 1:5,000 or smaller. The level of
1100 investigations should be in sufficient detail to delineate the geology and the potential for tectonic
1101 deformation at or near the ground surface. The investigations should use the methods described
1102 in subsections D.2.2 and D.2.3 that are appropriate for the tectonic regime to characterize
1103 seismic sources.

1104 The areas of investigations may be asymmetrical and may cover larger areas than those
1105 described above in regions of late Quaternary activity, regions with high rates of historical seismic
1106 activity (felt or instrumentally recorded data), or sites that are located near a capable tectonic
1107 source such as a fault zone.

1108 Data from investigations at the site (approximately 1 km²) should be presented at a scale
1109 of 1:500 or smaller. Important aspects of the site investigations are the excavation and logging of
1110 exploratory trenches and the mapping of the excavations for the plant structures, particularly
1111 plant structures that are characterized as Seismic Category I. In addition to geological,
1112 geophysical, and seismological investigations, detailed geotechnical engineering investigations,
1113 as described in Regulatory Guide 1.132 (Ref. D.5) and NUREG/CR-5738 (Ref. D.6), should be
1114 conducted at the site.

1115 The investigations needed to assess the suitability of the site with respect to effects of
1116 potential ground motions and surface deformation should include determination of (1) the
1117 lithologic, stratigraphic, geomorphic, hydrologic, geotechnical, and structural geologic
1118 characteristics of the site and the area surrounding the site, including its seismicity and geological
1119 history, (2) geological evidence of fault offset or other distortion such as folding at or near ground
1120 surface within the site area (8 km radius), and (3) whether or not any faults or other tectonic
1121 structures, any part of which are within a radius of 8 km (5 mi) from the site, are capable tectonic
1122 sources. This information will be used to evaluate tectonic structures underlying the site area,
1123 whether buried or expressed at the surface, with regard to their potential for generating
1124 earthquakes and for causing surface deformation at or near the site. This part of the evaluation
1125 should also consider the possible effects caused by human activities such as withdrawal of fluid
1126 from or addition of fluid to the subsurface, extraction of minerals, or the loading effects of dams
1127 and reservoirs.

1128 **D.2.2 Reconnaissance Investigations, Literature Review, and Other Sources of** 1129 **Preliminary Information**

1130 Regional literature and reconnaissance-level investigations should be planned based on
1131 reviews of available documents and the results of previous investigations. Possible sources of
1132 information, in addition to refereed papers published in technical journals, include universities,
1133 consulting firms, and government agencies. The following guidance is provided but it is not
1134 considered all-inclusive. Some investigations and evaluations will not be applicable to every site,
1135 and situations may occur that require investigations that are not included in the following
1136 discussion. In addition, it is anticipated that new technologies will be available in the future that
1137 will be applicable to these investigations.

1138 **D.2.3 Detailed Site Vicinity and Site Area Investigations**

1139 The following methods are suggested but they are not all-inclusive and investigations
1140 should not be limited to them. Some procedures will not be applicable to every site, and
1141 situations will occur that require investigations that are not included in the following discussion. It
1142 is anticipated that new technologies will be available in the future that will be applicable to these
1143 investigations.

1144 **D.2.3.1 Surface Investigations**

1145 Surface exploration to assess the geology and geologic structure of the site area is
1146 dependent on the site location and may be carried out with the use of any appropriate
1147 combination of the geological, geophysical, and seismological techniques summarized in the
1148 following paragraphs. However, not all of these methods must be carried out at a given site.

1149 **D.2.3.1.1.** Geological interpretations should be performed of aerial photographs and other
1150 remote-sensing as appropriate for the particular site conditions, to assist in identifying rock

1151 outcrops, faults and other tectonic features, fracture traces, geologic contacts, lineaments, soil
1152 conditions, and evidence of landslides or soil liquefaction.

1153 **D.2.3.1.2.** Mapping topographic, geomorphic, and hydrologic features should be
1154 performed at scales and with contour intervals suitable for analysis and descriptions of
1155 stratigraphy (particularly Quaternary), surface tectonic structures such as fault zones, and
1156 Quaternary geomorphic features. For coastal sites or sites located near lakes or rivers, this
1157 includes topography, geomorphology (particularly mapping marine and fluvial terraces),
1158 bathymetry, geophysics (such as seismic reflection), and hydrographic surveys to the extent
1159 needed to describe the site area features.

1160 **D.2.3.1.3.** Vertical crustal movements should be evaluated using: (1) geodetic land
1161 surveying and (2) geological analyses (such as analysis of regional dissection and degradation
1162 patterns), marine and lacustrine terraces and shorelines, fluvial adjustments (such as changes in
1163 stream longitudinal profiles or terraces), and other long-term changes (such as elevation changes
1164 across lava flows).

1165 **D.2.3.1.4.** Analysis should be performed to determine the tectonic significance of offset,
1166 displaced, or anomalous landforms such as displaced stream channels or changes in stream
1167 profiles or the upstream migration of knick-points; abrupt changes in fluvial deposits or terraces;
1168 changes in paleo-channels across a fault; or uplifted, down-dropped, or laterally displaced marine
1169 terraces.

1170 **D.2.3.1.5.** Analysis should be performed to determine the tectonic significance of
1171 Quaternary sedimentary deposits within or near tectonic zones such as fault zones, including (1)
1172 fault-related or fault-controlled deposits such as sag ponds, graben fill deposits, and colluvial
1173 wedges formed by the erosion of a fault paleo-scarp, and (2) non-fault-related, but offset,
1174 deposits such as alluvial fans, debris cones, fluvial terrace, and lake shoreline deposits.

1175 **D.2.3.1.6.** Identification and analysis should be performed of deformation features caused
1176 by vibratory ground motions, including seismically induced liquefaction features (sand boils,
1177 explosion craters, lateral spreads, settlement, soil flows), mud volcanoes, landslides, rockfalls,
1178 deformed lake deposits or soil horizons, shear zones, cracks or fissures.

1179 **D.2.3.1.7.** Analysis should be performed of fault displacements, including the
1180 interpretation of the morphology of topographic fault scarps associated with or produced by
1181 surface rupture. Fault scarp morphology is useful for estimating the age of last displacement (in
1182 conjunction with the appropriate geochronological methods described NUREG/CR-5562 (Ref.
1183 D.6), approximate magnitude of the associated earthquake, recurrence intervals, slip rate, and
1184 the nature of the causative fault at depth.

1185 **D.2.3.2 Subsurface Investigations at the Site [within 1 km (0.5 mi)]**

1186 Subsurface investigations at the site to identify and describe potential seismogenic
1187 sources or capable tectonic sources and to obtain required geotechnical information are
1188 described in Regulatory Guide 1.132 (Ref. D.5) and updated in NUREG/CR-5738 (Ref. D.7). The
1189 investigations include, but may not be confined to, the following:

1190 **D.2.3.2.1.** Geophysical investigations that have been useful in the past include magnetic
1191 and gravity surveys, seismic reflection and seismic refraction surveys, bore-hole geophysics,
1192 electrical surveys, and ground-penetrating radar surveys.

1193

1194 **D.2.3.2.2.** Core borings to map subsurface geology and obtain samples for testing such
1195 as determining the properties of the subsurface soils and rocks and geochronological analysis;

1196 **D.2.3.2.3.** Excavation and logging of trenches across geological features to obtain
1197 samples for the geochronological analysis of those features.

1198 **D.2.3.2.4.** At some sites, deep unconsolidated material/soil, bodies of water, or other
1199 material may obscure geologic evidence of past activity along a tectonic structure. In such cases,
1200 the analysis of evidence elsewhere along the structure can be used to evaluate its characteristics
1201 in the vicinity of the site.

1202 In the CEUS it may not be possible to reasonably demonstrate the age of youngest
1203 activity on a tectonic structure with adequate deterministic certainty. In such cases the
1204 uncertainty should be quantified; the NRC staff will accept evaluations using the methods
1205 described in NUREG/CR-5503 (Ref. D.3). A demonstrated tectonic association of such
1206 structures with geologic structural features or tectonic processes that are geologically old (at least
1207 pre-Quaternary) should be acceptable as an age indicator in the absence of conflicting evidence.

1208 **D.2.3.3 Surface-Fault Rupture and Associated Deformation at the Site**

1209 A site that has a potential for fault rupture at or near the ground surface and associated
1210 deformation should be avoided. Where it is determined that surface deformation need not be
1211 taken into account, sufficient data or detailed studies to reasonably support the determination
1212 should be presented. Requirements for setback distance from active faults for hazardous waste
1213 treatment, storage and disposal facilities can be found in U.S. Environmental Protection Agency
1214 regulations (40 CFR Part 264).

1215 The presence or absence of Quaternary faulting at the site needs to be evaluated to
1216 determine whether there is a potential hazard that is due to surface faulting. The potential for
1217 surface fault rupture should be characterized by evaluating (1) the location and geometry of faults
1218 relative to the site, (2) nature and amount of displacement (sense of slip, cumulative slip, slip per
1219 event, and nature and extent of related folding and/or secondary faulting), and (3) the likelihood
1220 of displacement during some future period of concern (recurrence interval, slip rate, and elapsed
1221 time since the most recent displacement). Acceptable methods and approaches for conducting
1222 these evaluations are described in NUREG/CR-5503 (Ref. D.3); acceptable geochronology dating
1223 methods are described in NUREG/CR-5562 (Ref. D.7).

1224 For assessing the potential for fault displacement, the details of the spatial pattern of the
1225 fault zone (e.g., the complexity of fault traces, branches, and en echelon patterns) may be
1226 important as they may define the particular locations where fault displacement may be expected
1227 in the future. The amount of slip that might be expected to occur can be evaluated directly based
1228 on paleoseismic investigations or it can be estimated indirectly based on the magnitude of the
1229 earthquake that the fault can generate.

1230 Both non-tectonic and tectonic deformation can pose a substantial hazard to an ISFSI or
1231 MRS, but there are likely to be differences in the approaches used to resolve the issues raised by
1232 the two types of phenomena. Therefore, non-tectonic deformation should be distinguished from
1233 tectonic deformation at a site. In past nuclear power plant licensing activities, surface
1234 displacements caused by phenomena other than tectonic phenomena have been confused with
1235 tectonically induced faulting. Such structures, such as found in karst terrain; and growth faulting,
1236 occurring in the Gulf Coastal Plain or in other deep soil regions, cause extensive subsurface fluid
1237 withdrawal.

1238 Glacially induced faults generally do not represent a deep-seated seismic or fault
1239 displacement hazard because the conditions that created them are no longer present. However,
1240 residual stresses from Pleistocene glaciation may still be present in glaciated regions, although
1241 they are of less concern than active tectonically induced stresses. These features should be
1242 investigated with respect to their relationship to current in situ stresses.

1243 The nature of faults related to collapse features can usually be defined through
1244 geotechnical investigations and can either be avoided or, if feasible, adequate engineering fixes
1245 can be provided.

1246 Large, naturally occurring growth faults as found in the coastal plain of Texas and
1247 Louisiana can pose a surface displacement hazard, even though offset most likely occurs at a
1248 much less rapid rate than that of tectonic faults. They are not regarded as having the capacity to
1249 generate damaging vibratory ground motion, can often be identified and avoided in siting, and
1250 their displacements can be monitored. Some growth faults and antithetic faults related to growth
1251 faults and fault zones should be applied in regions where growth faults are known to be present.
1252 Local human-induced growth faulting can be monitored and controlled or avoided.

1253 If questionable features cannot be demonstrated to be of non-tectonic origin, they should
1254 be treated as tectonic deformation.

1255 **D.2.4 Site Geotechnical Investigations and Evaluations**

1256 **D.2.4.1 Geotechnical Investigations**

1257 The geotechnical investigations should include, but not necessarily be limited to, (1)
1258 defining site soil and near-surface geologic strata properties as may be required for hazard
1259 evaluations, engineering analyses, and seismic design, (2) evaluating the effects of local soil and
1260 site geologic strata on ground motion at the ground surface, (3) evaluating dynamic properties of
1261 the near-surface soils and geologic strata, (4) conducting soil-structure interaction analyses, and
1262 (5) assessing the potential for soil failure or deformation induced by ground shaking (liquefaction,
1263 differential compaction, land sliding).

1264 The extent of investigation to determine the geotechnical characteristics of a site depends
1265 on the site geology and subsurface conditions. By working with experienced geotechnical
1266 engineers and geologists, an appropriate scope of investigations can be developed for a
1267 particular facility following the guidance contained in Regulatory Guide 1.132 (Ref. D.5) updated
1268 with NUREG/CR-5738 (Ref. D.6). The extent of subsurface investigations is dictated by the
1269 foundation requirements and by the complexity of the anticipated subsurface conditions. The
1270 locations and spacing of borings, soundings, and exploratory excavations should be chosen to
1271 adequately define subsurface conditions. Subsurface explorations should be chosen to
1272 adequately define subsurface conditions; exploration sampling points should be located to permit
1273 the construction of geological cross sections and soil profiles through foundations of safety-
1274 related structures and other important locations at the site.

1275 Sufficient geophysical and geotechnical data should be obtained to allow for reasonable
1276 assessments of representative soil profile and soil parameters and to reasonably quantify
1277 variability. The guidance found in Regulatory Guide 1.132 (Ref. D.5) and NUREG/CR-5738 (Ref.
1278 D.6) is acceptable. In general, this guidance should be adapted to the requirements of the site to
1279 establish the scope of geotechnical investigations for the site as well as the appropriate methods
1280 that will be used.

1281 For ISFSIs co-located with existing nuclear plants, site investigations should be conducted
 1282 if the existing site information is not available or insufficient. Soil/rock profiles (cross-sections) at
 1283 the locations of the facilities should be provided based on the results of site investigations. The
 1284 properties required are intimately linked to the designs and evaluations to be conducted. For
 1285 example, for analyses of soil response effects, assessment of strain dependent-soil-dynamic
 1286 modulus and damping characteristics are required. An appropriate site investigation program
 1287 should be developed in consultation with the geotechnical engineering representative of the
 1288 project team.

1289 Subsurface conditions should be investigated by means of borings, soundings, well logs,
 1290 exploratory excavations, sampling, geophysical methods (e.g., cross-hole, down-hole, and
 1291 geophysical logging) that adequately assess soil and ground water conditions and other methods
 1292 described in NUREG/CR-5738 (Ref. D.6). Appropriate investigations should be made to
 1293 determine the contribution of the subsurface soils and rocks to the loads imposed on the
 1294 structures.

1295 A laboratory testing program should be carried out to identify and classify the subsurface
 1296 soils and rocks and to determine their physical and engineering properties. Laboratory tests for
 1297 both static and dynamic properties (e.g., shear modulus, damping, liquefaction resistance, etc.)
 1298 are generally required. The dynamic property tests should include, as appropriate, cyclic triaxial
 1299 tests, cyclic simple shear tests, cyclic torsional shear tests, and resonant column tests. Both
 1300 static and dynamic tests should be conducted as recommended in American Society for Testing
 1301 and Materials (ASTM) standards or test procedures acceptable to the staff. The ASTM
 1302 specification numbers for static and dynamic laboratory tests can be found in the annual books of
 1303 ASTM Standards, Volume 04.08. Examples of soil dynamic property and strength tests are
 1304 shown in Table D.1. Sufficient laboratory test data should be obtained to allow for reasonable
 1305 assessments of mean values of soil properties and their potential variability.

1306 For coarse geological materials such as coarse gravels and sand-gravel mixtures, special
 1307 testing equipment and testing facility should be used. Larger sample size is required for
 1308 laboratory tests on this type of materials (e.g., samples with 12-inch diameter were used in the
 1309 Rockfalls Testing Facility). It is generally difficult to obtain in situ undisturbed samples of
 1310 unconsolidated gravelly soils for laboratory tests. If it is not feasible to collect test samples and,
 1311 thus, no laboratory test results are available, the dynamic properties should be estimated from
 1312 the published data of similar gravelly soils.

1313 **Table D.1 Examples of Soil Dynamic Property and Strength Tests**

1314 1315	D 3999-91 (Ref. D.8)	Standard Test Method for the Determination of the Modulus and Damping Properties of Soils Using the Cyclic Triaxial Apparatus
1316 1317	D 4015-92 (Ref. D.9)	Standard Test Methods for Modulus and Damping of Soils by the Resonant-Column Method
1318 1319	D 5311-92 (Ref. D10)	Standard Test Method for Load-Controlled Cyclic Triaxial Strength of Soil

1320 **D.2.4.2 Seismic Wave Transmission Characteristics of the Site**

1321 To be acceptable, the seismic wave transmission characteristics (spectral amplification or
 1322 deamplification) of the materials overlying bedrock at the site are described as a function of the

1323 significant structural frequencies. The following material properties should be determined for
1324 each stratum under the site: (1) thickness, seismic compressional and shear wave velocities, (2)
1325 bulk densities, (3) soil index properties and classification, (4) shear modulus and damping
1326 variations with strain level, and (5) the water table elevation and its variation throughout the site.

1327 Where vertically propagating shear waves may produce the maximum ground motion, a
1328 one-dimensional equivalent-linear analysis or nonlinear analysis may be appropriate. Where
1329 horizontally propagating shear waves, compressional waves, or surface waves may produce the
1330 maximum ground motion, other methods of analysis may be more appropriate. However, since
1331 some of the variables are not well defined and investigative techniques are still in the
1332 developmental stage, no specific generally agreed-upon procedures can be recommended at this
1333 time. Hence, the staff must use discretion in reviewing any method of analysis. To ensure
1334 appropriateness, site response characteristics determined from analytical procedures should be
1335 compared with historical and instrumental earthquake data, when such data are available.

1336 **D.2.4.3 Site Response Analysis for Soil Sites**

1337 As part of quantification of earthquake ground motions at an ISFSI or MRS site, an
1338 analysis of soil response effects on ground motions should be performed. A specific analysis is
1339 not required at a hard rock site. Site response analyses (often referred to as site amplification
1340 analyses) are relatively more important when the site surficial soil layer is a soft clay and/or when
1341 there is a high stiffness contrast (wave velocity contrast) between a shallow soil layer and
1342 underlying bedrock. Such conditions have shown strong local soil effects on ground motion. Site
1343 response analyses are always important for sites that have predominant frequencies within the
1344 range of interest for the DE ground motions. Thus, the stiffness of the soil and bedrock as well
1345 as the depth of soil deposit should be carefully evaluated.

1346 In performing a site response analysis, the ground motions (usually acceleration time
1347 histories) defined at bedrock or outcrop are propagated through an analytical model of the site
1348 soils to determine the influence of the soils on the ground motions. The required soil parameters
1349 for the site response analysis include the depth, soil type, density, shear modulus and damping,
1350 and their variations with strain levels for each of the soil layers. Internal friction angle, cohesive
1351 strength, and over-consolidation ratio for clay are also needed for non-linear analyses. The strain
1352 dependent shear modulus and damping curves should be developed based on site-specific
1353 testing results and supplemented as appropriate by published data for similar soils. The effects
1354 of confining pressures (that reflect the depths of the soil) on these strain-dependent soil dynamic
1355 characteristics should be assessed and considered in site response analysis. The variability in
1356 these properties should be accounted in the site response analysis. The results of the site
1357 response analysis should show the input motion (rock response spectra), output motion (surface
1358 response spectra), and spectra amplification function (site ground motion transfer function).

1359 **D.2.4.4 Ground Motion Evaluations**

1360 **D.2.4.4.1.** Liquefaction is a soil behavior phenomenon in which cohesionless soils (sand,
1361 silt, or gravel) under saturated conditions lose a substantial part or all of their strength because of
1362 high pore water pressures generated in the soils by strong ground motions induced by
1363 earthquakes. Potential effects of liquefaction include reduction in foundation bearing capacity,
1364 settlements, land sliding and lateral movements, flotation of lightweight structures (such as tanks)
1365 embedded in the liquefied soil, and increased lateral pressures on walls retaining liquefied soil.
1366 Guidance in Draft Regulatory Guide DG-1105, "Procedures and Criteria for Assessing Seismic
1367 Soil Liquefaction at Nuclear Power Plant Sites" (Ref. D.11), is being developed to be used for
1368 evaluating the site for liquefaction potential.

1369 Investigations of liquefaction potential typically involve both geological and geotechnical
1370 engineering assessments. The parameters controlling liquefaction phenomena are (1) the
1371 lithology of the soil at the site, (2) the ground water conditions, (3) the behavior of the soil under
1372 dynamic loadings, and (4) the potential severity of the vibratory ground motion. The following
1373 site-specific data should be acquired and used along with state-of-the-art evaluation procedures
1374 (e.g., Ref. D.12, Ref. D.13).

- 1375 • Soil grain size distribution, density, static and dynamic strength, stress history, and
1376 geologic age of the sediments;
- 1377 • Ground water conditions;
- 1378 • Penetration resistance of the soil, e.g., Standard Penetration Test (SPT), Cone
1379 Penetration Test (CPT);
- 1380 • Shear wave velocity of the soil velocity of the soil;
- 1381 • Evidence of past liquefaction; and
- 1382 • Ground motion characteristics.

1383 A soil behavior phenomenon similar to liquefaction is strength reduction in sensitive clays.
1384 Although this behavior phenomenon is relatively rare in comparison to liquefaction, it should not
1385 be overlooked as a potential cause for land sliding and lateral movements. Therefore, the
1386 existence of sensitive clays at the site should be identified.

1387 **D.2.4.4.2.** Ground settlement during and after an earthquake that is due to dynamic loads,
1388 change of ground water conditions, soil expansion, soil collapse, erosion, and other causes must
1389 be considered. Ground settlement that is due to the ground shaking induced by an earthquake
1390 can be caused by two factors: (1) compaction of dry sands by ground shaking and (2)
1391 settlement caused by dissipation of dynamically induced pore water in saturated sands.
1392 Differential settlement would cause more damage to facilities than would uniform settlement.
1393 Differential compaction of cohesionless soils and resulting differential ground settlement can
1394 accompany liquefaction or may occur in the absence of liquefaction. The same types of geologic
1395 information and soil data used in liquefaction potential assessments, such as the SPT value, can
1396 also be used in assessing the potential for differential compaction. Ground subsidence has been
1397 observed at the surface above relatively shallow cavities formed by mining activities (particularly
1398 coal mines) and where large quantities of salt, oil, gas, or ground water have been extracted (Ref.
1399 D.14). Where these conditions exist near a site, consideration and investigation must be given to
1400 the possibility that surface subsidence will occur.

1401 **D.2.4.4.3.** The stability of natural and man-made slopes must be evaluated when their
1402 failures would affect the safety and operation of an ISFSI or MRS. In addition to land sliding
1403 facilitated by liquefaction-induced strength reduction, instability and deformation of hillside and
1404 embankment slopes can occur from the ground shaking inertia forces causing a temporary
1405 exceedance of the strength of soil or rock. The slip surfaces of previous landslides, weak planes
1406 or seams of subsurface materials, mapping and dating paleo-slope failure events, loss of shear
1407 strength of the materials caused by the natural phenomena hazards such as liquefaction or
1408 reduction of strength due to wetting, hydrological conditions including pore pressure and
1409 seepage, and loading conditions imposed by the natural phenomena events must all be
1410 considered in determining the potential for instability and deformations. Various possible modes

1411 of failure should be considered. Both static and dynamic analyses must be performed for the
1412 stability of the slopes.

1413 The following information, at a minimum, is to be collected for the evaluation of slope
1414 instability:

- 1415 • Slope cross sections covering areas that would be affected the slope stability;
- 1416 • Soil and rock profiles within the slope cross sections;
- 1417 • Static and dynamic soil and rock properties, including densities, strengths, and
1418 deformability;
- 1419 • Hydrological conditions and their variations; and
- 1420 • Rock fall events.

1421 **D.2.5 Geochronology**

1422 An important part of the geologic investigations to identify and define potential seismic
1423 sources is the geochronology of geologic materials. An acceptable classification of dating
1424 methods is based on the rationale described in Reference D.15. The following techniques, which
1425 are presented according to that classification, are useful in dating Quaternary deposits.

1426 **D.2.5.1 Sidereal Dating Methods**

- 1427 • Dendrochronology
- 1428 • Varve chronology
- 1429 • Schlerochronology
- 1430 • Schlerochronology

1431 **D.2.5.2 Isotopic Dating Methods**

- 1433 • Radiocarbon
- 1434 • Cosmogenic nuclides - ^{36}Cl , ^{10}Be , ^{21}Pb , and ^{26}Al
- 1435 • Potassium argon and argon-39-argon-40
- 1436 • Uranium series - ^{234}U - ^{230}Th and ^{235}U - ^{231}Pa
- 1437 • ^{210}Pb
- 1438 • Uranium-lead, thorium-lead

1439 **D.2.5.3 Radiogenic Dating Methods**

- 1440 • Fission track
- 1441 • Luminescence

- 1442
1443
- Electron spin resonance

1444 **D.2.5.4 Chemical and Biological Dating Methods**

- 1445
- Amino acid racemization
- 1446
- Obsidian and tephra hydration
- 1447
- Lichenometry

1448 **D.2.5.6 Geomorphic Dating Methods**

- 1449
- Soil profile development
- 1450
- Rock and mineral weathering
- 1451
- Scarp morphology

1452 **D.2.5.7 Correlation Dating Methods**

- 1453
- Paleomagnetism (secular variation and reversal stratigraphy)
- 1454
- Tephrochronology
- 1455
- Paleontology (marine and terrestrial)
- 1456
- Global climatic correlations - Quaternary deposits and landforms, marine stable isotope records, etc.
- 1457

1458 In the CEUS, it may not be possible to reasonably demonstrate the age of last activity of a
1459 tectonic structure. In such cases the NRC staff will accept association of such structures with
1460 geologic structural features or tectonic processes that are geologically old (at least pre-
1461 Quaternary) as an age indicator in the absence of conflicting evidence.

1462 These investigative procedures should also be applied, where possible, to characterize
1463 offshore structures (faults or fault zones, and folds, uplift, or subsidence related to faulting at
1464 depth) for coastal sites or those sites located adjacent to landlocked bodies of water.
1465 Investigations of offshore structures will rely heavily on seismicity, geophysics, and bathymetry
1466 rather than conventional geologic mapping methods that normally can be used effectively
1467 onshore. However, it is often useful to investigate similar features onshore to learn more about
1468 the significant offshore features.

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1507 **APPENDIX E**

1508 **PROCEDURE FOR THE EVALUATION OF NEW GEOSCIENCES INFORMATION OBTAINED**
1509 **FROM THE SITE-SPECIFIC INVESTIGATIONS**

1510 **E.1 INTRODUCTION**

1511 This appendix provides methods acceptable to the NRC staff for assessing the impact of
1512 new information obtained during site-specific investigations on the data base used for the
1513 probabilistic seismic hazard analyses (PSHA).

1514 Regulatory Position 4 in this guide describes acceptable PSHAs that were developed by
1515 the Lawrence Livermore National Laboratory (LLNL) and the Electric Power Research Institute
1516 (EPRI) to characterize the seismic hazard for nuclear power plants and to develop the Safe
1517 Shutdown Earthquake (SSE). The procedure to determine the design earthquake ground motion
1518 (DE) outlined in this guide relies primarily on either the LLNL or EPRI PSHA results for the
1519 Central and Eastern United States (CEUS).

1520 It is necessary to evaluate the geological, seismological, and geophysical data obtained
1521 from the site-specific investigations to demonstrate that these data are consistent with the PSHA
1522 data bases of these two methodologies. If new information identified by the site-specific
1523 investigations would result in a significant increase in the hazard estimate for a site, and this new
1524 information is validated by a strong technical basis, the PSHA may have to be modified to
1525 incorporate the new technical information. Using sensitivity studies, it may also be possible to
1526 justify a lower hazard estimate with an exceptionally strong technical basis. However, it is
1527 expected that large uncertainties in estimating seismic hazard in the CEUS will continue to exist
1528 in the future, and substantial delays in the licensing process will result from trying to justify a
1529 lower value with respect to a specific site.

1530 In general, major recomputations of the LLNL and EPRI data base are planned
1531 periodically (approximately every 10 years), or when there is an important new finding or
1532 occurrence. The overall revision of the data base will also require a reexamination of the
1533 reference probability discussed in Appendix B.

1534 **E.2 POSSIBLE SOURCES OF NEW INFORMATION THAT COULD AFFECT THE SSE**

1535 Types of new data that could affect the PSHA results can be put in three general
1536 categories: seismic sources, earthquake recurrence models or rates of deformation, and ground
1537 motion models.

1538 **E.2.1 Seismic Sources**

1539 There are several possible sources of new information from the site-specific investigations
1540 that could affect the seismic hazard. Continued recording of small earthquakes, including
1541 microearthquakes, may indicate the presence of a localized seismic source. Paleoseismic
1542 evidence, such as paleoliquefaction features or displaced Quaternary strata, may indicate the
1543 presence of a previously unknown tectonic structure or a larger amount of activity on a known
1544 structure than was previously considered. Geophysical studies (aeromagnetic, gravity, and
1545 seismic reflection/refraction) may identify crustal structures that suggest the presence of
1546 previously unknown seismic sources. In situ stress measurements and the mapping of tectonic
1547 structures in the future may indicate potential seismic sources.

1548 Detailed local site investigations often reveal faults or other tectonic structures that were
1549 unknown, or reveal additional characteristics of known tectonic structures. Generally, based on
1550 past licensing experience in the CEUS, the discovery of such features will not require a
1551 modification of the seismic sources provided in the LLNL and EPRI studies. However, initial
1552 evidence regarding a newly discovered tectonic structure in the CEUS is often equivocal with
1553 respect to activity, and additional detailed investigations are required. By means of these detailed
1554 investigations, and based on past licensing activities, previously unidentified tectonic structures
1555 can usually be shown to be inactive or otherwise insignificant to the seismic design basis of the
1556 facility, and a modification of the seismic sources provided by the LLNL and EPRI studies will not
1557 be required. On the other hand, if the newly discovered features are relatively young, possibly
1558 associated with earthquakes that were large and could impact the hazard for the proposed
1559 facility, a modification may be required.

1560 Of particular concern is the possible existence of previously unknown, potentially active
1561 tectonic structures that could have moderately sized, but potentially damaging, near-field
1562 earthquakes or could cause surface displacement. Also of concern is the presence of structures
1563 that could generate larger earthquakes within the region than previously estimated.

1564 Investigations to determine whether there is a possibility for permanent ground
1565 displacement are especially important in view of the provision to allow for a combined licensing
1566 procedure under 10 CFR Part 52 as an alternative to the two-step procedure of the past
1567 (Construction Permit and Operating License). In the past at numerous nuclear power plant sites,
1568 potentially significant faults were identified when excavations were made during the construction
1569 phase prior to the issuance of an operating license, and extensive additional investigations of
1570 those faults had to be carried out to properly characterize them.

1571 **E.2.2 Earthquake Recurrence Models**

1572 There are three elements of the source zone's recurrence models that could be affected
1573 by new site-specific data: (1) the rate of occurrence of earthquakes, (2) their maximum
1574 magnitude, and (3) the form of the recurrence model (e.g., a change from truncated exponential
1575 to a characteristic earthquake model). Among the new site-specific information that is most likely
1576 to have a significant impact on the hazard is the discovery of paleoseismic evidence such as
1577 extensive soil liquefaction features, which would indicate with reasonable confidence that much
1578 larger estimates of the maximum earthquake than those predicted by the previous studies would
1579 ensue. The paleoseismic data could also be significant even if the maximum magnitudes of the
1580 previous studies are consistent with the paleo-earthquakes if there are sufficient data to develop
1581 return period estimates significantly shorter than those previously used in the probabilistic
1582 analysis. The paleoseismic data could also indicate that a characteristic earthquake model would
1583 be more applicable than a truncated exponential model.

1584 In the future, expanded earthquake catalogs will become available that will differ from the
1585 catalogs used by the previous studies. Generally, these new catalogues have been shown to
1586 have only minor impacts on estimates of the parameters of the recurrence models. Cases that
1587 might be significant include the discovery of records that indicate earthquakes in a region that
1588 had no seismic activity in the previous catalogs, the occurrence of an earthquake larger than the
1589 largest historic earthquakes, re-evaluating the largest historic earthquake to a significantly larger
1590 magnitude, or the occurrence of one or more moderate to large earthquakes (magnitude 5.0 or
1591 greater) in the CEUS.

1592 Geodetic measurements, particularly satellite-based networks, may provide data and
1593 interpretations of rates and styles of deformation in the CEUS that can have implications for
1594 earthquake recurrence. New hypotheses regarding present-day tectonics based on new data or
1595 reinterpretation of old data may be developed that were not considered or given high weight in
1596 the EPRI or LLNL PSHA. Any of these cases could have an impact on the estimated maximum
1597 earthquake if the result is larger than the values provided by LLNL and EPRI.

1598 **E.2.3 Ground Motion Attenuation Models**

1599 Alternative ground motion attenuation models may be used to determine the site-specific
1600 spectral shape as discussed in Regulatory Position 4 and Appendix F of this regulatory guide. If
1601 the ground motion models used are a major departure from the original models used in the
1602 hazard analysis and are likely to have impacts on the hazard results of many sites, a re-
1603 evaluation of the reference probability may be needed. Otherwise, a periodic (e.g., every 10
1604 years) reexamination of the PSHA and the associated data base is considered appropriate to
1605 incorporate new understanding regarding ground motion attenuation models.

1606 **E.3 PROCEDURE AND EVALUATION**

1607 The EPRI and LLNL studies provide a wide range of interpretations of the possible
1608 seismic sources for most regions of the CEUS, as well as a wide range of interpretations for all
1609 the key parameters of the seismic hazard model. The first step in comparing the new information
1610 with those interpretations is determining whether the new information is consistent with the
1611 following LLNL and EPRI parameters: (1) the range of seismogenic sources as interpreted by the
1612 seismicity experts or teams involved in the study, (2) the range of seismicity rates for the region
1613 around the site as interpreted by the seismicity experts or teams involved in the studies, and (3)
1614 the range of maximum magnitudes determined by the seismicity experts or teams. The new
1615 information is considered not significant and no further evaluation is needed if it is consistent with
1616 the assumptions used in the PSHA, no additional alternative seismic sources or seismic
1617 parameters are needed, or it supports maintaining or decreasing the site mean seismic hazard.

1618 An example is a new ISFSI co-located near an existing nuclear power plant site that was
1619 recently investigated by state-of-the-art geosciences techniques and evaluated by current hazard
1620 methodologies. Detailed geological, seismological, and geophysical site-specific investigations
1621 would be required to update existing information regarding the new site, but it is very unlikely that
1622 significant new information would be found that would invalidate the previous PSHA.

1623 On the other hand, after evaluating the results of the site-specific investigations, if there is
1624 still uncertainty about whether the new information will affect the estimated hazard, it will be
1625 necessary to evaluate the potential impact of the new data and interpretations on the mean of the
1626 range of the input parameters. Such new information may indicate the addition of a new seismic
1627 source, a change in the rate of activity, a change in the spatial patterns of seismicity, an increase
1628 in the rate of deformation, or the observation of a relationship between tectonic structures and
1629 current seismicity. The new findings should be assessed by comparing them with the specific
1630 input of each expert or team that participated in the PSHA. Regarding a new source, for
1631 example, the specific seismic source characterizations for each expert or team (such as tectonic
1632 feature being modeled, source geometry, probability of being active, maximum earthquake
1633 magnitude, or occurrence rates) should be assessed in the context of the significant new data
1634 and interpretations.

1635 It is expected that the new information will be within the range of interpretations in the
1636 existing data base, and the data will not result in an increase in overall seismicity rate or increase
1637 in the range of maximum earthquakes to be used in the probabilistic analysis. It can then be
1638 concluded that the current LLNL or EPRI results apply. It is possible that the new data may
1639 necessitate a change in some parameter. In this case, appropriate sensitivity analyses should be
1640 performed to determine whether the new site-specific data could affect the ground motion
1641 estimates at the reference probability level.

1642 An example is a consideration of the seismic hazard near the Wabash River Valley (Ref.
1643 E.1). Geological evidence found recently within the Wabash River Valley and several of its
1644 tributaries indicated that an earthquake much larger than any historic event had occurred several
1645 thousand years ago in the vicinity of Vincennes, Indiana. A review of the inputs by the experts
1646 and teams involved in the LLNL and EPRI PSHAs revealed that many of them had made
1647 allowance for this possibility in their tectonic models by assuming the extension of the New
1648 Madrid Seismic Zone northward into the Wabash Valley. Several experts had given strong
1649 weight to the relatively high seismicity of the area, including the number of magnitude five historic
1650 earthquakes that have occurred, and thus had assumed the larger event. This analysis of the
1651 source characterizations of the experts and teams resulted in the conclusion by the analysts that
1652 a new PSHA would not be necessary for this region because an event similar to the prehistoric
1653 earthquake had been considered in the existing PSHAs.

1654 A third step would be required if the site-specific geosciences investigations revealed
1655 significant new information that would substantially affect the estimated hazard. Modification of
1656 the seismic sources would more than likely be required if the results of the detailed local and
1657 regional site investigations indicate that a previously unknown seismic source is identified in the
1658 vicinity of the site. A hypothetical example would be the recognition of geological evidence of
1659 recent activity on a fault near a site in the SCR similar to the evidence found on the Meers Fault
1660 in Oklahoma (Ref. E.2). If such a source is identified, the same approach used in the active
1661 tectonic regions of the WUS should be used to assess the largest earthquake expected and the
1662 rate of activity. If the resulting maximum earthquake and the rate of activity are higher than those
1663 provided by the LLNL or EPRI experts or teams regarding seismic sources within the region in
1664 which this newly discovered tectonic source is located, it may be necessary to modify the existing
1665 interpretations by introducing the new seismic source and developing modified seismic hazard
1666 estimates for the site. The same would be true if the current ground motion models are a major
1667 departure from the original models. These occurrences would likely require performing a new
1668 PSHA using the updated data base, and may require determining the appropriate reference
1669 probability.

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1674 Power Plants," to 10 CFR Part 100; Enclosure (Viewgraphs): NUMARC, "Development
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1678 Southwestern Oklahoma," NUREG/CR-4852, USNRC, March 1987.²

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

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

APPENDIX F

PROCEDURE TO DETERMINE THE DESIGN EARTHQUAKE GROUND MOTION

F.1 INTRODUCTION

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

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

F.2 DISCUSSION

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

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

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

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

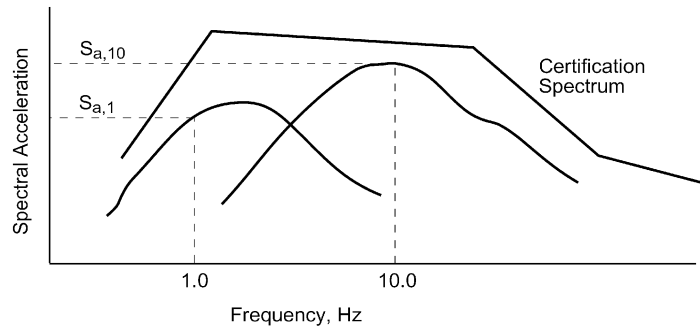


Figure F.1 Use of DE Spectrum of a Certified Design

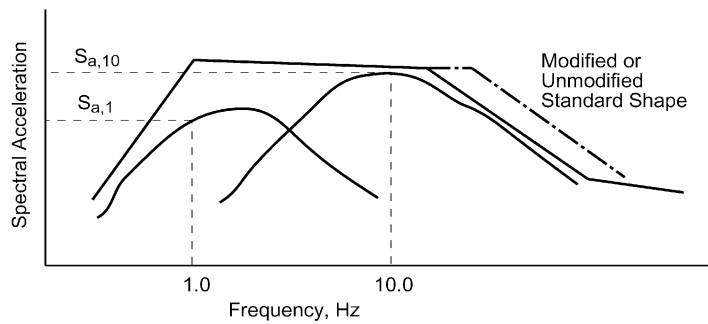


Figure F.2 Use of a Standard Shape for DE

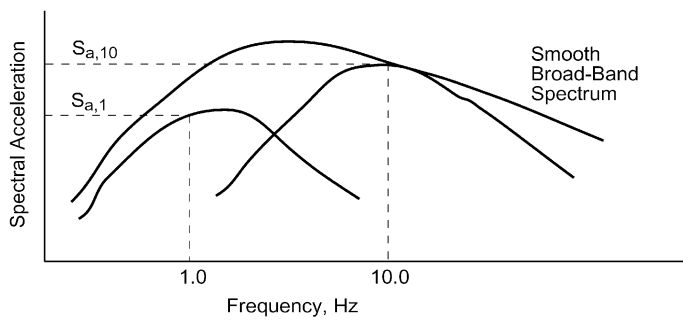


Figure F.3 Development of a Site-Specific DE Spectrum

illustrate
For other site

1713 (Note: The above figures
1714 situations for a rock site.
1715 conditions, the DE spectra are compared at free-field after performing site amplification studies
1716 as discussed in Step 3 of Regulatory Position 4.)

1717

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- 1718 F.1 R.K. McGuire, W.J. Silva, and C.J. Constantino, "Technical Basis for Revision of
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1720 Ground Motion Spectra Guidelines," NUREG/CR-6728, 2001.¹
- 1721 F.2 U.S. NRC, "Design Response Spectra for Seismic Design of Nuclear Power Plants,"
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¹ Copies are available at current rates from the U.S. Government Printing Office, P.O. Box 37082, Washington, DC 20402-9328 (telephone (202)512-1800); or from the National Technical Information Service by writing NTIS at 5285 Port Royal Road, Springfield, VA 22161; (telephone (703)487-4650; <<http://www.ntis.gov/ordernow>>. Copies are available for inspection or copying for a fee from the NRC Public Document Room at 11555 Rockville Pike, Rockville, MD; the PDR's mailing address is USNRC PDR, Washington, DC 20555; telephone (301)415-4737 or (800)397-4209; fax (301)415-3548; email is PDR@NRC.GOV.

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REGULATORY ANALYSIS

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A separate regulatory analysis was not prepared for this draft regulatory guide. The regulatory analysis "Regulatory Analysis of Geological and Seismological Characteristics for and Design of Dry Cask Independent Spent Fuel Storage Installations (10 CFR Part 72)," was prepared for the amendments, and it provides the regulatory basis for this guide and examines the costs and benefits of the rule as implemented by the guide. A copy of the regulatory analysis is available for inspection and copying for a fee at the NRC Public Document Room, as Attachment __ to SECY-_____. 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>.