ELECTRIC POWER
RESEARCH INSTITUTE

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Anthony R. Pietrangelo
Senior Vice President and Chief Nuclear Officer, Nuclear Generation
Nuclear Energy Institute
1201 F Street, NW, Suite 1100
Washington, DC 20004

Subject: **Fleet Seismic Core Damage Frequency Estimates for Central and Eastern U.S. Nuclear Power Plants Using New Site-Specific Seismic Hazard Estimates**

Dear Mr. Pietrangelo:

The Electric Power Research Institute (EPRI) has recently completed site-specific seismic hazard evaluations for nuclear plants in the central and eastern United States (CEUS) using the guidance in Electric Power Research Institute (EPRI) 1025287 (EPRI 2013a). To provide perspective regarding the safety implications of these new seismic hazard estimates, EPRI has performed an initial assessment of the changes in the seismic core-damage frequency relative to earlier fleet-wide estimates.

A description of the fleet evaluation is attached.

If you have questions or would like to discuss this evaluation, please contact John Richards at 704-595-2707 or jrichards@epri.com.

Sincerely,

Stuart Lewis
Program Manager
Risk and Safety Management

RSM-031114-077

Attachment

Fleet Seismic Core Damage Frequency Estimates for Central and Eastern U.S. Nuclear Power Plants Using New Site-Specific Seismic Hazard Estimates

Electric Power Research Institute Project Manager
J. Richards

This evaluation was prepared by Simpson Gumpertz & Heger Inc., under contract to the Electric Power Research Institute.

The principal authors are G. Hardy, T. Graf, F. Grant, and Y. Tang.

1 BACKGROUND

Following the accident at the Fukushima Daiichi Nuclear Power Plant resulting from the March 11, 2011, Great Tohoku Earthquake and subsequent tsunami, the U.S. Nuclear Regulatory Commission (USNRC) established a Near Term Task Force (NTTF) to conduct a systematic review of USNRC processes and regulations, and to determine if the agency should make additional improvements to its regulatory system. The NTTF developed a set of recommendations intended to clarify and strengthen the regulatory framework for protection against natural phenomena such as earthquakes. Subsequently, the USNRC issued a 50.54(f) letter that requests information to ensure that all U.S. nuclear power plants address these recommendations. This letter requests that licensees and holders of construction permits under 10 CFR Part 50 reevaluate the seismic hazards at their sites against present-day USNRC requirements and guidance.

In response to the 50.54(f) letter, site-specific seismic hazard estimates have been developed for nuclear plants in the central and eastern United States (CEUS) using the guidance in Electric Power Research Institute (EPRI) 1025287 (EPRI, 2013a) and in a 2013 letter from the Nuclear Energy Institute (NEI, 2013). These hazards form the basis for determining whether further seismic evaluation may be needed on a plant-by-plant basis.

The USNRC has requested that interim actions (that is, actions that can be implemented before more extensive seismic evaluations could be completed) be taken for plants whose ground motion response spectrum (GMRS) exceeds the design basis (USNRC, 2012; USNRC, 2014). In response to this request, the U.S. nuclear industry proposed an Expedited Seismic Evaluation Process (ESEP) as an effective interim action. Guidance for conducting such an evaluation was developed by EPRI (EPRI, 2013b), and the process and guidance were endorsed by the USNRC (USNRC, 2013). The expedited evaluation is being carried out for any site with a GMRS that exceeds the safe shutdown earthquake (SSE) in the spectral frequency range from 1 to 10 Hz. As an input to the consideration of whether additional interim actions may be warranted, EPRI has estimated, for the fleet of nuclear power plants operating in the CEUS, the seismic core-damage frequencies (SCDFs) based on the newly completed site-specific seismic hazards.

2 OBJECTIVES

Because it does not explicitly account for the capability of a nuclear power plant to maintain a safe condition during an earthquake, the GMRS calculated from the new seismic hazard characterization provides an incomplete perspective regarding overall seismic safety. The objective of this study is to provide an initial assessment of the safety implications of the new seismic hazard estimates across the CEUS fleet of operating plants. This assessment involves comparing SCDF estimates reflecting the new seismic hazard estimates for the fleet of operating plants to SCDF estimates previously developed by the USNRC in its 2010 Safety / Risk Assessment for GI-199 (USNRC, 2010). To perform this assessment, point estimates of the SCDF have been developed using (1) the methods defined by the USNRC in the 2010 Safety / Risk Assessment for GI-199, (2) the plant-level fragilities determined by the USNRC in the GI-199 Assessment, and (3) new site-specific seismic hazard estimates. The resulting SCDF estimates are compared with the baseline SCDFs developed by the USNRC in 2010 using the 2008 U.S. Geological Survey (USGS) and 1994 Lawrence Livermore National Laboratory (LLNL) seismic hazard curves. These are, respectively, the most recent seismic hazard assessment available at the time of the 2010 study, and the hazard assessment used by the USNRC in its review of seismic evaluations submitted as part of the Individual Plant Examination of External Events (IPEEE) in the 1990s.

3 ESTIMATING SEISMIC CORE DAMAGE FREQUENCY

As described in Section 1, new probabilistic seismic hazard analyses (PSHA) have been completed for all U.S. nuclear power plant sites located in the CEUS. The potential safety and risk implications of these new seismic hazard estimates can most comprehensively be assessed with a modern Seismic Probabilistic Risk Assessment (SPRA) in accordance with the PRA Standard (ASME, 2013), but these modern SPRAs are not yet available for most plants. In 2010, the USNRC used a simplified approach to estimate the SCDF for all of the CEUS plants as part of the GI-199 program. The GI-199 program was associated with the changing understanding of seismic hazards in much of the United States and the implications of that understanding for nuclear plant safety. The USNRC simplified seismic risk estimation approach involved estimating the plant seismic fragility (i.e., conditional probability of plant damage at a given seismic hazard input level) from the results of the earlier IPEEE submittals, and convolving that plant fragility estimate with the new seismic hazard to obtain an SCDF estimate. EPRI is conducting a similar assessment of SCDFs for the fleet of CEUS plants using the same IPEEE-derived plant-level fragilities combined with the new site-specific seismic hazard curves.

4 SITE-SPECIFIC SEISMIC HAZARDS

The first major step in responding to Enclosure 1 of the 50.54(f) letter (USNRC, 2012) is to calculate seismic hazards at existing plant sites following the USNRC endorsed guidance in the Screening, Prioritization and Implementation Details (SPID) (EPRI, 2013a). These seismic hazards incorporate PSHA methods using the recently developed CEUS Seismic Source Characterization (CEUS-SSC) for Nuclear Facilities (CEUS-SSC, 2012), together with an updated ground-motion model (GMM) for the CEUS (EPRI, 2013c), and site-specific site amplification calculations. CEUS plants will submit these site-specific seismic hazards by March 31, 2014, in accordance with NEI's letter dated 9 April 2013 (NEI, 2013). These newly developed seismic hazard characterizations were used for the subject fleet SCDF calculations.

5 PLANT-LEVEL FRAGILITIES

Plant-level fragility curves for each GI-199 plant were developed by the USNRC as part of the 2010 Safety / Risk Assessment based on information provided in the IPEEE submittals. Appendix C of the USNRC GI-199 report (USNRC, 2010) defines three methods for estimating a plant-level fragility from information reported in the IPEEE submittals. The methods are briefly summarized in Table C.1 of the USNRC report (2010), which is reproduced below as Table 1.

About one-third of the plants in the CEUS performed an SPRA as part of their IPEEE program. Many of the plants that performed SPRAs provided plant-level fragility information in their IPEEE submittals (Method 1a below), and the remaining plants that performed SPRAs 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 approximated in the USNRC GI-199 assessment by estimating and matching the reported SCDFs and using engineering judgment (Methods 1b and 1c below). In cases where reasonable engineering judgments could not be readily made, the USNRC performed sensitivity studies to estimate the potential plant level fragilities. This resulted in more than one potential plant level fragility for a number of specific plant sites / units.

Two-thirds of the plants conducted a seismic margins analysis (SMA) as part of their IPEEE program. For these plants, the USNRC estimated the plant-level fragility based on the reported plant-level high confidence of a low probability of failure (HCLPF) value and an estimate of the composite variability, β_c (Methods 2, 3a, and 3b below). The USNRC used a β_c of 0.4 to develop the plant-level fragilities for the SMA plants.

Table 1 –Summary of USNRC GI-199 Methods for Estimating Plant Damage State Fragilities

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 β_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 β_C = 0.4.
3a	SMA (HCLPF = RLE)	C_{50} found by using the stated HCLPF/RLE Assumed β_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 β_C = 0.4 Note: The SSE is a lower bound on the actual HCLPF; applies to reduced scope SMA plants.

* C_{50} is the median (50^{th} percentile) plant-level acceleration capacity and β_c is the composite variability

These plant-level fragility values developed by the USNRC (USNRC, 2010) were used directly for the SCDF calculations in this current EPRI fleet risk assessment, which allows for a direct comparison of the SCDF estimates using the newly developed seismic hazards and the USNRC's SCDF estimates in 2010 using the 2008 USGS and 1994 LLNL seismic hazards. For convenience, the plant-level fragilities from the GI-199 Safety / Risk Assessment are reproduced in Table 2 below. As noted above, some SPRA plants have more than one plant-level fragility estimate (sensitivity studies were conducted in the NRC GI-199 Safety / Risk Assessment for those plants where adequate information was not submitted as part of the IPEEE process).

The columns to the right side of Table 2 summarize the sixty-one CEUS sites for which new site-specific seismic hazards have been calculated. For purposes of the SCDF calculations in this study, the following decisions are made relative to calculating a single SCDF for each of these sixty-one sites:

- For sites with multiple units, the plant-level fragility that results in the highest SCDF estimate is conservatively selected (most sites with multiple units have the same plant-level fragilities defined due to similarity, but several sites had submitted different plant-level fragilities as part of their IPEEE efforts).
- For sites where the USNRC defined multiple plant-level fragilities (due to uncertainty in the correct spectral ratios from the IPEEE submittals), the plant-level fragility that results in the highest resulting SCDF value is conservatively selected.

These sixty-one plant level "bounding" fragilities are documented on the right half of Table 2.

Table 2 – Plant-Level Fragilities from USNRC Safety / Risk Assessment for GI-199 (USNRC, 2010)

GI-199 Safety Report - Appendix C "Plant" Data Point	Plant-Level Fragility from Appendix C of 2010 USNRC Safety/Risk Assessment					CEUS Site with New Hazard Estimates	Bounding Case * Plant Level Fragility from Appendix C of 2010 USNRC Safety/Risk Assessment				
	PGA Fragility **		Spectral Ratios				PGA Fragility **		Spectral Ratios		
	C_{50} (g)	β_C	10 Hz	5 Hz	1 Hz		C_{50} (g)	β_C	10 Hz	5 Hz	1 Hz
Arkansas Nuclear One 1	0.76	0.4	1.87	2.12	0.96	Arkansas Nuclear	0.76	0.4	1.87	2.12	0.96
Arkansas Nuclear One 2	0.76	0.4	1.87	2.12	0.96						
Beaver Valley 1	0.36	0.26	1.71	1.54	0.68	Beaver Valley	0.36	0.26	1.71	1.54	0.68
Beaver Valley 2	0.53	0.34	1.71	1.54	0.68						
Braidwood 1	0.76	0.4	1.87	2.12	0.96	Braidwood	0.76	0.4	1.87	2.12	0.96
Braidwood 2	0.76	0.4	1.87	2.12	0.96						
Browns Ferry 1	0.76	0.4	1.87	2.12	0.96	Browns Ferry	0.66	0.4	1.87	2.12	0.96
Browns Ferry 2	0.66	0.4	1.87	2.12	0.96						
Browns Ferry 3	0.66	0.4	1.87	2.12	0.96						
Brunswick 1	0.76	0.4	1.85	2.12	1.32	Brunswick	0.76	0.4	1.85	2.12	1.32
Brunswick 2	0.76	0.4	1.85	2.12	1.32						
Byron 1	0.76	0.4	1.87	2.12	0.96	Byron	0.76	0.4	1.87	2.12	0.96
Byron 2	0.76	0.4	1.87	2.12	0.96						
Callaway	0.76	0.4	1.85	2.12	1.32	Callaway	0.76	0.4	1.85	2.12	1.32
Calvert Cliffs 1	0.62	0.4	1.38	1.72	0.6	Calvert Cliffs	0.58	0.4	1.38	1.72	0.6
Calvert Cliffs 2	0.58	0.4	1.38	1.72	0.6						
Catawba 1	0.44	0.63	1.87	2.12	0.96	Catawba	0.44	0.63	1.87	2.12	0.96
Catawba 2	0.44	0.63	1.87	2.12	0.96						
Clinton (0098)	0.76	0.4	1.85	2.12	1.32	Clinton	0.76	0.4	1.67	1.81	0.59
Clinton(UHS)	0.76	0.4	1.67	1.81	0.59						
Comanche Peak 1	0.30	0.4	2.26	2.56	1.28	Comanche Peak	0.3	0.4	2.26	2.56	1.28
Comanche Peak 2	0.30	0.4	2.26	2.56	1.28						
Cooper	0.76	0.4	1.85	2.12	1.32	Cooper	0.76	0.4	1.85	2.12	1.32
Crystal River 3	0.25	0.4	1.22	1.51	1.58	Crystal River	0.25	0.4	1.22	1.51	1.58
D.C. Cook 1	0.48	0.27	2.27	2.13	0.65	D.C. Cook	0.48	0.27	2.27	2.13	0.65
D.C. Cook 2	0.48	0.27	2.27	2.13	0.65						
Davis-Besse	0.66	0.4	1.87	2.12	0.96	Davis-Besse	0.66	0.4	1.87	2.12	0.96
Dresden 2	0.51	0.4	1.87	2.12	0.96	Dresden	0.51	0.4	1.87	2.12	0.96
Dresden 3	0.51	0.4	1.87	2.12	0.96						
Duane Arnold	0.30	0.4	1.85	2.68	1.07	Duane Arnold	0.3	0.4	1.85	2.68	1.07

GI-199 Safety Report - Appendix C “Plant” Data Point	Plant-Level Fragility from Appendix C of 2010 USNRC Safety/Risk Assessment					CEUS Site with New Hazard Estimates	Bounding Case * Plant Level Fragility from Appendix C of 2010 USNRC Safety/Risk Assessment				
	PGA Fragility **		Spectral Ratios				PGA Fragility **		Spectral Ratios		
	C_{50} (g)	β_C	10 Hz	5 Hz	1 Hz		C_{50} (g)	β_C	10 Hz	5 Hz	1 Hz
Farley 1 (1st spectral ratios)	0.25	0.4	1.87	2.12	0.96	Farley	0.25	0.4	1.87	2.12	0.96
Farley 1 (2nd spectral ratios)	0.25	0.4	1.85	2.12	1.32						
Farley 2 (1st spectral ratios)	0.25	0.4	1.87	2.12	0.96						
Farley 2 (2nd spectral ratios)	0.25	0.4	1.85	2.12	1.32						
Fermi 2	0.76	0.4	1.87	2.12	0.96	Fermi	0.76	0.4	1.87	2.12	0.96
FitzPatrick	0.56	0.4	1.87	2.12	0.96	FitzPatrick	0.56	0.4	1.87	2.12	0.96
Fort Calhoun	0.63	0.4	1.85	2.12	1.32	Fort Calhoun	0.63	0.4	1.85	2.12	1.32
Ginna	0.51	0.4	2.14	2.42	1.36	Ginna	0.51	0.4	2.14	2.42	1.36
Grand Gulf 1	0.38	0.4	1.92	2.65	1.33	Grand Gulf	0.38	0.4	1.92	2.65	1.33
Harris 1	0.74	0.4	1.87	2.12	0.96	Harris	0.74	0.4	1.87	2.12	0.96
Hatch 1	0.76	0.4	1.85	2.12	1.32	Hatch	0.76	0.4	1.85	2.12	1.32
Hatch 2	0.76	0.4	1.85	2.12	1.32						
Hope Creek 1	1.66	0.7	1.97	2.27	0.98	Hope Creek	1.66	0.7	1.97	2.27	0.98
Indian Point 2	0.68	0.4	1.62	1.23	0.41	Indian Point	0.34	0.34	1.56	1.61	0.81
Indian Point 3	0.34	0.34	1.56	1.61	0.81						
Kewaunee	0.41	0.22	1.8	1.79	0.4	Kewaunee	0.41	0.22	1.8	1.79	0.4
La Salle 1 (0098)	1.32	0.4	1.85	2.12	1.32	La Salle	1.32	0.4	1.67	1.83	0.923
La Salle 1 (SSE)	1.32	0.4	1.85	2.62	1.31						
La Salle 1 (UHS)	1.32	0.4	1.67	1.83	0.923						
La Salle 2 (0098)	1.32	0.4	1.85	2.12	1.32						
La Salle 2 (SSE)	1.32	0.4	1.85	2.62	1.31						
La Salle 2 (UHS)	1.32	0.4	1.67	1.83	0.923						
Limerick 1	0.38	0.4	2.59	2.47	1.18	Limerick	0.38	0.4	2.59	2.47	1.18
Limerick 2	0.38	0.4	2.59	2.47	1.18						
McGuire 1	0.45	0.74	1.88	2.35	1.19	McGuire	0.45	0.74	1.88	2.35	1.19
McGuire 2	0.45	0.74	1.88	2.35	1.19						
Millstone 2	0.63	0.4	1.87	2.12	0.96	Millstone	0.54	0.4	2.27	2.27	1.26
Millstone 3	0.54	0.4	2.27	2.27	1.26						
Monticello	0.30	0.4	2.29	2.69	1.12	Monticello	0.3	0.4	2.29	2.69	1.12
Nine Mile Point 1	0.68	0.4	1.87	2.12	0.96	Nine Mile Point	0.58	0.4	1.87	2.12	0.96
Nine Mile Point 2	0.58	0.4	1.87	2.12	0.96						

GI-199 Safety Report - Appendix C “Plant” Data Point	Plant-Level Fragility from Appendix C of 2010 USNRC Safety/Risk Assessment					CEUS Site with New Hazard Estimates	Bounding Case * Plant Level Fragility from Appendix C of 2010 USNRC Safety/Risk Assessment				
	PGA Fragility **		Spectral Ratios				PGA Fragility **		Spectral Ratios		
	C_{50} (g)	β_C	10 Hz	5 Hz	1 Hz		C_{50} (g)	β_C	10 Hz	5 Hz	1 Hz
North Anna 1 (1st spectral ratios)	0.41	0.4	1.87	2.12	0.96	North Anna	0.41	0.4	1.85	2.12	1.32
North Anna 1 (2nd spectral ratios)	0.41	0.4	1.85	2.12	1.32						
North Anna 2 (1st spectral ratios)	0.41	0.4	1.87	2.12	0.96						
North Anna 2 (2nd spectral ratios)	0.41	0.4	1.85	2.12	1.32						
Oconee 1	0.62	0.32	1.66	1.32	0.35	Oconee	0.62	0.32	1.66	1.32	0.35
Oconee 2	0.62	0.32	1.66	1.32	0.35						
Oconee 3	0.62	0.32	1.66	1.32	0.35						
Oyster Creek	0.57	0.36	2	1.78	0.796	Oyster Creek	0.57	0.36	2	1.78	0.796
Palisades	0.49	0.35	2.13	2.44	0.74	Palisades	0.49	0.35	2.13	2.44	0.74
Peach Bottom 2	0.51	0.4	1.87	2.12	0.96	Peach Bottom	0.51	0.4	1.87	2.12	0.96
Peach Bottom 3	0.51	0.4	1.87	2.12	0.96						
Perry 1	0.76	0.4	1.87	2.12	0.96	Perry	0.76	0.4	1.87	2.12	0.96
Pilgrim 1	0.49	0.27	1.55	1.66	0.5	Pilgrim	0.49	0.27	1.55	1.66	0.5
Point Beach 1	0.45	0.45	1.78	1.75	0.675	Point Beach	0.45	0.45	1.78	1.75	0.675
Point Beach 2	0.45	0.45	1.78	1.75	0.675						
Prairie Island 1	0.71	0.4	1.85	2.12	1.32	Prairie Island	0.71	0.4	1.85	2.12	1.32
Prairie Island 2	0.71	0.4	1.85	2.12	1.32						
Quad Cities 1	0.23	0.4	1.87	2.12	0.96	Quad Cities	0.23	0.4	1.87	2.12	0.96
Quad Cities 2	0.23	0.4	1.87	2.12	0.96						
River Bend 1	0.25	0.4	2.35	2.75	1.41	River Bend	0.25	0.4	2.35	2.75	1.41
Robinson 2	0.71	0.4	1.85	2.12	1.32	Robinson	0.71	0.4	1.85	2.12	1.32
Saint Lucie 1 (s4)	0.25	0.4	1.18	1.5	0.8	Saint Lucie	0.25	0.4	1.18	1.5	0.8
Saint Lucie 1 (s5)	0.25	0.4	1.18	1.5	0.8						
Saint Lucie 2 (s4)	0.25	0.4	1.18	1.5	0.8						
Saint Lucie 2 (s5)	0.25	0.4	1.18	1.5	0.8						
Salem 1	1.31	0.84	1.97	2.27	0.68	Salem	1.31	0.84	1.97	2.27	0.68
Salem 2	1.31	0.84	1.97	2.27	0.68						
Seabrook 1	0.90	0.52	2.223	2.42	1.36	Seabrook	0.9	0.52	2.223	2.42	1.36
Sequoyah 1	0.68	0.4	1.87	2.12	0.96	Sequoyah	0.68	0.4	1.87	2.12	0.96

GI-199 Safety Report - Appendix C “Plant” Data Point	Plant-Level Fragility from Appendix C of 2010 USNRC Safety/Risk Assessment					CEUS Site with New Hazard Estimates	Bounding Case * Plant Level Fragility from Appendix C of 2010 USNRC Safety/Risk Assessment				
	PGA Fragility **		Spectral Ratios				PGA Fragility **		Spectral Ratios		
	C_{50} (g)	β_C	10 Hz	5 Hz	1 Hz		C_{50} (g)	β_C	10 Hz	5 Hz	1 Hz
Sequoyah 2	0.68	0.4	1.87	2.12	0.96						
South Texas 1	0.38	0.59	2.47	2.97	1.53	South Texas	0.38	0.59	2.47	2.97	1.53
South Texas 2	0.38	0.59	2.47	2.97	1.53						
Summer	0.56	0.4	1.87	2.12	0.96	Summer	0.56	0.4	1.87	2.12	0.96
Surry 1	0.74	0.66	2.08	1.95	0.97	Surry	0.74	0.66	2.08	1.95	0.97
Surry 2	0.74	0.66	2.08	1.95	0.97						
Susquehanna 1	0.53	0.4	1.87	2.12	0.96	Susquehanna	0.53	0.4	1.87	2.12	0.96
Susquehanna 2	0.53	0.4	1.87	2.12	0.96						
Three Mile Island 1	0.29	0.28	2.73	2.6	1.127	Three Mile Island	0.29	0.28	2.73	2.6	1.127
Turkey Point 3	0.38	0.4	1.26	1.58	0.85	Turkey Point	0.38	0.4	1.26	1.58	0.85
Turkey Point 4	0.38	0.4	1.26	1.58	0.85						
Vermont Yankee	0.63	0.4	1.87	2.12	0.96	Vermont Yankee	0.63	0.4	1.87	2.12	0.96
Vogtle 1	0.76	0.4	1.85	2.12	1.32	Vogtle	0.76	0.4	1.85	2.12	1.32
Vogtle 2	0.76	0.4	1.85	2.12	1.32						
Waterford 3	0.25	0.4	1.72	2.4	1.19	Waterford	0.25	0.4	1.72	2.4	1.19
Watts Bar 1 (rock)	0.76	0.4	1.87	2.12	0.96	Watts Bar	0.76	0.4	1.87	2.12	0.96
Watts Bar 1 (soil)	0.76	0.4	1.85	2.12	1.32						
Wolf Creek 1	0.51	0.4	1.83	2.25	0.32	Wolf Creek	0.51	0.4	1.83	2.25	0.32

* Plant level fragility that results in the maximum SCDF for the site when combined with the newly developed site-specific seismic hazard (2013/2014)
** C_{50} is the median (50th percentile) plant-level acceleration capacity and β_c is the composite variability

6 QUANTIFICATION APPROACH

The USNRC used approximate methods to estimate the SCDF for each operating nuclear plant as part of their 2010 study to assess the safety implications of changing seismic hazards as part of GI-199. These approximate SCDF estimates were developed using a method that involved integrating the mean seismic hazard curve and an approximation of the mean plant-level fragility curve for each plant. This approximate method was first developed by Kennedy (Kennedy, 1999) and is discussed in Section 10-B.9 of the ASME/ANS RA-Sa-2009 Standard (ASME, 2009), as well as Appendix D of the SPID (EPRI, 2013a). This same approach is judged to be the most appropriate method to assess this latest set of new site-specific seismic hazard estimates developed in accordance with the USNRC's 50.54(f) letter.

In the NRC Safety/Risk Assessment of GI-199, SCDF estimates were computed at four spectral frequencies: 10 Hz, 5 Hz, 1 Hz and the peak ground acceleration (PGA). The terminology defined within the GI-199 Safety/Risk Assessment included the concept of a "derived SCDF estimate" which consisted of an estimate of the seismic core-damage frequency that was developed from these four spectral SCDF estimates:

- $SCDF_{pga}$ = 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

The seismic core damage frequency for a plant can most accurately be generated by incorporating each individual seismic fragility function into the complete plant logic model and convolving with the hazard to develop the SCDF. However, since the plant logic model was not typically included as part of the IPEEE submittal, this approximate approach is the best alternative to estimating these SCDFs. Past SPRAs have demonstrated that the actual plant risk is a function of the seismic response at a variety of spectral frequencies. The plant risk is very site specific and is a function of:

- Failure modes governing the lower capacity structures, systems and components
- Soil frequencies for those structures founded on soil columns
- Structure fundamental frequencies
- Equipment fundamental frequencies

The frequency ranges that drive the plant seismic risk are typically very broad, including contributions from 1 Hz to PGA. One of the methods to account for the spectral frequency contribution to the SCDF used in the GI-199 Safety / Risk Assessment considered each of the four frequencies (1, 5, 10 Hz and PGA) to contribute equally to the overall SCDF. The resulting "derived SCDF estimate" associated with this spectral weighting is shown mathematically in the equation below:

$$\text{SCDF}_{avg} = \frac{1}{4}SCDF_{pga} + \frac{1}{4}SCDF_{10} + \frac{1}{4}SCDF_{5} + \frac{1}{4}SCDF_{1}$$

This averaging of the four frequencies approach is judged to be appropriate for this study as past SPRAs have demonstrated that typically there are risk contributions from all these frequencies due to the variety of equipment, systems and structures that end up contributing to the risk. In addition, EPRI has conducted some limited additional sensitivity studies related to this frequency weighting (expanding the number of frequencies from 4 to 6 and also considering an alternate approach in the GI-199 Safety / Risk Assessment referred to as the "IPEEE weighted average SCDF" approach) and the overall results and conclusions are relatively insensitive to the approach taken. EPRI does not recommend using any very conservative approaches to estimate the SCDF such as use of the maximum SCDFs calculated at any one frequency. This type of bounding approach is overly conservative and judged to not provide realistic risk estimates consistent with SCDFs calculated in actual SPRAs.

7 SCDF RESULTS

To provide an initial assessment of the safety implications of the new seismic hazard estimates across the fleet of CEUS operating plants, point estimates of the mean SCDF are developed using the new site-specific seismic hazard curves. These are compared with the baseline SCDFs developed by the USNRC in 2010 using the 2008 USGS and 1994 LLNL seismic hazard curves.

Figure 1 provides a comparison of the cumulative fleet SCDF distribution calculated using the new site-specific seismic hazards, the 1994 LLNL seismic hazards, and the 2008 USGS seismic hazards. The SCDF values computed using the new hazard range from approximately 4E-7/year to 6E-5/year. The comparison shows that the overall distribution of SCDFs for the fleet has not changed significantly due to the new site-specific seismic hazards.

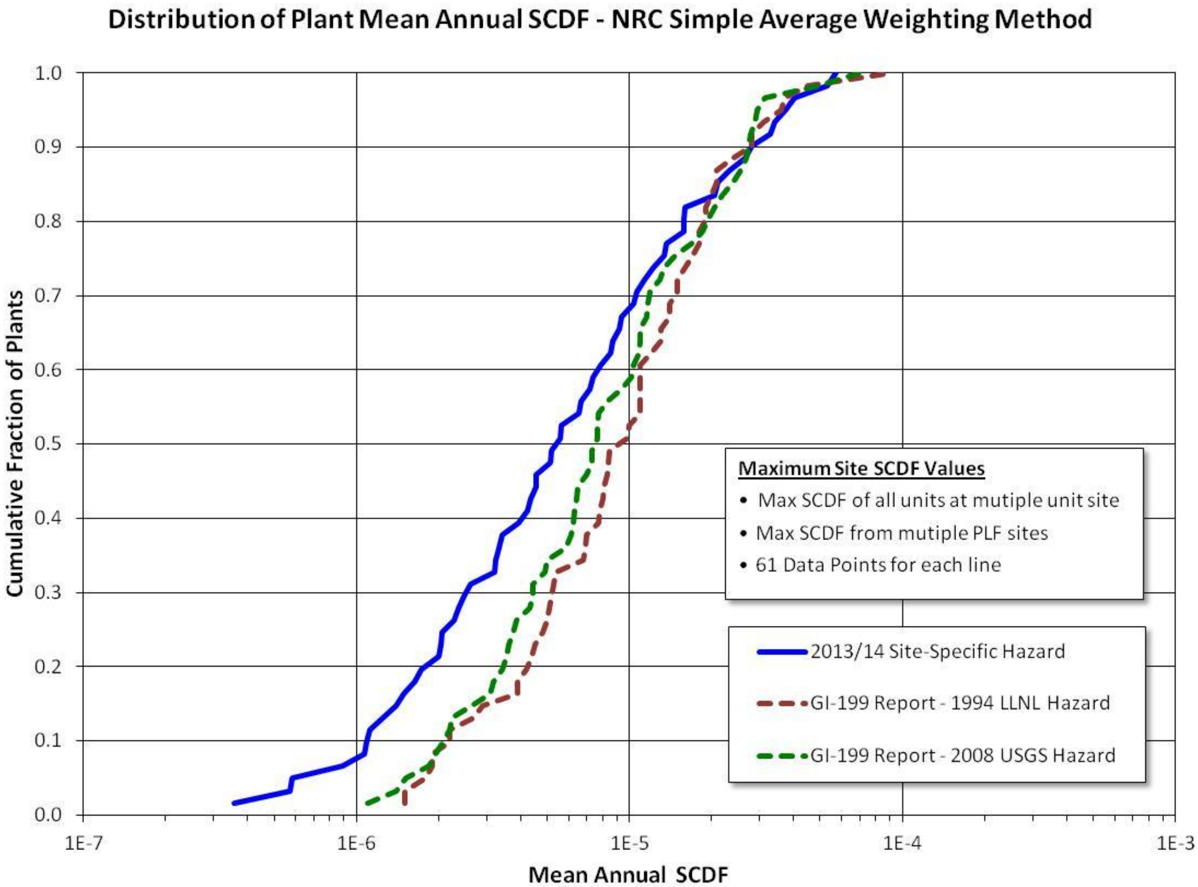

Figure 1 – Comparison of CEUS NPP Site Cumulative Distribution of Seismic CDFs

8 CONCLUSIONS

In 2010, the USNRC conducted a Safety / Risk Assessment for the GI-199 program and developed simplified methods to calculate a point estimate of the SCDF. The USNRC developed an estimate of the seismic hazard at that time using the 2008 USGS seismic source to develop a new rock hazard, and EPRI site amplification factors. This 2008 hazard, along with the previously developed 1994 LLNL hazard, was then used to estimate the SCDFs for the fleet of U.S. plants using the plant-level fragilities estimated from each plant's IPEEE submittals.

The USNRC concluded in 2010 that the overall SCDF estimates are indicative of performance consistent with the Commission's Safety Goal Policy Statement because they are within the subsidiary objective of 1E-4/year. The specific USNRC statement from the GI-199 Safety / Risk Assessment (USNRC, 2010) was:

> *"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."

New seismic hazard analyses have been completed for all sixty-one CEUS nuclear power plant sites. EPRI calculated the approximate SCDFs for each of these sites using methods that the USNRC used to assess changing seismic hazard in the past. As can be seen from Figure 1 above, the overall distribution of SCDFs for the fleet indicates that the impact of the updated seismic hazard has been to reduce risk for most plants relative to estimates obtained using either the 2008 USGS or the 1994 LLNL hazard assessments.

- The range of SCDFs still falls between 1E-7/year and 1E-4/year.
- For individual plants, some plant SCDF estimates have increased, but the vast majority have decreased somewhat.
- In the case of the sites for which increases were seen, none of the SCDF values approaches 1E-4/year.

Comparisons of the SCDF estimates developed in 2010 by the USNRC to the SCDF estimates developed by EPRI for the new site-specific seismic hazards show that there clearly has not been an overall increase in seismic risk for the fleet of U.S. plants. In addition, all sixty-one of the CEUS sites have SCDF estimates below the 1E-4/year threshold considered in the USNRC 2010 Safety / Risk Assessment. Thus it can be concluded that the current seismic design of operating reactors continues to provide a safety margin to withstand potential earthquakes exceeding the seismic design basis, as was concluded in the USNRC 2010 Safety / Risk Assessment.

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