Response to

Request for Additional Information No. 8, Supplement 1, Revision 0

5/22/2008
U. S. EPR Standard Design Certification
AREVA NP Inc.
Docket No. 52-020
SRP Section: 19.01 - Determining the Technical Adequacy of Probabilistic Risk Assessment Results for Risk-Informed
Application Section: 19.1.5.1
SEB2 Branch

Question 19.01-1:

DCD, rev.0, Section 19.1.5.1.1 provides the seismic risk evaluation using a PRA-based seismic margin approach (SMA). As described in Subsection 19.1.5.1.1.2, the SMA was conducted in accordance with the NRC guidance in SECY 93-087 and a review level earthquake (RLE) was defined at 1.67 times the design basis SSE. The staff considers the Design Basis SSE as the certified seismic design response spectra (CSDRS) which includes the ground motion acceleration across the entire frequency range of interest. The staff also considers that the RLE is defined to be 1.67 times the SSE. The staff requests that AREVA incorporate the above staff position in the SMA assessment.

Response to Question 19.01-1:

The CSDRS for the U.S. EPR is shown in U.S. EPR Final Safety Analysis Report (FSAR) Tier 2 Figure 3.7.1-1. The CSDRS is the ground response spectra for European Utility Requirements (EUR) Control Motions Hard (EURH), Medium (EURM), and Soft (EURS) Soils. The PRA based seismic margin assessment was performed in accordance with the guidance in SECY 93-087, and demonstrates that there is a minimum seismic margin of 1.67 times the CSDRS (i.e., safe shutdown earthquake (SSE)).

The calculations of the seismic margin for different systems, structures, and components (SSC) were performed using the seismic fragility analysis method wherein the median seismic capacity and variabilities were estimated. Therefore, the median ground motion response spectral shape was used. AREVA NP used the NUREG/CR-0098 median shape for rock sites and for soil sites as the median ground motion spectra. These response spectra were confirmed to be conservative by comparing them with the Uniform Hazard Spectra at 1E-4 and 5E-5 annual probability of exceedance for the 28 sites studied by the Electric Power Institute (EPRI) (U.S. EPR FSAR Tier 2, Section 19.1.9, Reference 37). NUREG/CR-0098 median shapes were recommended for use in individual plant examination of external events (IPEEE) per NUREG-1407. Additionally, ANSI/ANS 58.21 (U.S. EPR FSAR Tier 2, Section 19.1.9, Reference 7) recommends the use of NUREG/CR-0098 shapes as one acceptable alternative for seismic margin assessment.

AREVA NP evaluated different ways of anchoring the ground motion spectra. An indicator recommended by EPRI TR-103959 (U.S. EPR FSAR Tier 2, Section 19.1.9, Reference 38) is the average peak spectral acceleration in the frequency range of interest (i.e., 2 to 10 Hz for this study). Based on U.S. EPR FSAR Tier 2, Figure 3.7.1-1, AREVA NP estimated this value to be 0.70g for EURH, 0.81g for EURM, and 0.87g for EURS. Therefore, the seismic margin requirement for the U.S. EPR is 1.67 times 0.70g (i.e., 1.17g average spectral acceleration for rock sites) and 1.45g for the envelope of the EURM and EURS soil sites.

The median ground motion response spectrum for rock sites meets or exceeds the requirements for average spectral acceleration of 1.17g; and meets or exceeds the peak spectral acceleration of the EURH for the requirement of 1.67 times the CSDRS. The average spectral acceleration of 1.3g was selected, which corresponds to a peak ground acceleration (PGA) of 0.61g. This ground motion response spectrum shape was used in the fragility analysis and is shown in Figure RAI 19.01-1-1.

The same methodology was used for soil sites. The median ground motion response spectrum for soil sites meets or exceeds the requirements for average spectral acceleration of 1.45g and meets or exceeds the peak spectral acceleration of the EURM and EURS for the requirement of 1.67 times the CSDRS. The average spectral acceleration of 1.55g was selected, which corresponds to a PGA of 0.73g. This ground motion response spectrum shape was used in the fragility analysis and is shown in Figure RAI 19.01-1-1. For rock and soil sites, these response spectra shapes meet or exceed the requirements to demonstrate minimum high confidence, low probability of failure (HCLPF) capacity of 1.67 times the design basis. The resulting response spectra are anchored to PGA values of 0.61g for rock and 0.73g for soil sites, which exceed the PGA target of 0.5g.

AREVA NP determined the in-structure response spectra for the Nuclear Island (NI) buildings. The primary modes of dynamic response are in the 2–10 Hz range as a function of site conditions and CSDRS definitions (see U.S. EPR FSAR Tier 2, Table 3.7.1-6 which provides the generic soil profiles and the corresponding CSDRS). The primary frequency range of interest for the softer soil sites and the EURS is 2–4 Hz. The primary frequency range of interest for the stiffer soil and rock sites is 4–8 Hz. The selected ground motion response spectral shapes are the appropriate shapes to represent these frequency ranges.

Figures RAI 19.01-1-1 and RAI 19.01-1-2 show the plot of the required 1.67 times the CSDRS, referred to as the review level earthquake (RLE), compared to the median NUREG/CR-0098 response spectra for rock and soil sites, referred to as the seismic margin earthquake (SME). For the rock case, the SME spectrum falls slightly below the RLE in the high frequency range. This does not impact the calculation of seismic margin of the SSCs for the following reasons:

- The overall structure response, and consequently the seismic design of the NI buildings and foundations, is governed by the low frequency response (i.e., the dynamic response in the 4–8 Hz range for very stiff soil and rock). In this frequency range, the seismic margin earthquake equals or exceeds the requirement of 1.67 times the CSDRS.

- Two physical aspects of rock-structure interaction, not modeled in the soil structure interaction analyses, will minimize these high frequency effects. Kinematic interaction (i.e., the spatial variation of the ground motion over the embedment depth of the NI buildings) in the soil or rock will significantly reduce peaks in the ISRS at frequencies above about 10 Hz. Taking into account incoherence of ground motion will further reduce any such peaks. Neither of these effects was included in the seismic design analyses performed for the U.S. EPR.

- The design and qualification of SSCs will be performed for the resulting in-structure response spectra (ISRS).

Based on the above information, the seismic margin earthquake ground motion response spectra shapes satisfy the regulatory requirements and guidance for seismic margin assessments.

U.S. EPR FSAR Tier 2, Sections 19.1.5.1.1.1 and 19.1.5.1.1.2 will be revised to reflect the information provided in this RAI response. Specifically:

- U.S. EPR FSAR Tier 2, Section 19.1.5.1.1.1 is being revised to revise the terminology in this section to be consistent with the RAI response.

- The majority of U.S. EPR FSAR Tier 2, Sections 19.1.5.1.1.2 has been deleted and replaced with the information in this RAI response.

- New Figure 19.1-31 has been added which reflects the information in Figures RAI 19.01-1-1 and RAI 19.01-1-2 attached to this RAI response.

FSAR Impact:

U.S. EPR FSAR Tier 2 Sections 19.1.5.1.1.1 and 19.1.5.1.1.2 will be revised as described in the response and indicated in the enclosed markup.

Figure RAI 19.01-1-1—Comparison of SME and RLE for Rock Site (EURH)

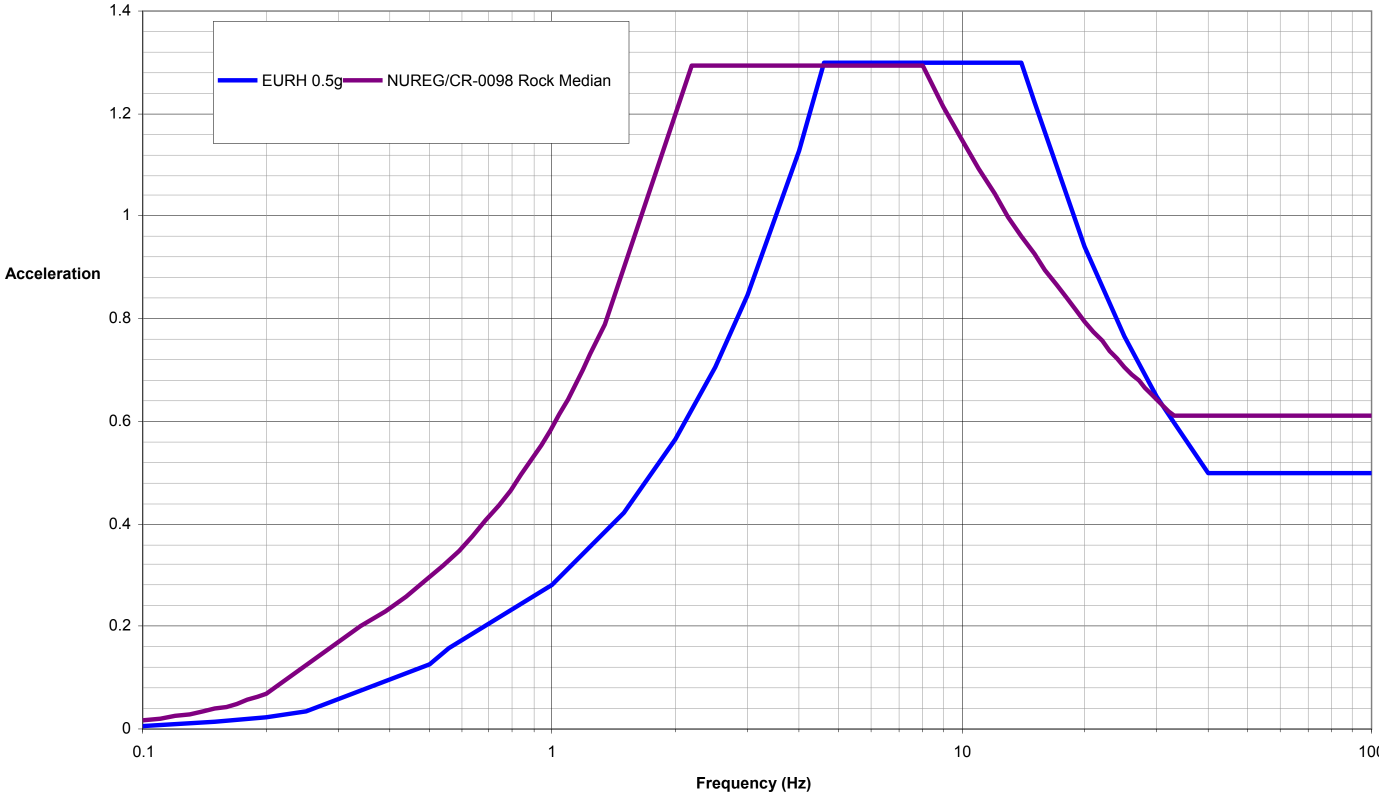
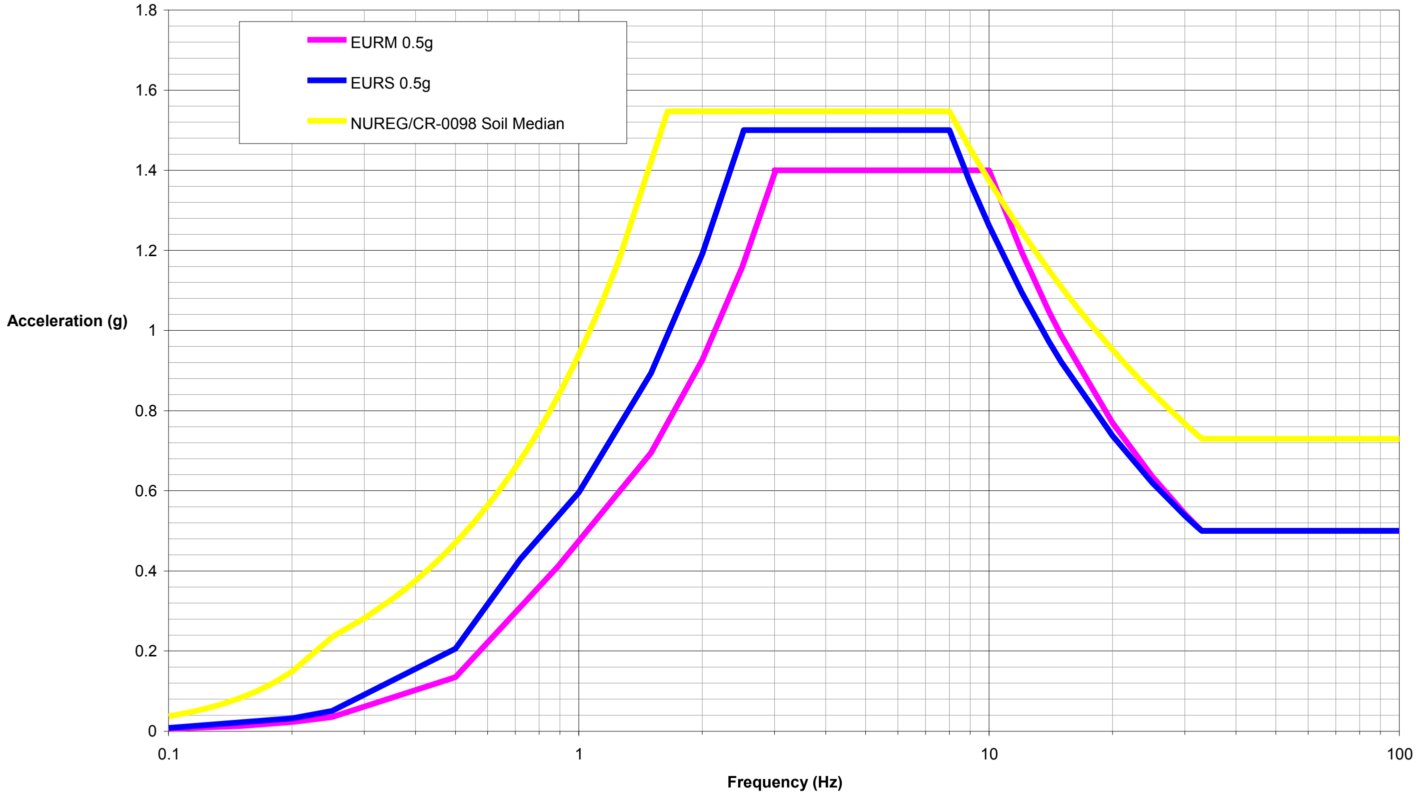


Figure RAI 19.01-1-2—Comparison of SME and RLE for Soil Sites



Question 19.01-2:

The staff considers the RLE to be the earthquake level for which the HCLPF capacities of structures, systems, and components (SSC) are estimated. In the 2nd paragraph of Subsection 19.1.5.1.1.2 of DCD, AREVA states "The RLE is the criterion to which the HCLPF values are compared." The staff considers this interpretation to be inconsistent with SECY 93-087. The staff requests that AREVA revise this statement to reflect the staff position on the use of RLE in the determination of HCLPF capacities.

Response to Question 19.01-2:

See AREVA NP's response to RAI No. 8, Supplement 1, Question 19.01-1. In accordance with the guidance of SECY 93-087, AREVA NP uses review level earthquake (RLE) as 1.67 times certified seismic design response spectra (CSDRS). AREVA NP has established a high confidence of low probability of failure (HCLPF) capacities of SSC using the NUREG/CR-0098 median ground motion spectra as the basis. Additionally, the minimum seismic margin for the standard plant exceeds the RLE.

FSAR Impact:

The U.S. EPR FSAR will be revised as described in the response to RAI No. 8, Supplement 1, Question 19.01-1 and indicated in the enclosed markup.

Question 19.01-3:

The staff believes that the HCLPF values should be estimated using the RLE for an SMA assessment. The 5th paragraph of Subsection 19.1.5.1.1.2 of DCD stated that "... the median ground response spectrum is taken to be the median ground response spectrum from NUREG/CR-0098, anchored to 0.3g." The staff requests that the AREVA clarify its position on this issue.

Response to Question 19.01-3:

See AREVA NP's response to RAI No. 8, Supplement 1, Question 19.01-1. For calculation of seismic fragilities, AREVA NP used NUREG/CR-0098 spectra as the median ground response spectra.

FSAR Impact:

The U.S. EPR FSAR will be revised as described in the response to RAI No. 8, Supplement 1, Question 19.01-1 and indicated in the enclosed markup.

Question 19.01-4:

The 1st paragraph of Subsection 19.1.5.1.1.3 of DCD states “The capacity of a component to maintain its function during and following strong ground motion and the uncertainties associated with that capacity were estimated on the basis of PGA.” Since Subsection 19.1.5.1.1.2 already stated that the SMA assessment computes HCLPFs based on averaged spectral values in the frequencies between 2 to 10 Hz, the HCLPF statements made in subsequent sections should be consistent with that HCLPF statement. The staff requests that AREVA makes corrections in this subsection and other sections, if such inconsistency is identified.

Response to Question 19.01-4:

AREVA NP concurs with the NRC comments. U.S. EPR FSAR Tier 2, Section 19.1.5.1.1.3 will be revised to address the inconsistencies noted in the NRC question.

FSAR Impact:

U.S. EPR FSAR Tier 2, Section 19.1.5.1.1.3 will be revised as described in the response and indicated in the enclosed markup.

Question 19.01-5:

DCD, rev 0, Section 19.1.5.1.1.4 describes accident sequences constructed for the SMA assessment. Event trees for at-power were provided for two initiating events: seismic induced loss of offsite power (S LOOP) and seismic induced small LOCA (S LOCA). Detailed delineation of these event trees were provided in Figures 19.1-10 and 19.1-11. S LOOP is typically considered in the seismic PRA due to its large contribution to CDF. However, it is not appropriate to include S LOOP in a SMA assessment, because of its lower seismic capacity (less than 0.1 g) and typically being assumed to fail for any seismic event and therefore, would not provide any useful insight in the plant HCLPF capacity (larger that a plant SSE). The staff requests that AVERA provide: 1) seismic induced initiating event categories such as structural failures, different sizes of LOCA, ATWS, vessel failure, etc., 2) associated event trees, and 3) fault trees logics for the systems appeared across the top of these event trees.

Response to Question 19.01-5:

The most likely event during an earthquake is a loss of offsite power (LOOP); since this is a probabilistic risk assessment (PRA) based seismic margin assessment (SMA), the LOOP event tree model was evaluated first in developing the seismic equipment list. A LOOP can occur with a probability of 1.0 from a qualitative seismic margins perspective. Then, a small loss of coolant accident (S LOCA) was assumed and evaluated with LOOP because there would be no leakage for large earthquakes even though the reactor coolant system (RCS) high confidence of low probability of failure (HCLPF) meets the review level earthquake (RLE) (1.67 times certified seismic design response spectra (CSDRS) as described in the response to Question 19.01-1). Additionally, since this is a PRA based SMA and there are other small LOCA causes such as reactor coolant pump (RCP) seal LOCA in the LOOP model, it is necessary to model small LOCA mitigation in developing the seismic equipment list. Although additional initiating event trees were not required and developed, the full spectrum of events were considered in the evaluation. The following summarizes treatment of other initiators:

- Structural Failures – the failure of key safety structures are assumed to cause core damage and they have high HCLPF values (>RLE) as described in the responses to RAI No. 8, Supplement 1, Questions 19.01-6 and 19.01-7. Since these are single element cutsets and have high seismic capacities there is no reason to create event trees or fault trees.
- Different Size LOCA – as described previously an S LOCA is assumed in developing the equipment list and evaluation. Sequences associated with larger LOCA sizes were not evaluated with event trees because the reactor coolant system (RCS) piping has a high capacity (>RLE as described in response to RAI No. 8, Supplement 1, Question 19.01-6) and core damage can be assumed if these events occurred. In addition, although the success criteria are different for larger LOCA sizes, there is no new equipment to evaluate.
- Anticipated Transient Without Scram (ATWS) – response to scram failure is included in the S LOOP and S LOCA event tree evaluations. The seismic capacity of the scram function is relatively high (HCLPF is greater than RLE) and failures go directly to core damage.
- Vessel Failure – similar to structural and RCS failure, this initiator is assumed to go directly to core damage. There is no reason to communicate this in an event tree or fault tree (HCLPF is greater than RLE).

Therefore, there is no need for additional event trees or fault trees because these additional initiating event failures of safety structures and piping represent core damage single element cutsets.

FSAR Impact:

The U.S. EPR FSAR will not be changed as a result of this question.

Question 19.01-6:

For the basic events (in terms of plant's SSCs) included in the fault trees, the staff requests that AREVA provide: 1) detailed description of methodologies employed for obtaining the SSC's HCLPF capacities, 2) detailed description of HCLPF capacities for SSC if obtained through calculations, and 3) strategies for ensuring adequate as-built HCLPF capacities for those SSCs whose capacities were determined by means other than calculations.

Response to Question 19.01-6:

1) The fragility analysis methodology described in Electric Power Research Institute (EPRI) TR-103959 (U.S. EPR FSAR Tier 2, Section 19.1.9, Reference 38) was followed in the U.S. EPR seismic margin assessment (SMA).

   Seismic capacities of buildings that house the safety-related systems were evaluated using a combination of design information and design criteria supplemented by generic information based on past seismic probabilistic risk assessments (PRA). Equipment capacities were estimated using the design and qualification criteria supplemented by generic design assumptions (e.g., standard anchorage design).

   In cases where component specific fragility evaluations were not feasible, fragility values were assigned as recommended in the EPRI Advanced Light Water Reactor Utility Requirements Document (ALWR URD)(U.S. EPR FSAR Tier 2, Section 19.1.9, Reference 14).

2) Table RAI 19.01-6-1 shows the calculated seismic fragilities of the safety-related buildings on a rock site based on design criteria and preliminary design details. As shown in Table RAI 19.01-6-2, seismic fragilities of the mechanical and electrical equipment on a rock site were either calculated using design and qualification criteria or assigned based on the EPRI ALWR URD. In Table RAI 19.01-6-2, AREVA NP has provided the "reasonably achievable" fragilities for a U.S. EPR plant on a rock site European Utility Requirements (EUR) Control Motions Hard Soils (EURH). The minimum high confidence of low probability of failure (HCLPF) capacities of structures and equipment considered in this PRA based SMA are larger than the 1.3g spectral acceleration averaged over a frequency range of 2 to 10 Hz.

   An examination of the models and criteria used in the seismic response analyses for soil sites rated European Utility Requirements (EUR) Control Motions Medium and Soft soils (EURM and EURS) determined that there is at least a safety factor of 1.25 over the rock sites arising from the conservatism in the soil-structure interaction (SSI) modeling. This factor applies to sites with uniform soil layers with different thicknesses and shear wave velocities. Therefore, the minimum seismic margin of structures and equipment of plants on these sites would be 1.6g (1.3g times 1.25) spectral acceleration averaged over the frequency range of 2 to 10 Hz. This exceeds the target of 1.5g average spectral acceleration.

3) Using a combination of U.S. EPR specific design criteria and generic information based on past studies, AREVA NP has determined that the seismic fragilities of components modeled in the PRA based SMA meet the required target values. These fragilities are

expected to be reasonably achievable. Actual capacities of structures and equipment are expected to exceed these capacities.

It was assumed that the anchorage design will follow ASME/ACI 349 Appendix B requirements and that the tensile failure of the bolt material will be the governing failure mode. Additionally, it was assumed that the anchorage capacity would be higher than the functional failure capacity of the equipment.

The fragility evaluation is based on the assumption that equipment will be installed as designed and that there are no potential spatial interaction concerns in the as-built configuration (e.g., adjacent cabinets are bolted together, collapse of non-seismically designed equipment or masonry wall onto safety-related equipment is precluded and no likelihood of seismically induced fire or flood impacting safety-related equipment).

U.S. EPR FSAR Tier 2, Section 19.1.5.1.1.3 will be revised to reflect the information in this RAI response and to add Table RAI 19.01-6-1 and Table RAI 19.01-6-2 (including appropriate renumbering).

FSAR Impact:

U.S. EPR FSAR Tier 2, Section 19.1.5.1.1.3 will be revised as described in the response and indicated in the enclosed markup.

Table RAI 19.01-6-1—U.S. EPR Safety-Related Structures Seismic Fragilities

Building/ Structure	Designation/ Location	Failure Mode	A_m (g)	β_R	β_U	HCLPF (g)
Reactor Bldg & Annulus (I)	0UJA, 0UJB	Shear failure of containment wall	8.9	0.25	0.41	3.0
Containment Internal Structure (I)	0UJA	Shear failure of internal structure walls	6.4	0.25	0.42	2.1
Safeguards Bldgs (I)	1UJH and 4UJH; 1UJK and 4UJK; 1UJE and 4UJE	Shear failure of concrete shear wall	4.9	0.26	0.41	1.6
Safeguards Bldgs (I)	UJH/UJK 2+3; UJE 2+3	Shear failure of concrete shear wall	5.8	0.26	0.42	1.9
Fuel Bldg (I)	0UFA	Shear failure of concrete shear wall	5.8	0.26	0.42	1.9
Diesel Bldgs (I)	1UBP through 4UBP	Shear failure of concrete shear wall	5.6	0.26	0.41	1.8
Nuclear Auxiliary Bldg (II)	0UKA	—	—	—	N/A	1.3

Table RAI 19.01-6-2—U.S. EPR Mechanical and Electrical Equipment Seismic Fragilities

Equipment Category	A_m g, spectral acceleration	β_R	β_U	HCLPF (g)
Battery	7.0	0.25	0.37	2.5
Cable Tray	7.9	0.34	0.43	2.2
Charger	4.3	0.26	0.39	1.5
Chiller	5.2	0.30	0.35	1.8
Compressor	5.2	0.20	0.40	1.9
Converter	4.3	0.26	0.39	1.5
Engine Generator	N/A	N/A	N/A	1.3
Fan	5.2	0.20	0.40	1.9
Filter	5.2	0.30	0.35	1.8
Instrument on Rack	—	—	—	1.3
Inverter	4.3	0.26	0.39	1.5
MCC	4.3	0.26	0.39	1.5
Offsite power	0.8	0.40	0.38	0.2
Piping	7.9	0.34	0.43	2.2
Pump	5.2	0.20	0.40	1.9
Switchgear	4.3	0.26	0.39	1.5
Tank	5.2	0.30	0.35	1.8
Transformer	6.2	0.25	0.37	2.2
Valve	7.9	0.34	0.43	2.2

Question 19.01-7:

DCD, rev 0, Section 19.1.5.1.1.5 states that “failures of structures which house safety-related systems were not added to the fault tree. These structures are expected to have high capacities, although their failures would also likely to cause core damage.” The staff considers that failures of Category I structures will lead directly to core damage. The staff requests that AREVA demonstrate in details that the structures housing safety systems possess the HCLPF capacity equal to 1.67 times CSDRS.

Response to Question 19.01-7:

AREVA NP has calculated the seismic fragilities of buildings housing safety-related systems based on the U.S. EPR design criteria and generic information based on past seismic probabilistic risk assessments (PRA) (see Table RAI 19.01-6-1). The high confidence of low probability of failure (HCLPF) capacities of these buildings range from 1.6g to 3.0g average spectral acceleration for rock sites. For soil sites, this range is 2.0g to 3.8g. This substantially exceeds the review level earthquake (RLE) of 1.3g and 1.5g for rock and soil sites, respectively. These high capacities preclude the need to add these structural failures to the fault trees.

U.S. EPR FSAR Tier 2 Sections 19.1.5.1.1.4, 19.1.5.1.1.5, and 19.1.5.1.2 will be revised to reflect the information in this response.

FSAR Impact:

U.S. EPR FSAR Tier 2 Sections 19.1.5.1.1.4, 19.1.5.1.1.5, and 19.1.5.1.2 will be revised as described in the response and indicated in the enclosed markup.

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Question 19.01-10:

Section 19.1.4.2.1.3 of DCD Tier 2 Revision 0 provides a high-level description of the containment pressure fragility development. However, an in-depth description and associated data are needed by the staff in its evaluation. The staff requests that the applicant provide: 1) a discussion to justify that the fragility was only developed for the temperature 170 C(338 F), 2) a discussion of the analytical process for estimating the median capacity and the composite logarithmic standard deviation used to establish the fragility curve in Figure 19.1-8, 3) a discussion of the failure criteria and material limits based for the fragility development, 4) a discussion of the failure modes for the six failure locations identified in Table 19.1-21, 5) material data utilized in the fragility development.

Response to Question 19.01-10:

1) A refinement of the calculation that determines the median failure pressures and values of Beta for the U.S. EPR containment structures has been performed. The detailed analysis resulting in the fragility of the containment was performed at 72.5º F (22.5 ºC) with a 6% reduction factor for temperature effects to be applied at 395ºF (202ºC).

   This reduction in containment capacity is not significant, and is attributable to reduced mechanical properties for the liner plate, thermal expansion of the liner plate, and heat transfer through the concrete wall. This lower pressure capacity was used to characterize the U.S. EPR containment capacity.

2) The composite fragility curve in the U.S. EPR FSAR Tier 2, Figure 19.1-8 was calculated according to the following equation:

$$\mathrm{P}_{fail}(p) = 1 - \prod_{i=1}^{6}[1 - P_{fail\,i}(p)]$$

   where

   $P_{fail}(p)$ is the probability that the containment as a whole will fail at a pressure less than or equal to P

   and

   $P_{faili}(p)$ is the probability that the individual failure locations will fail at a pressure less than or equal to P.

   The composite curve is not a lognormal function, and an estimated median capacity and the composite logarithmic standard deviation were not developed for the purposes of the load/capacity convolution. Instead, a sampling process, using the individual (lognormal) failure mode curves to generate the composite curve, was performed each time it was used in the load/capacity spreadsheet calculations. This composite fragility curve is in the U.S. EPR FSAR Tier 2, Figure 19.1-8.

   The refinement to the calculation described previously has resulted in a change to the values in the U.S. EPR FSAR Tier 2, Table 19.1-21 and in the U.S. EPR FSAR Tier 2,

Figure 19.1-8. The updated values are shown in the attached revised U.S. EPR FSAR Tier 2, Table 19.1-21. The updated composite fragility curve is shown in the attached revised U.S. EPR Tier 2 FSAR, Figure 19.1-8.

This update to the composite fragility curve was determined not to affect the results of the Level 2 PRA in the U.S. EPR FSAR Tier 2, Chapter 19.

3) The containment ultimate strength capacity is calculated with consideration to variations in material properties and modeling uncertainties. The failure criterion (ultimate stress) for tendons is set at 3% strain and the stress-strain relationship for the liner plate and reinforcement is considered perfectly elastic-plastic. The associated median stresses for materials used are shown in Table RAI 19.1-10-1.

4) Six pressure boundary locations in containment listed in U.S. EPR FSAR Tier 2, Table 19.1-21 are selected for evaluation. The main failure modes are as follows:

- Cylinder wall: Hoop membrane failure in a typical zone of the cylinder wall away from discontinuities.
- Center of dome: Membrane failure in a typical zone of the dome away from the dome belt.
- Base of cylinder: Flexural failure of the base of the cylinder wall.
- Base of dome: Flexural failure of the dome belt.
- Equipment hatch: Flexural failure around the equipment hatch – vertical and horizontal symmetry planes (excluding the steel equipment hatch cover and cylinder).

5) The fragility is developed utilizing the data (median failure pressures and betas) provided in the U.S. EPR FSAR Tier 2, Table 19.1-21. The material data (betas) used in the evaluation is given in Table RAI 19.1-10-2.

FSAR Impact:

U.S. EPR FSAR Tier 2, Section 19.1.4.2.1.3, Table 19.1-21, and Figure 19.1-8 will be revised as described in the response and indicated in the enclosed markup.

Table RAI 19.1-10-1— Median Stresses for Materials

Material	Median Stress (ksi)
Liner (median yield strength)	30.2
Reinforcing Bars (median yield strength)	70.8
Tendons (median ultimate strength @ 3% strain)	280
Concrete	10.08

Table RAI 19.1-10-2— Material Data (Betas) for Materials

Material	β_s
Liner	0.10
Reinforcing Bars	0.10
Tendons	0.022
Concrete (Compressive State)	0.12

U.S. EPR Final Safety Analysis Report Markups

19.1.5.1.1 Description of the Seismic Risk Evaluation

19.1.5.1.1.1 Methodology

19.01-1, 19.01-2, and 19.01-3

The PRA-based seismic margin~~s~~ assessment employed an approach described in SECY 93-087 (Reference 2). This assessment also followed guidance provided in ANSI/ ANS-58.21 (Reference 35), particularly Section 3.7 and Appendix B, as applicable to seismic margin~~s~~ assessment. The PRA-based seismic margin~~s~~ assessment allows potential vulnerabilities in the design (relative to margin above the safe shutdown earthquake (SSE)) to be identified so that ~~corrective~~ measures ~~can~~could be taken to reduce the risk associated with seismic events.

The primary tasks in the PRA-based seismic margin~~s~~ assessment are as follows:

- Identify the seismic hazard.
- Evaluate the seismic fragility to ~~assess~~obtain high confidence of low probability of failure (HCLPF) capacities ~~values~~ for SSCs.
- Incorporate seismic failures into the system and sequence models to identify their significance with respect to the potential for core damage.
- Assess an overall HCLPF ~~value~~capacity at a sequence level to identify the SSCs that are limiting with respect to the potential for core damage.

The U.S. EPR PRA model developed for internal initiating events provides the framework for addressing potential failures induced by seismic events. This model also provides the primary basis for establishing the seismic equipment list (SEL), which identifies equipment and structures for seismic fragility analysis. Because this assessment is being conducted early in the plant design, fragility assumptions are documented to support seismic design development in the detailed design phase.

19.1.5.1.1.2 Seismic Hazard Input

19.01-1, 19.01-2, and 19.01-3

The input to the seismic margin~~s~~ assessment representing the seismic hazard is based on a characterization of the SSE. For the seismic design of the U.S. EPR, the SSE is based on the European ~~u~~Utility ~~r~~Requirements (EUR) spectral shapes for ground motion, anchored to a peak ground acceleration (PGA) of 0.3g. This PGA applies to both horizontal and vertical motions. FSAR Section 3.7 discusses the EUR spectral shapes.

The certified seismic design response spectra (CSDRS) for the U.S. EPR are shown in Figure 3.7.1-1 of the FSAR. These are ground response spectra for EUR Control Motions—hard (EURH), medium (EURM), and soft (EURS) soils. The PRA-based seismic margin assessment follows the guidance in SECY 93-087 and demonstrates that there is a minimum seismic margin of 1.67 times the CSDRS.

The calculations of the seismic margin for different SSCs were performed using the seismic fragility analysis method wherein the median seismic capacity and variabilities were estimated. For this purpose, the median ground motion response spectral shape was used. The NUREG/CR-0098 (Reference 39) median shape for rock sites and for soil sites was used as the median ground motion spectra. These response spectra were confirmed to be conservative by comparison with the Uniform Hazard Spectra at E-04 and 5E-05 annual probability of exceedance for the 28 sites studied by the Electric Power Institute (EPRI) (Reference 36). NUREG/CR-0098 median shapes were recommended by the NRC for use in individual plant examination of external events (IPEEE) per NUREG-1407 (Reference 8).

There are different ways of anchoring the ground motion spectra. The use of peak ground motion, specifically peak ground acceleration (PGA), has been questioned by industry experts and they have suggested use of the average peak spectral acceleration in the frequency range of 2–10 Hz (refer to EPRI TR-103959, Reference 38). Based on Figure 3.7.1-1, the average peak spectral acceleration would be 0.70g for EURH, 0.81g for EURM, and 0.87g for EURS. Therefore, the seismic margin requirement for the U.S. EPR is expressed as 1.67 times the above values (i.e., 1.17g average spectral acceleration for rock sites, and 1.45g for the envelope of the EURM and EURS soil sites).

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The median ground motion response spectrum for rock sites is equal to or greater than the requirements for average spectral acceleration of 1.17g and is equal to or greater than the peak spectral acceleration of the EURH for the requirement of 1.67 times the CSDRS. The average spectral acceleration of 1.3g corresponds to a PGA of 0.61g. This ground motion response spectrum shape was used in the fragility analysis and is shown in Figure 19.1-31.

The same methodology was used for soil sites. The median ground motion response spectrum for soil sites is equal to or greater than the requirements for average spectral acceleration of 1.45g and is equal to or greater than the peak spectral acceleration of the EURM and EURS for the requirement of 1.67 times the CSDRS. The average spectral acceleration of 1.55g corresponds to a PGA of 0.73g. This ground motion response spectrum shape was used in the fragility analysis and is shown in Figure 19.1-31.

For rock and soil sites, these response spectra shapes meet or exceed the requirements to demonstrate minimum HCLPF capacity of 1.67 times the design basis. The resulting response spectra are anchored to PGA values of 0.61g for rock and 0.73g for soil sites, which exceed the PGA target of 0.5g.

For the in-structure response spectra for the Nuclear Island (NI) buildings, the primary modes of dynamic response are in the 2–10 Hz range as a function of site conditions and CSDRS definitions (refer to Table 3.7.1-6 which provides the generic soil profiles

19.01-1, 19.01-2, and 19.01-3

and the corresponding CSDRS). The primary frequency range of interest for the softer soil sites and the EURS is 2–4 Hz. The primary frequency range of interest for the stiffer soil and rock sites is 4–8 Hz. The selected ground motion response spectral shapes are the appropriate shapes to represent these frequency ranges.

Figure 19.1-31 shows the plot of the required 1.67 times the CSDRS, referred to as the review level earthquake (RLE), compared to the median NUREG/CR-0098 response spectra for rock and soil sites, referred to as the seismic margin earthquake (SME). For the rock case, the SME spectrum is below the RLE in the high frequency range. This does not impact the calculation of seismic margin of the SSCs based on the following:

- The overall structure response, and consequently the seismic design of the NI buildings and foundations, is governed by the low frequency response (i.e., the dynamic response in the 4–8 Hz range for very stiff soil and rock). In this frequency range, the seismic margin earthquake equals or exceeds the requirement of 1.67 times the CSDRS.
- Two physical aspects of rock-structure interaction, not modeled in the soil structure interaction analyses, will minimize these high frequency effects. Kinematic interaction—the spatial variation of the ground motion over the embedment depth of the NI buildings in the soil or rock—will significantly reduce peaks in the in-structure response spectra (ISRS) at frequencies above about 10 Hz. Additionally, incoherence of ground motion will further reduce any such peaks. Neither of these effects was included in the seismic design analyses performed for the U.S. EPR.
- The design and qualification of SSCs will be performed for the resulting ISRS with adequate seismic margin.

Therefore, the seismic margin earthquake ground motion response spectra shapes meet the standards for seismic margin assessments.

~~To apply the seismic margins approach, it is necessary to specify a review level earthquake (RLE). For purposes of design certification and consistent with NRC guidance in SECY 93-087 (Reference 2), the RLE is defined to be a value 1.67 times the SSE. The RLE is the criterion to which the HCLPF values are compared. This is different from a seismic PRA which would require definition of the probabilistic seismic hazard in terms of frequency of exceedance as a function of earthquake intensity.~~

~~Recent seismic hazard studies have shown that the ground motion spectra at high frequencies could exceed the EUR ground motion spectrum. The Electric Power Research Institute (EPRI) is, however, conducting research indicating these high frequency motions are not damaging to nuclear power plant structures and equipment (Reference 36 and Reference 37). Industry experts have also questioned the use of PGA as an appropriate indicator of seismic capacity and have suggested use of average~~

19.01-1, 19.01-2, and 19.01-3

~~peak spectral acceleration in the frequency range of 2 to 10 Hz as an alternative indicator (refer to EPRI TR-103959 , Reference 38).~~

~~Based on the EPR EUR design spectra, the average peak spectral acceleration would be approximately 0.78g for a rock site and 0.9g for soft soil sites. Therefore, the seismic margins assessment for the U.S. EPR uses a RLE of 1.67 times these values for average spectral acceleration. This yields values of 1.3g and 1.5g relative to average spectral acceleration in the frequency range of 2 to 10 Hz for rock and soft soil sites, respectively.~~

~~In the fragility analysis, the spectral shape factor accounts for the conservatism between the design ground response spectrum and the median ground response spectrum. For the U.S. EPR, the median ground response spectrum is taken to be the median ground response spectrum from NUREG/CR-0098, anchored to 0.3g (Reference 39). The average spectral acceleration from this median ground response spectrum for rock sites is 0.59g and 0.61g for soil sites. A recent study of 28 sites performed by EPRI (Reference 36 and Reference 37) arrived at the following values for the average spectral acceleration:~~

- ~~For an exceedence frequency of 1 x 10-4/yr:~~
  - ~~Average spectral acceleration (at 84th percentile) for rock sites is 0.31g.~~
  - ~~Average spectral acceleration (at 84th percentile) for soil sites is 0.43g.~~
- ~~For an exceedence frequency of 5 x 10-5/yr:~~
  - ~~Average spectral acceleration (at 84th percentile) for rock sites is 0.43g.~~
  - ~~Average spectral acceleration (at 84th percentile) for soil sites is 0.56g.~~

~~Therefore, the use of the median response spectrum from Reference 39 is judged to be conservative for all potential EUR sites.~~

19.1.5.1.1.3 Seismic Fragility Evaluation

19.01-4 and 19.01-6

The fragility evaluation characterizes the capacities of SSCs to withstand the ground motion due to an earthquake. Fragility is expressed as the conditional probability of failure of a SSC as a function of earthquake ~~intensity~~size. The capacity of a component to maintain its function during and following strong ground motion and the uncertainties associated with that capacity were estimated~~ on the basis of PGA~~, taking into account the seismic response at the component's location in a structure. The resulting fragilities are characterized by the median capacity (average spectral acceleration), logarithmic standard deviations that account for randomness and uncertainty, and HCLPF capacity. The set of SSCs for which fragility was estimated was defined through the development of a SEL, as discussed in the next section.

The seismic assessment included evaluating design information and qualification criteria to estimate the factors of safety (or margin) between the design capacity of a component and its actual capacity. This margin arises, for example, because the actual stress a component could experience might be much less than the allowable stress level, or because the equipment is tested to an enveloping spectrum while the actual floor response spectrum at that equipment location may be significantly lower. For the design certification, some details of the design, including specification of anchorage and detailed stress calculations, are not yet available. Therefore, for most SSCs generic estimates for these designseismic margins were obtained from Reference 14 and Reference 38.

19.01-4 and 19.01-6

As noted previously, the HCLPF valuecapacity is a measure of a component's seismic capacity. The HCLPF valuecapacity is the acceleration below which there is 95 percent confidence that the failure probability is less than 5 percent. This value can be calculated from the median capacity (A_m) for the component and two logarithmic standard deviations, accounting for variability due to uncertainty and randomness (β_U and β_R, respectively). This relationship is as follows:

$$HCLPF = A_m \exp [-1.65 (\beta_R + \beta_U)] \qquad (A)$$

Table 19.1-106 and Table 19.1-107 show the seismic fragility values and HCLPF capacities assigned to structures and equipment modeled in this PRA-based seismic margin assessment (SMA). The median and HCLPF capacities are measured in terms of spectral ground accelerations averaged over the frquency range of 2–10 Hz.

The median capacity and the two standard deviations can be used to define a family of curves representing fragility. For some applications, a single mean fragility curve is adequate. To develop this mean curve, a composite standard deviation is calculated as follows:

$$\beta c = (\beta R2 + \beta U2)1/2$$

Using this composite characterization, the HCLPF value can be calculated as follows:

$$HCLPF = Am \exp (-2.33 \beta c)(B)$$

In the seismic margins assessment for the U.S. EPR, the definition of HCLPF capacity per Equation A is used when the individual values of β_R and β_U have been calculated.

19.1.5.1.1.4 Systems and Accident Sequence Analysis

A seismic-margins model was developed from the event trees and fault trees that comprise the model for internal initiating events so that potentially important accident sequences were considered. So that the relationships among seismic failures and other failure modes could be captured, the seismic-margins model also retains random failures and human failure events from the internal events PRA.

The initiating events and event trees in the at-power internal events model were reviewed to identify which events needed to be included in the seismic model to account for the types of sequences that could be important following an earthquake. The following consequential initiating events were identified and included in the seismic model:

- Seismic loss of offsite power (S LOOP) –LOOP is the most likely plant initiating event that would result from a seismic event. The LOOP event tree developed for internal events was modified for use in the seismic model. In particular, events related to the restoration of offsite power were removed, as were events that reflected the use of systems that are not seismically qualified. For further completeness in defining the SEL and modeling of potential sequences, the LOOP model retained a transfer to an ATWS event tree for sequences involving failure of the reactor to trip. The S LOOP event tree is shown in Figure 19.1-10—Event Tree for Seismic Loss of Offsite Power (S LOOP).

- Seismic small LOCA (S SLOCA) – The S SLOCA event tree accounts for LOCA sequences that could result from a seismic event (e.g., due to failure of multiple instrument impulse lines). The event tree for internal events was modified to develop the S SLOCA event tree. It is noted that the capacity of the RCS may be substantially higher than the RLE; however the SLOCA model was developed to enhance completeness of the SEL and of the sequences considered. The S SLOCA event tree is shown in Figure 19.1-11—Event Tree for Seismic Small LOCA (S SLOCA).

19.01-7 Structures and other passive components not typically included in the internal events PRA were added to the SEL. ~~In some cases failures of these SSCs are equivalent to initiating events and these are outside the structure of the S LOOP and S SLOCA seismic event trees.~~

Fault trees developed in the internal events PRA were used to investigate system failure modes and dependencies, and to establish the SEL for fragility analysis. Seismic failures were addressed as follows:

- Basic events representing seismic failures of SSCs for which fragility evaluations were performed were added at appropriate points in the fault trees.

- Seismic failures were treated as common events for all trains of a system. For example, the same basic event representing seismic failure of a pump was applied for all similar trains of a system. Complete correlation in that manner
19.01-7 ~~assures~~assumes that redundant components fail if one component fails.

- Systems not qualified for seismic loadings were set to a failure probability of 1.0. Thus, for example, the seismic model treats both offsite power and the SBODGs as unavailable following a seismic event. No credit is given for recovery of offsite power. Removal of these non-qualified systems allowed simplification of the models.

- Human failure events were retained in the fault-tree models, but were set to failure with a probability of 1.0. This allowed any potentially important events to be visible during the quantification process.

The solution of the integrated fault-tree and event-tree models to evaluate the seismic margin is addressed in the next section.

19.1.5.1.1.5 HCLPF Sequence Assessment

19.01-7

The seismic margins assessment evaluates the ~~risk associated with~~ impact of seismic initiators by determining whether there is adequate margin ~~above the SSE (0.3g)~~. This is done by searching for scenarios in which combinations of seismic failures, random events, and failures of human actions could result in an effective seismic capacity less than the RLE. ~~The RLE is defined at 1.67 times the SSE (i.e., 0.5g PGA).~~

To make this evaluation, seismic failures were added to the fault-tree models developed for internal initiating events, as discussed in the previous section.

The "MIN-MAX" method of evaluating accident sequences at the cut-set level was used to assess the plant-level HCLPF capacity. The MIN-MAX method assesses the accident sequence HCLPF by taking the lowest HCLPF ~~value~~capacity for components analyzed under OR-gate logic and the highest HCLPF ~~value~~capacity for components analyzed under AND-gate logic. Random component failures and human actions are also considered in the evaluation.

The product of this evaluation is identification of the structures and components that arise in the core damage cutsets and that limit the plant-level HCLPF capacity. The HCLPF capacity results and PRA insights from this evaluation are assessed to identify potential seismic vulnerabilities relative to the RLE and to suggest ~~potential~~appropriate measures to reduce their impact.

~~As described in the section that follows, failures of structures which house safety-related systems were not added to the fault trees. These structures are expected to have high capacities, although their failures would also be likely to cause core damage. The fragility assessment of structures to support the PRA-based margins assessment is based on calculations and generic information.~~

19.1.5.1.2 Results from the Seismic Risk Evaluation

19.1.5.1.2.1 Risk Metrics

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The PRA-based seismic margin~~s~~ assessment investigated the margin incorporated into the design of the U.S. EPR. This entailed evaluating the plant-level HCLPF, and comparing it to the RLE, which is defined as a factor of 1.67 times the design-basis SSE. That is, the assessment focused on identifying any potential vulnerabilities in the design, defined as components that would not meet the criterion of 95 percent confidence that the probability of failure would be less than 5 percent at the RLE. This requirement has been met as described ~~further~~ below.

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19.1.5.1.2.2 Significant Initiating Events and Sequences

Loss of offsite power is the most important initiating event because equipment needed for offsite power to function (e.g., ceramic insulators) typically has low seismic capacity and its failure has effects on safety and non-safety systems. Loss of offsite power results in the loss of main and startup feedwater, the main condenser as a heat sink, and maintenance ventilation systems. The LOOP also presents a demand for the EDGs to supply power to the safety systems. The next section discusses the expected dominant seismic and non-seismic failures that contribute to the LOOP accident sequences.

For purposes of the seismic margins assessment, it is also assumed that a seismic event would lead to leakage from the RCS equivalent to an SLOCA. This assumption is made even though the RCS is expected to have a sufficiently high seismic capacity such that a failure resulting in an SLOCA would be unlikely. The seismically induced SLOCA is included so that a broader set of equipment will be considered in the SEL and associated fragility evaluations than would be the case if only systems needed to respond to a LOOP were included. The primary difference with respect to the cutsets obtained for the S LOOP sequences and those for S SLOCA was the requirement for cooling of the IRWST for the latter. This requirement added cutsets relating to seismic failure of the CCWS and LHSI/RHR to those obtained for LOOP scenarios.

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Seismic failures of key structures that house safety-related systems are also considered as initiating events that are assumed to result in core damage. Structures were assessed to have relatively high capacities and were assigned ~~a~~ HCLPF ~~at the level of 1.67 times the SSE and above based on calculations and generic information. All structures are expected to have high capacities and not dominate seismic risk relative to equipment failures described in the next section~~capacities larger than the RLE based on calculations and generic information.

19.1.5.1.2.3 Significant Functions, SSCs, and Operator Actions

The following addresses the accident sequences, which reflect seismic fragilities of systems and equipment, non-seismic failure of equipment, and operator actions.

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Table 19.1-37—Summary of Cutsets for Seismic Sequences with LOOP summarizes the S LOOP cutsets; these are limiting with respect to the plant-level HCLPF capacity. ~~Only cutsets with single seismic elements are included. Additional elements of the~~

19.01-7 → ~~cutsets include non-seismic failures and human failure events.~~ These cutsets reflect the following contributions:

- Seismic failure of AC power cabinets (event AC), I&C cabinets (event I&C), emergency diesels-generators (event EDG), batteries (event BAT), ESW (event ESWS) or room cooling (event SAC) represent single element cutsets that limit the plant level HCLPF.
- Seismic failure of emergency feedwater (event EFW) and failure of the operators to initiate feed-and-bleed cooling (event OPE-FB-90M) constitute the first two-element cutset.
- Seismic failure of CCW (event CCWS) and a consequential RCP seal LOCA (event PROB SEAL LOCA) comprise the next two-element cutset.
- The next two cutsets include two seismic failures and failure of an operator action. One of the operator actions is to perform fast cooldown (failure event OPE-FCD-40M) to permit injection by LHSI following a seal LOCA and MHSI failure, and the other is to initiate feed-and-bleed cooling (event OPE-FB-40M).
- The last three cutsets include seismic failure of emergency feedwater (event EFW) and non-seismic failures of equipment and failure of operator action.

The seismic SLOCA results are similar to those presented in Table 19.1-37 for seismic LOOP sequences. These cutsets also include two types of single-element cutsets that reflect seismic failures; these include failure of CCWS and failure of LHSI. Either failure results in a loss of IRWST cooling, which is required in the long term following a LOCA. Since the HCLPF for the SLOCA initiating event is much higher than that for LOOP, these sequences are less significant and are not discussed further.

The S LOOP event tree includes a transfer to the ATWS event tree for scenarios involving failure of the reactor to trip. All ATWS cutsets include seismically induced binding of the control rods, such that they failed to insert. The most important cutset includes operator failure to initiate the EBS, which results in core damage. Since seismic failures leading to ATWS have capacities greater than the RLE, these are not discussed further.

19.1.5.1.2.4 Key Assumptions and Insights

Assumptions and insights from the PRA-based seismic margin~~s~~ ~~analysis~~assessment are as follows:

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- Plant level HCLPF – Based on the seismic margin~~s~~ assessment performed, the plant level HCLPF capacity is greater than RLE~~is ≥1.67 SSE~~.
- Seismic PRA model – although the seismic PRA model is quite extensive in that SLOCA and ATWS were included, as well as all success paths in the internal events PRA.~~,~~ ~~e~~Equipment and structures that are not seismically qualified are not

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credited in the model. This treatment is judged conservative for a seismic margins assessment because of inherent seismic capacity and ruggedness that exists in non-seismic structures and equipment.

- A COL applicant that references the U.S. EPR design certification will confirm that the design-specific U.S. EPR PRA-based seismic margins assessment is bounding for their specific site.

19.1.5.1.2.5 Sensitivities and Uncertainties

Uncertainties are taken into account explicitly in the fragility development and in evaluating non-seismic failures of equipment. Because the seismic margins assessment analysis is primarily qualitative, no sensitivity studies are conducted.

19.1.5.2 Internal Flooding Risk Evaluation

19.1.5.2.1 Description of Internal Flooding Risk Evaluation

19.1.5.2.1.1 Methodology

Based on good spatial separation between safety buildings containing safety trains in the U.S. EPR, a bounding internal flooding analysis method is used to evaluate risk from the internal flooding events. The aim of this bounding analysis is to show that the CDF/LRF, as a result of a more detailed internal flooding evaluation, will not change the conclusion that the overall CDF/LRF meets the U.S. EPR design objective.

The bounding internal flooding analysis method implies that the floods are analyzed for the entire building, that the worst PRA scenario resulting from the failure of all SSCs in the building is modeled, and that the total building flooding frequency is applied to that scenario. Based on this approach, for each building containing SSCs credited in the PRA, the internal flooding evaluation is performed in the following steps:

- Calculate flooding frequency based on the flooding sources and piping segments. Where detailed design information is not available, use conservative estimates of flooding frequency from available industry references.

- Analyze possible flooding scenarios for each location and, based on the PRA model, select the worst scenario.

- Apply the total building flooding frequency to the worst scenario, and calculate the corresponding CDF and LRF.

Table 19.1-21—Probability Distributions (Lognormal) for the Six Dominant Failure Modes

Failure modelocation	Pmedian (psi)	ß (=σ)	5%ile (psi)
cylinder wall	260250.8	0.0340.029	239.4
center of dome	189221.4	0.0290.029	210.9
base of cylinder	284247.9	0.250.18	184.3
base of dome	187181.4	0.160.173	136.8
Eq hatch V2	227217.7	0.160.06	197.0
Eq hatch H2	288281.1	0.130.08	245.3

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Table 19.1-106—Seismic Fragilities of Safety-Related Structures

Building/ Structure	Designation/ Location	Failure Mode	Am (g)	βR	βU	HCLPF (g)
Reactor Bldg & Annulus (I)	0UJA, 0UJB	Shear failure of containment wall	8.9	0.25	0.41	3.0
Contain-ment Internal Structure (I)	0UJA	Shear failure of internal structure walls	6.4	0.25	0.42	2.1
Safeguards Bldgs (I)	1UJH and 4UJH; 1UJK and 4UJK; 1UJE and 4UJE	Shear failure of concrete shear wall	4.9	0.26	0.41	1.6
Safeguards Bldgs (I)	UJH/UJK 2+3; UJE 2+3	Shear failure of concrete shear wall	5.8	0.26	0.42	1.9
Fuel Bldg (I)	0UFA	Shear failure of concrete shear wall	5.8	0.26	0.42	1.9
Diesel Bldgs (I)	1UBP through 4UBP	Shear failure of concrete shear wall	5.6	0.26	0.41	1.8
Nuclear Auxiliary Bldg (II)	0UKA	--	--	--	--	1.30

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Table 19.1-107—Seismic Fragilities of Mechanical and Electrical Equipment

-

Equipment Category	Am (g) spectral accel.	β_R	β_U	HCLPF g
Battery	7.0	0.25	0.37	2.5
Cable Tray	7.9	0.34	0.43	2.2
Charger	4.3	0.26	0.39	1.5
Chiller	5.2	0.30	0.35	1.8
Compressor	5.2	0.20	0.40	1.9
Converter	4.3	0.26	0.39	1.5
Engine Generator	--	--	--	1.3
Fan	5.2	0.20	0.40	1.9
Filter	5.2	0.30	0.35	1.8
Instrumentation Rack	--	--	--	1.3
Inverter	4.3	0.26	0.39	1.5
MCC	4.3	0.26	0.39	1.5
Offsite power	0.8	0.40	0.38	0.2
Piping	7.9	0.34	0.43	2.2
Pump	5.2	0.20	0.40	1.9
Switchgear	4.3	0.26	0.39	1.5
Tank	5.2	0.30	0.35	1.8
Transformer	6.2	0.25	0.37	2.2
Valve	7.9	0.34	0.43	2.2

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Figure 19.1-8—Composite Containment Fragility Curve at 395°F ~~170°C~~

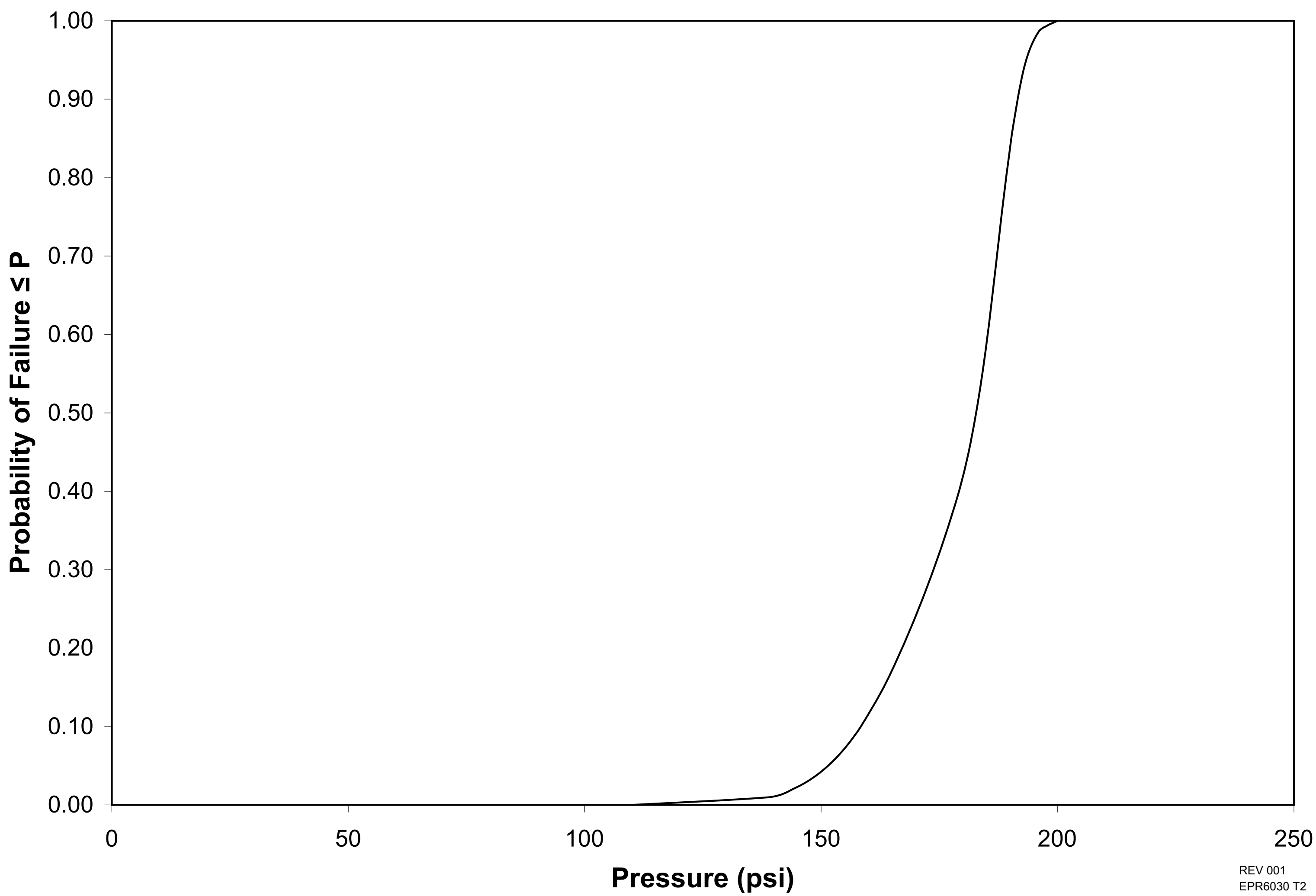

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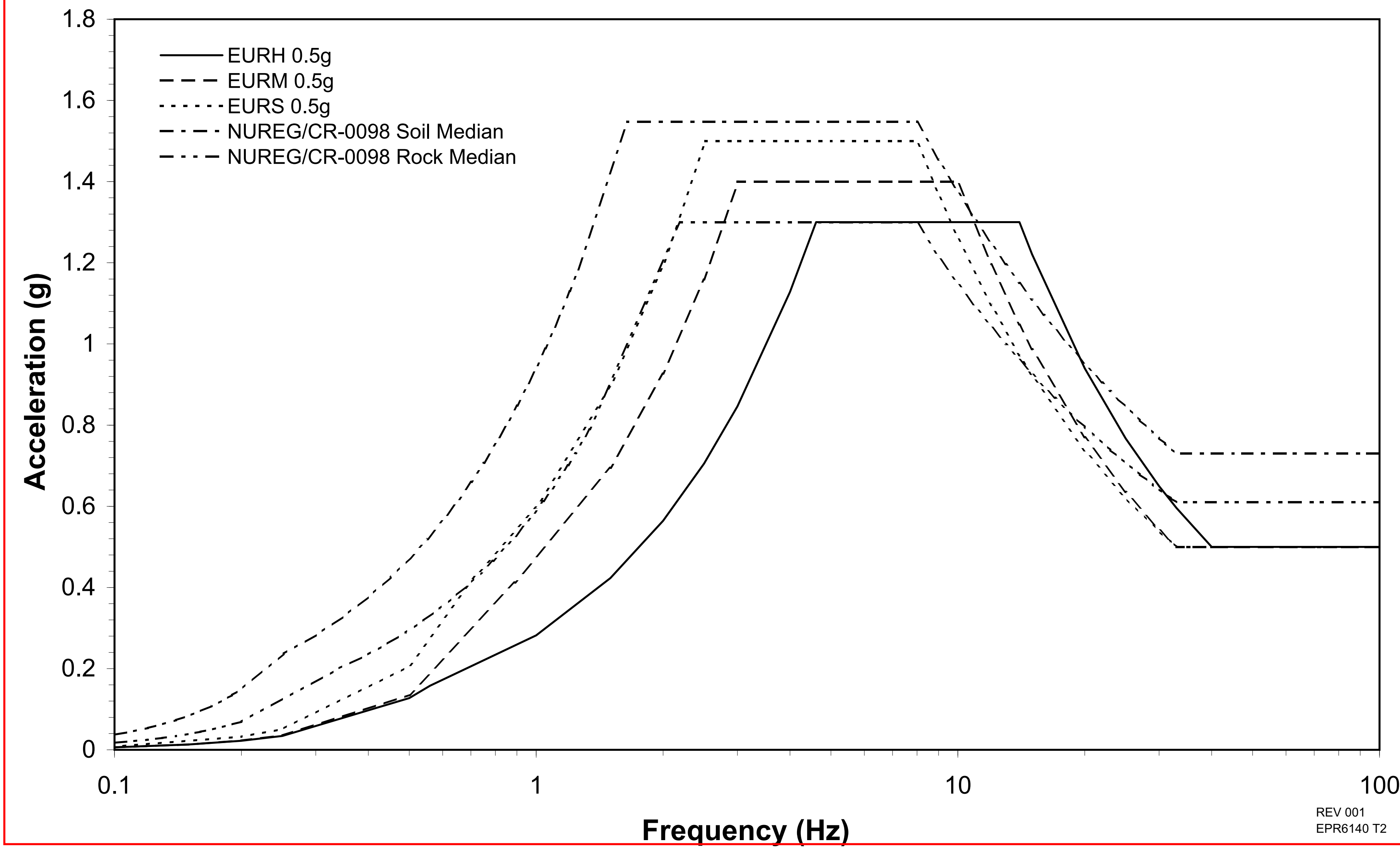
Figure 19.1-31—Comparison of SME and RLE for Hard and Soft Soil Sites



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