September 2, 2010

MEMORANDUM TO: Brian W. Sheron, Director
Office of Nuclear Regulatory Research

FROM: Patrick Hiland, Chairman **/RA/**
Safety/Risk Assessment Panel for Generic Issue 199

SUBJECT: SAFETY/RISK ASSESSMENT RESULTS FOR GENERIC ISSUE 199, "IMPLICATIONS OF UPDATED PROBABILISTIC SEISMIC HAZARD ESTIMATES IN CENTRAL AND EASTERN UNITED STATES ON EXISTING PLANTS"

In accordance with Management Directive (MD) 6.4, "Generic Issues Program," a Safety/Risk Assessment panel was established to:

- Determine, on a generic basis, if the risk associated with Generic Issue (GI) 199, "Implications of Updated Probabilistic Seismic Hazard Estimates in Central and Eastern United States (CEUS) on Existing Plants," warrants further investigation for potential imposition as a cost-justified backfit.

- Provide a recommendation regarding the next step (i.e., should the issue continue to the Regulatory Assessment Stage for identification and evaluation of potential generic, cost-justified backfits, be dropped due to low risk, or have other actions taken outside the Generic Issues Program [GIP]).

The panel completed its independent review of the Safety/Risk Assessment (see Enclosure 1) for GI-199. The panel reached the following conclusions and observations:

- Overall seismic core damage risk estimates are consistent with the Commission's Safety Goal Policy Statement because they are within the subsidiary objective of 10^{-4}/year for core damage frequency. The GI-199 Safety/Risk Assessment, based in part on information from the U.S. Nuclear Regulatory Commission's (NRC's) Individual Plant Examination of External Events (IPEEE) program, indicates that no concern exists regarding adequate protection and that the current seismic design of operating reactors provides a safety margin to withstand potential earthquakes exceeding the original design basis.

- The changes in seismic core-damage frequency (SCDF) estimated in the Safety/Risk Assessment Stage of GI-199 for numerous plants lie in the range of 10^{-4}/yr to 10^{-5}/yr, which meet the numerical risk criteria for an issue to proceed to the Regulatory Assessment Stage of the GIP.

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- New consensus seismic-hazard estimates will become available in late 2010 or early 2011 (these are a product of a joint NRC, U.S. Department of Energy, U.S. Geological Survey (USGS) and Electric Power Research Institute (EPRI) project). These consensus seismic-hazard estimates will supersede the existing EPRI, Lawrence Livermore National Laboratory, and USGS hazard estimates used in the GI-199 Safety/Risk Assessment.

- Certain factors that affect the development of realistic SCDF estimates will remain unresolved even after the new consensus seismic hazard estimates are developed. The issue is primarily that many IPEEEs did not produce SCDF estimates and so lack some of the information needed to produce such estimates.

  - For a number of the plants that performed reduced-scope seismic margins analyses as part of the IPEEE program, limited detailed information exists regarding plant seismic capacity (the ability of a plant’s structures, systems, and components [SSCs] to successfully withstand an earthquake) beyond the required design-basis level.

  - The approach used in the attached Safety/Risk Assessment to estimate SCDF considers the plant-level seismic capacity and, therefore, does not provide insight into which SSCs are important to seismic risk. Such knowledge would be required in order to postulate potential cost-beneficial backfits.

- IPEEE submittals generally provided limited, qualitative information about the seismic capability of containments. Any regulatory analysis of GI-199 should consider potential plant modifications for reducing the probability of seismically induced containment failure as discussed in Section 3.3.1 of NUREG/BR-0058, “Regulatory Analysis Guidelines of the U.S. Nuclear Regulatory Commission.”

The panel recommends the following:

- Transfer lead responsibility for subsequent GI-199 actions to the Office of Nuclear Reactor Regulation for regulatory office implementation, including maintenance of the GI-199 Communication Plan and stakeholder briefings and interactions. (Note: the GIP will continue to track the issue and report its status in the Generic Issues Management Control System until all actions are completed).

- Take further actions to address GI-199 outside the GIP (i.e. obtain information and develop methods, as needed, to complete plant-specific value-impact analyses of potential backfits to reduce seismic risk). Any needed Office of Nuclear Regulatory Research support can be obtained using the User Need Request process.

Enclosure:
Safety/Risk Assessment for GI-199

Approved: **/RA/** Date: 9/2/2010
Brian W. Sheron, Director
Office of Nuclear Regulatory Research

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Enclosure:
Safety/Risk Assessment for GI-199

Approved: /RA/ Date: 9/2/2010
Brian W. Sheron, Director
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Memo to Brian W. Sheron from Patrick L. Hiland dated September 2, 2010

SUBJECT: SAFETY/RISK ASSESSMENT RESULTS FOR GENERIC ISSUE 199, “IMPLICATIONS OF UPDATED PROBABILISTIC SEISMIC HAZARD ESTIMATES IN CENTRAL AND EASTERN UNITED STATES ON EXISTING PLANTS”

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GENERIC ISSUE 199 (GI-199)

IMPLICATIONS OF UPDATED PROBABILISTIC SEISMIC HAZARD ESTIMATES IN CENTRAL AND EASTERN UNITED STATES ON EXISTING PLANTS

SAFETY/RISK ASSESSMENT

August 2010

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EXECUTIVE SUMMARY

RES staff developed and implemented a methodology to assess the risk associated with this issue. Preliminary results indicate that the issue should continue to the Regulatory Analysis Stage of the Generic Issues Program (GIP) for further investigation to identify candidate backfits and evaluate their potential cost-justified imposition. The information needed to perform the Regulatory Assessment is not currently available to the staff. The methodology, analyses, results and limitations of the safety risk assessment are summarized below.

Risk Methodology

Seismic core damage frequency (SCDF) was chosen as the appropriate risk metric because it is expected to be more sensitive than other metrics (either large-early release fraction or public dose) to changes in the seismic hazard. In addition, SCDF can be estimated using Individual Plant Examination of External Events (IPEEE) information. Conversely, the IPEEE program did not produce sufficient quantitative information to perform estimation of alternate risk metrics.

The staff performed a two-stage assessment to determine the implications of updated probabilistic seismic hazards in the Central and Eastern U.S. (CEUS) on existing nuclear power plants (NPPs). The change in seismic hazard with respect to previous estimates at individual NPPs was evaluated in the first stage, and the change in SCDF as a result of the change in the seismic hazard for each operating NPP was estimated in the second stage. The seismic hazard at each NPP site is dependent on the unique seismology and geology surrounding the site which necessitated separately determining the implications of updated probabilistic seismic hazard for each of the 96 operating NPPs in the CEUS.

Approximate SCDF estimates were developed using a method which includes integrating the mean seismic hazard curve and the mean plant-level fragility curve for each NPP. This method, developed by Kennedy (1997), is discussed in Section 10.8.9 of AMSE/ANS RA-Sa-2009 and has previously been used by the staff in the resolution of GI-194, “Implications of Updated Probabilistic Seismic Hazard Estimates,” and during reviews of various risk-informed license amendments. This approach was discussed with EPRI under an NRC-EPRI seismic research memorandum of understanding. EPRI agreed that this is a reasonable approach for evaluating GI-199.

Performance of the Safety/Risk Assessment

The following describes the details of performing the Safety/Risk Assessment and associated limitations. There are two discrete inputs required for the methodology described above, plant-specific seismic hazard information and estimates of plant-specific seismic fragility.

Seismic Hazard Curves

SCDF estimates were produced using three sets of mean seismic hazard curves representing a range of different assumptions and the changing state of knowledge:

- EPRI, 1989
- Lawrence Livermore National Laboratory (LLNL), 1994
- NRC based on U.S. Geological Survey (USGS), 2008

Plant-Level Fragility Curves

Plant-level fragility curves were developed from information provided in the IPEEE submittals. About one-third of the plants in the CEUS performed a seismic probabilistic risk assessment (SPRA) as part of their IPEEE program. About two-thirds of the SPRA plants provided plant-level fragility information (either in tabular or graphic format) in their IPEEE submittals. The remaining one-third of the SPRA plants provided SCDF estimates based on a variety of seismic hazard curves (EPRI 1989, LLNL1994, or site-specific curves developed specifically for the IPEEE program). For these remaining plants, plant-level fragility values were back-calculated by matching the reported SCDFs and using engineering judgment. In cases where reasonable engineering judgments could not be readily made, sensitivity studies were performed.

The other two thirds of the plants conducted a seismic margins analysis (SMA) as part of their IPEEE program. The figure of merit for an SMA is the plant-level high confidence of low probability of failure (HCLPF) value.

Analyses Performed

For each of the three sets of seismic hazard curves (EPRI, LLNL, NRC/USGS), four SCDF estimates were developed. These four SCDF estimates were developed for a discrete series of representative spectral response frequencies (peak ground acceleration (PGA), 10, 5, and 1-Hz) and utilized spectral shapes based on the plant-specific IPEEE evaluations. For each NPP and hazard curve combination, the discrete spectral SCDF estimates were combined using four different weighting schemes to produce final plant-level SCDF estimates.

Evaluation of Changes in Seismic Hazard Estimates

The evaluation of the potential significance of changes in seismic hazards was performed in a stepwise fashion by posing a series of questions that indicated the degree of deviation of seismic hazard estimates developed using the most recent seismic hazard information and staff guidance from previously developed assessments. The previous assessments included the Safe Shutdown Earthquake (SSE), the review level earthquake (RLE) used in the IPEEE assessment, and the 1989 EPRI and 1994 LLNL seismic hazard studies. The comparison of results indicated a substantial increase in the estimated seismic hazard values relative to all previous assessments for a number of plants.

Risk Results

For those plants with increases in seismic hazard estimates, the study next evaluated if there was any significant change in the risk metric (SCDF). To perform this assessment, the point estimates of the mean SCDF developed using the NRC/USGS hazard curves were compared with the baseline SCDFs developed using the original LLNL or EPRI seismic hazard curves. The SCDF changes for a number of plants lie in the range of 10-4/year to 10-5/year, which meet the numerical risk criteria for an issue to proceed to the GIP Regulatory Assessment Stage.

Overall seismic risk estimates remain small in an absolute sense. All operating plants in the CEUS have seismic core-damage frequency (SCDF) less than or equal to 10^{-4}/year, confirming that there is no immediate concern regarding adequate protection.

Limitations of the Risk Methodology and Data Used

The approach used to estimate SCDF in the Safety/Risk Assessment is highly sensitive to the inputs used. While work to date supports a decision to continue to the GIP Regulatory Assessment Stage; the methodology, input assumptions, and data are not sufficiently developed to support other regulatory decisions or actions.

The approach used to estimate SCDF in the Safety/Risk Assessment does not provide insight into which structures, systems, and components (SSCs) are important to seismic risk. Such knowledge provides the basis for postulating plant backfits and conducting a value-impact analysis of potential backfits during a regulatory analysis.

Little useful information exists regarding plant seismic capacity (the ability of a plant's SSCs to successfully withstand an earthquake) beyond the required design-basis level for a number of plants that performed reduced-scope SMAs.

In general, only limited, qualitative information about the seismic capability of containments is provided in IPEEE submittals.

The integration of the mean seismic hazard curve and the mean plant-level fragility curve is not equal to the mean SCDF; accordingly, the SCDF estimates produced by the approach are point estimates.

The approach does not provide a quantitative estimate of the parametric uncertainty in the SCDF. Although the USGS approach explicitly includes uncertainties, the USGS has not published fractile curves for its seismic hazard estimates.

New consensus seismic hazard estimates for the CEUS will become available in late 2010 or early 2011 (these are a product of a joint NRC, Department of Energy, USGS, and EPRI project), and underscore the need to develop a regulatory mechanism to routinely and promptly evaluate new seismic hazard information as it becomes available.

Problems that currently exist with producing realistic SCDF estimates will continue even after the new consensus seismic hazard estimates are developed. The main problem is that many IPEEEs did not produce SCDF estimates and so lack some of the information needed to produce updated SCDF estimates. As such, the available seismic margins can only be grossly estimated and may be eroding as new seismic hazard estimates are developed.

Information Needed to Perform the Regulatory Analysis Stage of GI-199

The following four categories of information are needed to perform the Regulatory Analysis Stage of the GIP for GI-199:

- *Site-specific, updated EPRI hazard curves* used to evaluate plant seismic risk in the recent study conducted by EPRI for industry. The hazard curves should cover a range of appropriate structural frequencies (PGA to 0.5 Hz), and be in a tabular, digital form.

- *Frequency dependent, site-specific amplification functions* used to translate seismic motions from hard rock conditions to appropriate surface conditions. These functions should be consistent with the recent seismic evaluation performed by EPRI using updated seismic hazard results (see previous item), and be in tabular, digital form.

- *Plant-level fragility information* used in the recent study conducted by EPRI. Specific information needed includes the median seismic capacity (C_{50}), the composite logarithmic standard deviation (β_C), and spectral ratios (relative to PGA) for 1, 5, and 10 Hz (at a minimum), representative of the currently operated plant.

- *Plant-specific significant contributors to seismic risk.* Identify the SSCs that are significant contributors to seismic risk and the approach used to identify them.

Conclusions

Results of the Safety/Risk Assessment indicate that there is no immediate concern regarding adequate protection, but that the issue should continue to the Regulatory Analysis Stage of the GIP (for further investigation regarding possible cost-justified backfits). The information and methods needed to perform the Regulatory Assessment are not yet available to the staff, but have been identified.

LIST OF ACRONYMS AND INITIALISMS

AEF	annual exceedance frequency
CAV	cumulative absolute velocity
CDF	core-damage frequency
CEUS	Central and Eastern United States
COL	Combined License
EPRI	Electric Power Research Institute
EPRI-SOG	Electric Power Research Institute-Seismicity Owners Group
ESP	Early Site Permit
FSAR	Final Safety Analysis Report
GIP	Generic Issues Program
GMRS	ground motion response spectrum
HCLPF	high confidence of low probability of failure
HR	hard rock
IPEEE	Individual Plant Examination of External Events
LERF	large early-release frequency
LLNL	Lawrence Livermore National Laboratory
MD	Management Directive
MOU	Memorandum of Understanding
NPP	nuclear power plant
NRR	Office of Nuclear Reactor Regulation
PGA	peak ground acceleration
PSHA	probabilistic seismic hazard analysis
RLE	review-level earthquake
SA	spectral acceleration
SCDF	seismic core-damage frequency
SCDOT	South Carolina Department of Transportation
SMA	seismic margins analysis
SPRA	seismic probabilistic risk analysis
SR	soft rock
SSC	structures, systems, and components
SSE	safe shutdown earthquake
SSHAC	Senior Seismic Hazard Analysis Committee
TFI	Technical Facilitator Integrator
TIP	Trial Implementation Program
TVA	Tennessee Valley Authority
UHS	uniform hazard spectrum
USGS	United States Geological Survey
Vs	shear wave velocity
WUS	Western United States

GLOSSARY

- *Annual exceedance frequency (AEF)* – Expected number of occurrences per year where a site's ground motion exceeds a specified acceleration.

- *Design basis earthquake* or *safe shutdown earthquake (SSE)* – A design basis earthquake is a commonly employed term for the SSE: that earthquake for which certain structures, systems and components are designed to remain functional. In the past, the SSE has been commonly characterized by a standardized spectral shape anchored to a "peak ground acceleration" value.

- *Ground acceleration* – Acceleration at the ground surface produced by seismic waves, typically expressed in unit of g, the acceleration of gravity at the Earth's surface.

- *High confidence of low probability of failure (HCLPF) capacity* – A measure of seismic margin. In seismic risk assessment, this is defined as the earthquake motion level at which there is a high confidence (95%) of a low probability (at most 5%) of failure.

- *Seismic hazard* – Any physical phenomenon, such as ground motion or ground failure, that is associated with an earthquake and may produce adverse effects on human activities (such as posing a risk to a nuclear facility).

- *Seismic margin* – The difference between a plant's HCLPF capacity and its seismic design basis (safe shutdown earthquake, SSE).

- *Seismic risk* – The risk (frequency of occurrence multiplied by its consequence) of severe accidents at a nuclear power plant that are initiated by earthquakes. A severe accident is an accident that causes core damage and, possibly, a subsequent release of radioactive materials to the environment. Several risk metrics may be used to express seismic risk, such as seismic core-damage frequency and seismic large early release frequency.

GENERIC ISSUE 199 (GI-199)
IMPLICATIONS OF UPDATED PROBABILISTIC SEISMIC HAZARD ESTIMATES IN CENTRAL AND EASTERN UNITED STATES ON EXISTING PLANTS

SAFETY/RISK ASSESSMENT

1. BACKGROUND

In support of early site permits for new reactors, the U.S. Nuclear Regulatory Commission (NRC) staff reviewed updates to seismic source and ground motion models provided by applicants. The seismic update information included new models to estimate earthquake ground motion and updated models for earthquake sources in seismic regions around Charleston, South Carolina, New Madrid, Missouri, and southern Illinois and Indiana. The new data and models resulted in increased estimates of the seismic hazards at many plants in the Central and Eastern United States (CEUS), but these estimates remain small in an absolute sense. The staff reviewed and evaluated this new information along with recent U.S. Geological Survey (USGS) seismic hazard estimates for the CEUS. From this review, the staff identified that the estimated seismic hazard levels at some current CEUS operating sites might be higher than seismic hazard values used in design and previous evaluations. Figure 1 shows a comparison of response spectral values based on Early Site Permit (ESP) seismic hazard results with those previously developed as part of the 1989 Electric Power Research Institute-Seismicity Owners Group (EPRI-SOG) study for an annual exceedance frequency (AEF) of 10^{-5}. The figure shows that for four of the ESP submittals (North Anna, Grand Gulf, Vogtle, and Clinton), the seismic hazard is higher over most of the frequency range compared to the earlier EPRI-SOG study results.

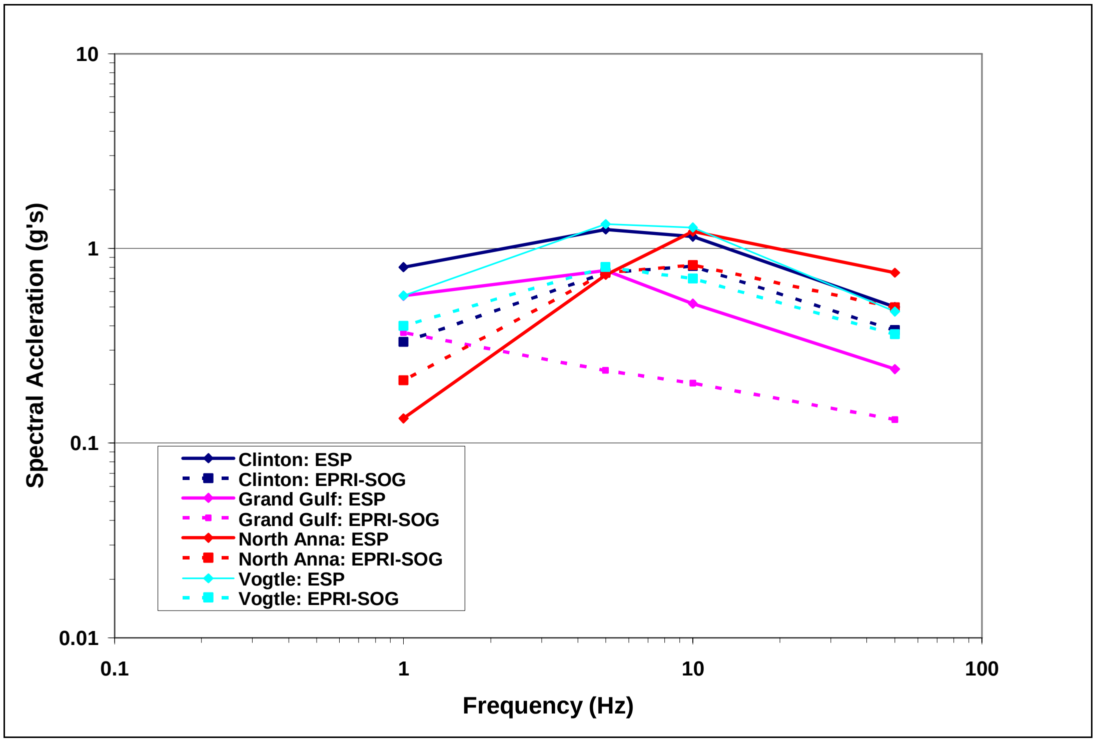

Figure 1. Comparison of Seismic Hazard Results for Four Early Site Permit Submittals (Solid Lines) to 1989 EPRI-SOG Results (Dashed Lines). Curves are response spectral values (5-percent damping) at an annual exceedance frequency of 10^{-5}.

The staff of NRC's Office of Nuclear Reactor Regulation (NRR) compared the new seismic hazard data with the earlier evaluations conducted as part of the Individual Plant Examination of External Events (IPEEE) Program. From this comparison, the staff determined that seismic designs of operating plants in the CEUS still provide adequate safety margins; however, the staff continues to evaluate new seismic hazard data and models and their potential impact on plant risk estimates. At the same time, the staff also recognized that the new seismic data and models could reduce available safety margins because of increased estimates of the probability associated with seismic hazards at some of the currently operating sites in the CEUS. The licensing basis for these plants does not include a probabilistic assessment of seismic hazards or a probabilistic assessment of their potential impact on plant structures, systems, and components (SSCs). Rather, the licensing basis for these plants is based on deterministic analysis for design basis loads from the maximum earthquake level that is determined from historical data (10 CFR 100 Appendix A). On May 26, 2005, the NRR staff issued a memorandum (ADAMS Accession No. ML051450456) recommending that the new data and models on CEUS seismic hazards be examined using a probabilistic approach under the Generic Issues Program (GIP) to help assess the potential reduction in available safety margins.

The staff completed a screening analysis using guidance contained in Management Directive (MD) 6.4 and SECY-07-0022 in December 2007 and reconvened the screening panel in January 2008. On February 1, 2008, the RES Director approved the screening panel's recommendation (ADAMS Accession No. ML073400477) to begin the Safety/Risk Assessment Stage of the Generic Issue Process. On February 6, 2008, the staff met with the public and stakeholders to discuss the results of the Screening Stage of Generic Issue 199.

On March 14, 2007, NRC and the Electric Power Research Institute (EPRI) signed a Memorandum of Understanding (MOU) on Cooperative Nuclear Safety Research. On July 11, 2008, NRC signed an addendum to this MOU concerning seismic risk, and on July 22, 2008, EPRI also signed the addendum. Program Element 3A of this addendum addresses updated seismic hazard assessments in support of GI-199. NRC and EPRI met on December 3, 2008, in Ft. Lauderdale, Florida, and March 17-18, 2009, in Palo Alto, California, to exchange information about seismic risk methodology, seismic hazard curves, and current seismic core-damage frequency estimates for operating nuclear power plants (NPPs). Under the terms of the MOU, data acquired during the course of collaborative work are considered privileged information and thus are routinely withheld from release until the final reports on this work are made publically available.

2. PURPOSE

The purpose of the Safety/Risk Assessment Stage is twofold:

- Determine, on a generic basis, if the risk associated with Generic Issue (GI) 199, “Implications of Updated Probabilistic Seismic Hazard Estimates in Central and Eastern United States (CEUS) on Existing Plants,” warrants further investigation for potential imposition as a cost-justified back-fit.

- Provide a recommendation regarding the next step (i.e., should the issue continue to the Regulatory Assessment Stage for identification and evaluation of potential generic, cost-justified backfits, be dropped due to low risk, or have other actions taken outside the Generic Issues Program).

3. APPROACH

To determine the implications of updated probabilistic seismic hazard estimates in the CEUS on existing NPPs, the staff performed a two-stage assessment. One stage involved evaluating the change in seismic hazard with respect to previous estimates at individual NPPs (discussed in section 4.2). The second stage estimated the change in seismic core-damage frequency (SCDF) as a result of the change in the seismic hazard for each operating NPP in the CEUS (discussed in section 4.1). This approach was based on the following considerations:

- The estimation of seismic hazards is complex and significant uncertainties are associated with many of the input parameters in the hazard models. This is especially true for regions of lower seismic activity such as the CEUS. Evaluation of any new seismic hazard estimates with respect to previous estimates is prudent to ensure the changes are significant and not merely representative of the fidelity in the seismic hazard estimation process.

- MD 6.4 states that the risk-informed technical assessment of a generic issue may be conducted using core-damage frequency (CDF), large early-release frequency (LERF), public dose (person-rem), or a combination of these risk metrics. The selection of the appropriate risk metric(s) to assess a generic issue depends on the specific nature of the generic issue being assessed. The Safety/Risk Assessment of GI-199 involves the implications of updated probabilistic seismic hazard estimates that describe the distribution (frequency and size) of seismically induced site vibratory ground motions at NPP sites. Although each of the three risk metrics (CDF, LERF, and public dose) depends on the seismic hazard, SCDF is expected to be the most sensitive to changes in the seismic hazard.

- Given a limited number of assumptions, SCDF can be readily estimated using the seismic hazard and information from the IPEEE requested by Generic Letter 88-20, Supplement 4. In contrast, the containment performance analyses conducted under the IPEEE program did not produce sufficient quantitative information to allow the estimation of either LERF or public dose.

- Typically, the Safety/Risk Assessment of a generic issue is based upon a surrogate probabilistic risk assessment (PRA) or a small set of surrogate PRAs that model classes of plants (e.g., four-loop Westinghouse pressurized-water reactors [PWRs], Babcock and Wilcox PWRs, boiling-water reactors [BWRs], etc.). However, the seismic hazard at each NPP site is unique because it depends on the seismology and the geology surrounding the site. Figure 2 illustrates this point and illustrates the large variation in the seismic hazard across the United States. The Safety/Risk Assessment needed to determine the extent of GI-199 (e.g., determine how many plants are potentially affected). Therefore, it was necessary to determine the implications of updated probabilistic seismic hazard estimates in the CEUS at each operating NPP.

With respect to the Safety/Risk Assessment Stage, the term “Central and Eastern United States” refers to operating NPPs that are located east of the Rocky Mountains. Table 1 lists the 96 operating NPPs that are located within the CEUS.

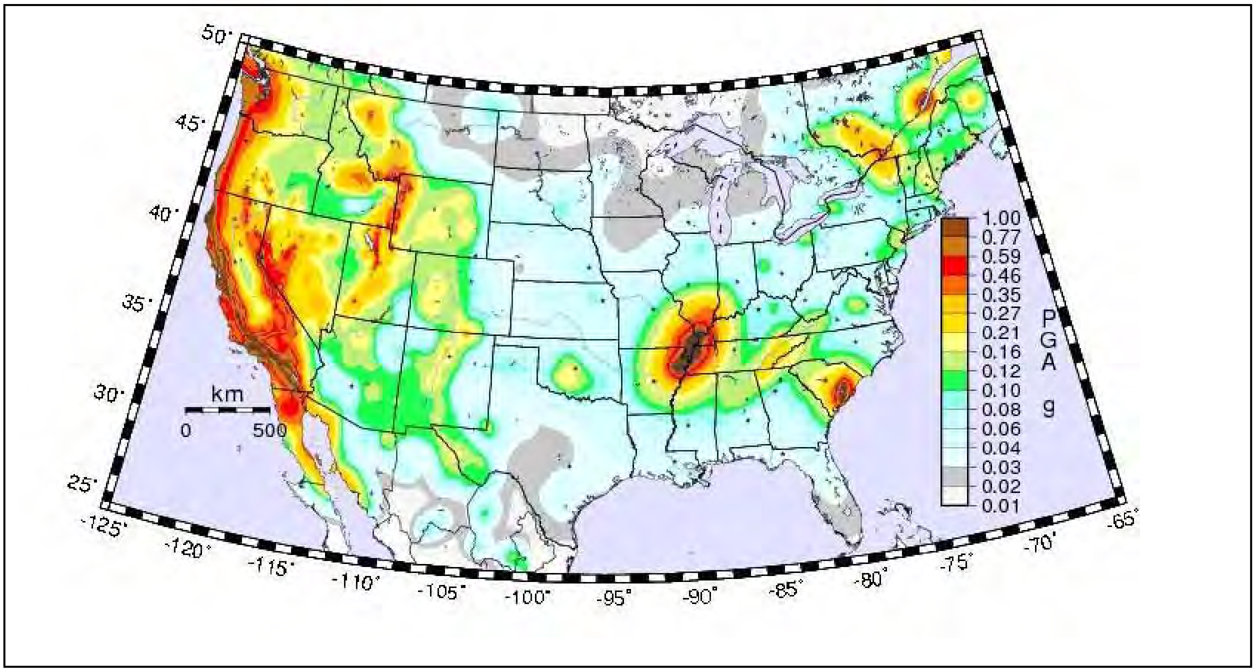

Figure 2. Peak Horizontal Acceleration (%*g*) for 2-Percent Probability of Exceedance in 50 Years for Conterminous United States. Source: USGS.

Table 1. List Of Operating Nuclear Power Plants Located Within the Central And Eastern United States.

Plant	Docket Number	Plant	Docket Number
Arkansas Nuclear 1	05000313	Millstone 2	05000336
Arkansas Nuclear 2	05000368	Millstone 3	05000423
Beaver Valley 1	05000334	Monticello	05000263
Beaver Valley 2	05000412	Nine Mile Point 1	05000220
Braidwood 1	05000456	Nine Mile Point 2	05000410
Braidwood 2	05000457	North Anna 1	05000338
Browns Ferry 1	05000259	North Anna 2	05000339
Browns Ferry 2	05000260	Oconee 1	05000269
Browns Ferry 3	05000296	Oconee 2	05000270
Brunswick 1	05000325	Oconee 3	05000287
Brunswick 2	05000324	Oyster Creek	05000219
Byron 1	05000454	Palisades	05000255
Byron 2	05000455	Peach Bottom 2	05000277
Callaway	05000483	Peach Bottom 3	05000278
Calvert Cliffs 1	05000317	Perry 1	05000440
Calvert Cliffs 2	05000318	Pilgrim 1	05000293
Catawba 1	05000413	Point Beach 1	05000266
Catawba 2	05000414	Point Beach 2	05000301

Table 1. List Of Operating Nuclear Power Plants Located Within the Central And Eastern United States.

Plant	Docket Number	Plant	Docket Number
Clinton	05000461	Prairie Island 1	05000282
Comanche Peak 1	05000445	Prairie Island 2	05000306
Comanche Peak 2	05000446	Quad Cities 1	05000254
Cooper	05000298	Quad Cities 2	05000265
Crystal River 3	05000302	River Bend 1	05000458
D.C. Cook 1	05000315	Robinson 2	05000261
D.C. Cook 2	05000316	Saint Lucie 1	05000335
Davis-Besse	05000346	Saint Lucie 2	05000389
Dresden 2	05000237	Salem 1	05000272
Dresden 3	05000249	Salem 2	05000311
Duane Arnold	05000331	Seabrook 1	05000443
Farley 1	05000348	Sequoyah 1	05000327
Farley 2	05000364	Sequoyah 2	05000328
Fermi 2	05000341	South Texas 1	05000498
FitzPatrick	05000333	South Texas 2	05000499
Fort Calhoun	05000285	Summer	05000395
Ginna	05000244	Surry 1	05000280
Grand Gulf 1	05000416	Surry 2	05000281
Harris 1	05000400	Susquehanna 1	05000387
Hatch 1	05000321	Susquehanna 2	05000388
Hatch 2	05000366	Three Mile Island 1	05000289
Hope Creek 1	05000354	Turkey Point 3	05000250
Indian Point 2	05000247	Turkey Point 4	05000251
Indian Point 3	05000286	Vermont Yankee	05000271
Kewaunee	05000305	Vogtle 1	05000424
La Salle 1	05000373	Vogtle 2	05000425
La Salle 2	05000374	Waterford 3	05000382
Limerick 1	05000352	Watts Bar 1	05000390
Limerick 2	05000353	Wolf Creek 1	05000482
McGuire 1	05000369		
McGuire 2	05000370		

3.1 Seismic Core-Damage Frequency Estimates

Approximate SCDF estimates were developed by integrating the mean seismic hazard curve and the mean plant-level fragility curve for each NPP. This method, developed by Kennedy (1997), is discussed in Section 10.8.9 of AMSE/ANS RA-Sa-2009 and has previously been used by the staff in the resolution of GI-194, “Implications of Updated Probabilistic Seismic Hazard Estimates” and is the basis for the seismic performance-based approach for determining the site SSE and described in Regulatory Guide 1.208. Appendix A provides a detailed explanation of the method and its implementation.

The approach used in the Safety/Risk Assessment to approximate SCDF uses the available seismic risk information from IPEEEs and is computationally efficient. Computational efficiency is an important consideration because SCDFs need to be generated for each operating NPP located in the CEUS using various seismic hazard estimates to fully assess the implications of GI-199. However, the following are some recognized limitations to the approach:

- The integration of the mean seismic hazard curve and the mean plant-level fragility curve is not equal to the mean SCDF; accordingly, the SCDF estimates produced by the approach are point estimates. However, the numerical criteria in MD 6.4 are posed in terms of mean values.

- The approach does not provide a quantitative estimate of the parametric uncertainty in the SCDF. It should be noted that the mean seismic hazard curves produced by the USGS do not explicitly include uncertainty information.

- The approach does not provide any insight into which SSCs are important to seismic risk. This knowledge is needed if a regulatory analysis is required because it provides the basis for postulating plant backfits and conducting a value-impact analysis.

SCDF estimates were produced using three sets of mean seismic hazard curves that have been generated at various times and by various organizations as follows:

1. Electric Power Research Institute, 1989,
2. Lawrence Livermore National Laboratory, 1994.
3. NRC based on U.S. Geological Survey, 2008.

The following eight SCDF estimates were developed from each set of seismic hazard curves:

1. $SCDF_{pga}$ – integration of the pga-based seismic hazard and plant-level fragility curves.

2. $SCDF_{10}$ – integration of the 10-Hz seismic hazard and plant-level fragility curves.

3. $SCDF_5$ – integration of the 5-Hz seismic hazard and plant-level fragility curves.

4. $SCDF_1$ – integration of the 1-Hz seismic hazard and plant-level fragility curves.

5. $SCDF_{max}$ – maximum of the $SCDF_{pga}$, $SCDF_{10}$, $SCDF_5$, and $SCDF_1$ estimates.

6. $SCDF_{avg}$ – simple average of the $SCDF_{pga}$, $SCDF_{10}$, $SCDF_5$, and $SCDF_1$ estimates.

7. $SCDF_{IPEEE}$ – weighted average of the $SCDF_{pga}$, $SCDF_{10}$, $SCDF_5$, and $SCDF_1$ estimates, where the weights were obtained from Appendix A of NUREG-1407 ($SCDF_{pga}$ was weighted by one-seventh and the other SCDF estimates were weighted by two-sevenths).

8. $SCDF_{wl}$ – SCDF estimate based on the weakest link model described in Appendix A

3.2 Seismic Hazard Curves

As discussed earlier, the approach taken in the Safety/Risk Assessment was to assess changes in seismic hazard estimates with respect to previous estimates and then evaluate any risk significance of those changes using the Generic Issues decision framework. To proceed, it is necessary to develop both a current estimate of seismic hazard and an estimate of change in hazard for each NPP site of interest. This requires the specification of seismic hazards using current tools (i.e., the U.S. Geological Survey [USGS] hazard model results discussed below) and previous seismic hazard estimates that were considered to be acceptable. For this assessment, the seismic hazard estimates developed by EPRI-SOG (1989) and Lawrence Livermore National Laboratory (LLNL) (NUREG-1488, 1993) were used as the “baseline” cases from which changes could be evaluated. Both the EPRI and LLNL hazard results were identified as acceptable for use in the IPEEE evaluations, and the resulting SCDF values (either implied or explicitly computed) were deemed acceptable at the time. The results of the current SCDF and Delta-SCDF computations are discussed in more detail in subsequent sections.

The estimates of seismic hazard used in this Safety/Risk Assessment were obtained using the seismic hazard model developed by the USGS available during the fall of 2008. Other recent comprehensive seismic hazard studies have been conducted at various locations in the CEUS. Examples of these studies include the Trial Implementation Program (TIP) conducted by LLNL for NRC (NUREG-6607, 2002), a study for the South Carolina Department of Transportation (SCDOT), and a study performed for the Tennessee Valley Authority (TVA) Dam Safety Analysis Program. Unfortunately, these studies focused on small regions (or individual sites) and would not be useful for a systematic evaluation of all NPP sites in the CEUS.

As stated earlier in the Background section of this report, industry has updated the EPRI-SOG (1989) seismic source models as well as the ground motion prediction models for the CEUS in support of the ESP and Combined License (COL) applications submitted to NRC. These updated probabilistic seismic hazard analysis (PSHA) estimates would provide the staff with an ideal comparison to the earlier PSHA estimates; however, under program element 3A of the MOU, industry has only provided a very limited amount of information for NRC staff to use. As a result, the staff has primarily used the 2008 version of the USGS hazard model although it also evaluated the seismic hazard results provided by industry and submitted as part of the ESP and COL applications.

This USGS seismic hazard model has been developed and refined over a number of years (Frankel et al., 1996; 2002; Peterson et al., 2008). The USGS National Seismic Hazard Mapping Program follows a structured process to develop the seismic hazard models and computational programs used in the development of the national seismic hazard maps. This process involves a series of regional workshops used to elicit information and data from the research community and includes internal and external peer review of the resulting model. The results of this process are seismic hazard estimates for a dense grid of locations in the United States that are used as the basis for seismic design parameters in the current building codes (see Figure 2 for an example). Although not specifically designed to conform to the guidelines for performing high-level seismic hazard studies outlined in the Senior Seismic Hazard Analysis Committee (SSHAC) report (NUREG/CR-6372, 1997), the USGS process possesses many of the attributes of a Level 3 study as discussed in the SSHAC report. Likewise, although the EPRI-SOG (1989) study predated the SSHAC guidelines, the study had many of the attributes of a Level 4 study, and the updates being performed for the ESP and COL submittals are consistent with the SSHAC (Level 2) guidelines. The USGS seismic hazard models have not been used to site critical facilities such as NPPs although the NRC staff and industry have used the USGS hazard results for comparison to the EPRI-SOG models submitted in support of the ESP and COL applications. Recent regional or site-specific studies such as the TIP, SCDOT, and TVA studies mentioned above have been evaluated during the development of the USGS model as well as the updated EPRI-SOG model used in the ESP-COL applications.

For this assessment, the 2008 version of the USGS hazard model was used to compute seismic hazard estimates for individual plant locations (defined by latitude and longitude). For multiunit sites, the computation location was defined as the approximate center of the nuclear complex. The calculations assumed rock site conditions with near-surface shear wave velocity of 2,500 meters/second. Not all NPP sites can be reasonably represented as having hard rock site conditions. The definition of site type for individual units was generally consistent with the generic site classifications contained in the EPRI-SOG study (1989). For plants not evaluated in the EPRI-SOG (1989) study, the Final Safety Analysis Report (FSAR) was consulted to define a representative generic site classification. For any soil sites that had site-specific site amplifications available, those functions were used in lieu of the generic functions. Table B-2 in Appendix B summarizes the assumed site-type classifications for each NPP site.

As part of its preparation for submitting COL and ESP applications, industry has refined its site-specific amplification functions for many if not all of the CEUS NPP sites. However, the NRC staff has had access to only a few sites in addition to the ESP and COL sites that are collocated with a currently operating NPP. These site amplification functions can be quite different even for sites located very close together. Different assumptions regarding site amplification functions can have a very significant impact on hazard results (and subsequently on risk metrics). Figure B-5 in Appendix B illustrates this effect.

Seismic hazard estimates for each site were computed for four spectral frequencies (peak ground acceleration or PGA, 10, 5, and 1 Hz). Figure 3 illustrates representative results for rock hazard at the Ginna NPP site. Note that the hazard curves ($H(a)$) are monotonically decreasing and about linear in log-log-space. This figure illustrates the general (but not universal) characteristics of the comparison for many plants. Specifically, the latest USGS results are greater than the 1989 EPRI-SOG results but similar to, or in some cases less than, the 1993 LLNL results. Appendix B contains additional details on the computation of seismic hazard and additional comparisons.

As described in the next section, the results of the IPEEE program were utilized to develop fragility estimates to use with the seismic hazard results to produce plant-specific seismic CDF estimates. However, the IPEEE results represent the plant-level fragility in terms of PGA only; specifically, either directly or indirectly as a high confidence of low probability of failure PGA value ($HCLPF_{PGA}$). It is recognized that, at the plant level, the design response spectrum varies with frequency (Hz) (see Figure 4) and different elements within the plant may respond to different frequencies. As a result, it is desirable to estimate a frequency-dependent SCDF value over a range of frequencies of interest. This was accomplished by noting that as part of the IPEEE submittals, each NPP defined a review-level earthquake (RLE) spectral shape that was used in the review and analysis process. Table B-2 in Appendix B summarizes the IPEEE evaluation method, high confidence of low probability of failure (HCLPF) value, and RLE spectral shape for each NPP in the CEUS.

By anchoring the RLE spectrum to the $HCLPF_{PGA}$ –value and knowing the ratio between the spectral values of interest (10, 5, and 1 Hz) and PGA in the RLE spectrum, it is possible to compute $HCLPF_{10Hz}$, $HCLPF_{5Hz}$, and $HCLPF_{1Hz}$ values in addition to $HCLPF_{PGA}$. Figure 4 illustrates this procedure. Those plants that performed a seismic margins analysis (SMA) as part of the IPEEE evaluation generally utilized a smooth, broad-band RLE spectrum (NUREG-0098 or similar). However, for the plants that performed a seismic probabilistic risk assessment (SPRA), the RLE spectrum was generally based on a site-specific uniform hazard spectrum (UHS). In some cases this UHS fell below the plant-specific safe shutdown earthquake (SSE) (or design basis) spectrum at lower frequencies, implying the $\mathrm{HCLPF}_{1\mathrm{Hz}}$, for example, would be well below the design basis value. Figure 4 shows this effect. The NRC staff conducting this evaluation believes it is unlikely that the HCLPF would be ***less*** than the design value if the recommendations/requirements contained in the Standard Review Plan were followed. As a result, for this assessment, we have decided to test the spectral HCLPF values against the design values and have chosen the maximum of the two values (i.e., for each spectral frequency of interest: $\mathrm{HCLPF}_{\mathrm{SA}} = \max[\mathrm{RLE}_{\mathrm{SA}}, \mathrm{SSE}_{\mathrm{SA}}]$).

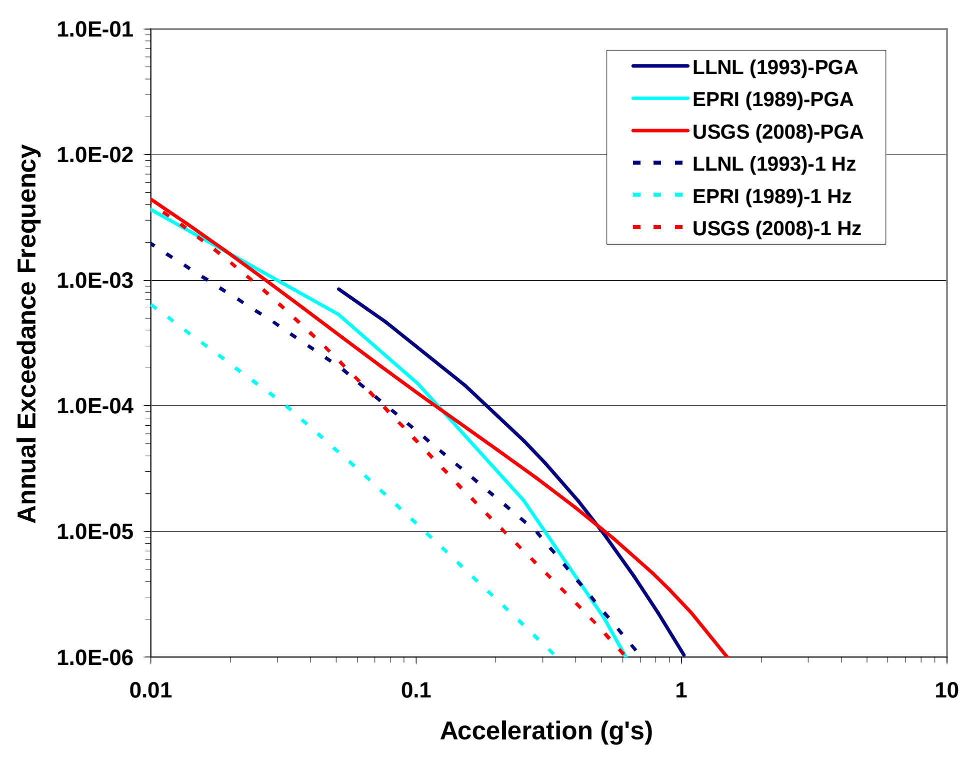

Figure 3. Comparison of Seismic Hazard Curves for the Ginna NPP Site. These curves were developed using the 2008 USGS seismic hazard model (red curves), the 1993 LLNL results (blue curves), and 1989 EPRI results (turquoise curves). Results for PGA are indicated by solid curves and for 1-Hz spectral acceleration by dashed curves.

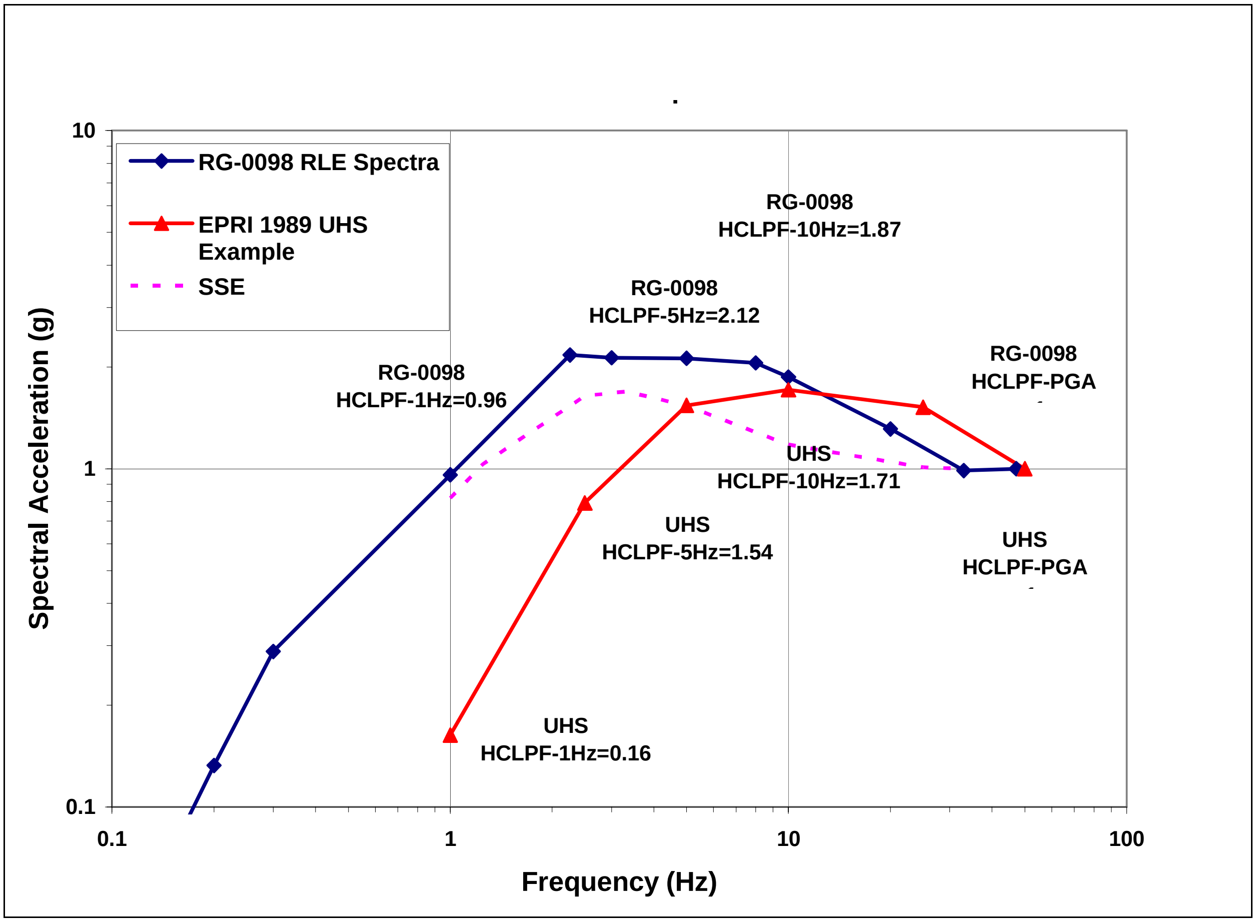

Figure 4. Illustration of Normalized Spectral Shapes Used in IPEEE Analyses. The blue curve is the spectral shape from RG-0098 that was used as the RLE in many IPEEE SMA assessments, the red curve is an example uniform hazard (UHS) spectrum similar to many used in the IPEEE SPRAs. The dashed curve is an example SSE spectrum (normalized). The HCLPF values for spectral frequencies other than PGA were assigned based on the ratio between the frequency of interest and PGA ($HCLPF_{10Hz} = 1.87*HCLPF_{PGA}$ for the RG-0098 example shown here). For plants that used a UHS in the IPEEE assessment, the individual spectral HCLPF values (e.g., $HCLPF_{5Hz}$) were tested to see if they fell below the SSE spectrum at that frequency (SSE_{5Hz}); if so, the maximum of the two values was assigned.

3.3 Plant-Level Fragility Curves

The plant-level fragility curves were developed from information provided in the IPEEE submittals. It is recognized that plants may have made modifications that changed the plant-level fragility subsequent to completion of their IPEEEs; however, no regulatory requirement exists for plants to reflect the impact of such modifications in their IPEEEs (or, in fact, for plants licensed under 10 CFR Part 50 to maintain a PRA).

About one-third of the plants performed a SPRA as part of their IPEEE program. Licensees were not required to provide the actual SPRAs to NRC. Of the plants that performed SPRAs, about two-thirds provided plant-level fragility information (either in tabular or graphical format) in their IPEEE submittals. The remaining one-third of the SPRA plants provided SCDF estimates based on a variety of seismic hazard curves (EPRI 1989, LLNL 1994, or site-specific curves developed specifically for the IPEEE program). For these remaining plants, plant-level fragility values were back-calculated by matching the reported SCDFs and using engineering judgment. In cases where reasonable engineering judgments could not readily be made (e.g., the shape of the review-level ground motion ground spectrum), sensitivity studies were performed.

About two-thirds of the plants conducted a SMA as part of their IPEEE program. The figure of merit for an SMA is the plant-level HCLPF. Two SMA methodologies were recognized in Generic Letter 88-20, Supplement 4, for conducting an SMA—the EPRI methodology and the NRC methodology. Both methods utilize an RLE, which is specified in NUREG-1407 for each plant (listed in Table B-2 of Appendix B). In the EPRI methodology, two success paths are identified, where a success path consists of a selected group of safety functions capable of bringing the plant to a safe state after an earthquake larger than design basis and maintaining it there for 72 hours. The individual SSCs needed to accomplish each of the two success paths are then screened with respect to the RLE (if an SSC has a HCLPF that is less than the RLE, then the SMA uses the actual HCLPF; otherwise, the RLE is used). The individual SSC HCLPF values are then propagated through the success paths using simplified bounding logic to determine the plant-level HCLPF. The NRC approach uses fault tree logic (as opposed to success paths).

It is important to recognize that the actual plant-level HCLPF may not be determined by an SMA; that is, the RLE may be a lower bound for the actual plant-level HCLPF. This was acceptable for the IPEEE program because it was focused on identifying vulnerabilities and risk insights. However, it poses a challenge for the Safety/Risk Assessment because SCDF estimates based on the RLE may be conservative. This conservatism is opposed, however, by limitations in the basic SMA approach, which only treats random equipment failures (nonseismic failures) and operator errors in a simplified fashion.

Appendix C provides a detailed discussion of the development of the plant-level fragility curves and tabulates the fragility parameters used in the Safety/Risk Assessment.

4. RESULTS

4.1 SCDF Estimates

Using the 2008 USGS seismic hazard curves, all operating plants in the CEUS have SCDF less than or equal to 10^{-4} per year. This result confirms NRR's conclusion that currently operating plants are adequately protected against the change in seismic hazard estimates because the guidelines in NRR Office Instruction LIC-504, "Integrated Risk-Informed Decision Making Process for Emergent Issues," are not exceeded.

Generic Issues Program guidance contains numerical screening criteria in the form of an x-y plot, where the x-axis is the total baseline core-damage frequency and the y-axis is the change in core-damage frequency associated with the generic issue. The staff does not have estimates of the total core-damage frequency for each plant located within the CEUS (no information is available on external events such as fires, external floods, etc.). Moreover, establishing the baseline SCDF is problematic because this depends on which set of seismic hazard curves are used. Possible candidates include the 1989 EPRI-SOG results and the 1994 LLNL results because both were accepted by the staff for use in the IPEEE process. It must be noted that the licensing basis for plants located in the CEUS is based on deterministic analysis for design basis loads from the maximum earthquake level that is determined from historical data. Consequently, the licensing basis for these plants does not include a probabilistic assessment of seismic hazards or their potential impacts on plant risk. Figure 5 provides a comparison against the MD 6.4 criteria using both the EPRI data and the LLNL data to establish the baseline seismic risk. Continued evaluation is warranted for plants that lie in the shaded region of Figure 5.

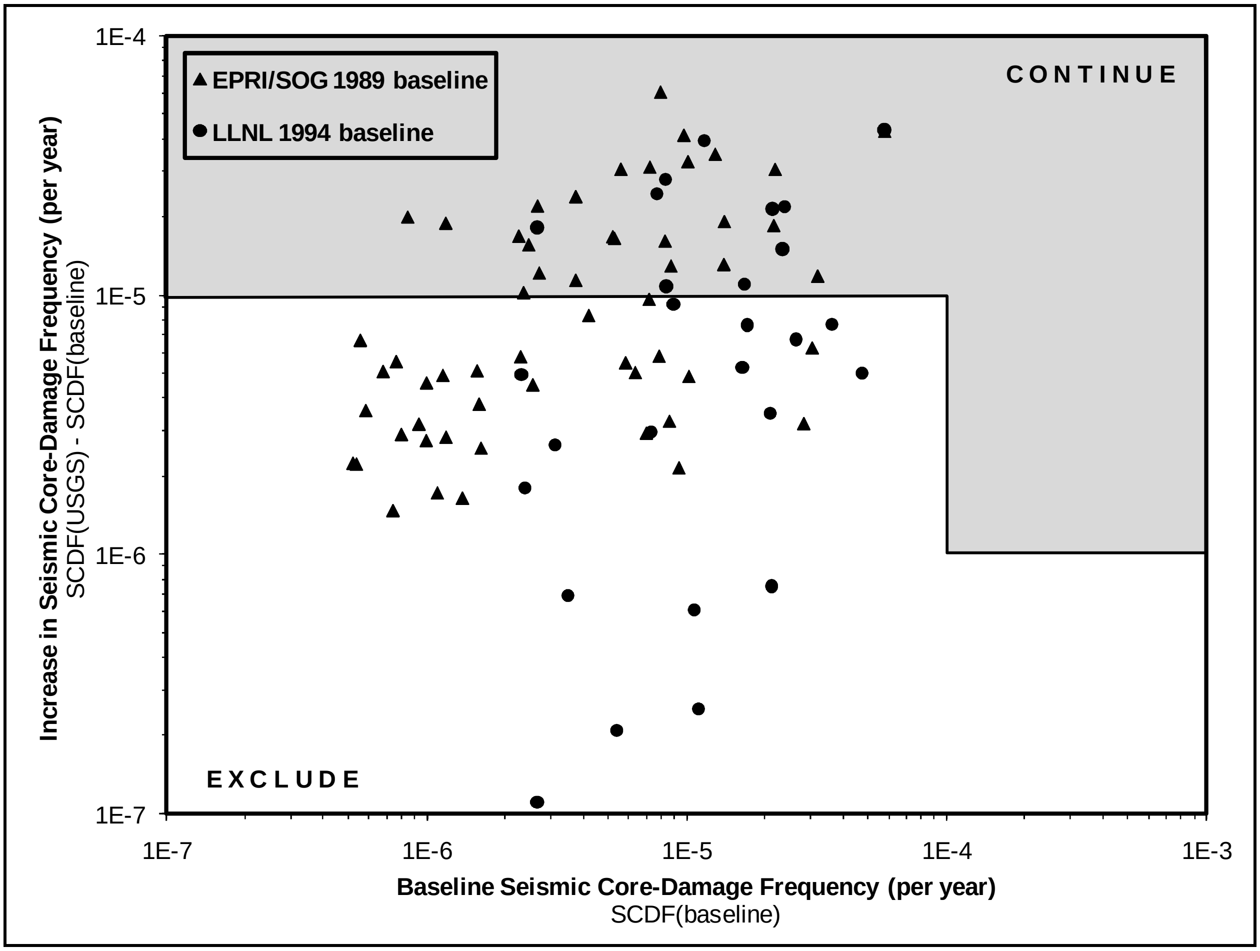

Figure 5. Comparison of Results from the Safety/Risk Assessment for GI-199 to the Screening Criteria in MD 6.4.

If the 1989 EPRI-SOG data are used to establish the baseline SCDF, then 36 plants lie in the “continue” region; if the 1994 LLNL data is used, only 11 plants lie in the “continue” region.” These results do not change if the contribution from internal events, as computed by the staff’s Standardized Plant Analysis of Risk (SPAR) models, is added to the baseline SCDF.

Another approach to review the results of the Safety/Risk Assessment is to develop fleetwide population variability distributions of the SCDF estimates. Figure 6 provides “box-and-whisker” plots of these distributions.

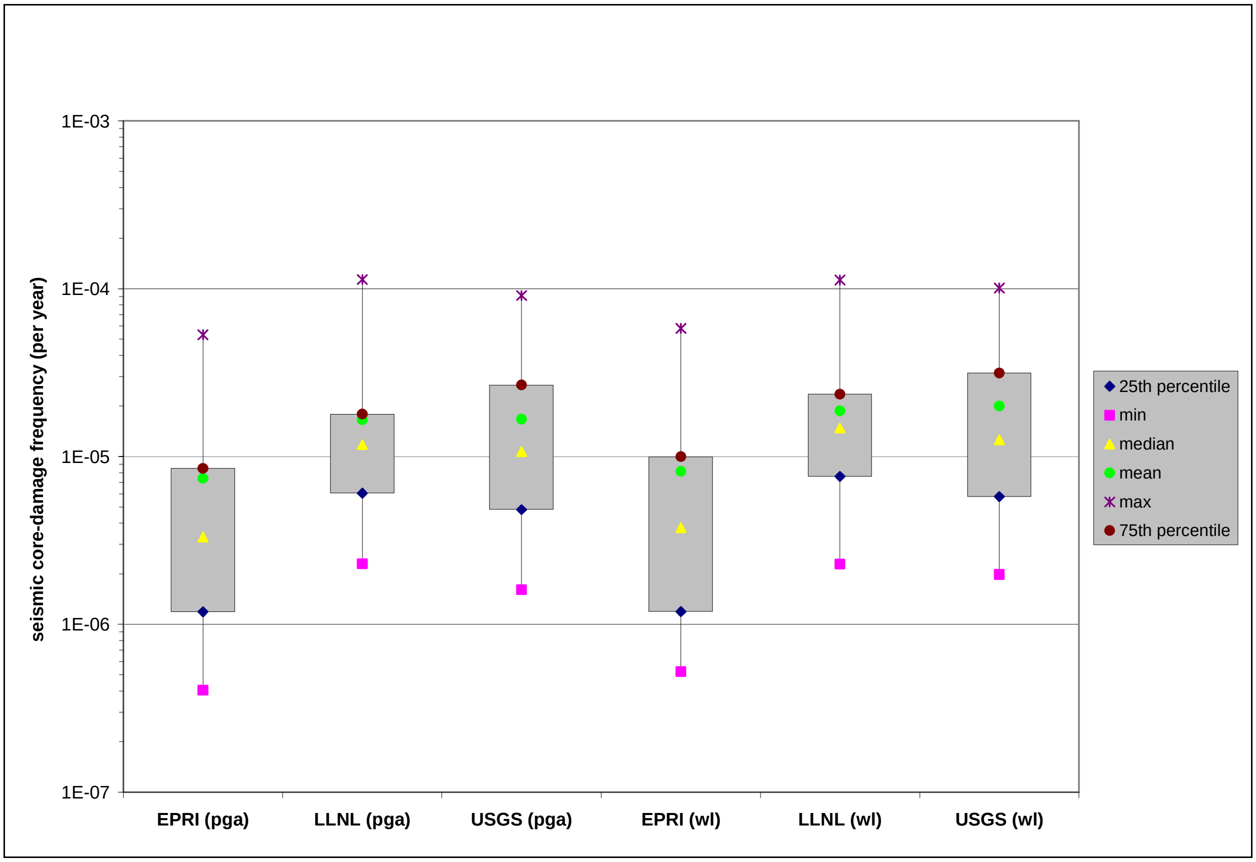

Figure 6. Fleetwide Population Variability Distributions of the Seismic Core-Damage Frequency Estimates.

Figure 6 indicates that the distribution of SCDF based on the 2008 USGS data is about the same as the distribution of SCDF based on the 1994 LLNL data. These results suggest that no change has been made in the fleetwide seismic risk since completion of the IPEEE program. However, Figure 6 must be carefully interpreted because the SCDF estimates at individual plants may have either increased or decreased. Figure 7 illustrates this observation by providing “box-and-whisker” plots of the distribution of the change in SCDF.

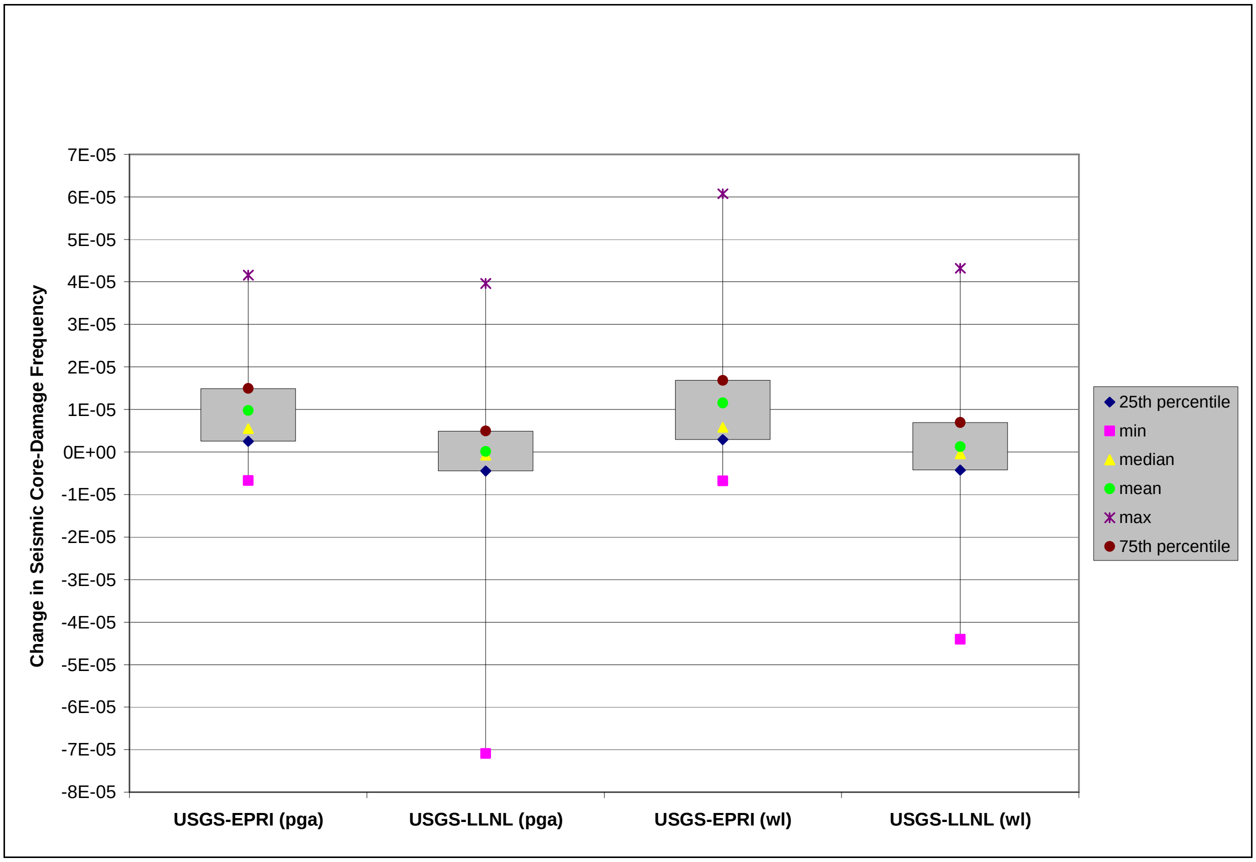

Figure 7. Fleetwide Population Variability Distributions of the Change in Seismic Core-Damage Frequency.

As a further aid to interpreting the results of the Safety/Risk Assessment, Figure 8 provides a plot that was constructed to simultaneously show the change in SCDF with respect to the 1989 EPRI data and the change in SCDF with respect to the 1994 LLNL data (this plot is termed the “delta-delta plot”). A “continue zone” was developed to identify plants where one change in SCDF is above 10^{-5} per year and the other change in SCDF is positive. Plants that lie in the “continue zone” are of potential interest because the SCDF based on the 2008 USGS seismic hazard data is greater than either of SCDF estimates based on the 1989 EPRI and 1994 LLNL seismic hazard data. The results of the Safety/Risk Assessment indicate that 24 plants lie in the “continue zone.”

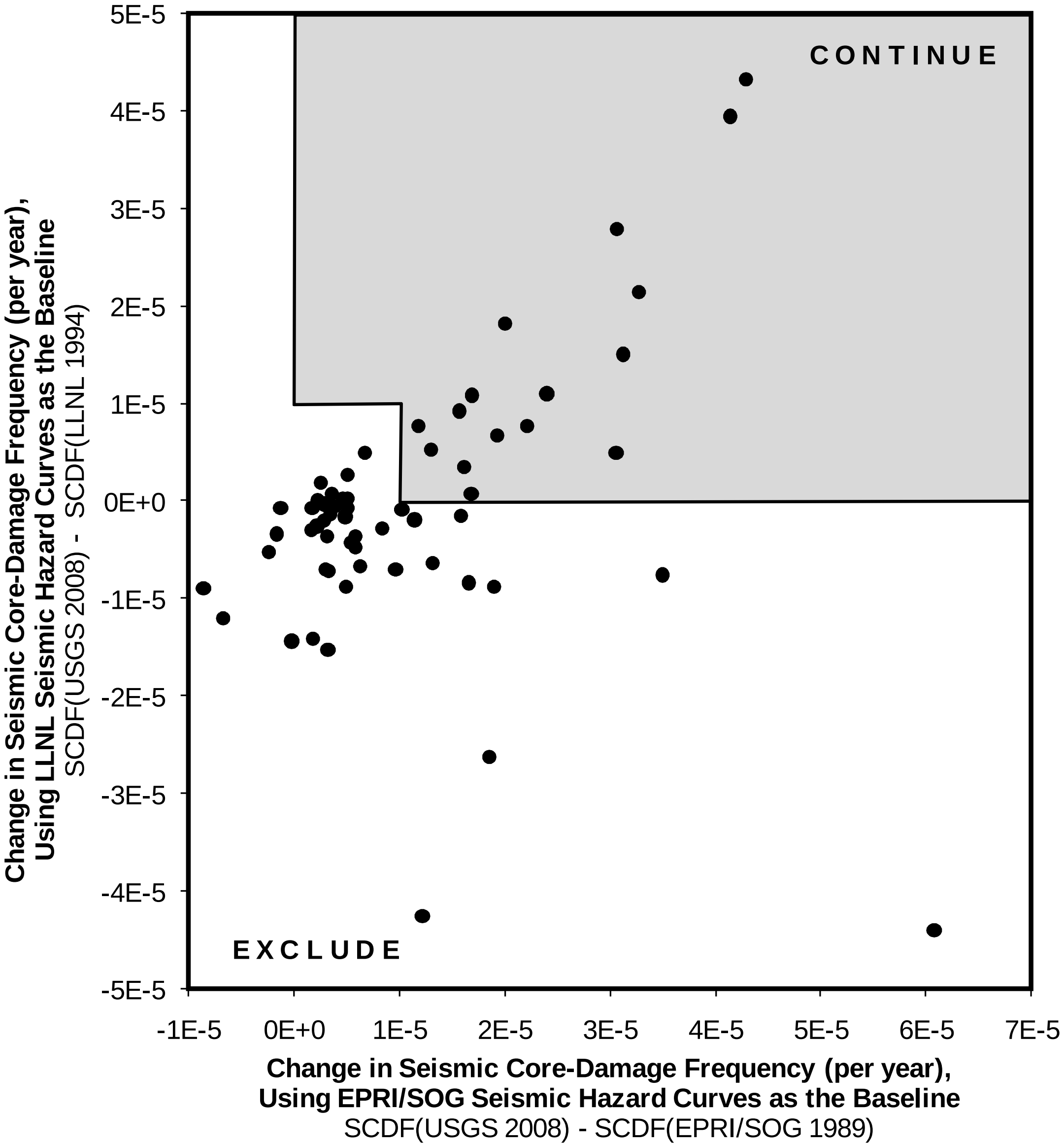

Figure 8. Change in SCDF with Respect to the 1989 EPRI and 1994 LLNL Seismic Hazard Data Sets Based on 2008 USGS Seismic Hazard Data (Delta-Delta Plot).

4.2 Evaluation of Changes in Seismic Hazard Estimates

To develop insights that may help in the Safety and Risk Assessment Stage, additional comparisons of the changes in seismic hazard were made. This evaluation of the potential significance of changes in seismic hazards was performed in a stepwise fashion posing a series of questions that, if answered in the negative, indicated no substantive change in the estimate of seismic hazard at a particular NPP. If the answer to the question was affirmative, the NPP was included in the next step of the assessment process.

Question 1. Does current staff guidance produce different design spectrum than the SSE?

The original development of seismic design bases for the existing reactor fleet was deterministic and not consistent with current practice. This does not necessarily mean that the seismic design basis (the Safe Shutdown Earthquake, or SSE, spectrum) was, or is, deficient in some fashion. If the process currrently defined in Regulatory Guide 1.208 is applied to develop a seismic design basis spectrum (the Ground Motion Response Spectrum [GMRS]), will it be different than the SSE for an individual site? To try and answer this question, the GMRS developed using the USGS-based hazard estimates is compared to the SSE.

Note: RG 1.208 provides an alternative for use in satisfying the requirements set forth in 10 CFR 100.23. Specifically, RG 1.208 was developed to provide general guidance on methods acceptable to the NRC staff for (1) conducting geological, geophysical, seismological, and geotechnical investigations; (2) identifying and characterizing seismic sources; (3) conducting a probabilistic seismic hazard assessment (PSHA); (4) determining seismic wave transmission (soil amplification) characteristics of soil and rock sites; and (5) determining a site-specific, performance-based GMRS. RG 1.208 states that a PSHA in the CEUS must account for credible alternative seismic source models through the use of a decision tree with appropriate weighting factors that are based on the most up-to-date information and relative confidence in alternative characterizations for each seismic source. It recognizes that the seismic sources identified and characterized by the Lawrence Livermore National Laboratory (LLNL) and the Electric Power Research Institute Seismic Owners Group (EPRI/SOG) have been used for studies in the CEUS in the past, and that the United States Geological Survey also maintains a large database of seismic sources for both the CEUS and the WUS which may be beneficial in identifying the seismic sources that are relevant to a given nuclear power plant site. Although the LLNL, EPRI/SOG, or the USGS seismic hazard curves used in the GI-199 Safety/Risk Assessment do not, as-is, meet the guidance in RG 1.208, they are adequate for determining if GI-199 should proceed to the Regulatory Analysis Stage of the GIP.

To perform this comparison, several assumptions are required. First, the site characteristics and amplification functions are assumed to be similar to those defined in EPRI NP-6935 and free-surface motions are developed. Second, the seismic spectrum can be characterized by two intervals—peak ground acceleration (PGA) and spectral acceleration averaged between 5 and 10 Hz ($SA_{Avg5\text{-}10}$). PGA has been widely used to develop fragility estimates and represents the performance of SSCs that are sensitive to inertial effects. For SSCs that are sensitive to in-structure response, the $SA_{Avg5\text{-}10}$ captures the loading characteristics. Third, the GMRS is computed as:

$$GMRS_{USGS}=SA_{USGS}(\text{at Annual Exceedance Frequency of } 10^{-4})*DF$$

where DF is a design factor given by:

$$DF=\max(1.0,\ 0.6*Ar^{0.8}) \text{ and}$$

Ar is the ratio between SA at 10^{-5} and 10^{-4} annual exceedance frequencies.

The screening was based on identifying those plants where $(GMRS_{USGS}/SSE)^{PGA} > 1$ **and** $(GMRS_{USGS}/SSE)^{SAAvg5\text{-}10} > 1$. Figure 9 shows the results—61 of the 94 plants in the CEUS study area have increased PGA and $SA_{Avg5\text{-}10}$ relative to the SSE. For a plant to be "screened-in" using this criteria, both points plotted in Figure 9 must lie above the GMRS/SSE =1 line for that plant. The same logic holds for Figure 10 as well.

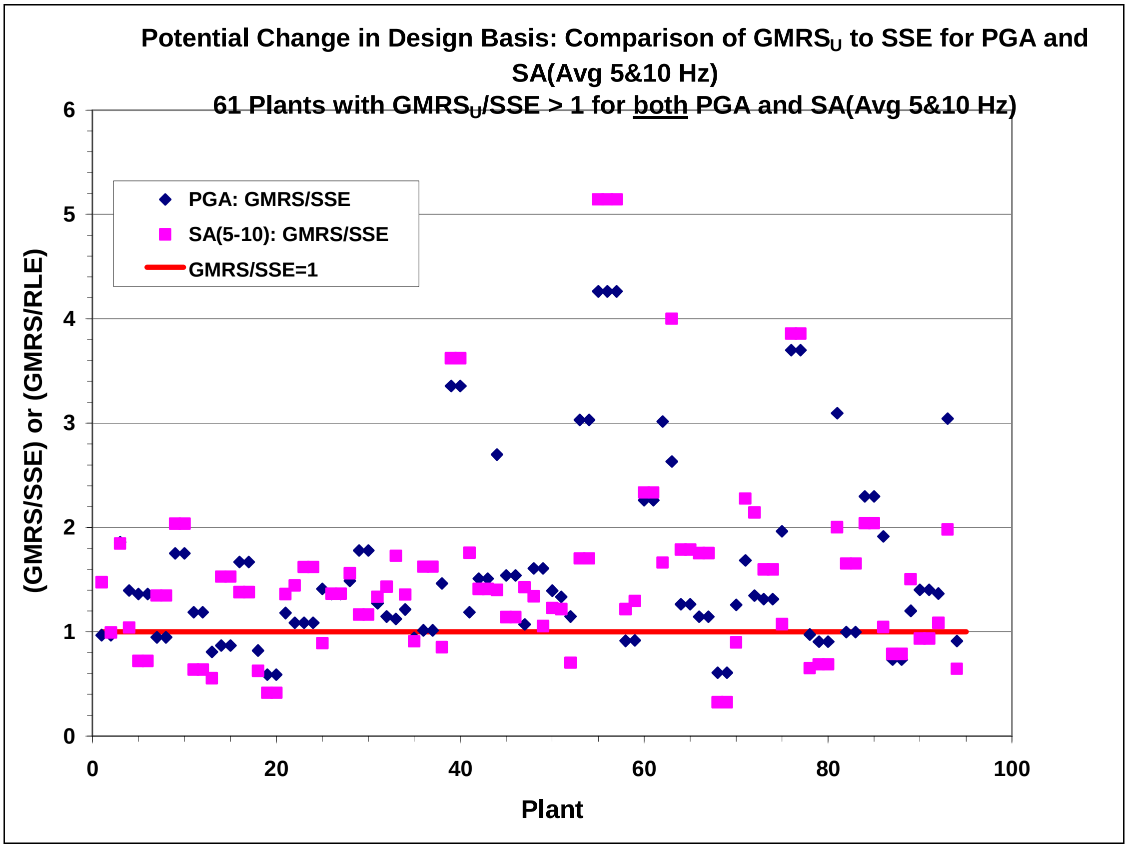

Figure 9. Comparison of GMRS$_{USGS}$ to SSE for PGA and SA$^{Avg5\text{-}10}$ for Plant Sites in CEUS. In this screening, 94 plants were evaluated and plotted.

Question 2. Does the current estimate of GMRS exceed the Review Level Earthquake (RLE) used in the IPEEE program?

All of the plants were evaluated under the IPEEE program, and many of them were evaluated for beyond-design basis earthquake loadings. The same strategy was employed as with the GMRS$_{USGS}$/SSE comparison. The SA$_{Avg5\text{-}10}$ values for the RLE were developed using the spectral ratios consistent with the spectral shapes suggested by NUREG-1742 (2001). Plants were identified that met the GMRS$_{USGS}$/SSE>1 criteria (Question 1) and where (GMRS$_{USGS}$/RLE)^{PGA} >1 **and** (GMRS$_{USGS}$/RLE)$^{SAAvg5\text{-}10}$ >1. Figure 10 shows the results—33 plants satisfy both the GMRS$_{USGS}$>SSE and GMRS$_{USGS}$>RLE screening criteria.

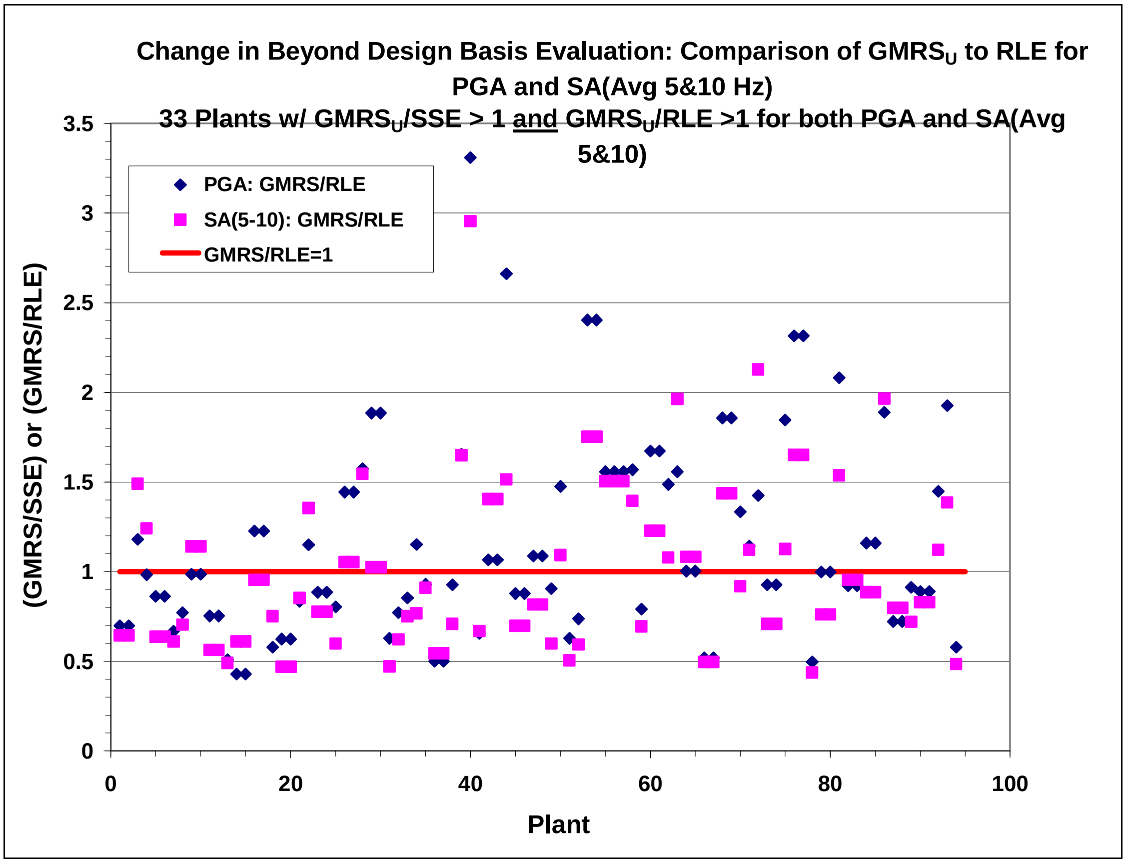

Figure 10. Comparison of $GMRS_{USGS}$ to RLE for PGA and $SA^{Avg5-10}$ for Plant Sites in CEUS.

Question 3. For those plants with increases in GMRS relative to the SSE and RLE is the change significant relative to previous seismic hazard estimates?

In addition to the SSE and RLE, previous seismic hazard estimates were developed as part of the LLNL and EPRI-SOG studies. It is appropriate to test the 2008 results against these previous estimates; if the latest hazard estimates fall within the range implied by the earlier studies, it seems reasonable to conclude no significant change has occurred. Conversely, if the latest estimates exceed both the LLNL and EPRI results, then a significant increase is likely in the hazard estimate. The same strategy was employed as with the $GMRS_{USGS}$/SSE and $GMRS_{USGS}$/RLE comparisons. Plants were identified that met the $GMRS_{USGS}$/SSE>1 criteria (Question 1), the $GMRS_{USGS}$/RLE >1 criteria (Question 2), and where $(GMRS_{USGS}/GMRS_{EPRI})^{PGA}$ >1, $(GMRS_{USGS}/GMRS_{EPRI})^{SAAvg5-10}$ >1 **and** $(GMRS_{USGS}/GMRS_{LLNL})^{PGA}$ >1, $(GMRS_{USGS}/GMRS_{LLNL})^{SAAvg5-10}$ >1. Figure 11 shows the results for $GMRS_{USGS}$>SSE, $GMRS_{USGS}$>RLE, and $GMRS_{USGS}$>$GMRS_{EPRI/LLNL}$ screening criteria. For a plant to be "screened-in" using this criteria, all four points plotted in Figure 11 must lie above the $GMRS_{USGS}/GMRS_{EPRI/LLNL}$=1 line for that plant. Of the 94 plants evaluated, 22 satisfy this screening criteria.

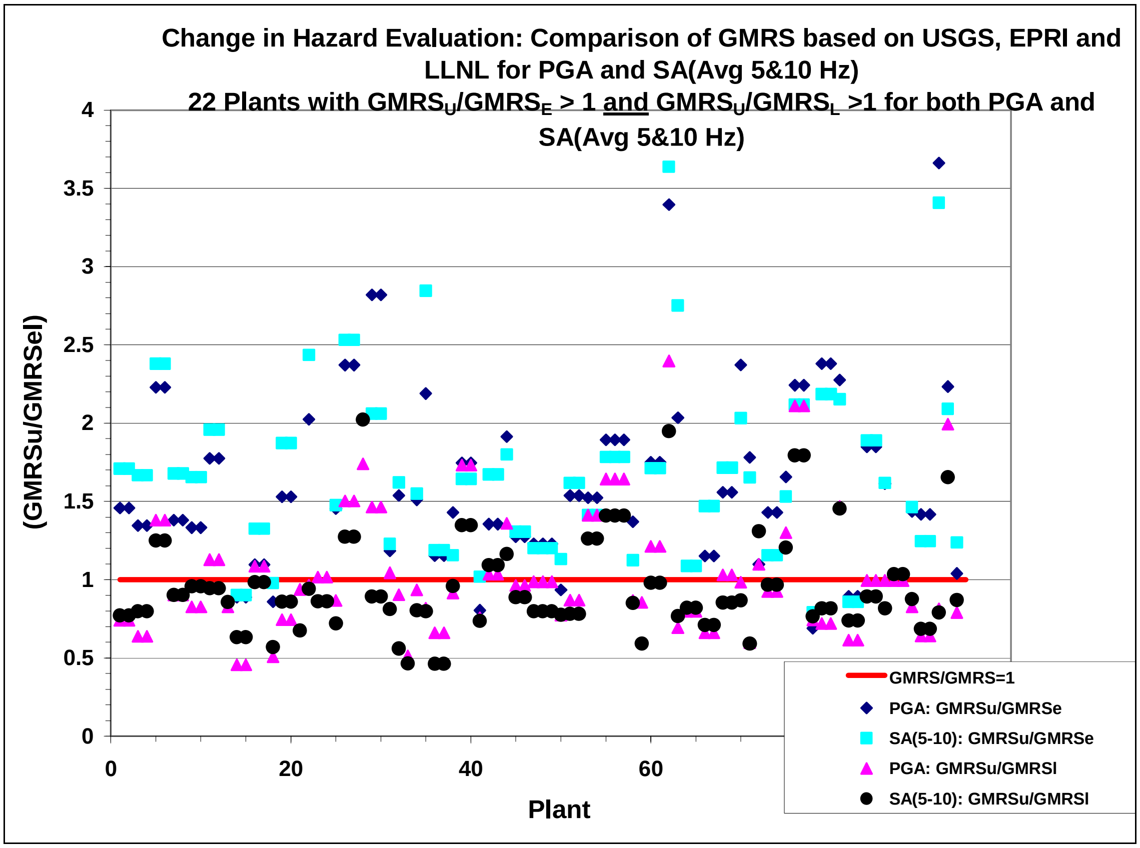

Figure 11. Comparison of GMRS$_{USGS}$ to GMRS$_{EPRI/LLNL}$ for PGA and SA$^{Avg5\text{-}10}$ for Plant Sites in CEUS.

Question 4. For those plants with increases in seismic hazard estimate, is there any significant change in risk metric?

To perform this assessment, the point estimates of mean seismic core damage frequency (SCDF) and change in SCDF (Δ-SCDF) are used. Sections 3 and 4 describe the development of these estimates. Use of SCDF and Δ-SCDF is consistent with MD 6.4 and will yield a general ranking of plants by risk. It must be recognized that the estimates are based on the available IPEEE data that are of variable quality and fidelity.

To compute an estimate of Δ-SCDF, a baseline SCDF must be defined. This is complicated because two sets of hazard curves exist that could be used for this computation (LLNL or EPRI-SOG). To try and alleviate this potential ambiguity, the delta-delta plot shown in Figure 8 was used. To answer Question 4, it is necessary to determine if any of the 22 plants identified in Question 3 appear in the "continue zone" of Figure 8. Of the 22 plants identified as having ground motion response spectrum (GMRS) values that exceed the SSE, exceed the RLE used in the IPEEE program, and exceed GMRS values based on previous EPRI and LLNL data, 21 appear in the continue zone of Figure 8.

5. DISCUSSION AND CONCLUSIONS

5.1 Discussion

The preceding sections summarize the analyses conducted for the Safety/Risk Assessment phase of the Generic Issues Process. It has been necessary to make a number of assumptions to perform these analyses. Prior to developing any conclusions, it is appropriate to specifically state some of the assumptions and limitations in the analyses as they impact some of the major conclusions.

- The use of the USGS-2008 seismic hazard model provides a representative estimate of the seismic hazard at specific NPP sites in the CEUS. However, this model has been developed and used for purposes other than critical facilities such as NPPs. The relative impact (and appropriateness) of certain assumptions within that model for the small annual AEF important for the safety evaluation of NPPs is still an open question. A different set of plants could be identified if a different hazard model was utilized.

- Very simplified, generic site response functions were assumed for the nonrock sites. This may produce very different estimates of seismic hazard (and consequently SCDF) relative to more accurate site specific response functions. At least some fraction of the sites identified in EPRI-SOG (1989) as “rock” are probably not appropriately classified as such when considering the most recent ground motion prediction equations.

- The Safety/Risk Assessment phase of GI-199 used a simplified approach based on combining plant-level fragility information developed from the IPEEE results with seismic hazard information to develop a point-estimate of SCDF. • The approach used to estimate SCDF does not provide any insight into which SSCs are important to seismic risk.

- The IPEEE studies were conducted to identify seismic vulnerabilities in the existing NPPs. In the GI-199 Safety/Risk Assessment, NRC staff is attempting to use that information for a different purpose—specifically to develop quantitative risk information. Significant differences in applicable information exist within the IPEEE results due to the different types of analyses conducted (PRA vs. full-, focused-, or reduced-scope SMAs) and screening level. •For a number of the plants that performed reduced-scope SMA analyses as part of the IPEEE program, little useful information exists regarding plant capacity.

- For many of the plants that performed a PRA and used a uniform hazard spectrum as the RLE-spectrum, NRC staff assumed that the HCLPF-point was at least equal to the SSE value for all structural frequencies.

- The IPEEE submittals generally provided limited information regarding the seismic capability of containments.

5.2 Conclusions

- **Seismic hazard estimates have increased:** Updates to seismic data and models indicate that estimates of the seismic hazard, at some operating nuclear power plant sites in the Central and Eastern United States, have increased.

- **There is no immediate safety concern:** Plants have seismic margin and the results of the GI-199 Safety/Risk Assessment confirm that overall seismic risk estimates remain small. GI-199 is not an adequate protection issue.

- **Assessment of GI-199 should continue:** Using available seismic hazard and plant seismic fragility information, the Safety/Risk Assessment found that the increase in core-damage frequency for about one-fourth of the currently operating plants is large enough to warrant continued evaluation under the Generic Issues Program. This conclusion is corroborated by the finding that, for many currently operating CEUS plants, a GMRS developed using the technical approach currently endorsed by the NRC staff is not bounded by the SSE (licensing basis) and exceeds previous "beyond design basis" evaluations (IPEEE RLE).

- **Additional information is needed to complete the assessment of GI-199:** Section 5.1 broadly discusses what additional information is needed to complete the assessment of GI-199. Specific additional information needs are listed below:

    - New site-specific seismic hazard curves: The staff is aware that EPRI has prepared new site-specific seismic hazard curves for many currently operating CEUS plants. In addition, new seismic hazard estimates for the CEUS will become available in late 2010 or early 2011 (these are a product of a joint NRC, DOE, USGS, and EPRI project). The hazard curves should cover a range of appropriate structural frequencies (PGA to 0.5 Hz), and be in a tabular, digital form.

    - New frequency dependent, site-specific amplification functions: Amplification functions are used to translate seismic motions from hard rock conditions to appropriate surface conditions. These functions should be consistent with the recent seismic evaluations performed by EPRI using updated seismic hazard results (see previous item), and be in tabular, digital form.

    - Current plant-level fragility information: The staff recognizes that many plants have been modified since completion of their IPEEEs, and believes that the plant-level fragility information used to complete the assessment of GI-199 should reflect the best available information. Specific information needed includes the median seismic capacity (C_{50}), the composite logarithmic standard deviation (β_C), and spectral ratios (relative to PGA) for 1, 5, and 10 Hz (at a minimum).

    - Plant-specific significant contributors to seismic risk: In order to progress with the Regulatory Analysis Stage, a comprehensive list of candidate plant backfits must be identified for subsequent value-impact analysis. One way to develop such a list is to consider the significant contributors to seismic core-damage risk and the approach used to identify them. It is also important to identify significant contributors to containment seismic performance.

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APPENDIX A
SEISMIC CORE-DAMAGE FREQUENCY ESTIMATES

A.1 Elementary Estimates

An equation for seismic core-damage frequency (SCDF) can be developed from the site-specific seismic hazard curve and the plant-level fragility, which are defined in Table 2:

Table 2. Definitions and Properties of Seismic Hazard and Plant-Level Fragility

Common Name	Symbol	Definition	Properties
Seismic hazard curve	$H(a)$	The annual frequency at which the site earthquake-induced vibratory ground motion exceeds a given value, *a*.	• $H(a) \geq 0$ for $a \geq 0$ • $H(a)$ is not defined for $a < 0$ • $H(a)$ is a monotonic decreasing function: $H(a_1) \geq H(a_2)$ for $a_1 \leq a_2$)
Plant-level fragility	$P_{CD}(a)$	The probability of core damage as a function of the site earthquake-induced vibratory ground motion, *a*.	• $0 \leq P_{CD}(a) \leq 1$ for $a \geq 0$ • $P_{CD}(a)$ is not defined for $a < 0$ • $P_{CD}(a)$ is a monotonic increasing function: $P_{CD}(a_1) \leq P_{CD}(a_2)$ for $a_1 \leq a_2$)

In nuclear power plant seismic risk assessment, the site earthquake-induced vibratory ground motion is usually expressed in terms of the peak ground acceleration (PGA). Other characterizations of the vibratory ground motion may also be used (e.g., individual spectral accelerations, the average spectral acceleration over a select band of spectral frequencies). An estimate of the SCDF using a single ground motion characterization is called an “elementary SCDF estimate.”

The SCDF resulting from earthquakes that cause site ground motions in the interval $[a_L, a_U]$ can be found by partitioning the interval $[a_L, a_U]$ into *n* subintervals $[a_{i-1}, a_i]$, each of which is tagged with a distinguishing point a^*_i such that $a_{i-1} \leq a^*_i \leq a_i$. Let $\Delta a_i = a_i - a_{i-1}$ be the width of each subinterval. Adding up the contributions from each subinterval (a Riemann sum) provides an estimate of the SCDF over the interval $[a_L, a_U]$:

$$SCDF(a_L, a_U) \approx \sum_{i=1}^{n} [H(a_i) - H(a_i + \Delta a_i)] P_{CD}(a_i^*) \tag{A-1}$$

The difference $H(a_i) - H(a_i + \Delta a_i)$ is the frequency of earthquakes that cause site ground motions in the interval [ai, ai + Δa_i]. This frequency is analogous to the frequency of an initiating event defined in an internal event probabilistic risk assessment (PRA) (i.e., each subinterval can be interpreted as a unique seismic initiating event). Thus, each term in the Riemann sum represents the core-damage frequency due to its associated seismic initiating event, and the Riemann sum itself approximates the total seismic core-damage frequency resulting from earthquakes that cause site ground motions in the interval $[a_L, a_U]$.

Multiplying and dividing each term in the Riemann sum by Δa_i and rearranging gives:

$$SCDF(a_L, a_U) \approx \sum_{i=1}^{n} P_{CD}(a_i^*) \left[-\frac{H(a_i + \Delta a_i) - H(a_i)}{\Delta a_i} \right] \Delta a_i \qquad \text{(A-2)}$$

As the number of subintervals, n, increases, the width, Δa_i, of each subinterval decreases. In the limit:

$$\lim_{\Delta a_i \to 0} -\frac{H(a_i + \Delta a_i) - H(a_i)}{\Delta a_i} = -\frac{dH(a_i)}{da} \qquad \text{(A-3)}$$

In the limit, the Riemann sum converges to a definite integral:

$$SCDF(a_L, a_U) = \int_{a_L}^{a_U} P_{CD}(a) \left[-\frac{dH(a)}{da} \right] da \qquad \text{(A-4)}$$

The total SCDF is obtained by setting $a_L = 0$ and $a_U = \infty$:

$$SCDF = \int_{0}^{\infty} P_{CD}(a) \left[-\frac{dH(a)}{da} \right] da \qquad \text{(A-5)}$$

A.2 Solution of the Elementary Equation

Given functional forms for *H(a)* and *P*$_{CD}$*(a)*, it is straightforward to numerically integrate Equation (A-5). However, probabilistic seismic hazard analysis typically presents *H(a)* in tabular form, leading to the need to interpolate and extrapolate to determine the value of *H(a)* for any arbitrary value of *a*. Double logarithmic interpolation and extrapolation (i.e., ln *H(a)* is a linear function of ln *a*) is a commonly used approach and has been adopted in this analysis. Note that linear interpolation and extrapolation on log-log axes implies power-law behavior.

It is assumed that the seismic hazard curve is defined by *n* points:

$$\{a_i, H_i \mid i = 1, 2, \ldots, n\} \qquad \text{where } H_i = H(a_i) \text{ and } a_1 < a_2 < \ldots < a_n \qquad \text{(A-6)}$$

Using any two adjacent points, *i-1* and *i*, the seismic hazard curve can be approximated with a power law:

$$H_i(a) = K_{I,i} a^{-K_{H,i}} \qquad \textit{for } a_{i-1} \le a \le a_i \qquad \text{(A-7)}$$

where:

$$\left.\begin{aligned} K_{I,i} &= H_{i-1} - a_{i-1}^{K_{H,i}} \\ K_{H,i} &= \frac{\ln\left(\dfrac{H_i}{H_{i-1}}\right)}{\ln\left(\dfrac{a_i}{a_{i-1}}\right)} \end{aligned}\right\} \quad i = 2,3,\ldots,n \tag{A-8}$$

Seismic PRAs often provide either a tabulation or graph of $P_{CD}(a)$, which is reasonably approximated by a log-normal function over a wide range of ground motions (see Appendix C for a detailed discussion of plant-level fragility):

$$P_{CD}(a) = \Phi\left[\frac{\ln a - \mu}{\beta_C}\right] = \int_0^a \frac{1}{\sqrt{2\pi}\beta_C x} \exp\left[-\frac{(\ln x - \mu)^2}{2\beta_C^2}\right] dx \qquad \text{for } C_{50}, \beta_C > 0 \textit{ and } \mu = \ln C_{50} \tag{A-9}$$

where C_{50} denotes the median seismic capacity and β_C denotes composite logarithmic standard deviation. The derivative of $P_{CD}(a)$ with respect to a is:

$$\frac{dP_{CD}(a)}{da} = \frac{1}{\sqrt{2\pi}\beta_C a} \exp\left[-\frac{(\ln a - \mu)^2}{2\beta_C^2}\right] \tag{A-10}$$

As a result, Equation (A-5) could be numerically integrated by using Equations (A-7) and (A-9). However, numerical integration is not needed because Equation (A-5) has a closed-form solution under these assumptions.

Equation (A-5) can be broken into *n-1* integrals according to the points of the seismic hazard curve:

$$\begin{aligned} SCDF &= SCDF(0,a_2) + SCDF(a_2,a_3) + \cdots + SCDF(a_{n-1},\infty) \\ &= \int_0^{a_2} P_{CD}(a)\left[-\frac{dH_2(a)}{da}\right] da + \int_{a_2}^{a_3} P_{CD}(a)\left[-\frac{dH_3(a)}{da}\right] da + \ldots + \int_{a_{n-1}}^{\infty} P_{CD}(a)\left[-\frac{dH_n(a)}{da}\right] da \end{aligned} \tag{A-11}$$

Integrating Equation (A-4) by parts yields:

$$SCDF(a_i, a_{i-1}) = \int_{a_{i-1}}^{a_i} H_i(a)\left[\frac{dP_{CD}(a)}{da}\right] da - H_i(a)P_{CD}(a)\Big|_{a_{i-1}}^{a_i} \tag{A-12}$$

Substituting Equations (A-7) and (A-10) into the first term on the right-hand side of Equation (A-12):

$$I(a_{i-1},a_i)=\int_{a_{i-1}}^{a_i} H_i(a)\left[\frac{dP_{CD}(a)}{da}\right]da=\frac{K_{I,i}}{\sqrt{2\pi}\,\beta_C}\int_{a_1}^{a_2}\exp\left[-\frac{(\ln a-\mu)^2}{2\beta_C^2}-K_{H,i}\ln a\right]\frac{da}{a} \tag{A-13}$$

To further reduce Equation (A-13), it is convenient to make a change of variable in the integral:

$$x=\frac{\ln a-\mu}{\beta_C} \quad \Rightarrow \quad dx=\frac{da}{\beta_C a} \tag{A-14}$$

After making the change of variable, Equation (A-13) becomes:

$$I(a_{i-1},a_i)=\frac{K_{I,i}}{\sqrt{2\pi}}\exp\left(-K_{H,i}\mu\right)\int_{x_{i-1}}^{x_i}\exp\left(-\frac{x^2}{2}-K_{H,i}\beta_C x\right)dx \tag{A-15}$$

Completing the square in the exponential term inside the integral:

$$-\frac{x^2}{2}-K_{H,i}\beta_C x=-\frac{1}{2}\left[\left(x+K_{H,i}\beta_C\right)^2-K_{H,i}^2\beta_C^2\right] \tag{A-16}$$

Substituting Equation (A-16) into Equation (A-15) yields:

$$\begin{aligned} I(a_{i-1},a_i)&=K_{I,i}\exp\left(-K_{H,i}\mu+\frac{1}{2}K_{H,i}^2\beta_C^2\right)\int_{x_{i-1}}^{x_i}\frac{1}{\sqrt{2\pi}}\exp\left[-\frac{\left(x+K_{H,i}\beta_C\right)^2}{2}\right]dx \\ &=K_{I,i}\exp\left(-K_{H,i}\mu+\frac{1}{2}K_{H,i}^2\beta_C^2\right)\left[\Phi\left(\frac{\ln a_i-\mu}{\beta_C}+K_{H,i}\beta_C\right)-\Phi\left(\frac{\ln a_{i-1}-\mu}{\beta_C}+K_{H,i}\beta_C\right)\right] \end{aligned} \tag{A-17}$$

The second term on the right-hand side of Equation (A-12) is readily determined as:

$$H(a)P_{CD}(a)\Big|_{a_{i-1}}^{a_i}=K_{I,i}a_1^{-K_{H,i}}\Phi\left(\frac{\ln a_i-\mu}{\beta_C}\right)-K_{I,i}a_2^{-K_{H,i}}\Phi\left(\frac{\ln a_{i-1}-\mu}{\beta_C}\right) \tag{A-18}$$

Combining Equations (A-17) and (A-18) gives the closed-form solution to Equation (A-12):

$$\begin{aligned} &SCDF(a_{i-1},a_i) \\ &=K_{I,i}\exp\left(-K_{H,i}\mu+\frac{1}{2}K_{H,i}^2\beta_C^2\right)\left[\Phi\left(\frac{\ln a_i-\mu}{\beta_C}+K_{H,i}\beta_C\right)-\Phi\left(\frac{\ln a_{i-1}-\mu}{\beta_C}+K_{H,i}\beta_C\right)\right] \\ &\qquad +K_{I,i}a_{i-1}^{-K_{H,i}}\Phi\left(\frac{\ln a_{i-1}-\mu}{\beta_C}\right)-K_{I,i}a_i^{-K_{H,i}}\Phi\left(\frac{\ln a_i-\mu}{\beta_C}\right) \end{aligned} \tag{A-19}$$

The total seismic core-damage frequency, SCDF< can be determined by substituting Equation (A-19) into Equation (A-11):

$$
\begin{aligned}
SCDF &= K_{I,2}\exp\left(-K_{H,2}\mu+\frac{1}{2}K_{H,2}^{2}\beta_{C}^{2}\right)\Phi\left(\frac{\ln a_{2}-\mu}{\beta_{C}}+K_{H,2}\beta_{C}\right)\\
&+\sum_{i=3}^{n-1}K_{I,i}\exp\left(-K_{H,i}\mu+\frac{1}{2}K_{H,i}^{2}\beta_{C}^{2}\right)\left[\Phi\left(\frac{\ln a_{i}-\mu}{\beta_{C}}+K_{H,i}\beta_{C}\right)-\Phi\left(\frac{\ln a_{i-1}-\mu}{\beta_{C}}+K_{H,i}\beta_{C}\right)\right]\\
&+K_{I,n}\exp\left(-K_{H,n}\mu+\frac{1}{2}K_{H,n}^{2}\beta_{C}^{2}\right)\left[1-\Phi\left(\frac{\ln a_{n}-\mu}{\beta_{C}}+K_{H,n}\beta_{C}\right)\right]
\end{aligned}
\qquad \text{(A-20)}
$$

A.3 Derived Estimates

As discussed in Section A.1, the site earthquake-induced vibratory ground motion is usually expressed in terms of the peak ground acceleration. Other characterizations of the ground motion could also be used in Equation (A-20). In the Safety/Risk Assessment of GI-199, elementary SCDF estimates were computed for the 10-Hz, 5-Hz, and 1-Hz spectral accelerations in addition to the peak ground acceleration.

A "derived SCDF estimate" is an estimate of the seismic core-damage frequency that is developed from the four elementary SCDF estimates. Let:

$SCDF_{pga}$ = SCDF estimate obtained by using the PGA-based seismic hazard and plant-level fragility curves
$SCDF_{10}$ = SCDF estimate obtained by using the 10-Hz seismic hazard and plant-level fragility curves
$SCDF_{5}$ = SCDF estimate obtained by using the 5-Hz seismic hazard and plant-level fragility curves
$SCDF_{1}$ = SCDF estimate obtained by using the 1-Hz seismic hazard and plant-level fragility curves

Three derived SCDF estimates are defined as follows:

$$SCDF_{\max} = \max\left(SCDF_{pga}, SCDF_{10}, SCDF_{5}, SCDF_{1}\right) \tag{A-21}$$

$$SCDFavg = \frac{1}{4}SCDF_{pga} + \frac{1}{4}SCDF_{10} + \frac{1}{4}SCDF_{5} + \frac{1}{4}SCDF_{1} \tag{A-22}$$

$$SCDF_{IPEEE} = \frac{1}{7}SCDF_{pga} + \frac{2}{7}SCDF_{10} + \frac{2}{7}SCDF_{5} + \frac{2}{7}SCDF_{1} \tag{A-23}$$

Equation (A-23) is termed the "IPPEE weighted average SCDF" because the weights were obtained from Appendix A of NUREG-1407.

A.4 Weakest Link Model

In general, the four elementary SCDF estimates are unique (i.e., they yield different values of the SCDF). This effect happens because the seismic hazard curves at various spectral frequencies are not parallel; rather, they have different slopes. The derived estimates represent an attempt to reconcile the different elementary SCDF estimates but cannot be developed from fundamental principles. Specifically, no technical basis exists for assigning the weights.

An alternative to the log-normal function used to characterize the plant-level fragility, $P_{CD}(a)$, can be developed by considering the relationship between the spectral shape used to determine the PGA-based plant-level fragility curve and the uniform hazard spectrum at a given annual exceedance frequency, *h*. The uniform hazard spectrum at a given annual exceedance frequency, h, may be determined from the following four-step process.

- Step 1. Select a set of spectral frequencies from a range of spectral frequencies that govern system, structure, and component fragilities. In the Safety/Risk Assessment, four spectral frequencies were selected: 1 Hz, 5, Hz, 10 Hz, and PGA.

- Step 2. Obtain the spectral seismic hazard curves that correspond to the selected spectral frequencies, for example, H1(a1), H5(a5, H10(a10), and Hpga(apga).

- Step 3. For the given annual exceedance frequency, h, find the corresponding spectral accelerations by inverting each spectral hazard curve (see Figure A-1):

$$\begin{aligned} & h = H_1(a_1) = H_5(a_5) = H_{10}(a_{10}) = H_{pga}(a_{pga}) \\ & \rightarrow a_1 = H_1^{-1}(h), a_5 = H_5^{-1}(h), a_{10} = H_{10}^{-1}(h), \text{and } a_{pga} = H_{pga}^{-1}(h) \end{aligned} \tag{A-24}$$

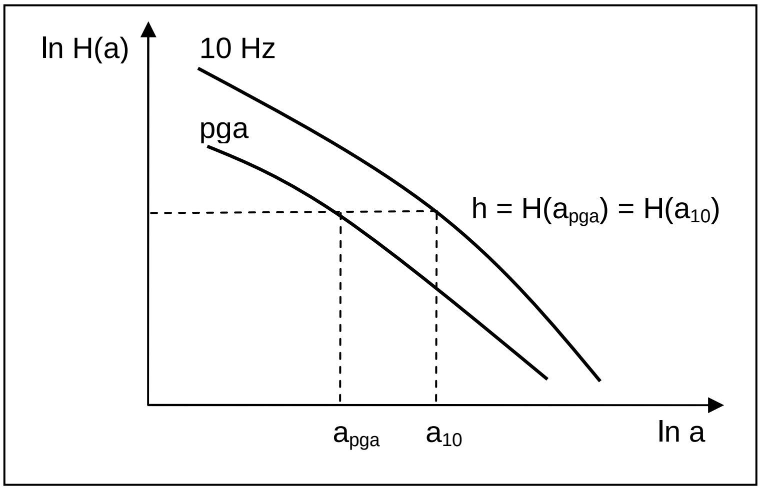

Figure A-1. Construction of a Uniform Hazard Spectrum.

- Step 4. Plot the corresponding spectral accelerations against their spectral frequencies (see Figure A-2).

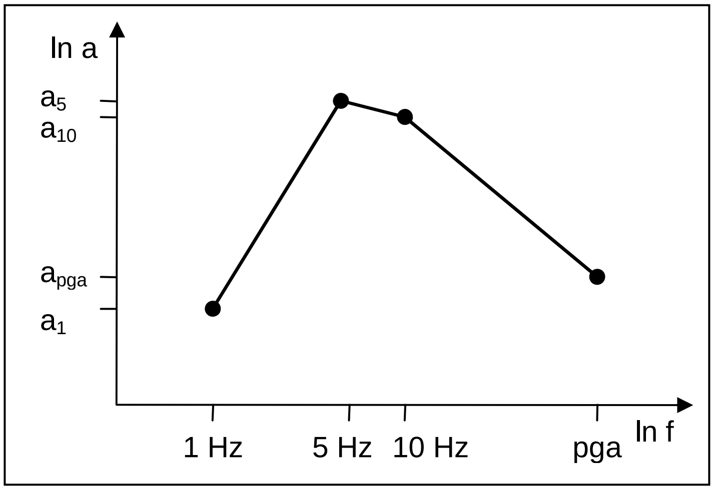

Figure A-2. A Uniform Hazard Spectrum.

In general, the shape of the normalized uniform hazard spectrum (UHS) depends on annual exceedance frequency (it is typical to normalize response spectra with respect to the peak ground acceleration). In addition, the shape of the normalized UHS is different, in general, than the shape of the response spectrum used to develop the PGA-based plant-level fragility curve. (Even if the 10^{-4} per year UHS is used to develop the PGA-based plant-level fragility curve, it will have a different normalized shape than, for example, the normalized 10^{-5} UHS.)

The fragility of an SSC is usually developed at that SSC's natural (fundamental) frequency. This is done because the presence of the natural frequency causes the SSC to resonate, which greatly increases the forces and moments impressed on the SSC. In general, the natural frequency for one SSC will be different than the natural frequency for another SSC, depending on the SSC's design. In a seismic PRA, these differing natural frequencies are converted to peak ground acceleration by using a review-level response spectrum. The key parameter in this process is the spectral ratio. The spectral ratio for a given spectral frequency, m_f, is defined as the ratio of the spectral ordinate on the review-level response spectrum corresponding to that spectral frequency to the spectral ordinate on the review-level response spectrum for the peak ground acceleration. For example, suppose that the natural frequency of an SSC is 10 Hz and that analysis indicates the SSC will fail when the 10-Hz spectral acceleration exceeds 1.5 g. If the 10-Hz spectral ratio, m_{10}, is 2, then the SCC is assumed to fail when the peak ground acceleration reaches 1.5 g / 2 = 0.75 g.

In a seismic PRA, seismically induced failure is not a threshold effect; rather, various probabilities of failure exist depending on the acceleration caused by an earthquake. These failure probabilities are described by the fragility curve, which can be interpreted using random variables and load-strength interference theory. Let C be a random variable that represents the PGA-based seismic capacity. Then, an SSC will fail if C is less than the acceleration caused by an earthquake, and the probability of failure as a function of the peak ground acceleration (the fragility) can be expressed as:

$$\Pr\{failure\} = \Pr\{C \le a\} \tag{A-25}$$

Considering how fragilities are developed in a seismic PRA, it is reasonable to assume that the seismic capacity at an arbitrary spectral frequency, C_f, would be the product of the spectral ratio for that spectral frequency and the PGA-based seismic capacity:

$$\Pr\{failure\} = \Pr\{C_f \le a_f\} = \Pr\{m_f C \le a_f\} \tag{A-26}$$

Figure A-3 illustrates the relationships among the 1-hz, 5-Hz, and 10-Hz spectral fragilities and the PGA-based fragility for an arbitrary SSC. For example, suppose that an earthquake causes a peak ground acceleration equal to the HCLPF, then the probability of failure is 0.01. If the 10-Hz spectral ratio, m_{10}, is 2, then the occurrence of an earthquake that causes a 10-Hz spectral acceleration of twice the HCLPF also implies a failure probability of 0.01.

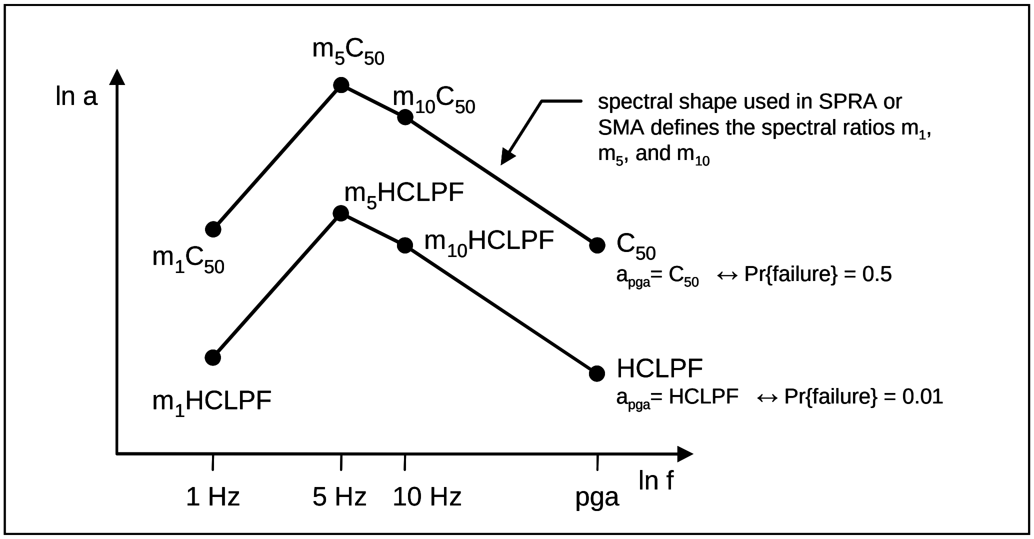

Figure A-3. The Definition of Spectral Fragility.

To define the probability of failure based on a UHS and the definition of spectral fragility just discussed, consider Figure A-4 that shows the UHS superimposed onto the review-level response spectrum:

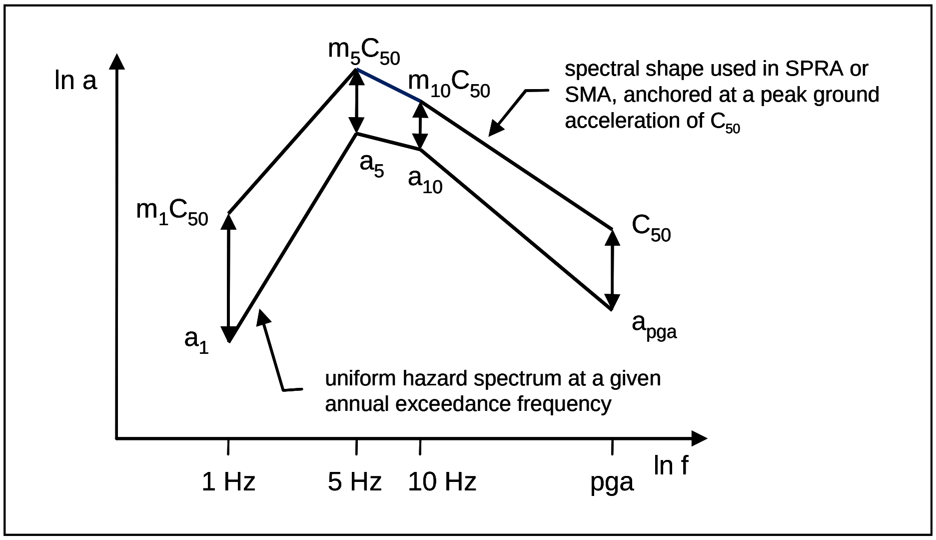

Figure A-4. Development of the Weakest Link Model.

Figure A-4 indicates that the probability of failure depends on “how close” the UHS is to the spectral fragility curve. Specifically:

$$
\begin{aligned}
\Pr\{\mathit{failure}\} &= 1-\Pr\left[C > a \text{ and } C_1 > a_1 \text{ and } C_5 > a_5 \text{ and } C_{10} > a_{10}\right] \\
&= 1-\Pr\left[C > a \text{ and } m_1 C > a_1 \text{ and } m_5 C > a_5 \text{ and } m_{10} C > a_{10}\right] \\
&= 1-\Pr\left[C > a \text{ and } C > \frac{a_1}{m_1} \text{ and } C > \frac{a_5}{m_5} \text{ and } C > \frac{a_{10}}{m_{10}}\right] \\
&= 1-\Pr\left[C > \max\left(a, \frac{a_1}{m_1}, \frac{a_5}{m_5}, \frac{a_{10}}{m_{10}}\right)\right]
\end{aligned}
\tag{A-27}
$$

The relationship described by Equation (A-27) is termed the “weakest link” model in this assessment.

APPENDIX B
SEISMIC HAZARD ESTIMATES

This appendix contains additional discussion of the U.S. Geological Survey (USGS) seismic hazard model used to develop the hazard estimates used in this Safety/Risk Assessment, the site-specific adjustments to the rock hazard estimates for sites that could not be considered to be founded on hard rock, and a summary of results. A brief discussion and summary of the Lawrence Livermore National Laboratory (LLNL) and Electric Power Research Institute (EPRI) results that were available at the time of the Individual Plant Examination for External Events (IPEEE) assessments are also included.

B.1 USGS Hazard Model and Site Amplification

The hazard results used this evaluation were produced with the publicly available source codes and input files obtained from the USGS National Hazard Mapping group. These codes and example inputs can be obtained from the USGS Web site (hazgridXnga2.f and hazFXnga7.f and associated batch scripts). These codes and inputs form the basis of the 2008 National Seismic Hazard maps and were developed in a UNIX operating environment. NRC staff recompiled the codes (with minor modifications) to operate in an MS-Windows environment. The codes were successfully benchmarked against publicly available USGS hazard results assuming a near-surface shear wave velocity of 760 meters/second at several sites.

The USGS model recognizes that significant epistemic uncertainty exists in numerous elements of the model and incorporates those uncertainties using a logic tree approach. Simple batch scripts are used to produce results for each branch through the logic tree and to combine intermediate results. Figures B.1 shows the logic structure of the seismicity-derived hazard component in the central and eastern United States (CEUS), and Figures B.2 and B.3 show the logic trees for the New Madrid, and Charleston source zone components of hazard, respectively. The maximum magnitude (M_{MAX}) that is assigned in the model to compute the seismicity-based hazard contribution is dependent on location within the CEUS. Figure B.4 shows a map with the distribution of M_{MAX} by region. Extensive discussion and documentation on the approach to estimating seismic hazards in the CEUS is contained in the publicly available USGS literature (Frankel and others, 1996; 2002; and Petersen and others, 2008).

Current NRC guidance for the estimation of design ground motions for new plants (Regulatory Guide 1.208) allows for a period and amplitude-dependent reduction in event frequency to represent the observation that some fraction of earthquake ground motions of a given amplitude fall below the threshold of damage for most engineered structures. One measure of this threshold is the cumulative absolute velocity (or CAV) value. The present assessment has not included the CAV-threshold effect for two reasons. First, some portion of the uncertainty included in the estimate of fragility may be due to a mixed population of CAV values (i.e., some above the threshold, some below). No obvious documentation exists that illustrates only records that exceed a specific CAV threshold were used to estimate fragilities. In the interest of avoiding a double-counting of this effect, no CAV-filtering has been applied. Second, the existing USGS hazard code does not include a CAV-threshold effect. To add this feature would require significant software modification. In the interest of moving forward in the safety/risk assessment phase of this project, no CAV modifications were added to the USGS hazard code.

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Figure 2. Logic tree for seismicity-derived hazard component in the Central and Eastern United States (CEUS). Each maximum-magnitude branch includes craton (c) and margin (m) estimates. Parameters in this figure include some aleatory variability as well as depicted epistemic uncertainty. We treat aleatory variability in ground motion in the hazard code.

Figure B.1. Logic Tree for Seismicity-Derived Hazard Component Used in the USGS Model for the CEUS (from USGS Open-File Rep. 2008-1128).

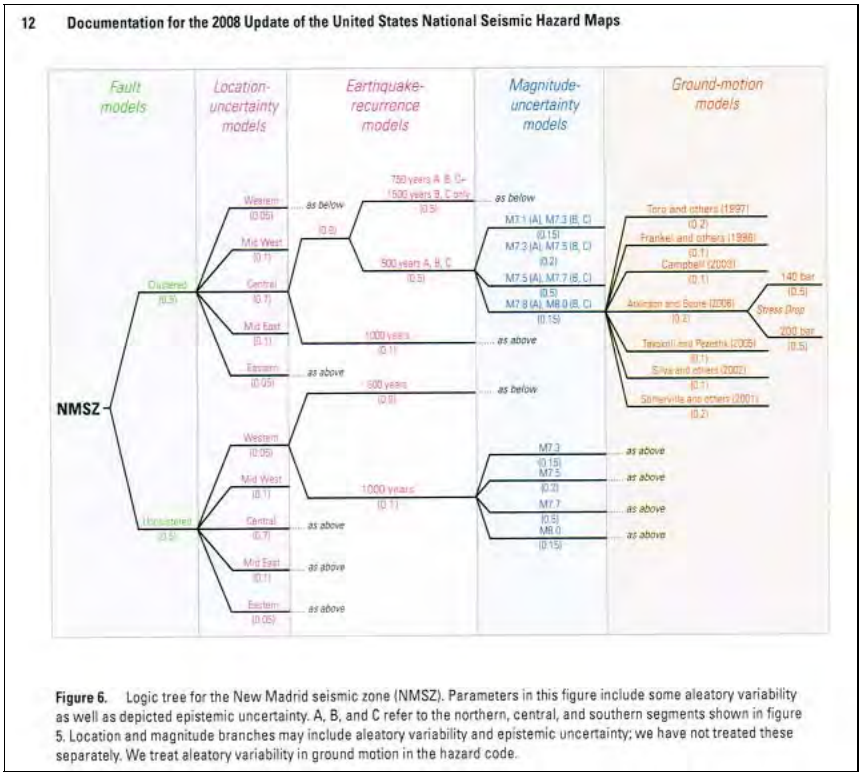

Figure 6. Logic tree for the New Madrid seismic zone (NMSZ). Parameters in this figure include some aleatory variability as well as depicted epistemic uncertainty. A, B, and C refer to the northern, central, and southern segments shown in figure 5. Location and magnitude branches may include aleatory variability and epistemic uncertainty; we have not treated these separately. We treat aleatory variability in ground motion in the hazard code.

Figure B.2. Logic Tree for New Madrid Seismic Zone Used in USGS Seismic Hazard Model (from U.S.G.S Open-File Rep. 2008-1128).

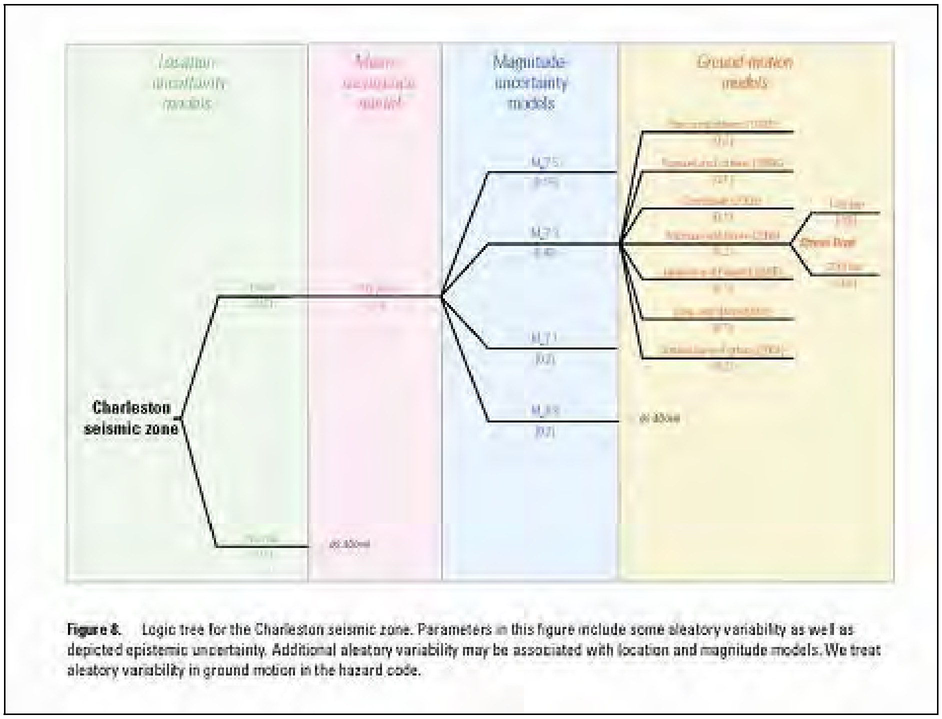

Figure 8. Logic tree for the Charleston seismic zone. Parameters in this figure include some aleatory variability as well as depicted epistemic uncertainty. Additional aleatory variability may be associated with location and magnitude models. We treat aleatory variability in ground motion in the hazard code.

Figure B.3. Logic Tree for Charleston Seismic Zone Used in USGS Seismic Hazard Model (from U.S.G.S Open-File Rep. 2008-1128).

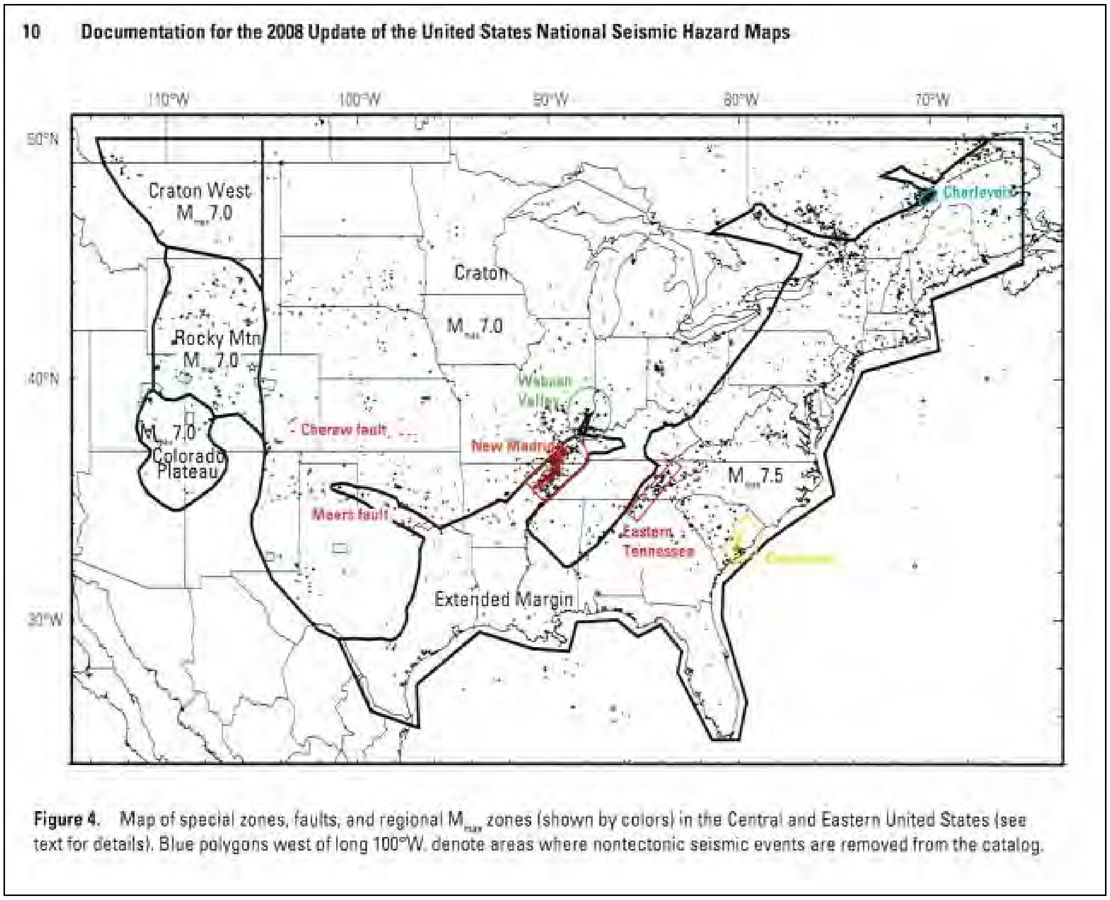

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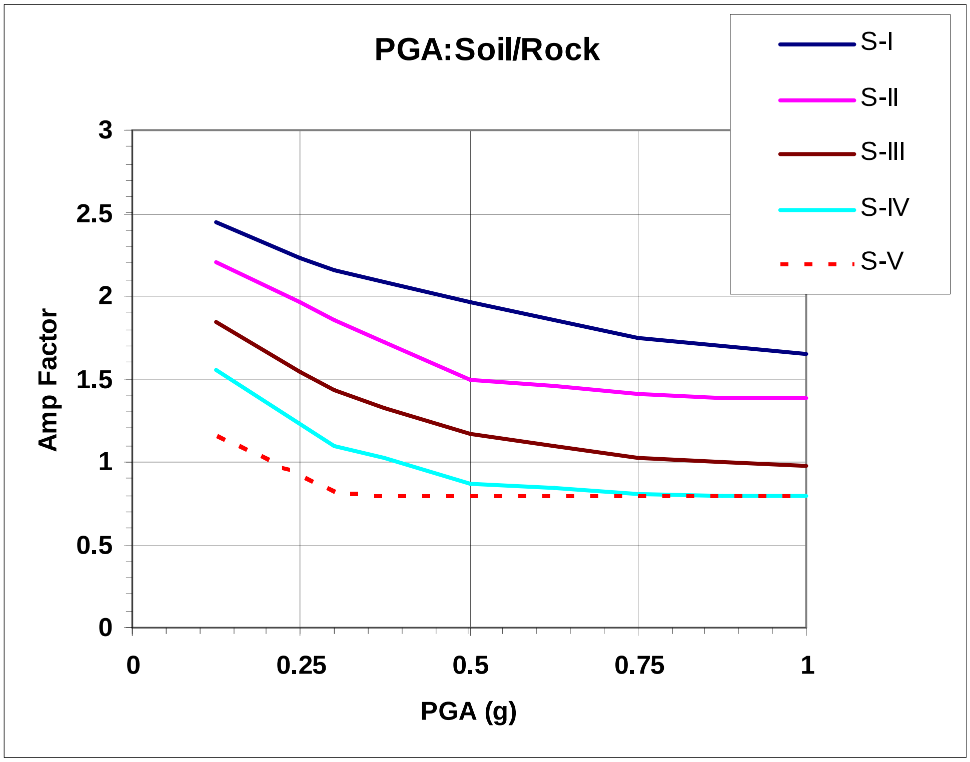
Figure 4. Map of special zones, faults, and regional M_{max} zones (shown by colors) in the Central and Eastern United States (see text for details). Blue polygons west of long 100°W. denote areas where nontectonic seismic events are removed from the catalog.

Figure B.4. Map of CEUS illustrating regions with different M_{MAX} assigned (from USGS Open-File Rep. 2008-1128).

To produce site-specific results appropriate for this assessment, the hazard codes were run (consistent with the logic trees outlined in the 2008 hazard documentation) for the latitude and longitude of each nuclear power plant (NPP) assuming a near-surface shear wave velocity of 2,500 meters/second. This velocity is consistent with “hard-rock” for all the attenuation relationships used in the calculations. For those NPPs with soil site conditions, site conditions were assigned to be consistent with the definitions in EPRI-NP-6935 (1989). These site conditions are denoted as S1, S2, S3, S4, S5 or SS (site-specific). The period and amplitude dependent site amplification factors in EPRI-NP-6935 (1989) do not extend to high enough amplitude to cover the complete range of contribution to seismic core-damage frequency (SCDF). Hence, it was necessary to extrapolate the amplification factors. Some judgment was required for this step. The existing EPRI site amplification curves do not allow the amplification to fall below 0.8. To be consistent, the extrapolated curves were not allowed to fall below 0.8. For thin soil site types where the site amplifications were increasing, some curvature or truncation was introduced in the curves to prevent very high levels of amplification from occurring at high amplitude because nonlinear effects will be manifested in even thin soils at high amplitude levels. Figure B.5 shows example soil amplification factors.



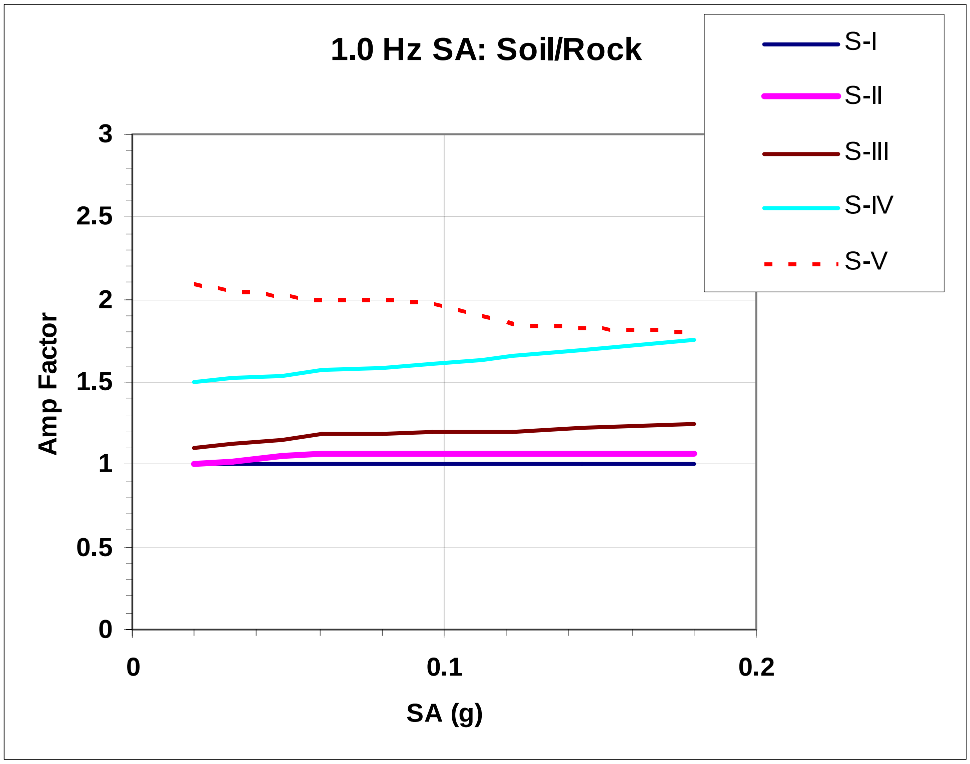


Figure B-5. Generic Site Amplification Factors Used for Soil Sites, Factors for PGA (top) and 1-sec SA (bottom). The site amplification factors are from EPRI-NP-6935 (1989).

Table B.1 summarizes the generic site characteristics assumed in the EPRI-NP-6935 (1989) analyses. Table B.2 summarizes the site types, IPEEE evaluation method, spectral shape, safe shutdown earthquake (SSE_{PGA}), and high confidence of a low probability of failure ($HCLPF_{PGA}$) values for each NPP site.

Table B.1. Site Categories and Depth Ranges

[from EPRI NP-6395-D]

Category	Average Depth		Depth Range		Soil Avg Vs	Soil Avg Vs
	ft	*m*	*ft*	*m*	*f/s*	*m/s*
I	20	6	10.0-30	3.0-9	1125	343
II	50	15	30-80	9.0-24	1325	404
III	120	37	80-180	24-55	1600	488
IV	250	76	180-400	55-122	1900	579
V	500	152	>400	>122	2234	681

Table B.2. Summary of Site Types, Evaluation Methods, HCLPF, and SSE Values

Site	Site Type	IPEEE Evaluation Approach	RLE Spectral Shape	$HCLPF_{PGA}$ (g's)	SSE_{PGA} (g's)
Arkansas 1	Rock	Full-Scope EPRI-SMA	Rock-NUREG-0098	0.3	0.2
Arkansas 2	Rock	Focused-Scope EPRI-SMA	Rock-NUREG-0098	0.3	0.2
Beaver Valley 1	Soil III	Seismic PRA	EPRI-UHS	0.2	0.12
Beaver Valley 2	Soil III	Seismic PRA	EPRI-UHS	0.24	0.12
Braidwood 1&2	Rock	Focused-Scope EPRI-SMA	Rock-NUREG-0098	0.3	0.2
Browns Ferry 1	Rock	Focused-Scope EPRI-SMA	Rock-NUREG-0098	0.3	0.2
Browns Ferry 2	Rock	Focused-Scope EPRI-SMA	Rock-NUREG-0098	0.26	0.2
Brunswick 1&2	Soil III	Focused-Scope EPRI-SMA	Soil-NUREG-0098	0.3	0.16
Byron 1&2	Rock	Focused-Scope EPRI-SMA	Rock-NUREG-0098	0.3	0.2
Callaway	Rock	Focused-Scope EPRI-SMA	Soil-NUREG-0098	0.3	0.2
Calvert Cliffs 1&2	Soil V	Seismic PRA	LLNL-UHS	0.3	0.15
Catawba 1&2	Rock	Seismic PRA	Sequoyah Spectra	0.23	0.15
Clinton	Soil IV	Focused-Scope EPRI-SMA	Multiple-Soil	0.3	0.25
Comanche Peak 1&2	Rock	Reduced-Scope EPRI-SMA	Plant-SSE	0.12	0.12
Cooper	Soil III fsar	Focused-Scope EPRI-SMA	Soil-NUREG-0098	0.3	0.2
Crystal River	Rock	Reduced-Scope EPRI-SMA	Housner-Soil	0.1	0.1
D.C. Cook 1&2	Soil II fsar	Seismic PRA	EPRI-UHS	0.26	0.2
Davis Besse	Rock	Reduced-Scope EPRI-SMA	Rock-NUREG-0098	0.26	0.15
Dresden 2&3	Rock	Focused-Scope EPRI-SMA	Rock-NUREG-0098	0.2	0.2
Duane Arnold	Soil II fsar	Reduced-Scope EPRI-SMA	SSE-Rock/Soil	0.12	0.12
Farley 1&2	Rock	Focused-Scope EPRI-SMA	Plant-SSE	0.1	0.1
Fermi 2	Rock	Focused-Scope EPRI-SMA	Rock-NUREG-0098	0.3	0.15
Fitzpatrick	Rock	Focused-Scope EPRI-SMA	Rock-NUREG-0098	0.22	0.15
Fort Calhoun 1	Soil III fsar	Focused-Scope EPRI-SMA	Soil-NUREG-0098	0.25	0.17
Ginna	Rock	Focused-Scope EPRI-SMA	R.G. 1.60 Rock	0.2	0.2
Grand Gulf	Soil V	Reduced-Scope EPRI-SMA	SSE Soil	0.15	0.15
Hatch 1&2	Soil V	Focused-Scope EPRI-SMA	Soil-NUREG-0098	0.3	0.15
Hope Creek	Soil V	Seismic PRA	EPRI-UHS	0.3	0.2
Indian Point 2	Rock	Seismic PRA	EPRI-UHS	0.3	0.15
Indian Point 3	Rock	Seismic PRA	LLNL-UHS	0.15	0.15
Kewaunee	Soil (SS)	Seismic PRA	LLNL-UHS	0.23	0.12
LaSalle 1&2	Soil III	Simplified Seismic PRA	Unknown	0.3	0.2
Limerick	Rock	Reduced-Scope EPRI-SMA	Plant-SSE	0.15	0.15
McGuire 1&2	Rock	Seismic PRA	NUREG-0098	0.26	0.15
Millstone 2	Rock	Focused-Scope EPRI-SMA	Rock-NUREG-0098	0.25	0.17
Millstone 3	Rock	Seismic PRA	Site Specific	0.3	0.17

Monticello	Soil II	Reduced-Scope EPRI-SMA	Plant-SSE	0.12	0.12
Nine Mile Point 1	Rock	Focused-Scope EPRI-SMA	Rock-NUREG-0098	0.27	0.11
Nine Mile Point 2	Rock	SPRA &Focused EPRI-SMA	Rock-NUREG-0098	0.23	0.15
North Anna 1&2	Rock	Focused-Scope EPRI-SMA	Rock/Soil-NUREG-0098	0.16	0.12
Oconee 1,2&3	Rock	Seismic PRA	EPRI-UHS	0.29	0.1
Oyster Creek	Soil V	Seismic PRA	EPRI-UHS	0.16	0.17
Palisades	Soil III fsar	Seismic PRA	LLNL-UHS	0.22	0.2
Peach Bottom 2&3	Rock	Focused-Scope EPRI-SMA	Rock-NUREG-0098	0.2	0.12
Perry	Rock	Focused-Scope EPRI-SMA	Rock-NUREG-0098	0.3	0.15
Pilgrim 1	Soil III	Seismic PRA	LLNL-UHS	0.25	0.15
Point Beach 1&2	Soil II	Seismic PRA	LLNL-UHS	0.16	0.12
Prairie Island 1&2	Soil II	Focused-Scope EPRI-SMA	Soil-NUREG-0098	0.28	0.12
Quad Cities 1&2	Rock	Focused-Scope EPRI-SMA	Rock-NUREG-0098	0.09	0.24
River Bend	Soil (SS)	Reduced-Scope EPRI-SMA	SSE-Soil	0.1	0.1
Robinson (HR)	Soil V	Full-Scope EPRI-SMA	Soil-NUREG-0098	0.28	0.2
Saint Lucie	Soil V fsar	Site-Specific	Plant-SSE	0.1	0.1
Salem 1&2	Soil V	Seismic PRA	EPRI-UHS	0.3	0.2
Seabrook	Rock	Seismic PRA	R.G. 1.60 Rock	0.27	0.25
Sequoyah 1&2	Rock	Full-Scope EPRI-SMA	NUREG-0098	0.27	0.18
Shearon Harris 1	Rock	Focused-Scope EPRI-SMA	Rock-NUREG-0098	0.29	0.15
South Texas 1&2	Soil (SS)	Seismic PRA	River Bend Spectra	0.096	0.1
Summer	Rock	Focused-Scope EPRI-SMA	NUREG-0098 Rock/Soil	0.22	0.15
Surry 1&2	Soil V	Seismic PRA	EPRI-UHS	0.16	0.15
Susquehanna 1&2	Rock	Focused-Scope EPRI-SMA	NUREG-0098 Rock/Soil	0.21	0.1
Three Mile Island 1	Rock	Seismic PRA	EPRI-UHS	0.15	0.12
Turkey Point 3&4	Rock	Site-Specific	Plant-SSE	0.15	0.15
Vermont Yankee	Rock	Focused-Scope EPRI-SMA	Rock-NUREG-0098	0.25	0.14
Vogtle 1&2	Soil V	Focused-Scope EPRI-SMA	Soil-NUREG-0098	0.3	0.2
Waterford 3	Soil (SS)	Focused-Scope EPRI-SMA	SSE-Soil	0.1	0.1
Watts Bar	Rock	Focused-Scope EPRI-SMA	NUREG-0098 Rock/Soil	0.3	0.18
Wolf Creek	Rock	Focused-Scope EPRI-SMA	Plant-SSE	0.2	0.12

B.2 Comparison of Hazard Results

As discussed in Section 3 of the report, to perform an evaluation of the implications of changes in seismic hazard it is necessary to have hazard estimates from previously accepted studies in addition to the USGS results described above. To facilitate this comparison, the seismic hazard results developed by EPRI-SOG (EPRI NP-6935) and LLNL (NUREG 1488; Bernrouter and others) were used. Both of these studies were accepted for use in the IPEEE evaluation and provide a baseline from which changes in seismic hazard estimates can be evaluated. The

EPRI-SOG study did not perform an evaluation for all sites. Figures B.6, B.7, B.8, and B.9 show hazard results for several sites.

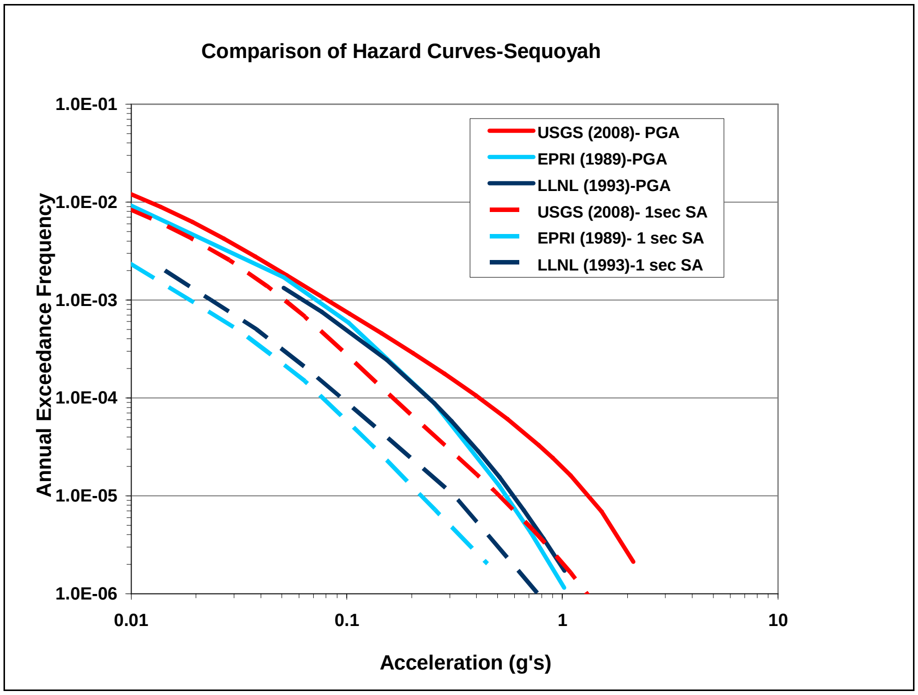


Figure B.6. Comparison of Hazard Results for the Sequoyah Site. The results from USGS (2008) are shown by red lines, EPRI (1989) by light blue lines, LLNL (1993) by dark blue lines, PGA by solid lines, and 1-sec SA by dashed lines.

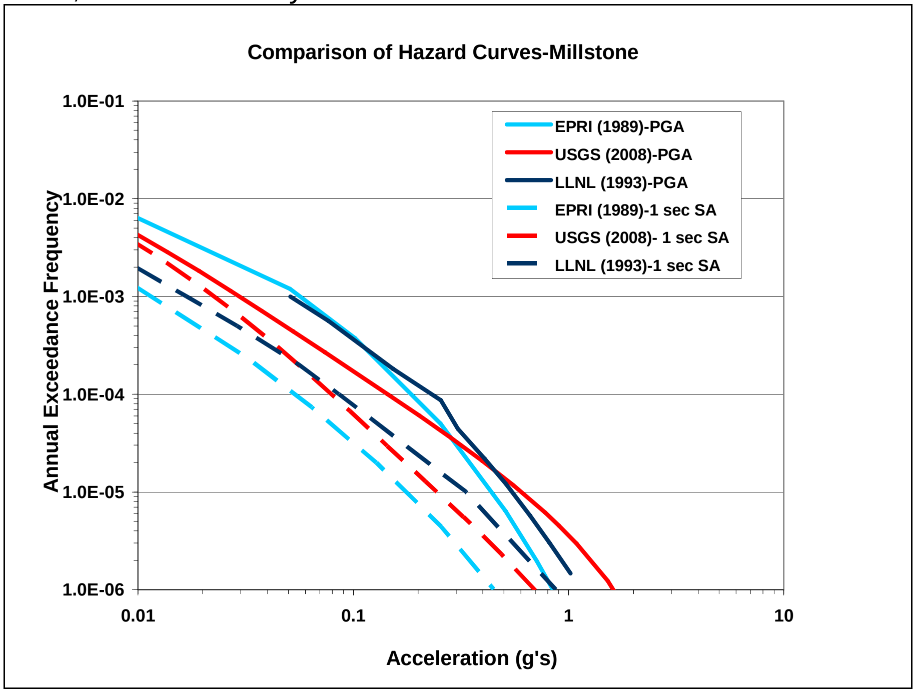


Figure B.7. Comparison of Hazard Results for the Millstone Site. The results from USGS (2008) are shown by red lines, EPRI (1989) by light blue lines, LLNL (1993) by dark blue lines, PGA by solid lines, and 1-sec SA by dashed lines.

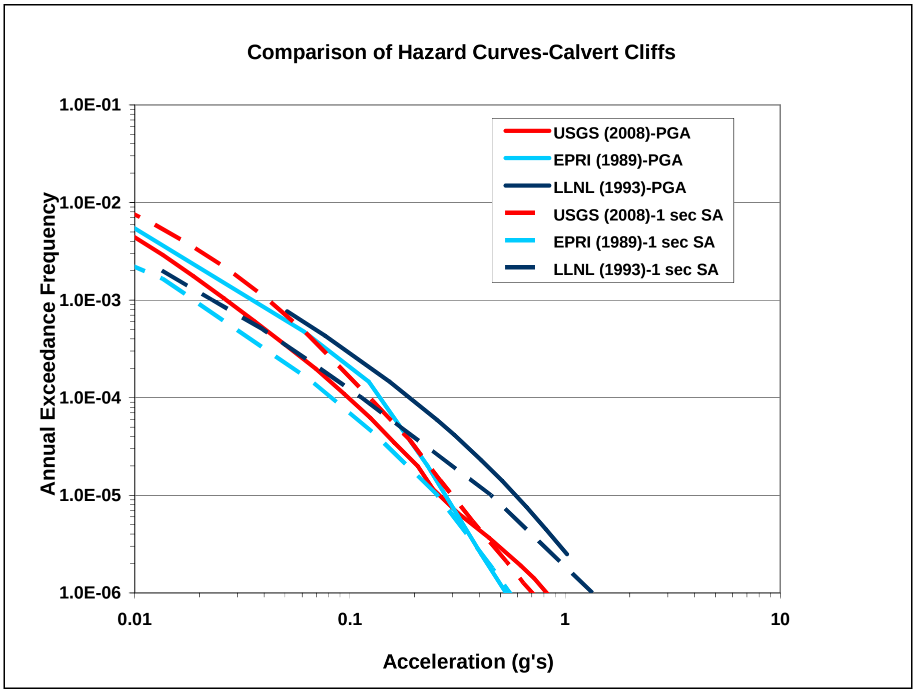


Figure B.8. Comparison of Hazard Results for the Calvert Cliffs Site. The results from USGS (2008) are shown by red lines, EPRI (1989) by light blue lines, LLNL (1993) by dark blue lines, PGA by solid lines, and 1-sec SA by dashed lines.

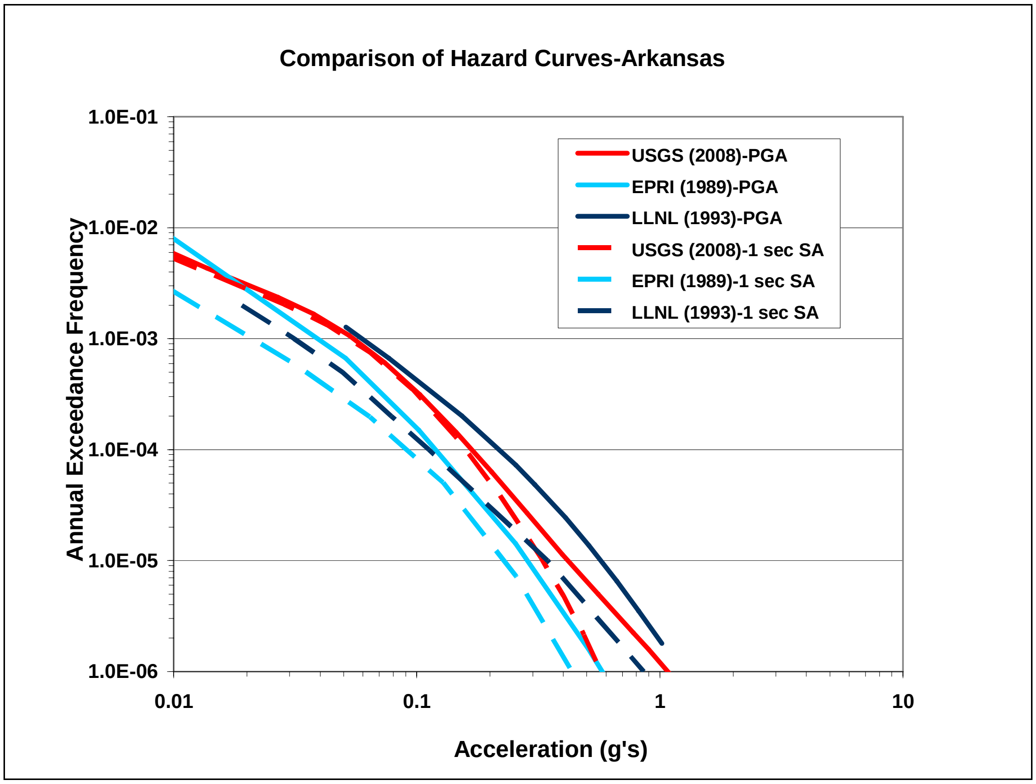


Figure B.9. Comparison of Hazard Results for the Arkansas Site. Results from USGS (2008) are shown by red lines, EPRI (1989) shown by light blue lines, and LLNL (1993) shown by dark blue lines, for PGA (solid lines) and 1-sec SA (dashed lines).

The general observation is that the more recent USGS hazard results are higher than the EPRI-SOG (EPRI-NP-6935, 1989) results at most sites. The difference is most pronounced for the 1-sec SA results. The difference becomes greatest for high amplitudes (i.e., low annual frequency of exceedance). The difference appears to be related primarily to two factors: (1) larger values assigned to M_{MAX} in the USGS model relative to the EPRI model and (2) the use of larger aleatory variability values in the modern ground motion attenuation models. The appropriate approach for developing M_{MAX} estimates in the CEUS is a topic of active discussion in the geosciences community. However, the aleatory variability estimates currently in use are considered superior to those used in the 1980-vintage studies. The USGS hazard estimates are generally higher than the 1993 LLNL study (especially at 1-sec SA), but at some locations the LLNL results are much higher than either the EPRI or USGS results.

B.3 Evaluation of Changes in Seismic Hazard Estimates

To develop additional insights that may help in the Safety and Risk Assessment Stage, additional comparisons of the changes in seismic hazard were made. Section 4 of the main body of the report shows the results of these comparisons. In addition, Figures B.10 and B.11

show a comparison of PGA and 5 Hz SA for an annual exceedance frequency (AFE) of 1E-5. This comparison shows trends in USGS (2008), EPRI (1989), and LLNL (1993) hazard results across the entire suite of CEUS plants. The general trend is consistent with time in that the relative ranking of plants is generally the same (for example plant #30 is high on all estimates and plant #50 is low on all indices). However, it is apparent that the EPRI (1989) results are generally lower than either the LLNL or USGS results. Figures B.10 and B.11 show results from recent early site permits (ESP) and combined licenses (COL) submittals as well. Direct comparison of the ESP/COL data is complicated by the use of the CAV filter for some of the ESP/COL sites and because the site conditions for some of the ESP/COL sites are different than those for the nearby existing NPP site.

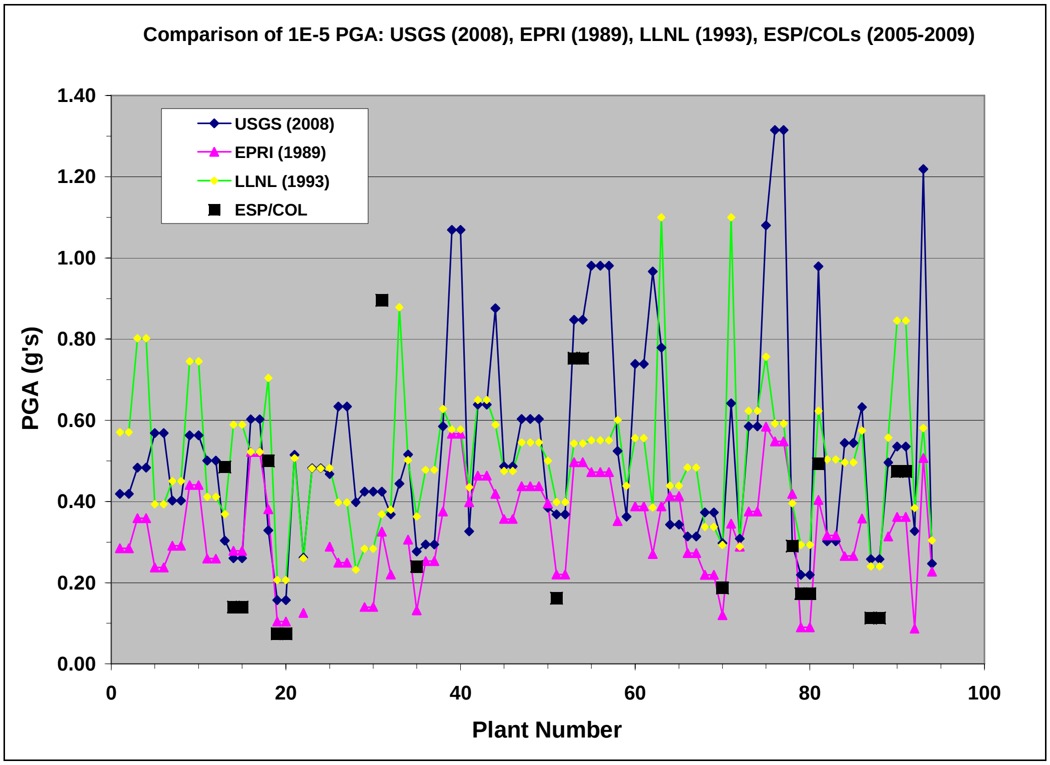


Figure B.10. Comparison of Peak Ground Acceleration (PGA) Hazard Results for CEUS Plant Sites at an AEF of 1E-5. The USGS (2008) results are shown by in dark blue, EPRI (1989) in magenta, and LLNL (1993) by green lines. Results from ESP and COL submittals indicated by black squares.

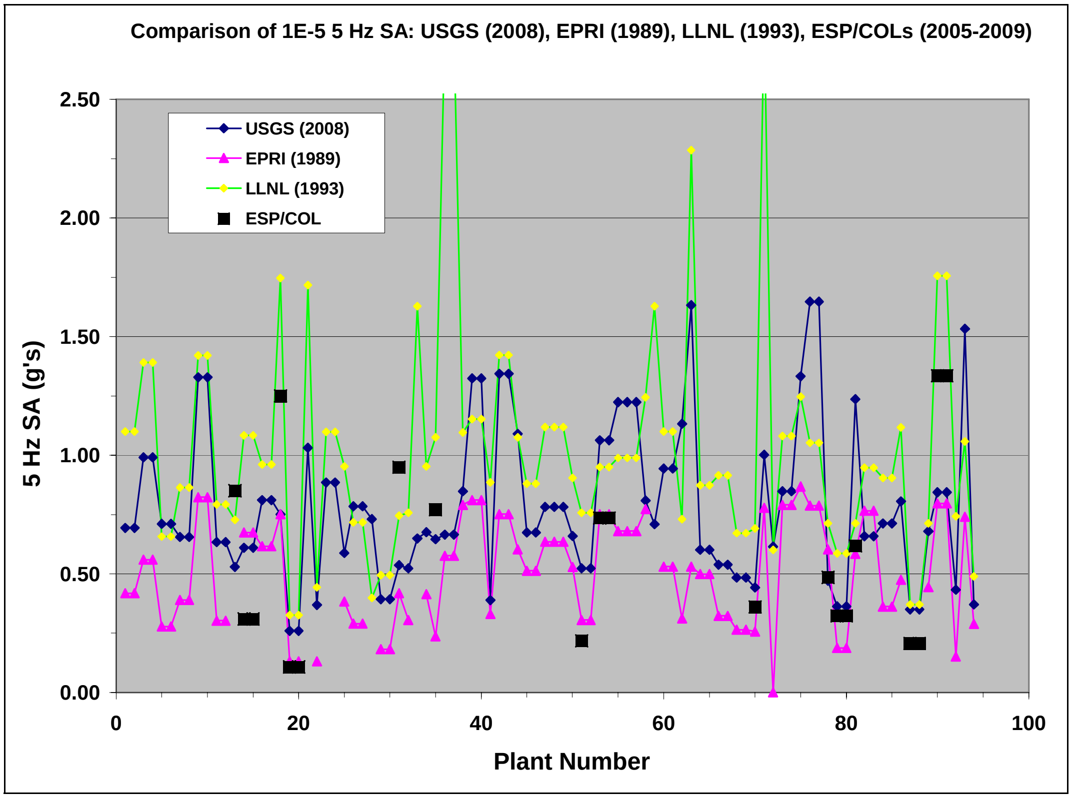


Figure B-11. Comparison of 5 Hz SA Hazard Results for CEUS Plant Sites at an AEF of 1E-5. The USGS (2008) results are shown by in dark blue, EPRI (1989) in magenta, and LLNL (1993) by green lines. Results from ESP and COL submittals are indicated by black squares.

As is discussed in Appendix A and shown by Kennedy (1997), an estimate of SCDF can be obtained directly from a basic set of plant-level fragility information (capacity expressed as either C_{50} or HCLPF and a measure of composite uncertainty, β_c) coupled with site-specific seismic hazard curves. In particular, because the seismic hazard curves are about linear over a relevant range of amplitudes in log-log space, the seismic hazard can be represented by two parameters: slope (represented by K_H) and intercept (represented by K_I). So, for a fixed set of assumptions regarding fragility at a particular site, the SCDF risk metric will change with changes in K_H and K_I. Figure B.12 compares the distribution of K_H vs. K_I for the 2008 USGS, 1989 EPRI, and 1993 LLNL PGA hazard results for rock sites in the CEUS. Although some overlap occurs, a clear distinction is noted between the three hazard results. Lower values of K_H and higher values of K_I indicate regions of increased SCDF (for fixed fragility assumptions). The USGS results generally indicate increased risk relative to previous estimates.

Figure B.13 is similar to Figure B.12 but compares the K_H vs. K_I results for 5 Hz SA. The conclusions are similar to those noted above for PGA. However, greater dispersion exists in the USGS results and more overlap between the USGS and LLNL results for the 5 Hz SA case.

The K_H and K_I values for these comparisons were derived from the USGS, EPRI, and LLNL hazard results over the 10^{-4} to 10^{-5} AEF range. The choice of amplitude range over which to perform the fit will influence the results. However, this amplitude range is consistent with a range relevant for the development of GMRS and based on more detailed calculations is a range that has a significant impact on SCDF. The comparison is made for rock sites as the influence of site-specific amplification functions can lead to very large changes for soil sites relative to rock.

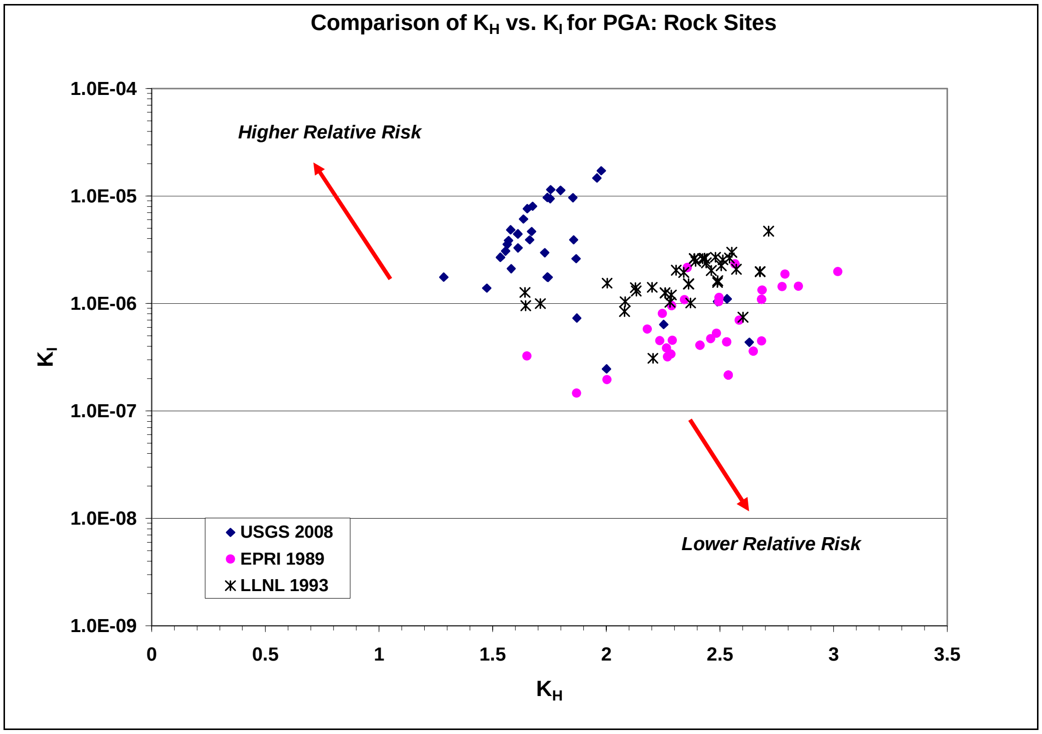


Figure B.12. Comparison of K_H vs. K_I Values for PGA at CEUS NPPs with Rock Site Conditions. The USGS (2008) results are shown by dark blue diamonds, EPRI (1989) with magenta circles, and LLNL (1993) by black stars. Regions of increasing and decreasing relative risk are indicated.

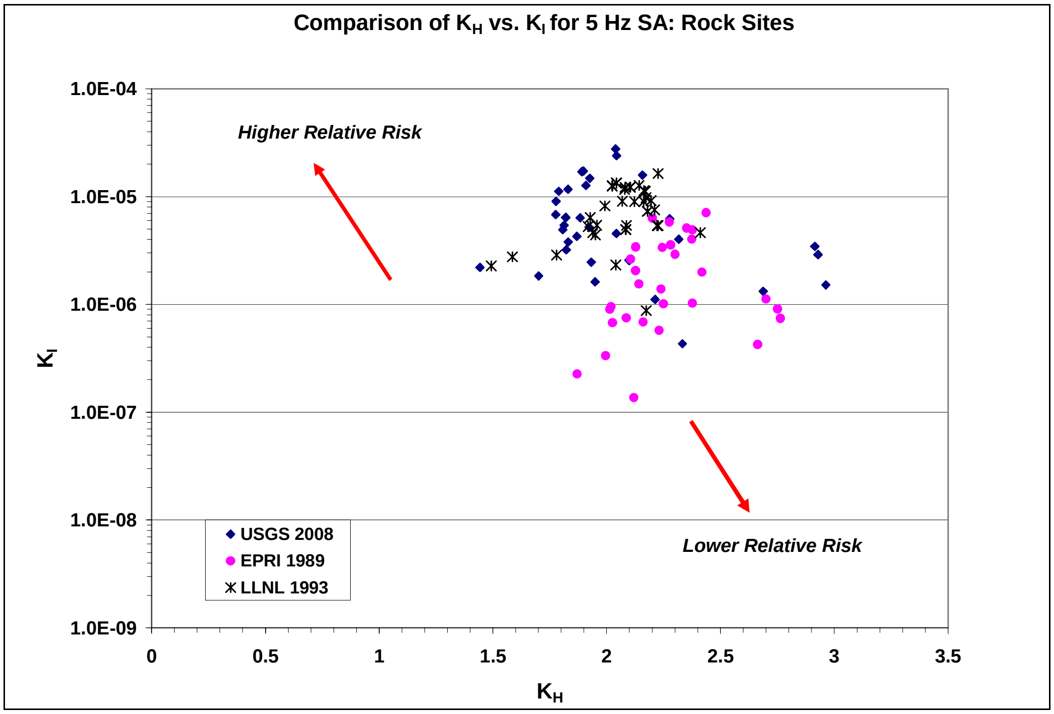


Figure B-13. Comparison of K_H vs. K_I Values for 5 Hz SA at CEUS NPPs with Rock Site Conditions. The USGS (2008) results are shown by dark blue diamonds, EPRI (1989) with magenta circles, and LLNL (1993) by black stars. Regions of increasing and decreasing relative risk are indicated.

APPENDIX C
PLANT-LEVEL FRAGILITY DATA

In the Safety/Risk Assessment, the plant-level seismic fragility has been modeled with a log-normal cumulative distribution function:

$$P_{CD}(a) = \Phi\left[\frac{\ln a - \mu}{\beta_C}\right] = \int_0^a \frac{1}{\sqrt{2\pi}\beta_C x} \exp\left[-\frac{(\ln x - \mu)^2}{2\beta_C^2}\right] dx \qquad \text{for } C_{50}, \beta_C > 0 \textit{ and } \mu = \ln C_{50} \qquad \text{(C-1)}$$

where C_{50} denotes the median seismic capacity and β_C denotes composite logarithmic standard deviation. Seismic probabilistic risk assessments (PRAs) have typically used a log-normal function to model the seismic fragilities for individual structures and components, and this practice is reflected in Table 5-2-2.7(f) of the “Standard for Level 1 / Large Early Release Frequency Probabilistic Risk Assessment for Nuclear Power Plant Applications, “ ASME/ANS-RA-Sa-2009. The assumption that the overall plant-level seismic fragility is reasonably modeled with a single log-normal function is discussed in Section 10-B.9 of the same standard.

The staff performed a confirmatory analysis of the reasonableness of the log-normal assumption by constructing probability plots of the plant-level fragility curves provided in Individual Plant Examination for External Events (IPEEE) submittals. A log-normal probability plot is constructed by observing that Equation (C-1) can be transformed into a linear equation:

$$y = mx + b \qquad \text{(C-2)}$$

where:

$$y = \Phi^{-1}\left[P_{CD}(a)\right]$$

$$x = \ln(a)$$

$$m = \frac{1}{\beta_C}$$

$$b = \frac{-\mu}{\beta_C}$$

If the log-normal assumption holds, then a plot of the plant-level fragility curve, as transformed, should appear as a straight line. Figures C.1 through C.4 provide log-normal probability plots for the plant-level seismic fragility curves for four plants and demonstrate the reasonableness of the log-normal assumption.

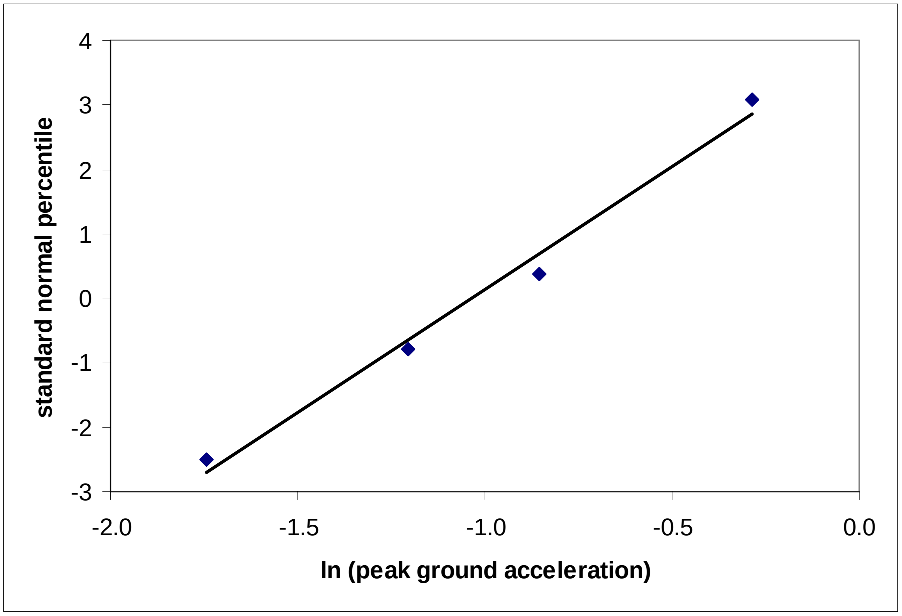


Figure C.1. Log-Normal Probability Plot of the Plant-Level Seismic Fragility Curve for Beaver Valley Unit 1.

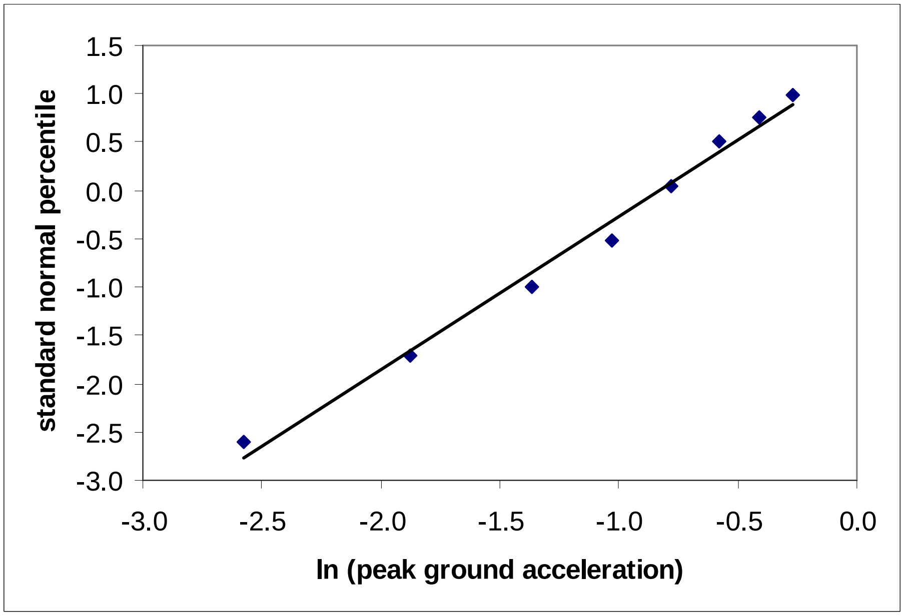


Figure C.2. Log-Normal Probability Plot of the Plant-Level Seismic Fragility Curve for Catawba Unit 1.

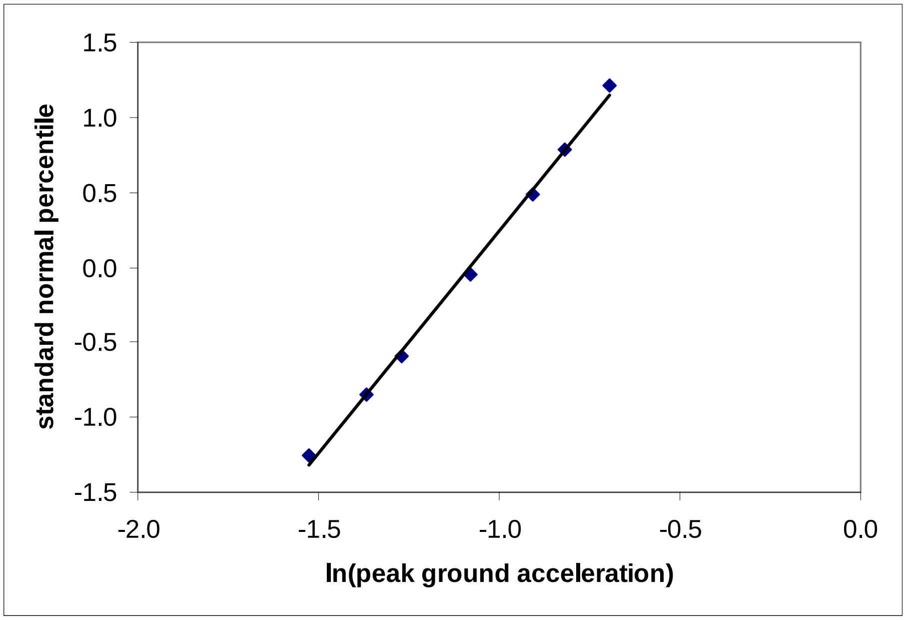


Figure C.3. Log-Normal Probability Plot of the Plant-Level Seismic Fragility Curve for Indian Point Unit 3.

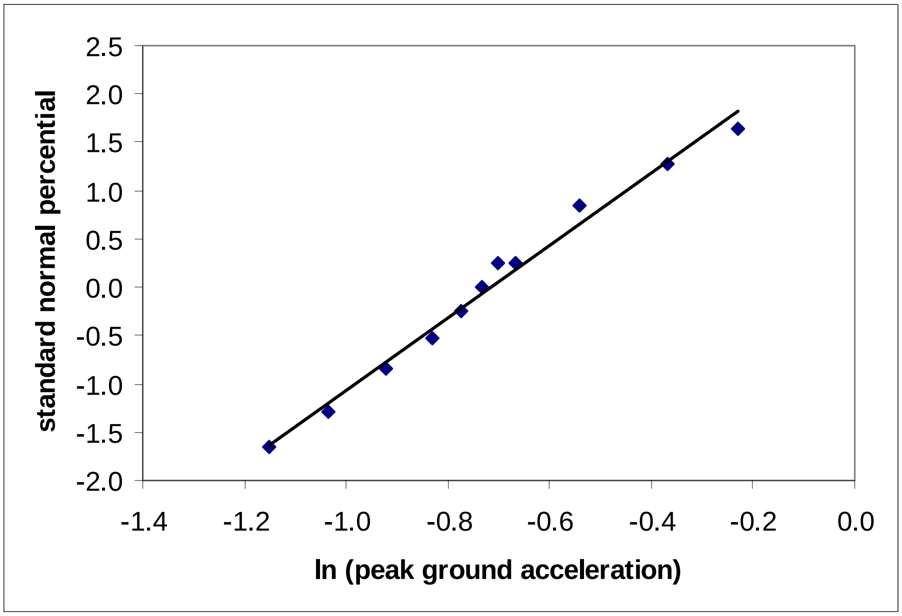


Figure C.4. Log-Normal Probability Plot of the Plant-Level Seismic Fragility Curve for Pilgrim.

Most of the available fragility information is expressed in terms of peak ground acceleration. In the Safety/Risk Assessment, this information was combined with information about the review-level response spectrum used in the IPEEE to develop fragility information at selected spectral frequencies (10 Hz, 5 Hz, and 1 Hz). The spectral ratio for a given spectral frequency, m_f, is defined as the ratio of the spectral ordinate on the review-level response spectrum corresponding to that spectral frequency to the spectral ordinate on the review-level response spectrum for the peak ground acceleration. Let C be a random variable that describes the plant's seismic capacity in terms of peak ground acceleration. Then, the cumulative distribution function of C is the peak ground acceleration (PGA)-based plant-level fragility, $P_{CD}(a)$. Thus, C is a log-normally distributed random variable with a median of C_{50} and a logarithmic standard deviation of β_C. Let C_f be a random variable that describes the plant's seismic capacity in terms of spectral frequency f. If $C_f = m_f C$, then C_f is also a log-normally distributed random variable with a median of $m_f C_{50}$ and a logarithmic standard deviation of β_C. Figure C.1 illustrates the relationships between C_f and C.

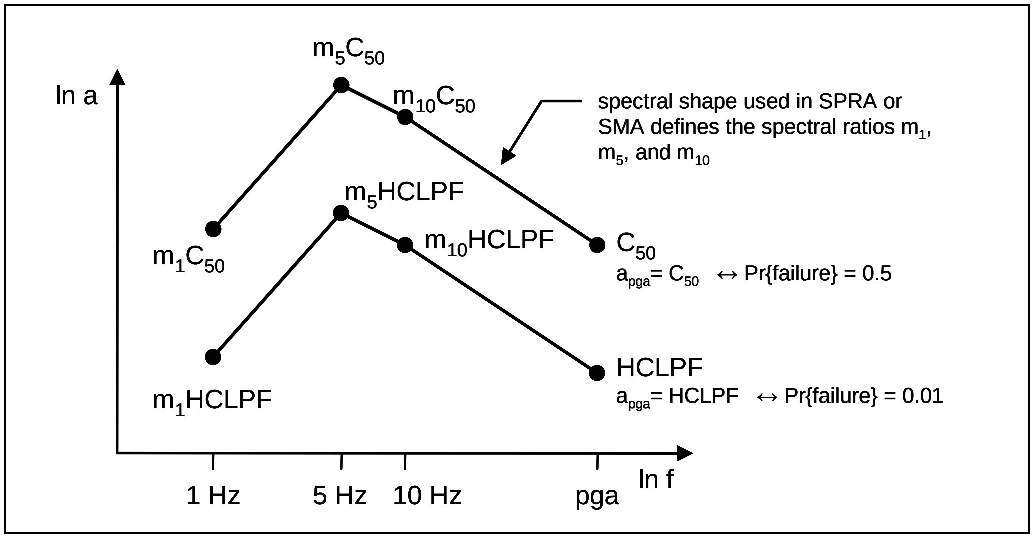


Figure C-1. The Definition of Spectral Fragility in Terms of the PGA-Based Fragility and the Review-Level Response Spectrum.

Parameters for the log-normal plant-level fragility curves were obtained by review of the IPEEE submittals. Table C.1 identifies the bases for establishing the plant-level fragility parameters from the available IPEEE information. Plant-level fragility curves (either in tabular or graphical form) were obtained for about two-thirds of the plants that performed a seismic PRA for the IPEEE (about one-third of all IPEEE submittals); if no plant-level fragility information was available, then the fragility parameters were back-calculated by matching reported seismic core-damage frequency (SCDFs) and using engineering judgment. The remaining two-thirds of plants performed a seismic margin analysis (SMA), which generated a plant-level high confidence of low probability of failure (HCLPF) value. The HCLPF is the peak ground acceleration that corresponds to a plant-level fragility of 0.01 (i.e., a 1-percent chance of core damage). The HCLPF is related to the median seismic capacity (C_{50}) as follows:

$$C_{50} = HCLPF \times \exp(2.3264\,\beta_C) \qquad \text{(C-3)}$$

Spectral ratios were obtained by review of the IPEEE submittals, which usually identified the specific spectral shape that was used (e.g., NUREG-0098). For some plants, the exact spectral shape could not be determined; in this case, several spectral shapes were postulated and carried through the entire analysis (i.e., SCDF estimates were made for each assumed spectral shape).

Table C.1. Bases for Establishing Plant-Level Fragility Curves Parameters From IPEEE Information.

Basis	Source	Parameters
1a	SPRA	C_{50} and β_C determined by probability plot of the reported plant-level fragility curve
1b	SPRA	C_{50} found by matching the computed SCDF to the SCDF stated in the IPEEE for the specified hazard curve (EPRI, LLNL, or plant-specific). Assumed $\beta_C = 0.4$.
1c	SPRA	C_{50} and β_C determined by matching computed SCDFs to IPEEE SCDFs for a pair of hazard curves.
2	SMA (HCLPF < RLE)	C_{50} found by using the stated HCLPF Assumed $\beta_C = 0.4$.
3a	SMA (HCLPF = RLE)	C_{50} found by using the stated HCLPF/RLE Assumed $\beta_C = 0.4$ Note: The RLE is a lower bound on the actual HCLPF.
3b	SMA (HCLPF = RLE = SSE)	C_{50} found by using the stated HCLPF/RLE/SSE Assumed $\beta_C = 0.4$ Note: The SSE is a lower bound on the actual HCLPF; applies to reduced scope SMA plants.

Table C-2 lists the plant-level fragility parameters used in the Safety/Risk Assessment.

Table C-2. Plant-Level Fragility Data.

Plant	Docket Number	IPEEE Method	PGA Fragility			Spectral Ratios			Basis
			HCL PF	C_{50}	β_C	10 Hz	5 Hz	1 Hz	
Arkansas Nuclear 1	05000313	0.3g full-scope EPRI SMA	0.3	0.76	0.4	1.87	2.12	0.96	3a
Arkansas Nuclear 2	05000368	0.3g focused-scope EPRI SMA	0.3	0.76	0.4	1.87	2.12	0.96	3a
Beaver Valley 1	05000334	seismic PRA		0.36	0.26	1.71	1.54	0.68	1a
Beaver Valley 2	05000412	seismic PRA		0.53	0.34	1.71	1.54	0.68	1a
Braidwood 1	05000456	0.3g focused-scope EPRI SMA	0.3	0.76	0.4	1.87	2.12	0.96	3a
Braidwood 2	05000457	0.3g focused-scope EPRI SMA	0.3	0.76	0.4	1.87	2.12	0.96	3a
Browns Ferry 1	05000259	0.3g focused-scope EPRI SMA	0.3	0.76	0.4	1.87	2.12	0.96	3a
Browns Ferry 2	05000260	0.3g focused-scope EPRI SMA	0.26	0.66	0.4	1.87	2.12	0.96	2
Browns Ferry 3	05000296	0.3g focused-scope EPRI SMA	0.26	0.66	0.4	1.87	2.12	0.96	2
Brunswick 1	05000325	0.3g focused-scope EPRI SMA	0.3	0.76	0.4	1.85	2.12	1.32	3a
Brunswick 2	05000324	0.3g focused-scope EPRI SMA	0.3	0.76	0.4	1.85	2.12	1.32	3a
Byron 1	05000454	0.3g focused-scope EPRI SMA	0.3	0.76	0.4	1.87	2.12	0.96	3a
Byron 2	05000455	0.3g focused-scope EPRI SMA	0.3	0.76	0.4	1.87	2.12	0.96	3a
Callaway	05000483	0.3g focused-scope EPRI SMA	0.3	0.76	0.4	1.85	2.12	1.32	3a
Calvert Cliffs 1	05000317	seismic PRA		0.62	0.4	1.38	1.72	0.6	1b
Calvert Cliffs 2	05000318	seismic PRA		0.58	0.4	1.38	1.72	0.6	1b
Catawba 1	05000413	seismic PRA		0.44	0.63	1.87	2.12	0.96	1a
Catawba 2	05000414	seismic PRA		0.44	0.63	1.87	2.12	0.96	1a
Clinton (0098)	05000461	0.3g focused-scope EPRI SMA	0.3	0.76	0.4	1.85	2.12	1.32	3a
Clinton(UHS)	05000461	0.3g focused-scope EPRI SMA	0.3	0.76	0.4	1.67	1.81	0.59	3a
Comanche Peak 1	05000445	reduced-scope EPRI SMA; SSE=0.12g	0.12	0.30	0.4	2.26	2.56	1.28	3b
Comanche Peak 2	05000446	reduced-scope EPRI SMA; SSE=0.12g	0.12	0.30	0.4	2.26	2.56	1.28	3b
Cooper	05000298	0.3g focused-scope EPRI SMA	0.3	0.76	0.4	1.85	2.12	1.32	3a

Table C-2. Plant-Level Fragility Data.

Plant	Docket Number	IPEEE Method	PGA Fragility			Spectral Ratios			Basis
			HCL PF	C_{50}	β_C	10 Hz	5 Hz	1 Hz	
Crystal River 3	05000302	reduced-scope EPRI SMA; SSE=0.1g	0.1	0.25	0.4	1.22	1.51	1.58	3b
D.C. Cook 1	05000315	seismic PRA		0.48	0.27	2.27	2.13	0.65	1a
D.C. Cook 2	05000316	seismic PRA		0.48	0.27	2.27	2.13	0.65	1a
Davis-Besse	05000346	reduced-scope EPRI SMA	0.26	0.66	0.4	1.87	2.12	0.96	2
Dresden 2	05000237	0.3g focused-scope EPRI SMA	0.2	0.51	0.4	1.87	2.12	0.96	2
Dresden 3	05000249	0.3g focused-scope EPRI SMA	0.2	0.51	0.4	1.87	2.12	0.96	2
Duane Arnold	05000331	reduced-scope EPRI SMA; SSE=0.12g	0.12	0.30	0.4	1.85	2.68	1.07	3b
Farley 1 (1st spectral ratios)	05000348	reduced-scope EPRI SMA; SSE=0.1g	0.1	0.25	0.4	1.87	2.12	0.96	3b
Farley 1 (2nd spectral ratios)	05000348	reduced-scope EPRI SMA; SSE=0.1g	0.1	0.25	0.4	1.85	2.12	1.32	3b
Farley 2 (1st spectral ratios)	05000364	reduced-scope EPRI SMA; SSE=0.1g	0.1	0.25	0.4	1.87	2.12	0.96	3b
Farley 2 (2nd spectral ratios)	05000364	reduced-scope EPRI SMA; SSE=0.1g	0.1	0.25	0.4	1.85	2.12	1.32	3b
Fermi 2	05000341	0.3g focused-scope EPRI SMA	0.3	0.76	0.4	1.87	2.12	0.96	3a
FitzPatrick	05000333	0.3g focused-scope NRC SMA	0.22	0.56	0.4	1.87	2.12	0.96	2
Fort Calhoun	05000285	0.3g focused-scope NRC SMA	0.25	0.63	0.4	1.85	2.12	1.32	2
Ginna	05000244	0.3g focused-scope EPRI SMA	0.2	0.51	0.4	2.14	2.42	1.36	2
Grand Gulf 1	05000416	reduced-scope EPRI SMA; SSE=0.15g	0.15	0.38	0.4	1.92	2.65	1.33	2
Harris 1	05000400	0.3g focused-scope EPRI SMA	0.29	0.74	0.4	1.87	2.12	0.96	2
Hatch 1	05000321	0.3g focused-scope EPRI SMA	0.3	0.76	0.4	1.85	2.12	1.32	3a
Hatch 2	05000366	0.3g focused-scope EPRI SMA	0.3	0.76	0.4	1.85	2.12	1.32	3a
Hope Creek 1	05000354	seismic PRA		1.66	0.70	1.97	2.27	0.98	1c
Indian Point 2	05000247	seismic PRA		0.68	0.4	1.62	1.23	0.41	1b
Indian Point 3	05000286	seismic PRA		0.34	0.34	1.56	1.61	0.81	1a
Kewaunee	05000305	seismic PRA		0.41	0.22	1.8	1.79	0.4	1a
La Salle 1 (0098)	05000373	seismic PRA		1.32	0.4	1.85	2.12	1.32	1b

Table C-2. Plant-Level Fragility Data.

Plant	Docket Number	IPEEE Method	PGA Fragility			Spectral Ratios			Basis
			HCL PF	C_{50}	β_C	10 Hz	5 Hz	1 Hz	
La Salle 1 (SSE)	05000373	seismic PRA		1.32	0.4	1.85	2.62	1.31	1b
La Salle 1 (UHS)	05000373	seismic PRA		1.32	0.4	1.67	1.83	0.923	1b
La Salle 2 (0098)	05000374	seismic PRA		1.32	0.4	1.85	2.12	1.32	1b
La Salle 2 (SSE)	05000374	seismic PRA		1.32	0.4	1.85	2.62	1.31	1b
La Salle 2 (UHS)	05000374	seismic PRA		1.32	0.4	1.67	1.83	0.923	1b
Limerick 1	05000352	reduced-scope EPRI SMA	0.15	0.38	0.4	2.59	2.47	1.18	3b
Limerick 2	05000353	reduced-scope EPRI SMA	0.15	0.38	0.4	2.59	2.47	1.18	3b
McGuire 1	05000369	seismic PRA		0.45	0.74	1.88	2.35	1.19	1a
McGuire 2	05000370	seismic PRA		0.45	0.74	1.88	2.35	1.19	1a
Millstone 2	05000336	0.3g focused-scope EPRI SMA	0.25	0.63	0.4	1.87	2.12	0.96	2
Millstone 3	05000423	seismic PRA		0.54	0.4	2.27	2.27	1.26	1b
Monticello	05000263	modified focused/expended reduced-scope EPRI SMA	0.12	0.30	0.4	2.29	2.69	1.12	3b
Nine Mile Point 1	05000220	0.3g focused-scope EPRI SMA	0.27	0.68	0.4	1.87	2.12	0.96	3b
Nine Mile Point 2	05000410	SPRA and focused-scope EPRI SMA	0.23	0.58	0.4	1.87	2.12	0.96	3b
North Anna 1 (1st spectral ratios)	05000338	0.3g focused-scope EPRI SMA	0.16	0.41	0.4	1.87	2.12	0.96	2
North Anna 1 (2nd spectral ratios)	05000338	0.3g focused-scope EPRI SMA	0.16	0.41	0.4	1.85	2.12	1.32	2
North Anna 2 (1st spectral ratios)	05000339	0.3g focused-scope EPRI SMA	0.16	0.41	0.4	1.87	2.12	0.96	2
North Anna 2 (2nd spectral ratios)	05000339	0.3g focused-scope EPRI SMA	0.16	0.41	0.4	1.85	2.12	1.32	2
Oconee 1	05000269	seismic PRA		0.62	0.32	1.66	1.32	0.35	1a
Oconee 2	05000270	seismic PRA		0.62	0.32	1.66	1.32	0.35	1a
Oconee 3	05000287	seismic PRA		0.62	0.32	1.66	1.32	0.35	1a

Table C-2. Plant-Level Fragility Data.

Plant	Docket Number	IPEEE Method	PGA Fragility			Spectral Ratios			Basis
			HCL PF	C_{50}	β_C	10 Hz	5 Hz	1 Hz	
Oyster Creek	05000219	seismic PRA		0.57	0.36	2	1.78	0.796	1a
Palisades	05000255	seismic PRA		0.49	0.35	2.13	2.44	0.74	1a
Peach Bottom 2	05000277	modified focused-scope EPRI SMA	0.2	0.51	0.4	1.87	2.12	0.96	3b
Peach Bottom 3	05000278	modified focused-scope EPRI SMA	0.2	0.51	0.4	1.87	2.12	0.96	3b
Perry 1	05000440	0.3g focused-scope EPRI SMA	0.3	0.76	0.4	1.87	2.12	0.96	3a
Pilgrim 1	05000293	seismic PRA		0.49	0.27	1.55	1.66	0.5	1a
Point Beach 1	05000266	seismic PRA		0.45	0.45	1.78	1.75	0.675	1a
Point Beach 2	05000301	seismic PRA		0.45	0.45	1.78	1.75	0.675	1a
Prairie Island 1	05000282	0.3g focused-scope EPRI SMA	0.28	0.71	0.4	1.85	2.12	1.32	2
Prairie Island 2	05000306	0.3g focused-scope EPRI SMA	0.28	0.71	0.4	1.85	2.12	1.32	2
Quad Cities 1	05000254	0.3g focused-scope EPRI SMA	0.09	0.23	0.4	1.87	2.12	0.96	2
Quad Cities 2	05000265	0.3g focused-scope EPRI SMA	0.09	0.23	0.4	1.87	2.12	0.96	2
River Bend 1	05000458	reduced-scope EPRI SMA; SSE=0.1g	0.1	0.25	0.4	2.35	2.75	1.41	3b
Robinson 2	05000261	0.3g full-scope EPRI SMA	0.28	0.71	0.4	1.85	2.12	1.32	2
Saint Lucie 1 (s4)	05000335	reduced-scope EPRI SMA; SSE=0.1g	0.1	0.25	0.4	1.18	1.5	0.8	3b
Saint Lucie 1 (s5)	05000335	reduced-scope EPRI SMA; SSE=0.1g	0.1	0.25	0.4	1.18	1.5	0.8	3b
Saint Lucie 2 (s4)	05000389	reduced-scope EPRI SMA; SSE=0.1g	0.1	0.25	0.4	1.18	1.5	0.8	3b
Saint Lucie 2 (s5)	05000389	reduced-scope EPRI SMA; SSE=0.1g	0.1	0.25	0.4	1.18	1.5	0.8	3b
Salem 1	05000272	seismic PRA		1.31	0.84	1.97	2.27	0.68	1c
Salem 2	05000311	seismic PRA		1.31	0.84	1.97	2.27	0.68	1c
Seabrook 1	05000443	seismic PRA		0.90	0.52	2.223	2.42	1.36	1a
Sequoyah 1	05000327	0.3g full-scope EPRI SMA	0.27	0.68	0.4	1.87	2.12	0.96	2
Sequoyah 2	05000328	0.3g full-scope EPRI SMA	0.27	0.68	0.4	1.87	2.12	0.96	2
South Texas 1	05000498	seismic PRA		0.38	0.59	2.47	2.97	1.53	1a

Table C-2. Plant-Level Fragility Data.

Plant	Docket Number	IPEEE Method	PGA Fragility			Spectral Ratios			Basis
			HCL PF	C_{50}	β_C	10 Hz	5 Hz	1 Hz	
South Texas 2	05000499	seismic PRA		0.38	0.59	2.47	2.97	1.53	1a
Summer	05000395	0.3g focused-scope EPRI SMA	0.22	0.56	0.4	1.87	2.12	0.96	2
Surry 1	05000280	seismic PRA		0.74	0.66	2.08	1.95	0.97	1a
Surry 2	05000281	seismic PRA		0.74	0.66	2.08	1.95	0.97	1a
Susquehanna 1	05000387	0.3g focused-scope EPRI SMA	0.21	0.53	0.4	1.87	2.12	0.96	2
Susquehanna 2	05000388	0.3g focused-scope EPRI SMA	0.21	0.53	0.4	1.87	2.12	0.96	2
Three Mile Island 1	05000289	seismic PRA		0.29	0.28	2.73	2.6	1.127	1a
Turkey Point 3	05000250	site-specific approach; SSE=0.15g	0.15	0.38	0.4	1.26	1.58	0.85	3b
Turkey Point 4	05000251	site-specific approach; SSE=0.15g	0.15	0.38	0.4	1.26	1.58	0.85	3b
Vermont Yankee	05000271	0.3g focused-scope EPRI SMA	0.25	0.63	0.4	1.87	2.12	0.96	2
Vogtle 1	05000424	0.3g focused-scope EPRI SMA	0.3	0.76	0.4	1.85	2.12	1.32	3a
Vogtle 2	05000425	0.3g focused-scope EPRI SMA	0.3	0.76	0.4	1.85	2.12	1.32	3a
Waterford 3	05000382	reduced-scope EPRI SMA; SSE=0.1g	0.1	0.25	0.4	1.72	2.4	1.19	3b
Watts Bar 1 (rock)	05000390	0.3g focused-scope EPRI SMA	0.3	0.76	0.4	1.87	2.12	0.96	3a
Watts Bar 1 (soil)	05000390	0.3g focused-scope EPRI SMA	0.3	0.76	0.4	1.85	2.12	1.32	3a
Wolf Creek 1	05000482	reduced-scope EPRI SMA	0.2	0.51	0.4	1.83	2.25	0.32	3b

APPENDIX D
SEISMIC CORE-DAMAGE FREQUENCIES

This appendix provides the seismic core- damage frequency (SCDF) estimates developed in the Safety/Risk Assessment. It is organized into four tables as follows:

- Table D-1: Seismic Core-Damage Frequencies Using 2008 USGS Seismic Hazard Curves

- Table D-2: Seismic Core-Damage Frequencies Using 1989 EPRI Seismic Hazard Curves

- Table D-3: Seismic Core-Damage Frequencies Using 1994 LLNL Seismic Hazard Curves

- Tables D-4: IPEEE SPRA Results and SPAR Model Results

Table D-1. Seismic Core-Damage Frequencies Using 2008 USGS Seismic Hazard Curves.

		Updated USGS								
Plant Name	Docket Number	PGA	10 Hz	5 Hz	1 Hz	max	controlling curve	simple average	IPEEE weighted average	weakest link model
Arkansas Nuclear 1	05000313	3.8E-06	3.9E-06	1.5E-06	1.4E-06	3.9E-06	10 Hz	2.6E-06	2.5E-06	4.1E-06
Arkansas Nuclear 2	05000368	3.8E-06	3.9E-06	1.5E-06	1.4E-06	3.9E-06	10 Hz	2.6E-06	2.5E-06	4.1E-06
Beaver Valley 1	05000334	2.6E-05	3.4E-05	4.8E-05	7.4E-06	4.8E-05	5 HZ	2.9E-05	2.9E-05	4.8E-05
Beaver Valley 2	05000412	1.1E-05	1.6E-05	2.2E-05	3.5E-06	2.2E-05	5 HZ	1.3E-05	1.3E-05	2.2E-05
Braidwood 1	05000456	7.3E-06	5.3E-06	2.2E-06	7.3E-07	7.3E-06	PGA	3.9E-06	3.4E-06	7.3E-06
Braidwood 2	05000457	7.3E-06	5.3E-06	2.2E-06	7.3E-07	7.3E-06	PGA	3.9E-06	3.4E-06	7.3E-06
Browns Ferry 1	05000259	3.5E-06	3.5E-06	1.3E-06	1.2E-06	3.5E-06	PGA	2.4E-06	2.2E-06	3.7E-06
Browns Ferry 2	05000260	5.0E-06	5.2E-06	2.0E-06	2.0E-06	5.2E-06	10 Hz	3.5E-06	3.3E-06	5.4E-06
Browns Ferry 3	05000296	5.0E-06	5.2E-06	2.0E-06	2.0E-06	5.2E-06	10 Hz	3.5E-06	3.3E-06	5.4E-06
Brunswick 1	05000325	9.5E-06	1.5E-05	1.2E-05	1.1E-06	1.5E-05	10 Hz	9.4E-06	9.4E-06	1.5E-05
Brunswick 2	05000324	9.5E-06	1.5E-05	1.2E-05	1.1E-06	1.5E-05	10 Hz	9.4E-06	9.4E-06	1.5E-05
Byron 1	05000454	5.8E-06	4.2E-06	1.8E-06	5.6E-07	5.8E-06	PGA	3.1E-06	2.7E-06	5.8E-06
Byron 2	05000455	5.8E-06	4.2E-06	1.8E-06	5.6E-07	5.8E-06	PGA	3.1E-06	2.7E-06	5.8E-06
Callaway	05000483	1.8E-06	1.9E-06	6.3E-07	1.5E-07	1.9E-06	10 Hz	1.1E-06	1.0E-06	2.0E-06
Calvert Cliffs 1	05000317	2.5E-06	5.0E-06	3.1E-06	9.9E-06	9.9E-06	1 HZ	5.1E-06	5.5E-06	1.0E-05
Calvert Cliffs 2	05000318	2.9E-06	6.0E-06	3.8E-06	1.2E-05	1.2E-05	1 HZ	6.1E-06	6.6E-06	1.2E-05
Catawba 1	05000413	3.6E-05	3.5E-05	2.0E-05	1.7E-05	3.6E-05	PGA	2.7E-05	2.6E-05	3.7E-05
Catawba 2	05000414	3.6E-05	3.5E-05	2.0E-05	1.7E-05	3.6E-05	PGA	2.7E-05	2.6E-05	3.7E-05
Clinton (0098)	05000461	1.6E-06	2.3E-06	1.7E-06	1.1E-06	2.3E-06	10 Hz	1.7E-06	1.7E-06	2.5E-06
Clinton(UHS)	05000461	1.6E-06	3.5E-06	3.1E-06	1.7E-05	1.7E-05	1 HZ	6.3E-06	6.9E-06	1.7E-05
Comanche Peak 1	05000445	4.0E-06	2.5E-06	1.3E-06	5.3E-07	4.0E-06	PGA	2.1E-06	1.8E-06	4.0E-06
Comanche Peak 2	05000446	4.0E-06	2.5E-06	1.3E-06	5.3E-07	4.0E-06	PGA	2.1E-06	1.8E-06	4.0E-06
Cooper	05000298	5.8E-06	7.0E-06	4.7E-06	3.2E-07	7.0E-06	10 Hz	4.4E-06	4.3E-06	7.0E-06

Table D-1. Seismic Core-Damage Frequencies Using 2008 USGS Seismic Hazard Curves.

		Updated USGS								
Plant Name	Docket Number	PGA	10 Hz	5 Hz	1 Hz	max	controlling curve	simple average	IPEEE weighted average	weakest link model
Crystal River 3	05000302	1.2E-05	2.2E-05	1.2E-05	1.3E-06	2.2E-05	10 Hz	1.2E-05	1.2E-05	2.2E-05
D.C. Cook 1	05000315	1.2E-05	9.0E-06	8.5E-06	1.4E-06	1.2E-05	PGA	7.7E-06	7.1E-06	1.2E-05
D.C. Cook 2	05000316	1.2E-05	9.0E-06	8.5E-06	1.4E-06	1.2E-05	PGA	7.7E-06	7.1E-06	1.2E-05
Davis-Besse	05000346	6.7E-06	5.0E-06	2.2E-06	6.7E-07	6.7E-06	PGA	3.6E-06	3.2E-06	6.7E-06
Dresden 2	05000237	1.9E-05	1.5E-05	7.0E-06	2.4E-06	1.9E-05	PGA	1.1E-05	9.7E-06	1.9E-05
Dresden 3	05000249	1.9E-05	1.5E-05	7.0E-06	2.4E-06	1.9E-05	PGA	1.1E-05	9.7E-06	1.9E-05
Duane Arnold	05000331	2.3E-05	3.2E-05	1.1E-05	1.3E-06	3.2E-05	10 Hz	1.7E-05	1.6E-05	3.2E-05
Farley 1 (1st spectral ratios)	05000348	2.8E-05	1.3E-05	7.4E-06	5.3E-06	2.8E-05	PGA	1.3E-05	1.1E-05	2.8E-05
Farley 1 (2nd spectral ratios)	05000348	2.8E-05	1.3E-05	7.4E-06	2.3E-06	2.8E-05	PGA	1.3E-05	1.1E-05	2.8E-05
Farley 2 (1st spectral ratios)	05000364	2.8E-05	1.3E-05	7.4E-06	5.3E-06	2.8E-05	PGA	1.3E-05	1.1E-05	2.8E-05
Farley 2 (2nd spectral ratios)	05000364	2.8E-05	1.3E-05	7.4E-06	2.3E-06	2.8E-05	PGA	1.3E-05	1.1E-05	2.8E-05
Fermi 2	05000341	4.2E-06	3.0E-06	1.3E-06	4.1E-07	4.2E-06	PGA	2.2E-06	2.0E-06	4.2E-06
FitzPatrick	05000333	6.1E-06	5.0E-06	2.5E-06	1.4E-06	6.1E-06	PGA	3.8E-06	3.4E-06	6.1E-06
Fort Calhoun	05000285	1.1E-05	1.3E-05	3.7E-06	2.0E-07	1.3E-05	10 Hz	7.0E-06	6.4E-06	1.3E-05
Ginna	05000244	1.3E-05	8.0E-06	4.0E-06	1.2E-06	1.3E-05	PGA	6.4E-06	5.6E-06	1.3E-05
Grand Gulf 1	05000416	8.4E-06	1.1E-05	4.7E-06	9.4E-06	1.1E-05	10 Hz	8.3E-06	8.3E-06	1.2E-05
Harris 1	05000400	2.3E-06	1.8E-06	8.7E-07	5.9E-07	2.3E-06	PGA	1.4E-06	1.3E-06	2.3E-06
Hatch 1	05000321	2.1E-06	1.7E-06	1.0E-06	1.1E-06	2.1E-06	PGA	1.5E-06	1.4E-06	2.2E-06
Hatch 2	05000366	2.1E-06	1.7E-06	1.0E-06	1.1E-06	2.1E-06	PGA	1.5E-06	1.4E-06	2.2E-06
Hope Creek 1	05000354	2.8E-06	2.0E-06	1.1E-06	2.0E-06	2.8E-06	PGA	1.9E-06	1.8E-06	2.8E-06
Indian Point 2	05000247	3.2E-05	3.1E-05	3.3E-05	2.4E-05	3.3E-05	5 HZ	3.0E-05	3.0E-05	3.3E-05
Indian Point 3	05000286	9.1E-05	1.0E-04	6.6E-05	2.3E-05	1.0E-04	10 Hz	7.0E-05	6.7E-05	1.0E-04
Kewaunee	05000305	7.1E-06	1.2E-05	3.2E-06	2.6E-06	1.2E-05	10 Hz	6.3E-06	6.2E-06	1.2E-05
La Salle 1 (0098)	05000373	2.3E-06	2.5E-06	1.4E-06	1.4E-07	2.5E-06	10 Hz	1.6E-06	1.5E-06	2.8E-06
La Salle 1 (SSE)	05000373	2.3E-06	2.5E-06	5.3E-07	1.5E-07	2.5E-06	10 Hz	1.4E-06	1.2E-06	2.8E-06
La Salle 1 (UHS)	05000373	2.3E-06	3.6E-06	2.5E-06	3.9E-07	3.6E-06	10 Hz	2.2E-06	2.2E-06	3.7E-06

Table D-1. Seismic Core-Damage Frequencies Using 2008 USGS Seismic Hazard Curves.

Plant Name	Docket Number	Updated USGS								
		PGA	10 Hz	5 Hz	1 Hz	max	controlling curve	simple average	IPEEE weighted average	weakest link model
La Salle 2 (0098)	05000374	2.3E-06	2.5E-06	1.4E-06	1.4E-07	2.5E-06	10 Hz	1.6E-06	1.5E-06	2.8E-06
La Salle 2 (SSE)	05000374	2.3E-06	2.5E-06	5.3E-07	1.5E-07	2.5E-06	10 Hz	1.4E-06	1.2E-06	2.8E-06
La Salle 2 (UHS)	05000374	2.3E-06	3.6E-06	2.5E-06	3.9E-07	3.6E-06	10 Hz	2.2E-06	2.2E-06	3.7E-06
Limerick 1	05000352	5.3E-05	2.5E-05	1.8E-05	7.1E-06	5.3E-05	PGA	2.6E-05	2.2E-05	5.3E-05
Limerick 2	05000353	5.3E-05	2.5E-05	1.8E-05	7.1E-06	5.3E-05	PGA	2.6E-05	2.2E-05	5.3E-05
McGuire 1	05000369	3.1E-05	3.0E-05	1.5E-05	1.1E-05	3.1E-05	PGA	2.2E-05	2.0E-05	3.1E-05
McGuire 2	05000370	3.1E-05	3.0E-05	1.5E-05	1.1E-05	3.1E-05	PGA	2.2E-05	2.0E-05	3.1E-05
Millstone 2	05000336	1.1E-05	9.0E-06	4.4E-06	2.0E-06	1.1E-05	PGA	6.7E-06	6.0E-06	1.1E-05
Millstone 3	05000423	1.5E-05	8.4E-06	5.4E-06	1.6E-06	1.5E-05	PGA	7.6E-06	6.5E-06	1.5E-05
Monticello	05000263	1.9E-05	1.5E-05	8.6E-06	7.6E-07	1.9E-05	PGA	1.1E-05	9.8E-06	1.9E-05
Nine Mile Point 1	05000220	4.2E-06	3.3E-06	1.6E-06	8.5E-07	4.2E-06	PGA	2.5E-06	2.2E-06	4.2E-06
Nine Mile Point 2	05000410	5.6E-06	4.5E-06	2.3E-06	1.3E-06	5.6E-06	PGA	3.4E-06	3.1E-06	5.6E-06
North Anna 1 (1st spectral ratios)	05000338	4.4E-05	3.7E-05	2.0E-05	8.8E-06	4.4E-05	PGA	2.7E-05	2.5E-05	4.4E-05
North Anna 1 (2nd spectral ratios)	05000338	4.4E-05	3.7E-05	2.0E-05	4.7E-06	4.4E-05	PGA	2.6E-05	2.4E-05	4.4E-05
North Anna 2 (1st spectral ratios)	05000339	4.4E-05	3.7E-05	2.0E-05	8.8E-06	4.4E-05	PGA	2.7E-05	2.5E-05	4.4E-05
North Anna 2 (2nd spectral ratios)	05000339	4.4E-05	3.7E-05	2.0E-05	4.7E-06	4.4E-05	PGA	2.6E-05	2.4E-05	4.4E-05
Oconee 1	05000269	2.8E-05	2.7E-05	2.7E-05	4.3E-05	4.3E-05	1 HZ	3.1E-05	3.2E-05	4.3E-05
Oconee 2	05000270	2.8E-05	2.7E-05	2.7E-05	4.3E-05	4.3E-05	1 HZ	3.1E-05	3.2E-05	4.3E-05
Oconee 3	05000287	2.8E-05	2.7E-05	2.7E-05	4.3E-05	4.3E-05	1 HZ	3.1E-05	3.2E-05	4.3E-05
Oyster Creek	05000219	1.0E-05	7.5E-06	1.1E-05	1.3E-05	1.3E-05	1 HZ	1.0E-05	1.0E-05	1.4E-05
Palisades	05000255	6.4E-06	5.5E-06	3.9E-06	1.5E-06	6.4E-06	PGA	4.3E-06	4.0E-06	6.4E-06
Peach Bottom 2	05000277	2.5E-05	2.0E-05	1.0E-05	4.6E-06	2.5E-05	PGA	1.5E-05	1.3E-05	2.4E-05
Peach Bottom 3	05000278	2.5E-05	2.0E-05	1.0E-05	4.6E-06	2.5E-05	PGA	1.5E-05	1.3E-05	2.4E-05
Perry 1	05000440	2.1E-05	1.5E-05	6.4E-06	1.8E-06	2.1E-05	PGA	1.1E-05	9.6E-06	2.1E-05
Pilgrim 1	05000293	4.3E-05	6.9E-05	6.2E-05	2.4E-05	6.9E-05	10 Hz	4.9E-05	5.0E-05	6.9E-05
Point Beach 1	05000266	8.3E-06	1.1E-05	8.6E-06	1.0E-06	1.1E-05	10 Hz	7.3E-06	7.2E-06	1.1E-05

Table D-1. Seismic Core-Damage Frequencies Using 2008 USGS Seismic Hazard Curves.

		Updated USGS								
Plant Name	Docket Number	PGA	10 Hz	5 Hz	1 Hz	max	controlling curve	simple average	IPEEE weighted average	weakest link model
Point Beach 2	05000301	8.3E-06	1.1E-05	8.6E-06	1.0E-06	1.1E-05	10 Hz	7.3E-06	7.2E-06	1.1E-05
Prairie Island 1	05000282	2.5E-06	3.0E-06	1.8E-06	4.3E-08	3.0E-06	10 Hz	1.9E-06	1.8E-06	3.0E-06
Prairie Island 2	05000306	2.5E-06	3.0E-06	1.8E-06	4.3E-08	3.0E-06	10 Hz	1.9E-06	1.8E-06	3.0E-06
Quad Cities 1	05000254	2.7E-05	2.6E-05	1.4E-05	8.6E-06	2.7E-05	PGA	1.9E-05	1.7E-05	2.7E-05
Quad Cities 2	05000265	2.7E-05	2.6E-05	1.4E-05	8.6E-06	2.7E-05	PGA	1.9E-05	1.7E-05	2.7E-05
River Bend 1	05000458	1.6E-05	9.8E-06	5.9E-06	1.5E-05	1.6E-05	PGA	1.2E-05	1.1E-05	2.5E-05
Robinson 2	05000261	1.2E-05	1.4E-05	9.2E-06	1.1E-05	1.4E-05	10 Hz	1.2E-05	1.2E-05	1.5E-05
Saint Lucie 1 (s4)	05000335	2.1E-05	4.6E-05	3.3E-05	1.2E-05	4.6E-05	10 Hz	2.8E-05	2.9E-05	4.6E-05
Saint Lucie 1 (s5)	05000335	2.1E-05	4.6E-05	3.3E-05	1.2E-05	4.6E-05	10 Hz	2.8E-05	2.9E-05	4.6E-05
Saint Lucie 2 (s4)	05000389	2.1E-05	4.6E-05	3.3E-05	1.2E-05	4.6E-05	10 Hz	2.8E-05	2.9E-05	4.6E-05
Saint Lucie 2 (s5)	05000389	2.1E-05	4.6E-05	3.3E-05	1.2E-05	4.6E-05	10 Hz	2.8E-05	2.9E-05	4.6E-05
Salem 1	05000272	7.2E-06	6.3E-06	4.5E-06	1.1E-05	1.1E-05	1 HZ	7.3E-06	7.4E-06	1.1E-05
Salem 2	05000311	7.2E-06	6.3E-06	4.5E-06	1.1E-05	1.1E-05	1 HZ	7.3E-06	7.4E-06	1.1E-05
Seabrook 1	05000443	2.2E-05	1.2E-05	5.9E-06	1.6E-06	2.2E-05	PGA	1.0E-05	8.6E-06	2.2E-05
Sequoyah 1	05000327	5.1E-05	3.9E-05	1.9E-05	8.1E-06	5.1E-05	PGA	2.9E-05	2.6E-05	5.1E-05
Sequoyah 2	05000328	5.1E-05	3.9E-05	1.9E-05	8.1E-06	5.1E-05	PGA	2.9E-05	2.6E-05	5.1E-05
South Texas 1	05000498	6.3E-06	3.5E-06	2.0E-06	9.1E-07	6.3E-06	PGA	3.2E-06	2.7E-06	6.3E-06
South Texas 2	05000499	6.3E-06	3.5E-06	2.0E-06	9.1E-07	6.3E-06	PGA	3.2E-06	2.7E-06	6.3E-06
Summer	05000395	3.9E-05	3.2E-05	1.6E-05	8.8E-06	3.9E-05	PGA	2.4E-05	2.2E-05	3.8E-05
Surry 1	05000280	4.4E-06	3.6E-06	4.6E-06	5.1E-06	5.1E-06	1 HZ	4.4E-06	4.4E-06	5.7E-06
Surry 2	05000281	4.4E-06	3.6E-06	4.6E-06	5.1E-06	5.1E-06	1 HZ	4.4E-06	4.4E-06	5.7E-06
Susquehanna 1	05000387	1.3E-05	1.0E-05	5.3E-06	2.6E-06	1.3E-05	PGA	7.7E-06	7.0E-06	1.3E-05
Susquehanna 2	05000388	1.3E-05	1.0E-05	5.3E-06	2.6E-06	1.3E-05	PGA	7.7E-06	7.0E-06	1.3E-05
Three Mile Island 1	05000289	4.0E-05	1.8E-05	1.3E-05	6.3E-06	4.0E-05	PGA	1.9E-05	1.6E-05	4.0E-05
Turkey Point 3	05000250	6.6E-06	1.0E-05	5.0E-06	1.6E-06	1.0E-05	10 Hz	5.9E-06	5.8E-06	1.0E-05
Turkey Point 4	05000251	6.6E-06	1.0E-05	5.0E-06	1.6E-06	1.0E-05	10 Hz	5.9E-06	5.8E-06	1.0E-05

Table D-1. Seismic Core-Damage Frequencies Using 2008 USGS Seismic Hazard Curves.

Plant Name	Docket Number	Updated USGS								
		PGA	10 Hz	5 Hz	1 Hz	max	controlling curve	simple average	IPEEE weighted average	weakest link model
Vermont Yankee	05000271	8.1E-06	6.5E-06	3.2E-06	1.7E-06	8.1E-06	PGA	4.9E-06	4.5E-06	8.1E-06
Vogtle 1	05000424	6.6E-06	5.8E-06	3.6E-06	4.0E-06	6.6E-06	PGA	5.0E-06	4.8E-06	7.1E-06
Vogtle 2	05000425	6.6E-06	5.8E-06	3.6E-06	4.0E-06	6.6E-06	PGA	5.0E-06	4.8E-06	7.1E-06
Waterford 3	05000382	1.8E-05	1.8E-05	7.0E-06	8.1E-06	1.8E-05	10 Hz	1.3E-05	1.2E-05	2.0E-05
Watts Bar 1 (rock)	05000390	3.6E-05	2.7E-05	1.3E-05	5.5E-06	3.6E-05	PGA	2.0E-05	1.8E-05	3.6E-05
Watts Bar 1 (soil)	05000390	3.6E-05	2.8E-05	1.3E-05	2.6E-06	3.6E-05	PGA	2.0E-05	1.8E-05	3.6E-05
Wolf Creek 1	05000482	3.5E-06	3.1E-06	1.2E-06	1.8E-05	1.8E-05	1 HZ	6.5E-06	6.9E-06	1.8E-05

Table D-2. Seismic Core-Damage Frequencies Using 1989 EPRI Seismic Hazard Curves.

		EPRI 1989								
Plant Name	Docket Number	PGA	10 Hz	5 Hz	1 Hz	max	controlling curve	simple average	IPEEE weighted average	weakest link model
Arkansas Nuclear 1	05000313	9.4E-07	6.5E-07	3.5E-07	4.3E-07	9.4E-07	PGA	5.9E-07	5.4E-07	9.4E-07
Arkansas Nuclear 2	05000368	9.4E-07	6.5E-07	3.5E-07	4.3E-07	9.4E-07	PGA	5.9E-07	5.4E-07	9.4E-07
Beaver Valley 1	05000334	1.2E-05	1.3E-05	1.3E-05	6.5E-07	1.3E-05	5 HZ	9.5E-06	9.1E-06	1.3E-05
Beaver Valley 2	05000412	4.5E-06	5.1E-06	5.3E-06	2.9E-07	5.3E-06	5 HZ	3.8E-06	3.7E-06	5.3E-06
Braidwood 1	05000456	5.6E-07	3.5E-07	1.5E-07	5.5E-08	5.6E-07	PGA	2.8E-07	2.4E-07	5.6E-07
Braidwood 2	05000457	5.6E-07	3.5E-07	1.5E-07	5.5E-08	5.6E-07	PGA	2.8E-07	2.4E-07	5.6E-07
Browns Ferry 1	05000259	1.0E-06	6.5E-07	2.8E-07	3.4E-07	1.0E-06	PGA	5.7E-07	5.1E-07	1.0E-06
Browns Ferry 2	05000260	1.6E-06	1.1E-06	4.5E-07	5.9E-07	1.6E-06	PGA	9.2E-07	8.2E-07	1.6E-06
Browns Ferry 3	05000296	1.6E-06	1.1E-06	4.5E-07	5.9E-07	1.6E-06	PGA	9.2E-07	8.2E-07	1.6E-06
Brunswick 1	05000325	3.3E-06	3.6E-06	2.6E-06	2.7E-07	3.6E-06	10 Hz	2.5E-06	2.3E-06	3.8E-06
Brunswick 2	05000324	3.3E-06	3.6E-06	2.6E-06	2.7E-07	3.6E-06	10 Hz	2.5E-06	2.3E-06	3.8E-06
Byron 1	05000454	6.8E-07	4.4E-07	1.9E-07	5.5E-08	6.8E-07	PGA	3.4E-07	2.9E-07	6.8E-07
Byron 2	05000455	6.8E-07	4.4E-07	1.9E-07	5.5E-08	6.8E-07	PGA	3.4E-07	2.9E-07	6.8E-07
Callaway	05000483									
Calvert Cliffs 1	05000317	1.6E-06	5.8E-06	3.8E-06	5.7E-06	5.8E-06	10 Hz	4.2E-06	4.6E-06	7.0E-06
Calvert Cliffs 2	05000318	2.0E-06	7.4E-06	4.8E-06	6.7E-06	7.4E-06	10 Hz	5.2E-06	5.7E-06	8.6E-06
Catawba 1	05000413	3.1E-05	2.2E-05	1.0E-05	3.8E-06	3.1E-05	PGA	1.7E-05	1.5E-05	3.0E-05
Catawba 2	05000414	3.1E-05	2.2E-05	1.0E-05	3.8E-06	3.1E-05	PGA	1.7E-05	1.5E-05	3.0E-05
Clinton (0098)	05000461	1.9E-06	2.6E-06	1.5E-06	7.3E-07	2.6E-06	10 Hz	1.7E-06	1.7E-06	2.7E-06
Clinton(UHS)	05000461	1.9E-06	3.8E-06	2.8E-06	7.2E-06	7.2E-06	1 HZ	3.9E-06	4.2E-06	7.2E-06
Comanche Peak 1	05000445	1.2E-06	4.9E-07	1.8E-07	5.2E-08	1.2E-06	PGA	4.8E-07	3.7E-07	1.2E-06
Comanche Peak 2	05000446	1.2E-06	4.9E-07	1.8E-07	5.2E-08	1.2E-06	PGA	4.8E-07	3.7E-07	1.2E-06
Cooper	05000298									
Crystal River 3	05000302	2.9E-06	5.2E-06	1.3E-06	5.8E-08	5.2E-06	10 Hz	2.4E-06	2.3E-06	5.2E-06
D.C. Cook 1	05000315									

Table D-2. Seismic Core-Damage Frequencies Using 1989 EPRI Seismic Hazard Curves.

		EPRI 1989								
Plant Name	Docket Number	PGA	10 Hz	5 Hz	1 Hz	max	controlling curve	simple average	IPEEE weighted average	weakest link model
D.C. Cook 2	05000316									
Davis-Besse	05000346	1.6E-06	1.0E-06	4.6E-07	3.0E-07	1.6E-06	PGA	8.3E-07	7.3E-07	1.6E-06
Dresden 2	05000237	2.3E-06	1.5E-06	5.5E-07	1.7E-07	2.3E-06	PGA	1.1E-06	9.5E-07	2.3E-06
Dresden 3	05000249	2.3E-06	1.5E-06	5.5E-07	1.7E-07	2.3E-06	PGA	1.1E-06	9.5E-07	2.3E-06
Duane Arnold	05000331									
Farley 1 (1st spectral ratios)	05000348	3.8E-06	2.7E-06	1.2E-06	5.1E-07	3.8E-06	PGA	2.0E-06	1.8E-06	3.8E-06
Farley 1 (2nd spectral ratios)	05000348	3.8E-06	2.8E-06	1.2E-06	2.3E-07	3.8E-06	PGA	2.0E-06	1.7E-06	3.8E-06
Farley 2 (1st spectral ratios)	05000364	3.8E-06	2.7E-06	1.2E-06	5.1E-07	3.8E-06	PGA	2.0E-06	1.8E-06	3.8E-06
Farley 2 (2nd spectral ratios)	05000364	3.8E-06	2.8E-06	1.2E-06	2.3E-07	3.8E-06	PGA	2.0E-06	1.7E-06	3.8E-06
Fermi 2	05000341	1.6E-06	1.1E-06	5.5E-07	2.3E-07	1.6E-06	PGA	8.8E-07	7.7E-07	1.6E-06
FitzPatrick	05000333	1.2E-06	7.5E-07	2.8E-07	2.1E-07	1.2E-06	PGA	6.0E-07	5.2E-07	1.2E-06
Fort Calhoun	05000285									
Ginna	05000244	4.2E-06	1.9E-06	8.9E-07	3.3E-07	4.2E-06	PGA	1.8E-06	1.5E-06	4.2E-06
Grand Gulf 1	05000416	9.3E-07	5.1E-07	1.4E-07	8.5E-06	8.5E-06	1 HZ	2.5E-06	2.8E-06	9.4E-06
Harris 1	05000400	3.6E-06	2.5E-06	1.4E-06	4.8E-07	3.6E-06	PGA	2.0E-06	1.8E-06	3.6E-06
Hatch 1	05000321	6.1E-07	6.3E-07	5.0E-07	5.8E-07	6.3E-07	10 Hz	5.8E-07	5.8E-07	7.4E-07
Hatch 2	05000366	6.1E-07	6.3E-07	5.0E-07	5.8E-07	6.3E-07	10 Hz	5.8E-07	5.8E-07	7.4E-07
Hope Creek 1	05000354	1.0E-06	8.8E-07	6.1E-07	6.3E-07	1.0E-06	PGA	7.8E-07	7.5E-07	1.1E-06
Indian Point 2	05000247	1.1E-05	1.1E-05	1.4E-05	8.3E-06	1.4E-05	5 HZ	1.1E-05	1.1E-05	1.4E-05
Indian Point 3	05000286	5.3E-05	5.8E-05	3.2E-05	7.8E-06	5.8E-05	10 Hz	3.8E-05	3.6E-05	5.8E-05
Kewaunee	05000305	1.0E-05	1.4E-05	1.9E-06	7.7E-07	1.4E-05	10 Hz	6.7E-06	6.2E-06	1.4E-05
La Salle 1 (0098)	05000373	4.1E-07	5.1E-07	3.3E-07	1.5E-08	5.1E-07	10 Hz	3.1E-07	3.0E-07	5.4E-07
La Salle 1 (SSE)	05000373	4.1E-07	5.1E-07	1.5E-07	1.5E-08	5.1E-07	10 Hz	2.7E-07	2.5E-07	5.2E-07
La Salle 1 (UHS)	05000373	4.1E-07	7.8E-07	5.4E-07	3.9E-08	7.8E-07	10 Hz	4.4E-07	4.5E-07	8.0E-07
La Salle 2 (0098)	05000374	4.1E-07	5.1E-07	3.3E-07	1.5E-08	5.1E-07	10 Hz	3.1E-07	3.0E-07	5.4E-07
La Salle 2 (SSE)	05000374	4.1E-07	5.1E-07	1.5E-07	1.5E-08	5.1E-07	10 Hz	2.7E-07	2.5E-07	5.2E-07

Table D-2. Seismic Core-Damage Frequencies Using 1989 EPRI Seismic Hazard Curves.

		EPRI 1989								
Plant Name	Docket Number	PGA	10 Hz	5 Hz	1 Hz	max	controlling curve	simple average	IPEEE weighted average	weakest link model
La Salle 2 (UHS)	05000374	4.1E-07	7.8E-07	5.4E-07	3.9E-08	7.8E-07	10 Hz	4.4E-07	4.5E-07	8.0E-07
Limerick 1	05000352	2.2E-05	6.6E-06	5.2E-06	1.4E-06	2.2E-05	PGA	8.8E-06	6.9E-06	2.2E-05
Limerick 2	05000353	2.2E-05	6.6E-06	5.2E-06	1.4E-06	2.2E-05	PGA	8.8E-06	6.9E-06	2.2E-05
McGuire 1	05000369	2.8E-05	2.1E-05	8.0E-06	2.3E-06	2.8E-05	PGA	1.5E-05	1.3E-05	2.8E-05
McGuire 2	05000370	2.8E-05	2.1E-05	8.0E-06	2.3E-06	2.8E-05	PGA	1.5E-05	1.3E-05	2.8E-05
Millstone 2	05000336	6.4E-06	4.4E-06	2.2E-06	7.8E-07	6.4E-06	PGA	3.4E-06	3.0E-06	6.4E-06
Millstone 3	05000423	1.0E-05	4.0E-06	2.9E-06	5.8E-07	1.0E-05	PGA	4.4E-06	3.6E-06	1.0E-05
Monticello	05000263	2.6E-05	1.5E-05	5.5E-06	2.6E-07	2.6E-05	PGA	1.2E-05	9.6E-06	2.6E-05
Nine Mile Point 1	05000220	5.8E-07	3.7E-07	1.4E-07	1.2E-07	5.8E-07	PGA	3.0E-07	2.6E-07	5.8E-07
Nine Mile Point 2	05000410	1.0E-06	6.5E-07	2.4E-07	1.9E-07	1.0E-06	PGA	5.2E-07	4.5E-07	1.0E-06
North Anna 1 (1st spectral ratios)	05000338	3.2E-05	2.3E-05	1.1E-05	3.8E-06	3.2E-05	PGA	1.8E-05	1.6E-05	3.2E-05
North Anna 1 (2nd spectral ratios)	05000338	3.2E-05	2.4E-05	1.1E-05	1.8E-06	3.2E-05	PGA	1.7E-05	1.5E-05	3.2E-05
North Anna 2 (1st spectral ratios)	05000339	3.2E-05	2.3E-05	1.1E-05	3.8E-06	3.2E-05	PGA	1.8E-05	1.6E-05	3.2E-05
North Anna 2 (2nd spectral ratios)	05000339	3.2E-05	2.4E-05	1.1E-05	1.8E-06	3.2E-05	PGA	1.7E-05	1.5E-05	3.2E-05
Oconee 1	05000269	6.7E-06	6.6E-06	8.5E-06	1.0E-05	1.0E-05	1 HZ	8.0E-06	8.1E-06	1.0E-05
Oconee 2	05000270	6.7E-06	6.6E-06	8.5E-06	1.0E-05	1.0E-05	1 HZ	8.0E-06	8.1E-06	1.0E-05
Oconee 3	05000287	6.7E-06	6.6E-06	8.5E-06	1.0E-05	1.0E-05	1 HZ	8.0E-06	8.1E-06	1.0E-05
Oyster Creek	05000219	4.1E-06	3.4E-06	7.2E-06	4.8E-06	7.2E-06	5 HZ	4.9E-06	5.0E-06	7.9E-06
Palisades	05000255									
Peach Bottom 2	05000277	8.3E-06	5.8E-06	2.8E-06	8.8E-07	8.3E-06	PGA	4.4E-06	3.9E-06	8.3E-06
Peach Bottom 3	05000278	8.3E-06	5.8E-06	2.8E-06	8.8E-07	8.3E-06	PGA	4.4E-06	3.9E-06	8.3E-06
Perry 1	05000440	8.5E-07	5.4E-07	2.3E-07	6.3E-08	8.5E-07	PGA	4.2E-07	3.6E-07	8.5E-07
Pilgrim 1	05000293	6.8E-06	8.0E-06	4.4E-06	3.4E-06	8.0E-06	10 Hz	5.6E-06	5.5E-06	8.0E-06
Point Beach 1	05000266	1.3E-05	1.2E-05	5.8E-06	3.0E-07	1.3E-05	PGA	7.6E-06	6.9E-06	1.3E-05
Point Beach 2	05000301	1.3E-05	1.2E-05	5.8E-06	3.0E-07	1.3E-05	PGA	7.6E-06	6.9E-06	1.3E-05
Prairie Island 1	05000282	1.3E-06	1.1E-06	4.5E-07	7.0E-09	1.3E-06	PGA	7.3E-07	6.5E-07	1.4E-06

Table D-2. Seismic Core-Damage Frequencies Using 1989 EPRI Seismic Hazard Curves.

		EPRI 1989								
Plant Name	Docket Number	PGA	10 Hz	5 Hz	1 Hz	max	controlling curve	simple average	IPEEE weighted average	weakest link model
Prairie Island 2	05000306	1.3E-06	1.1E-06	4.5E-07	7.0E-09	1.3E-06	PGA	7.3E-07	6.5E-07	1.4E-06
Quad Cities 1	05000254	1.4E-05	9.8E-06	3.6E-06	8.3E-07	1.4E-05	PGA	7.0E-06	6.0E-06	1.4E-05
Quad Cities 2	05000265	1.4E-05	9.8E-06	3.6E-06	8.3E-07	1.4E-05	PGA	7.0E-06	6.0E-06	1.4E-05
River Bend 1	05000458	2.5E-06	1.2E-06	7.2E-07	2.2E-06	2.5E-06	PGA	1.6E-06	1.5E-06	2.7E-06
Robinson 2	05000261	2.2E-06	2.4E-06	2.0E-06	1.7E-06	2.4E-06	10 Hz	2.1E-06	2.0E-06	2.7E-06
Saint Lucie 1 (s4)	05000335									
Saint Lucie 1 (s5)	05000335									
Saint Lucie 2 (s4)	05000389									
Saint Lucie 2 (s5)	05000389									
Salem 1	05000272	4.7E-06	4.6E-06	3.0E-06	4.0E-06	4.7E-06	PGA	4.1E-06	4.0E-06	5.8E-06
Salem 2	05000311	4.7E-06	4.6E-06	3.0E-06	4.0E-06	4.7E-06	PGA	4.1E-06	4.0E-06	5.8E-06
Seabrook 1	05000443	8.7E-06	3.5E-06	2.0E-06	4.5E-07	8.7E-06	PGA	3.7E-06	3.0E-06	8.7E-06
Sequoyah 1	05000327	9.8E-06	6.7E-06	3.4E-06	1.3E-06	9.8E-06	PGA	5.3E-06	4.6E-06	9.8E-06
Sequoyah 2	05000328	9.8E-06	6.7E-06	3.4E-06	1.3E-06	9.8E-06	PGA	5.3E-06	4.6E-06	9.8E-06
South Texas 1	05000498	7.7E-07	3.2E-07	1.9E-07	6.6E-08	7.7E-07	PGA	3.3E-07	2.7E-07	7.7E-07
South Texas 2	05000499	7.7E-07	3.2E-07	1.9E-07	6.6E-08	7.7E-07	PGA	3.3E-07	2.7E-07	7.7E-07
Summer	05000395	7.2E-06	5.2E-06	2.7E-06	1.4E-06	7.2E-06	PGA	4.1E-06	3.7E-06	7.2E-06
Surry 1	05000280	5.6E-06	5.1E-06	7.4E-06	3.8E-06	7.4E-06	5 HZ	5.5E-06	5.5E-06	8.1E-06
Surry 2	05000281	5.6E-06	5.1E-06	7.4E-06	3.8E-06	7.4E-06	5 HZ	5.5E-06	5.5E-06	8.1E-06
Susquehanna 1	05000387	2.4E-06	1.6E-06	7.6E-07	2.4E-07	2.4E-06	PGA	1.3E-06	1.1E-06	2.4E-06
Susquehanna 2	05000388	2.4E-06	1.6E-06	7.6E-07	2.4E-07	2.4E-06	PGA	1.3E-06	1.1E-06	2.4E-06
Three Mile Island 1	05000289	2.2E-05	5.7E-06	4.1E-06	1.3E-06	2.2E-05	PGA	8.2E-06	6.3E-06	2.2E-05
Turkey Point 3	05000250									
Turkey Point 4	05000251									
Vermont Yankee	05000271	2.3E-06	1.6E-06	7.3E-07	3.0E-07	2.3E-06	PGA	1.2E-06	1.1E-06	2.3E-06
Vogtle 1	05000424	2.1E-06	2.2E-06	1.9E-06	1.8E-06	2.2E-06	10 Hz	2.0E-06	1.9E-06	2.6E-06

Table D-2. Seismic Core-Damage Frequencies Using 1989 EPRI Seismic Hazard Curves.

Plant Name	Docket Number	EPRI 1989								
		PGA	10 Hz	5 Hz	1 Hz	max	controlling curve	simple average	IPEEE weighted average	weakest link model
Vogtle 2	05000425	2.1E-06	2.2E-06	1.9E-06	1.8E-06	2.2E-06	10 Hz	2.0E-06	1.9E-06	2.6E-06
Waterford 3	05000382	1.2E-06	9.8E-07	2.5E-07	5.2E-07	1.2E-06	PGA	7.3E-07	6.7E-07	1.2E-06
Watts Bar 1 (rock)	05000390	5.6E-06	3.9E-06	2.0E-06	8.0E-07	5.6E-06	PGA	3.1E-06	2.7E-06	5.6E-06
Watts Bar 1 (soil)	05000390	5.6E-06	4.0E-06	2.0E-06	3.6E-07	5.6E-06	PGA	3.0E-06	2.6E-06	5.6E-06
Wolf Creek 1	05000482	1.8E-06	1.3E-06	4.1E-07	2.5E-06	2.5E-06	1 HZ	1.5E-06	1.4E-06	2.5E-06

Table D-3. Seismic Core-Damage Frequencies Using 1994 LLNL Seismic Hazard Curves.

		LLNL 1994								
Plant Name	Docket Number	PGA	10 Hz	5 Hz	1 Hz	max	controlling curve	simple average	IPEEE weighted average	weakest link model
Arkansas Nuclear 1	05000313	7.8E-06	5.1E-06	5.4E-06	2.5E-06	7.8E-06	PGA	5.2E-06	4.8E-06	7.8E-06
Arkansas Nuclear 2	05000368	7.8E-06	5.1E-06	5.4E-06	2.5E-06	7.8E-06	PGA	5.2E-06	4.8E-06	7.8E-06
Beaver Valley 1	05000334	4.1E-05	4.5E-05	5.6E-05	4.6E-06	5.6E-05	5 HZ	3.6E-05	3.6E-05	5.6E-05
Beaver Valley 2	05000412	2.1E-05	2.2E-05	3.0E-05	2.3E-06	3.0E-05	5 HZ	1.9E-05	1.9E-05	3.0E-05
Braidwood 1	05000456	2.3E-06	1.6E-06	1.5E-06	6.5E-07	2.3E-06	PGA	1.5E-06	1.4E-06	2.3E-06
Braidwood 2	05000457	2.3E-06	1.6E-06	1.5E-06	6.5E-07	2.3E-06	PGA	1.5E-06	1.4E-06	2.3E-06
Browns Ferry 1	05000259	4.0E-06	3.0E-06	2.9E-06	1.4E-06	4.0E-06	PGA	2.8E-06	2.7E-06	4.0E-06
Browns Ferry 2	05000260	6.0E-06	4.6E-06	4.3E-06	2.1E-06	6.0E-06	PGA	4.2E-06	4.0E-06	6.0E-06
Browns Ferry 3	05000296	6.0E-06	4.6E-06	4.3E-06	2.1E-06	6.0E-06	PGA	4.2E-06	4.0E-06	6.0E-06
Brunswick 1	05000325	1.4E-05	1.7E-05	1.1E-05	1.0E-06	1.7E-05	10 Hz	1.1E-05	1.0E-05	1.7E-05
Brunswick 2	05000324	1.4E-05	1.7E-05	1.1E-05	1.0E-06	1.7E-05	10 Hz	1.1E-05	1.0E-05	1.7E-05
Byron 1	05000454	3.1E-06	2.3E-06	2.4E-06	1.0E-06	3.1E-06	PGA	2.2E-06	2.1E-06	3.1E-06
Byron 2	05000455	3.1E-06	2.3E-06	2.4E-06	1.0E-06	3.1E-06	PGA	2.2E-06	2.1E-06	3.1E-06
Callaway	05000483	2.3E-06	1.7E-06	1.8E-06	3.6E-07	2.3E-06	PGA	1.5E-06	1.4E-06	2.3E-06
Calvert Cliffs 1	05000317	1.3E-05	1.2E-05	1.3E-05	1.7E-05	1.7E-05	1 HZ	1.4E-05	1.4E-05	1.7E-05
Calvert Cliffs 2	05000318	1.5E-05	1.4E-05	1.5E-05	1.9E-05	1.9E-05	1 HZ	1.6E-05	1.6E-05	1.9E-05
Catawba 1	05000413	4.3E-05	3.1E-05	2.6E-05	1.0E-05	4.3E-05	PGA	2.8E-05	2.5E-05	4.3E-05
Catawba 2	05000414	4.3E-05	3.1E-05	2.6E-05	1.0E-05	4.3E-05	PGA	2.8E-05	2.5E-05	4.3E-05
Clinton (0098)	05000461	1.3E-05	7.6E-06	1.7E-05	3.6E-06	1.7E-05	5 HZ	1.0E-05	9.9E-06	1.7E-05
Clinton(UHS)	05000461	1.3E-05	9.8E-06	2.4E-05	2.2E-05	2.4E-05	5 HZ	1.7E-05	1.8E-05	2.4E-05
Comanche Peak 1	05000445	6.0E-06	2.6E-06	2.2E-06	6.9E-07	6.0E-06	PGA	2.9E-06	2.4E-06	6.0E-06
Comanche Peak 2	05000446	6.0E-06	2.6E-06	2.2E-06	6.9E-07	6.0E-06	PGA	2.9E-06	2.4E-06	6.0E-06
Cooper	05000298	2.2E-05	1.6E-05	1.4E-05	9.8E-07	2.2E-05	PGA	1.3E-05	1.2E-05	2.2E-05
Crystal River 3	05000302	1.4E-05	2.1E-05	1.5E-05	1.5E-06	2.1E-05	10 Hz	1.3E-05	1.3E-05	2.1E-05
D.C. Cook 1	05000315	1.2E-05	1.1E-05	1.2E-05	4.6E-06	1.2E-05	5 HZ	1.0E-05	9.8E-06	1.2E-05

Table D-3. Seismic Core-Damage Frequencies Using 1994 LLNL Seismic Hazard Curves.

		LLNL 1994								
Plant Name	Docket Number	PGA	10 Hz	5 Hz	1 Hz	max	controlling curve	simple average	IPEEE weighted average	weakest link model
D.C. Cook 2	05000316	1.2E-05	1.1E-05	1.2E-05	4.6E-06	1.2E-05	5 HZ	1.0E-05	9.8E-06	1.2E-05
Davis-Besse	05000346	7.4E-06	5.0E-06	5.5E-06	2.1E-06	7.4E-06	PGA	5.0E-06	4.7E-06	7.4E-06
Dresden 2	05000237	8.4E-06	5.8E-06	5.2E-06	1.9E-06	8.4E-06	PGA	5.3E-06	4.9E-06	8.4E-06
Dresden 3	05000249	8.4E-06	5.8E-06	5.2E-06	1.9E-06	8.4E-06	PGA	5.3E-06	4.9E-06	8.4E-06
Duane Arnold	05000331	7.7E-06	5.7E-06	3.0E-06	1.6E-06	7.7E-06	PGA	4.5E-06	4.1E-06	7.7E-06
Farley 1 (1st spectral ratios)	05000348	1.7E-05	1.3E-05	1.1E-05	4.3E-06	1.7E-05	PGA	1.1E-05	1.0E-05	1.7E-05
Farley 1 (2nd spectral ratios)	05000348	1.7E-05	1.4E-05	1.1E-05	2.3E-06	1.7E-05	PGA	1.1E-05	1.0E-05	1.7E-05
Farley 2 (1st spectral ratios)	05000364	1.7E-05	1.3E-05	1.1E-05	4.3E-06	1.7E-05	PGA	1.1E-05	1.0E-05	1.7E-05
Farley 2 (2nd spectral ratios)	05000364	1.7E-05	1.4E-05	1.1E-05	2.3E-06	1.7E-05	PGA	1.1E-05	1.0E-05	1.7E-05
Fermi 2	05000341	2.4E-06	2.1E-06	2.1E-06	8.7E-07	2.4E-06	PGA	1.9E-06	1.8E-06	2.4E-06
FitzPatrick	05000333	6.0E-06	2.1E-05	4.8E-06	1.8E-06	2.1E-05	10 Hz	8.5E-06	8.8E-06	1.5E-05
Fort Calhoun	05000285	2.7E-05	3.5E-05	1.9E-05	3.1E-06	3.5E-05	10 Hz	2.1E-05	2.0E-05	3.5E-05
Ginna	05000244	1.5E-05	7.7E-06	7.5E-06	1.7E-06	1.5E-05	PGA	8.1E-06	7.1E-06	1.5E-05
Grand Gulf 1	05000416	1.2E-05	8.6E-06	1.4E-05	1.2E-05	1.4E-05	5 HZ	1.2E-05	1.2E-05	1.4E-05
Harris 1	05000400	3.0E-06	1.9E-06	1.9E-06	7.8E-07	3.0E-06	PGA	1.9E-06	1.7E-06	3.0E-06
Hatch 1	05000321	5.0E-06	2.2E-06	2.0E-05	3.8E-06	2.0E-05	5 HZ	7.7E-06	8.1E-06	1.7E-05
Hatch 2	05000366	5.0E-06	2.2E-06	2.0E-05	3.8E-06	2.0E-05	5 HZ	7.7E-06	8.1E-06	1.7E-05
Hope Creek 1	05000354	3.6E-06	1.3E-06	1.7E-06	2.3E-06	3.6E-06	PGA	2.2E-06	2.0E-06	3.6E-06
Indian Point 2	05000247	1.1E-05	1.1E-05	2.7E-05	1.8E-05	2.7E-05	5 HZ	1.7E-05	1.8E-05	2.6E-05
Indian Point 3	05000286	5.2E-05	5.5E-05	5.7E-05	1.7E-05	5.7E-05	5 HZ	4.5E-05	4.4E-05	5.8E-05
Kewaunee	05000305	1.2E-05	1.1E-05	1.4E-05	6.5E-06	1.4E-05	5 HZ	1.1E-05	1.1E-05	1.4E-05
La Salle 1 (0098)	05000373	2.8E-06	2.3E-06	2.9E-06	4.2E-07	2.9E-06	5 HZ	2.1E-06	2.0E-06	2.9E-06
La Salle 1 (SSE)	05000373	2.8E-06	2.3E-06	1.8E-06	4.3E-07	2.8E-06	PGA	1.8E-06	1.7E-06	2.7E-06
La Salle 1 (UHS)	05000373	2.8E-06	3.0E-06	4.1E-06	8.8E-07	4.1E-06	5 HZ	2.7E-06	2.7E-06	4.0E-06
La Salle 2 (0098)	05000374	2.8E-06	2.3E-06	2.9E-06	4.2E-07	2.9E-06	5 HZ	2.1E-06	2.0E-06	2.9E-06
La Salle 2 (SSE)	05000374	2.8E-06	2.3E-06	1.8E-06	4.3E-07	2.8E-06	PGA	1.8E-06	1.7E-06	2.7E-06

Table D-3. Seismic Core-Damage Frequencies Using 1994 LLNL Seismic Hazard Curves.

Plant Name	Docket Number	LLNL 1994								
		PGA	10 Hz	5 Hz	1 Hz	max	controlling curve	simple average	IPEEE weighted average	weakest link model
La Salle 2 (UHS)	05000374	2.8E-06	3.0E-06	4.1E-06	8.8E-07	4.1E-06	5 HZ	2.7E-06	2.7E-06	4.0E-06
Limerick 1	05000352	4.8E-05	1.4E-05	1.8E-05	6.3E-06	4.8E-05	PGA	2.1E-05	1.8E-05	4.8E-05
Limerick 2	05000353	4.8E-05	1.4E-05	1.8E-05	6.3E-06	4.8E-05	PGA	2.1E-05	1.8E-05	4.8E-05
McGuire 1	05000369	4.7E-05	3.4E-05	2.3E-05	6.8E-06	4.7E-05	PGA	2.8E-05	2.5E-05	4.7E-05
McGuire 2	05000370	4.7E-05	3.4E-05	2.3E-05	6.8E-06	4.7E-05	PGA	2.8E-05	2.5E-05	4.7E-05
Millstone 2	05000336	1.1E-05	9.4E-06	8.8E-06	3.6E-06	1.1E-05	PGA	8.2E-06	7.8E-06	1.1E-05
Millstone 3	05000423	1.7E-05	8.6E-06	1.1E-05	2.8E-06	1.7E-05	PGA	9.8E-06	8.8E-06	1.7E-05
Monticello	05000263	3.2E-05	2.1E-05	1.4E-05	4.5E-06	3.2E-05	PGA	1.8E-05	1.6E-05	3.1E-05
Nine Mile Point 1	05000220	3.5E-06	2.6E-06	2.8E-06	1.1E-06	3.5E-06	PGA	2.5E-06	2.3E-06	3.5E-06
Nine Mile Point 2	05000410	5.4E-06	4.1E-06	4.3E-06	1.6E-06	5.4E-06	PGA	3.9E-06	3.6E-06	5.4E-06
North Anna 1 (1st spectral ratios)	05000338	3.6E-05	2.0E-05	1.7E-05	6.4E-06	3.6E-05	PGA	2.0E-05	1.8E-05	3.6E-05
North Anna 1 (2nd spectral ratios)	05000338	3.6E-05	2.1E-05	1.7E-05	3.1E-06	3.6E-05	PGA	1.9E-05	1.7E-05	3.6E-05
North Anna 2 (1st spectral ratios)	05000339	3.6E-05	2.0E-05	1.7E-05	6.4E-06	3.6E-05	PGA	2.0E-05	1.8E-05	3.6E-05
North Anna 2 (2nd spectral ratios)	05000339	3.6E-05	2.1E-05	1.7E-05	3.1E-06	3.6E-05	PGA	1.9E-05	1.7E-05	3.6E-05
Oconee 1	05000269	1.0E-05	8.9E-06	1.9E-05	2.1E-05	2.1E-05	1 HZ	1.5E-05	1.6E-05	2.1E-05
Oconee 2	05000270	1.0E-05	8.9E-06	1.9E-05	2.1E-05	2.1E-05	1 HZ	1.5E-05	1.6E-05	2.1E-05
Oconee 3	05000287	1.0E-05	8.9E-06	1.9E-05	2.1E-05	2.1E-05	1 HZ	1.5E-05	1.6E-05	2.1E-05
Oyster Creek	05000219	1.5E-05	6.2E-06	1.8E-05	1.4E-05	1.8E-05	5 HZ	1.4E-05	1.3E-05	1.8E-05
Palisades	05000255	1.0E-05	8.0E-06	1.0E-05	2.9E-06	1.0E-05	5 HZ	7.8E-06	7.5E-06	1.0E-05
Peach Bottom 2	05000277	2.1E-05	1.5E-05	1.4E-05	5.6E-06	2.1E-05	PGA	1.4E-05	1.3E-05	2.1E-05
Peach Bottom 3	05000278	2.1E-05	1.5E-05	1.4E-05	5.6E-06	2.1E-05	PGA	1.4E-05	1.3E-05	2.1E-05
Perry 1	05000440	2.7E-06	1.9E-06	2.0E-06	8.3E-07	2.7E-06	PGA	1.8E-06	1.7E-06	2.7E-06
Pilgrim 1	05000293	1.1E-04	1.1E-04	1.1E-04	3.7E-05	1.1E-04	PGA	9.2E-05	8.9E-05	1.1E-04
Point Beach 1	05000266	1.3E-05	1.2E-05	1.5E-05	2.6E-06	1.5E-05	5 HZ	1.1E-05	1.0E-05	1.5E-05
Point Beach 2	05000301	1.3E-05	1.2E-05	1.5E-05	2.6E-06	1.5E-05	5 HZ	1.1E-05	1.0E-05	1.5E-05
Prairie Island 1	05000282	6.1E-06	4.2E-06	4.9E-06	3.5E-07	6.1E-06	PGA	3.9E-06	3.6E-06	6.0E-06

Table D-3. Seismic Core-Damage Frequencies Using 1994 LLNL Seismic Hazard Curves.

		LLNL 1994								
Plant Name	Docket Number	PGA	10 Hz	5 Hz	1 Hz	max	controlling curve	simple average	IPEEE weighted average	weakest link model
Prairie Island 2	05000306	6.1E-06	4.2E-06	4.9E-06	3.5E-07	6.1E-06	PGA	3.9E-06	3.6E-06	6.0E-06
Quad Cities 1	05000254	3.3E-05	2.8E-05	2.5E-05	8.9E-06	3.3E-05	PGA	2.4E-05	2.3E-05	3.3E-05
Quad Cities 2	05000265	3.3E-05	2.8E-05	2.5E-05	8.9E-06	3.3E-05	PGA	2.4E-05	2.3E-05	3.3E-05
River Bend 1	05000458	1.7E-05	8.6E-06	1.2E-05	6.6E-06	1.7E-05	PGA	1.1E-05	1.0E-05	1.7E-05
Robinson 2	05000261	3.8E-05	2.0E-05	5.8E-05	3.1E-05	5.8E-05	5 HZ	3.7E-05	3.7E-05	5.7E-05
Saint Lucie 1 (s4)	05000335	1.6E-05	1.8E-05	2.4E-05	1.3E-05	2.4E-05	5 HZ	1.8E-05	1.8E-05	2.4E-05
Saint Lucie 1 (s5)	05000335	1.6E-05	1.8E-05	2.4E-05	1.3E-05	2.4E-05	5 HZ	1.8E-05	1.8E-05	2.4E-05
Saint Lucie 2 (s4)	05000389	1.6E-05	1.8E-05	2.4E-05	1.3E-05	2.4E-05	5 HZ	1.8E-05	1.8E-05	2.4E-05
Saint Lucie 2 (s5)	05000389	1.6E-05	1.8E-05	2.4E-05	1.3E-05	2.4E-05	5 HZ	1.8E-05	1.8E-05	2.4E-05
Salem 1	05000272	9.5E-06	4.2E-06	4.8E-06	9.7E-06	9.7E-06	1 HZ	7.0E-06	6.7E-06	1.1E-05
Salem 2	05000311	9.5E-06	4.2E-06	4.8E-06	9.7E-06	9.7E-06	1 HZ	7.0E-06	6.7E-06	1.1E-05
Seabrook 1	05000443	1.6E-05	4.8E-06	4.8E-06	1.2E-06	1.6E-05	PGA	6.8E-06	5.4E-06	1.6E-05
Sequoyah 1	05000327	1.2E-05	7.2E-06	6.3E-06	2.5E-06	1.2E-05	PGA	6.9E-06	6.2E-06	1.2E-05
Sequoyah 2	05000328	1.2E-05	7.2E-06	6.3E-06	2.5E-06	1.2E-05	PGA	6.9E-06	6.2E-06	1.2E-05
South Texas 1	05000498	1.0E-05	3.0E-06	4.6E-06	3.4E-06	1.0E-05	PGA	5.4E-06	4.6E-06	1.0E-05
South Texas 2	05000499	1.0E-05	3.0E-06	4.6E-06	3.4E-06	1.0E-05	PGA	5.4E-06	4.6E-06	1.0E-05
Summer	05000395	2.3E-05	2.1E-05	2.3E-05	1.0E-05	2.3E-05	5 HZ	1.9E-05	1.9E-05	2.3E-05
Surry 1	05000280	1.1E-05	5.9E-06	9.0E-06	7.2E-06	1.1E-05	PGA	8.3E-06	7.9E-06	1.1E-05
Surry 2	05000281	1.1E-05	5.9E-06	9.0E-06	7.2E-06	1.1E-05	PGA	8.3E-06	7.9E-06	1.1E-05
Susquehanna 1	05000387	1.4E-05	8.7E-06	8.1E-06	3.3E-06	1.4E-05	PGA	8.4E-06	7.7E-06	1.4E-05
Susquehanna 2	05000388	1.4E-05	8.7E-06	8.1E-06	3.3E-06	1.4E-05	PGA	8.4E-06	7.7E-06	1.4E-05
Three Mile Island 1	05000289	6.7E-05	2.0E-05	2.8E-05	1.1E-05	6.7E-05	PGA	3.1E-05	2.6E-05	6.7E-05
Turkey Point 3	05000250	5.1E-06	7.3E-06	5.1E-06	1.5E-06	7.3E-06	10 Hz	4.8E-06	4.7E-06	7.3E-06
Turkey Point 4	05000251	5.1E-06	7.3E-06	5.1E-06	1.5E-06	7.3E-06	10 Hz	4.8E-06	4.7E-06	7.3E-06
Vermont Yankee	05000271	1.2E-05	8.7E-06	8.3E-06	3.3E-06	1.2E-05	PGA	8.0E-06	7.5E-06	1.2E-05
Vogtle 1	05000424	2.0E-05	9.2E-06	1.9E-05	1.1E-05	2.0E-05	PGA	1.5E-05	1.4E-05	2.0E-05

Table D-3. Seismic Core-Damage Frequencies Using 1994 LLNL Seismic Hazard Curves.

		LLNL 1994								
Plant Name	Docket Number	PGA	10 Hz	5 Hz	1 Hz	max	controlling curve	simple average	IPEEE weighted average	weakest link model
Vogtle 2	05000425	2.0E-05	9.2E-06	1.9E-05	1.1E-05	2.0E-05	PGA	1.5E-05	1.4E-05	2.0E-05
Waterford 3	05000382	2.9E-05	1.8E-05	1.7E-05	1.3E-05	2.9E-05	PGA	1.9E-05	1.8E-05	2.9E-05
Watts Bar 1 (rock)	05000390	8.3E-06	5.4E-06	4.9E-06	1.9E-06	8.3E-06	PGA	5.1E-06	4.7E-06	8.3E-06
Watts Bar 1 (soil)	05000390	8.3E-06	5.6E-06	4.9E-06	8.7E-07	8.3E-06	PGA	4.9E-06	4.4E-06	8.3E-06
Wolf Creek 1	05000482	4.3E-06	2.6E-06	2.0E-06	8.9E-06	8.9E-06	1 HZ	4.4E-06	4.5E-06	8.9E-06

Table D-4. IPEEE SPRA Results and SPAR Model Results.

Plant Name	Docket Number	IPEEE SPRA Results			Internal Events CDF SPAR
		EPRI	LLNL	Plant Specific Hazard	
Arkansas Nuclear 1	05000313				9.9E-06
Arkansas Nuclear 2	05000368				3.3E-06
Beaver Valley 1	05000334	1.3E-05			8.4E-05
Beaver Valley 2	05000412	1.0E-05			3.5E-05
Braidwood 1	05000456				3.6E-05
Braidwood 2	05000457				3.6E-05
Browns Ferry 1	05000259				1.1E-06
Browns Ferry 2	05000260				1.0E-06
Browns Ferry 3	05000296				3.2E-06
Brunswick 1	05000325				1.6E-05
Brunswick 2	05000324				9.7E-06
Byron 1	05000454				3.5E-05
Byron 2	05000455				3.5E-05
Callaway	05000483				5.0E-05
Calvert Cliffs 1	05000317		1.3E-05		2.3E-05
Calvert Cliffs 2	05000318		1.5E-05		2.1E-05
Catawba 1	05000413	1.6E-05			3.5E-05
Catawba 2	05000414	1.6E-05			3.5E-05
Clinton (0098)	05000461				7.8E-06
Clinton(UHS)	05000461				7.8E-06
Comanche Peak 1	05000445				1.8E-05
Comanche Peak 2	05000446				1.8E-05
Cooper	05000298				7.8E-06
Crystal River 3	05000302				1.1E-05
D.C. Cook 1	05000315			3.2E-06	6.3E-05
D.C. Cook 2	05000316			3.2E-06	6.3E-05
Davis-Besse	05000346				5.6E-06
Dresden 2	05000237				7.1E-07
Dresden 3	05000249				7.1E-07
Duane Arnold	05000331				5.3E-06
Farley 1 (1st spectral ratios)	05000348				1.9E-04
Farley 1 (2nd spectral ratios)	05000348				1.9E-04
Farley 2 (1st spectral ratios)	05000364				1.9E-04
Farley 2 (2nd spectral ratios)	05000364				1.9E-04
Fermi 2	05000341				1.7E-05
FitzPatrick	05000333				4.3E-06
Fort Calhoun	05000285				1.3E-05
Ginna	05000244				1.3E-05

Table D-4. IPEEE SPRA Results and SPAR Model Results.

Plant Name	Docket Number	IPEEE SPRA Results EPRI	IPEEE SPRA Results LLNL	IPEEE SPRA Results Plant Specific Hazard	Internal Events CDF SPAR
Grand Gulf 1	05000416				3.8E-06
Harris 1	05000400				2.9E-05
Hatch 1	05000321				9.1E-06
Hatch 2	05000366				9.1E-06
Hope Creek 1	05000354	1.0E-06	3.6E-06		8.2E-06
Indian Point 2	05000247		1.1E-05		9.6E-06
Indian Point 3	05000286	5.9E-05	4.9E-05		1.0E-05
Kewaunee	05000305	1.1E-05	1.3E-05		1.2E-05
La Salle 1 (0098)	05000373			6.0E-07	6.1E-06
La Salle 1 (SSE)	05000373			6.0E-07	6.1E-06
La Salle 1 (UHS)	05000373			6.0E-07	6.1E-06
La Salle 2 (0098)	05000374			6.0E-07	6.1E-06
La Salle 2 (SSE)	05000374			6.0E-07	6.1E-06
La Salle 2 (UHS)	05000374			6.0E-07	6.1E-06
Limerick 1	05000352				2.6E-06
Limerick 2	05000353				2.6E-06
McGuire 1	05000369	1.1E-05			2.7E-05
McGuire 2	05000370	1.1E-05			2.7E-05
Millstone 2	05000336				4.9E-06
Millstone 3	05000423			9.1E-06	5.3E-06
Monticello	05000263				2.0E-06
Nine Mile Point 1	05000220				3.3E-06
Nine Mile Point 2	05000410				1.4E-05
North Anna 1 (1st spectral ratios)	05000338				2.9E-05
North Anna 1 (2nd spectral ratios)	05000338				2.9E-05
North Anna 2 (1st spectral ratios)	05000339				2.9E-05
North Anna 2 (2nd spectral ratios)	05000339				2.9E-05
Oconee 1	05000269	3.5E-05			9.6E-06
Oconee 2	05000270	3.5E-05			9.6E-06
Oconee 3	05000287	3.5E-05			9.6E-06
Oyster Creek	05000219	4.7E-06			1.9E-05
Palisades	05000255		8.9E-06		3.2E-05
Peach Bottom 2	05000277				2.9E-06
Peach Bottom 3	05000278				1.8E-06
Perry 1	05000440				3.3E-06
Pilgrim 1	05000293	5.8E-05	9.4E-05		1.4E-05
Point Beach 1	05000266	1.4E-05	1.3E-05		2.7E-04
Point Beach 2	05000301	1.4E-05	1.3E-05		2.7E-04
Prairie Island 1	05000282				7.2E-06

Table D-4. IPEEE SPRA Results and SPAR Model Results.

Plant Name	Docket Number	IPEEE SPRA Results			Internal Events CDF SPAR
		EPRI	LLNL	Plant Specific Hazard	
Prairie Island 2	05000306				7.2E-06
Quad Cities 1	05000254				5.0E-06
Quad Cities 2	05000265				5.0E-06
River Bend 1	05000458				4.9E-06
Robinson 2	05000261				1.8E-05
Saint Lucie 1 (s4)	05000335				4.4E-06
Saint Lucie 1 (s5)	05000335				4.4E-06
Saint Lucie 2 (s4)	05000389				3.5E-06
Saint Lucie 2 (s5)	05000389				3.5E-06
Salem 1	05000272	4.7E-06	9.5E-06		3.5E-05
Salem 2	05000311	4.7E-06	9.5E-06		3.5E-05
Seabrook 1	05000443				1.8E-05
Sequoyah 1	05000327				4.6E-05
Sequoyah 2	05000328				4.6E-05
South Texas 1	05000498		1.7E-05		7.9E-06
South Texas 2	05000499		1.7E-05		7.9E-06
Summer	05000395				5.1E-05
Surry 1	05000280	8.2E-06			3.6E-06
Surry 2	05000281	8.2E-06			3.6E-06
Susquehanna 1	05000387				3.0E-06
Susquehanna 2	05000388				6.9E-07
Three Mile Island 1	05000289	3.2E-05	8.4E-05		1.6E-05
Turkey Point 3	05000250				2.1E-06
Turkey Point 4	05000251				2.1E-06
Vermont Yankee	05000271				5.9E-06
Vogtle 1	05000424				4.2E-05
Vogtle 2	05000425				4.2E-05
Waterford 3	05000382				1.1E-05
Watts Bar 1 (rock)	05000390				3.2E-05
Watts Bar 1 (soil)	05000390				3.2E-05
Wolf Creek 1	05000482				2.0E-05