Seismic Hazard and Screening Report for the Callaway Energy Center

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1 Introduction

Following the accident at the Fukushima Daiichi nuclear power plant resulting from the March 11, 2011, Great Tohoku Earthquake and subsequent tsunami, the NRC established a Near Term Task Force (NTTF) to conduct a systematic review of NRC 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. Subsequently, the NRC issued a 50.54(f) (USNRC, 2012) letter that requests information to assure that these recommendations are addressed by all U.S. nuclear power plants. The 50.54(f) letter requests that licensees and holders of construction permits under 10 CFR Part 50 reevaluate the seismic hazards at their sites against present-day NRC requirements. Depending on the comparison between the reevaluated seismic hazard and the current design basis, the result is either no further risk evaluation or the performance of a seismic risk assessment. Risk assessment approaches acceptable to the staff include a seismic probabilistic risk assessment (SPRA), or a seismic margin assessment (SMA). Based upon this information, the NRC staff will determine whether additional regulatory actions are necessary.

This report provides the information requested in items (1) through (7) of the "Requested Information" section and Attachment 1 of the 50.54(f) letter pertaining to NTTF Recommendation 2.1 for the Callaway Energy Center (CEC), located in Callaway County, Missouri. In providing this information, Ameren Missouri followed the guidance provided in the *Seismic Evaluation Guidance: Screening, Prioritization, and Implementation Details (SPID) for the Resolution of Fukushima Near-Term Task Force Recommendation 2.1: Seismic* (EPRI 1025287, 2013a). The Augmented Approach, Seismic Evaluation Guidance: Augmented Approach for the Resolution of Fukushima Near-Term Task Force Recommendation 2.1: Seismic (EPRI 3002000704, 2013c), has been developed as the process for evaluating critical plant equipment prior to performing the complete plant seismic risk evaluations.

The original geologic and seismic siting investigations for the CEC were performed in accordance with Appendix A to 10 CFR Part 100 and meet General Design Criterion 2 in Appendix A to 10 CFR Part 50. The Safe Shutdown Earthquake Ground Motion (SSE) was developed in accordance with Appendix A to 10 CFR Part 100 and used for the design of seismic Category I systems, structures and components.

In response to the 50.54(f) letter and following the guidance provided in the SPID (EPRI 1025287, 2013a), a seismic hazard reevaluation for the CEC was performed. For screening purposes, a Ground Motion Response Spectrum (GMRS) was developed.

Based on the results of the screening evaluation, the CEC screens in for risk evaluation, a Spent Fuel Pool evaluation, and a High Frequency Confirmation (Relay Chatter).

2 Seismic Hazard Reevaluation

Refer to Section 2.5 of the Callaway Final Safety Analysis Review Site Addendum (FSAR SA) (Callaway Energy, 2013). The CEC is approximately 10 miles southeast of Fulton, Missouri, and 80 miles west of the St. Louis metropolitan area. The CEC site is located in an area of the central United States which has been relatively stable seismically. No historic earthquake epicenter has been reported within about 40 miles of the plant site. Only four earthquakes have been reported within 60 miles of the Site since the beginning of the 19th century, none of which were greater than Modified Mercalli Intensity (MMI) V. The 1811-1812 New Madrid event occurred approximately 200 miles southeast from the site with a maximum intensity of MMI XI-XII. Based on seismic investigations which were conducted, a Safe Shutdown Earthquake (SSE) has been determined for safety related structures. The SSE would generate a horizontal ground acceleration of 0.20g in above-average foundation supporting materials. The specified SSE is derived from consideration of the possible effects of an Intensity XII event occurring at the closest approach of the New Madrid Seismogenic Region to the site a distance of approximately 175 miles; an Intensity VII event occurring anywhere within the Chester-Dupo or Ste. Genevieve seismotectonic regions approximately 70 miles east-southeast of the site; or an MMI V event occurring within the Missouri Random Region near the site.

The results of comprehensive geotechnical investigations at the site demonstrate that competent foundation materials are present for establishing conservative design and construction criteria for support of the Category I facilities. All major Category I structures are supported on competent rock. There are no geologic features at or near the site that would preclude its use for the construction and operation of the nuclear power station.

Due to the use of the Standardized Nuclear Unit Power Plant Systems (SNUPPS) standard design, the seismic responses of the major seismic Category I structures (containment, auxiliary/control, diesel generator, and fuel building) were originally generated for four sites (Callaway, Wolf Creek, Sterling, and Tyrone). The final geological and seismological design of the power block SSC is based on three sites (Callaway, Wolf Creek and Sterling) to ensure conservatism in the seismic design envelope. Certain items, whose final design was completed prior to the cancellation of Tyrone (the fourth site), are within the envelope for the four original sites. The site design response spectra in both the horizontal and vertical directions for the 0.20g SSE envelopes the SNUPPS sites and thus governs for both site-related non-power block and power block safety-related Systems, Structures and Components (SSC).

2.1 Regional and Local Geology

Refer to FSAR SA Section 2.5. The CEC site is located in Callaway County, Missouri, approximately 10 miles southeast of the town of Fulton. The site is located in the Central Stable Region a region which was subjected to gentle structural uparching and downwarping during the Paleozoic and Mesozoic eras. The arches, basins, and other structures of the Central Stable Region were formed, with few exceptions, by vertical block tectonics during the Paleozoic Era. Geotechnical investigations conducted at the site and in the surrounding region have not identified the existence of any faults closer to the site than 12 miles.

Bedrock at the site is overlain by nonindurated glacial and postglacial deposits averaging 30 to 40 feet in thickness. These deposits consist of a modified loess accretion-gley, and glacial till. The uppermost bedrock unit at the CEC site is the Pennsylvanian Graydon chert conglomerate which consists of gravel- to boulder-size chert particles in a clay or silt matrix. The deposits are underlain by Mississippian limestone and sandstone of the Burlington and Bushberg formations respectively, and limestone, siltstone, and shale of the Devonian Snyder Creek and Callaway formations.

2.2 Probabilistic Seismic Hazard Analysis

2.2.1 Probabilistic Seismic Hazard Analysis Results

In accordance with the 50.54(f) letter and following the guidance in the SPID (EPRI, 2013a), a probabilistic seismic hazard analysis (PSHA) was completed using the recently developed Central and Eastern United States Seismic Source Characterization (CEUS-SSC) for Nuclear Facilities (CEUS-SSC, 2012) together with the updated EPRI Ground-Motion Model (GMM) for the CEUS (EPRI, 2013b). For the PSHA, a lower-bound moment magnitude of 5.0 was used, as specified in the 50.54(f) letter.

For the PSHA, the CEUS-SSC background seismic sources out to a distance of 400 miles (640 km) around the CEC were included. This distance exceeds the 200 mile (320 km) recommendation contained in USNRC (2007) and was chosen for completeness. Background sources included in this site analysis are the following:

1. Extended Continental Crust—Gulf Coast (ECC_GC)
2. Illinois Basin Extended Basement (IBEB)
3. Mesozoic and younger extended prior – narrow (MESE-N)
4. Mesozoic and younger extended prior – wide (MESE-W)
5. Midcontinent-Craton alternative A (MIDC_A)
6. Midcontinent-Craton alternative B (MIDC_B)
7. Midcontinent-Craton alternative C (MIDC_C)
8. Midcontinent-Craton alternative D (MIDC_D)
9. Non-Mesozoic and younger extended prior – narrow (NMESE-N)
10. Non-Mesozoic and younger extended prior – wide (NMESE-W)
11. Oklahoma Aulacogen (OKA)
12. Paleozoic Extended Crust wide (PEZ_W)
13. Reelfoot Rift (RR)
14. Reelfoot Rift including the Rough Creek Graben (RR-RCG)
15. Study region (STUDY_R)

For sources of large magnitude earthquakes, designated Repeated Large Magnitude Earthquake (RLME) sources in CEUS-SSC (2012), the following sources lie within 1,000 km of the site and were included in the analysis:

1. Cheraw
2. Commerce

3. Eastern Rift Margin Fault northern segment (ERM-N)
4. Eastern Rift Margin Fault southern segment (ERM-S)
5. Marianna
6. Meers
7. New Madrid Fault System (NMFS)
8. Wabash Valley

For each of the above background and RLME sources, the mid-continent version of the updated CEUS EPRI GMM was used.

2.2.2 Base Rock Seismic Hazard Curves

Consistent with the SPID (EPRI, 2013a), base rock seismic hazard curves are not provided as the site amplification approach referred to as Method 3 has been used. Seismic hazard curves are shown below in Section 3 at the SSE (Safe Shutdown Earthquake) control point elevation.

2.3 Site Response Evaluation

Following the guidance contained in Seismic Enclosure 1 of the 3/12/2012 50.54(f) Request for Information and in the SPID (EPRI, 2013a) for nuclear power plant sites that are not founded on hard rock (defined as 2.83 km/sec), a site response analysis was performed for the CEC.

2.3.1 Description of Subsurface Material

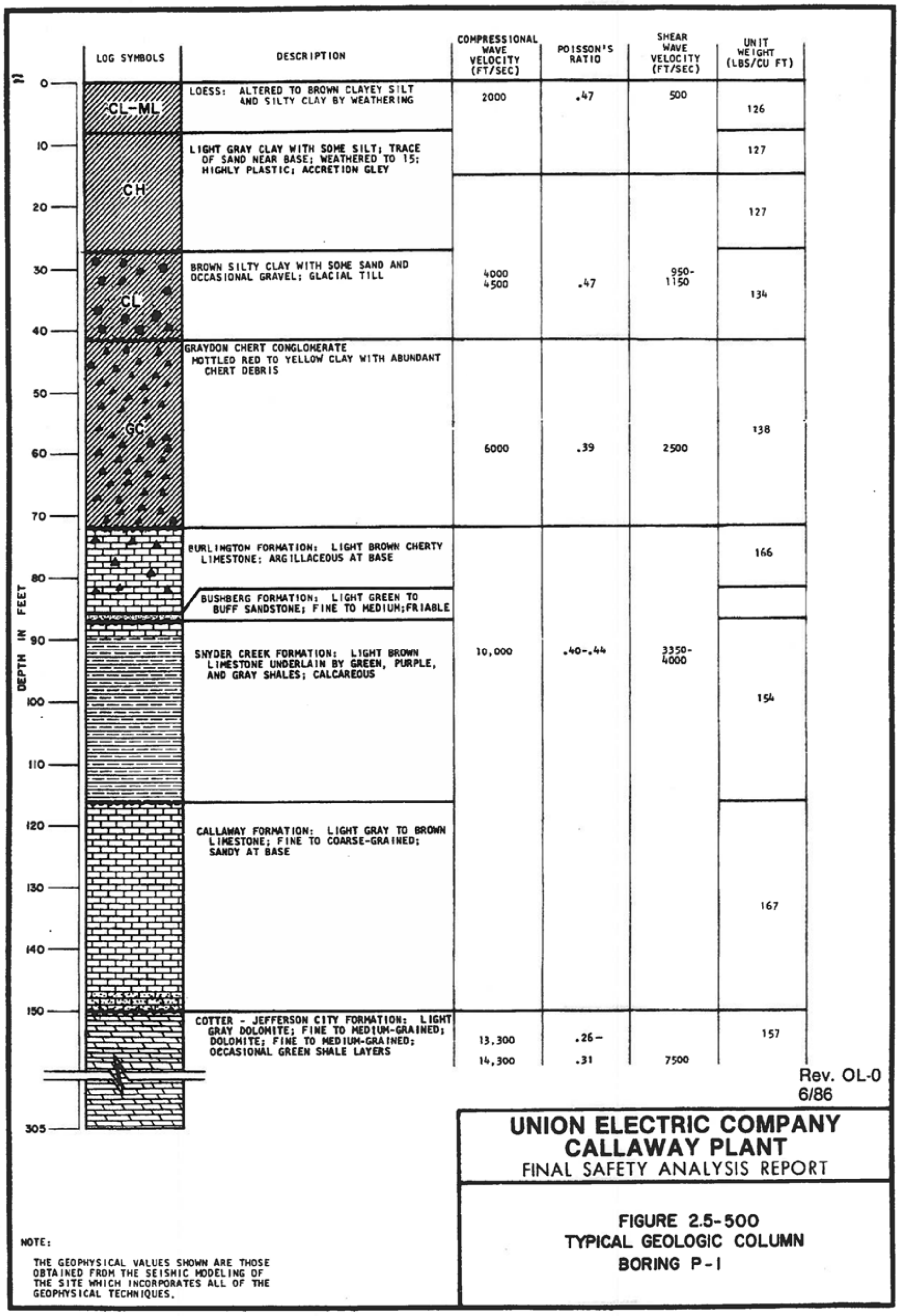
The CEC is located in Callaway County, Missouri about 80 miles (130 km) west of St. Louis. The site geologic profile at the CEC is shown in Figure 2.3.2-1 and consists of about 30.5 ft (9 m) of soils overlying about 2,174 ft (662 m) of sedimentary rocks with Precambrian basement at a depth of about 2,204 ft (672 m). This information was documented in the Callaway FSAR Unit 2 (UniStar Nuclear Services, 2009) and in the Callaway FSAR Unit 1 (Callaway Energy, 2013). As indicated in Callaway Energy (2014a), the SSE Control Point is at the free field at finish grade. Finish grade is at an elevation of 840 ft (256 m) in the accretion gley soil layer (Figure 2.3.2-1) (Callaway Energy, 2014a).

2.3.2 Development of Base Case Profiles and Nonlinear Material Properties

The basic information used to create the site geologic profile at the CEC was taken from UniStar Nuclear Services (2009) and Callaway Energy (2014a). Figure 2.3.2-1 (Callaway Energy, 2014a) shows the recommended shear-wave velocities, unit weights along with depths and corresponding stratigraphy. The surface elevation of the boring in Figure 2.3.2-1 is at 851.3 ft (259.5 m). The SSE control point is at the free field at finish grade at elevation 840 ft (256 m). Velocities shown in Figure 2.3.2-1 are from compressional wave refraction surveys at the site (Callaway Energy, 2014a). The shear wave velocity was calculated using an assumed Poisson ratio and the compressional wave velocity. Similar velocities from downhole, cross hole, suspension and reflection surveys at the site are documented in UniStar Nuclear Services (2009) (Table 2.5-56). Velocity measurement extends to a depth below the SSE of about 140 ft (43 m) (Callaway Energy, 2014a) and 330 ft (100 m) (UniStar Nuclear Services, 2009). Precambrian basement was estimated to be at a depth of about 2,204 ft (672 m).

The mean base-case profile (P1) was based on the shear-wave velocities in Figure 2.3.2-1 and Table 2.5-56 (UniStar Nuclear Services, 2009) with the deepest velocity of 8,333 ft/s (2,540 m/s) extended to Precambrian basement. Profile P3, the stiffest profile, encountered hard rock shear-wave velocities (9,285 ft/s, 2,890 m/s) at a depth below the SSE of about 139 ft (42 m).

Lower (P2) - and upper (P3) - range profiles were developed with scale factor of 1.25 for the entire profile. This assumption reflects the uncertainty in measured velocities to a depth of 330 ft (100 m) and also for the extension of the shear-wave velocity to Precambrian basement. The scale factor of 1.25 reflect a $\sigma_{\mu\ln}$ of about 0.2 based on the SPID (EPRI, 2013a) 10th and 90th fractiles which implies a scale factor of 1.28 on $\sigma_{\mu\ln}$. Depth to Precambrian basement was taken at 2,204 ft (672 m). The depth to Precambrian basement was randomized from 1,673 to 2,733 ft (510 to 833 m) based on the range in formation thicknesses in Figure 2.3.2-2 (Table 2.5-10; UniStar Nuclear Services, 2009). This depth randomization provides a realistic broadening of the fundamental resonance that reflects actual variations of the depth at this site. The three shear-wave velocity profiles are shown in Figure 2.3.2-3 and listed in Table 2.3.2-1.



LOG SYMBOLS	DESCRIPTION	COMPRESSIONAL WAVE VELOCITY (FT/SEC)	POISSON'S RATIO	SHEAR WAVE VELOCITY (FT/SEC)	UNIT WEIGHT (LBS/CU FT)
CL-ML	LOESS: ALTERED TO BROWN CLAYEY SILT AND SILTY CLAY BY WEATHERING	2000	.47	500	126
CH	LIGHT GRAY CLAY WITH SOME SILT; TRACE OF SAND NEAR BASE; WEATHERED TO 15; HIGHLY PLASTIC; ACCRETION GLEY				127 127
CL	BROWN SILTY CLAY WITH SOME SAND AND OCCASIONAL GRAVEL; GLACIAL TILL	4000 4500	.47	950- 1150	134
GC	GRAYDON CHERT CONGLOMERATE MOTTLED RED TO YELLOW CLAY WITH ABUNDANT CHERT DEBRIS	6000	.39	2500	138
	BURLINGTON FORMATION: LIGHT BROWN CHERTY LIMESTONE; ARGILLACEOUS AT BASE	10,000	.40-.44	3350- 4000	166
	BUSHBERG FORMATION: LIGHT GREEN TO BUFF SANDSTONE; FINE TO MEDIUM; FRIABLE				
	SNYDER CREEK FORMATION: LIGHT BROWN LIMESTONE UNDERLAIN BY GREEN, PURPLE, AND GRAY SHALES; CALCAREOUS				154
	CALLAWAY FORMATION: LIGHT GRAY TO BROWN LIMESTONE; FINE TO COARSE-GRAINED; SANDY AT BASE				167
	COTTER - JEFFERSON CITY FORMATION: LIGHT GRAY DOLOMITE; FINE TO MEDIUM-GRAINED; DOLOMITE; FINE TO MEDIUM-GRAINED; OCCASIONAL GREEN SHALE LAYERS	13,300 14,300	.26- .31	7500	157

NOTE:

THE GEOPHYSICAL VALUES SHOWN ARE THOSE OBTAINED FROM THE SEISMIC MODELING OF THE SITE WHICH INCORPORATES ALL OF THE GEOPHYSICAL TECHNIQUES.

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CALLAWAY PLANT
FINAL SAFETY ANALYSIS REPORT

FIGURE 2.5-500
TYPICAL GEOLOGIC COLUMN
BORING P-1

Figure 2.3.2-1. Summary of Stratigraphy and Shear-Wave Velocity for CEC (Callaway Energy, 2014a).

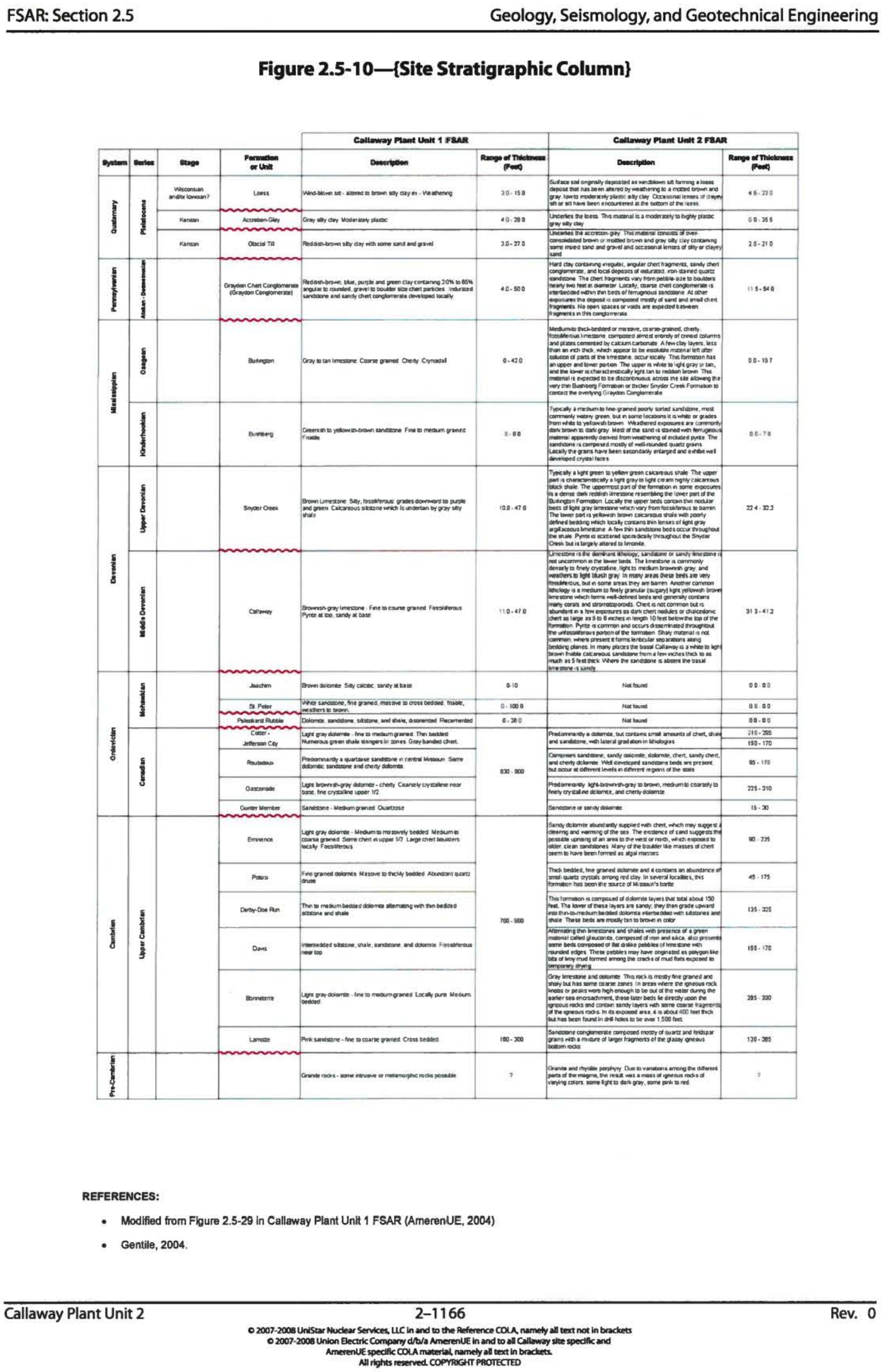


Figure 2.5-10—{Site Stratigraphic Column}

				Callaway Plant Unit 1 FSAR		Callaway Plant Unit 2 FSAR	
System	**Series**	**Stage**	**Formation or Unit**	**Description**	**Range of Thickness (Feet)**	**Description**	**Range of Thickness (Feet)**
Quaternary	Pleistocene	Wisconsian and/or Iowan?	Loess	Wind-blown silt - altered to brown silty clay ex - Weathering	3.0 - 15.0	Surface soil originally deposited as windblown silt forming a loess deposit that has been altered by weathering to a mottled brown and gray low to moderately plastic silty clay. Occasional lenses of clayey silt or silt have been encountered at the bottom of the loess.	4.6 - 22.0
		Kansan	Accretion-Gley	Gray silty clay. Moderately plastic	4.0 - 20.0	Underlies the loess. This material is a moderately to highly plastic gray silty clay	0.0 - 25.5
		Kansan	Glacial Till	Reddish-brown silty clay with some sand and gravel	3.0 - 27.0	Underlies the accretion-gley. This material consists of over-consolidated brown or mottled brown and gray silty clay containing some mixed sand and gravel and occasional lenses of silty or clayey sand	2.5 - 21.0
Pennsylvanian	Atokan - Desmoinesian		Graydon Chert Conglomerate (Graydon Conglomerate)	Reddish-brown, blue, purple and green clay containing 20% to 85% angular to rounded, gravel to boulder size chert particles. Indurated sandstone and sandy chert conglomerate developed locally	4.0 - 50.0	Hard clay containing irregular, angular chert fragments, sandy chert conglomerate, and local deposits of indurated, iron-stained quartz sandstone. The chert fragments vary from pebble-size to boulders nearly two feet in diameter. Locally, coarse chert conglomerate is interbedded within thin beds of ferruginous sandstone. At other exposures the deposit is composed mostly of sand and small chert fragments. No open spaces or voids are expected between fragments in this conglomerate.	11.5 - 54.0
Mississippian	Osagean		Burlington	Gray to tan limestone. Coarse grained. Cherty. Crinoidal	0 - 42.0	Medium-to thick-bedded or massive, coarse-grained, cherty, fossiliferous limestone composed almost entirely of crinoid columns and plates cemented by calcium carbonate. A few clay layers, less than an inch thick, which appear to be insoluble material left after solution of parts of the limestone, occur locally. This formation has an upper and lower portion. The upper is white to light gray or tan, and the lower is characteristically light tan to reddish brown. This material is expected to be discontinuous across the site allowing the very thin Bushberg Formation or thicker Snyder Creek Formation to contact the overlying Graydon Conglomerate	0.0 - 19.7
	Kinderhookian		Bushberg	Greenish to yellowish-brown sandstone. Fine to medium grained. Friable	0 - 8.0	Typically a medium-to fine-grained poorly sorted sandstone, most commonly watery green, but in some locations it is white or grades from white to yellowish brown. Weathered exposures are commonly dark brown to dark gray. Most of the sand is stained with ferruginous material apparently derived from weathering of included pyrite. The sandstone is composed mostly of well-rounded quartz grains. Locally the grains have been secondarily enlarged and exhibit well developed crystal faces	0.0 - 7.0
Devonian	Upper Devonian		Snyder Creek	Brown Limestone. Silty, fossiliferous: grades downward to purple and green. Calcareous siltstone which is underlain by gray silty shale	10.0 - 47.0	Typically a light green to yellow green calcareous shale. The upper part is characteristically a light gray to light cream highly calcareous block shale. The uppermost part of the formation in some exposures is a dense dark reddish limestone resembling the lower part of the Burlington Formation. Locally the upper beds contain thin nodular beds of light gray limestone which vary from fossiliferous to barren. The lower part is yellowish brown calcareous shale with poorly defined bedding which locally contains thin lenses of light gray argillaceous limestone. A few thin sandstone beds occur throughout the shale. Pyrite is scattered sporadically throughout the Snyder Creek but is largely altered to limonite.	22.4 - 32.2
	Middle Devonian		Callaway	Brownish-gray limestone - Fine to course grained. Fossiliferous. Pyrite at top, sandy at base	11.0 - 47.0	Limestone is the dominant lithology; sandstone or sandy limestone is not uncommon in the lower beds. The limestone is commonly densely to finely crystalline, light to medium brownish gray, and weathers to light bluish gray. In many areas these beds are very fossiliferous, but in some areas they are barren. Another common lithology is a medium to finely granular (sugary) light yellowish brown limestone which forms well-defined beds and generally contains many corals and stromatoporoids. Chert is not common but is abundant in a few exposures as dark chert nodules or chalcedonic chert as large as 5 to 8 inches in length 10 feet below the top of the formation. Pyrite is common and occurs disseminated throughout the unfossiliferous portion of the formation. Shaly material is not common, where present it forms lenticular separations along bedding planes. In many places the basal Callaway is a white to light brown friable calcareous sandstone from a few inches thick to as much as 5 feet thick. Where the sandstone is absent the basal limestone is sandy	31.3 - 41.2
Ordovician	Mohawkian		Joachim	Brown dolomite. Silty calcitic, sandy at base	0-10	Not found	0.0 - 0.0
			St. Peter	White sandstone, fine grained, massive to cross bedded, friable, weathers to brown.	0 - 100.0	Not found	0.0 - 0.0
			Paleokarst Rubble	Dolomite, sandstone, siltstone, and shale, disoriented. Recemented	0 - 38.0	Not found	0.0 - 0.0
	Canadian		Cotter - Jefferson City	Light gray dolomite - fine to medium grained. Thin bedded. Numerous green shale stringers in zones. Gray banded chert.	830 - 900	Predominantly a dolomite, but contains small amounts of chert, shale and sandstone, with lateral gradation in lithologies.	210 - 295 150 - 170
			Roubidoux	Predominantly a quartzose sandstone in central Missouri. Some dolomitic sandstone and cherty dolomite		Comprises sandstone, sandy dolomite, dolomite, chert, sandy chert, and cherty dolomite. Well developed sandstone beds are present but occur at different levels in different regions of the state	85 - 170
			Gasconade	Light brownish-gray dolomite - cherty. Coarsely crystalline near base, fine crystalline upper 1/2		Predominantly light-brownish-gray to brown, medium to coarsely to finely crystalline dolomite, and cherty dolomite	225 - 310
			Gunter Member	Sandstone - Medium grained. Quartzose		Sandstone or sandy dolomite	15 - 30
Cambrian	Upper Cambrian		Eminence	Light gray dolomite - Medium to massively bedded. Medium to coarse grained. Some chert in upper 1/2. Large chert boulders locally. Fossiliferous	700 - 960	Sandy dolomite abundantly supplied with chert, which may suggest a clearing and warming of the sea. The existence of sand suggests the possible uprising of an area to the west or north, which exposed to older, clean sandstones. Many of the boulder like masses of chert seem to have been formed as algal masses	90 - 235
			Potosi	Fine grained dolomite. Massive to thickly bedded. Abundant quartz druse		Thick bedded, fine grained dolomite and it contains an abundance of small quartz crystals among red clay. In several localities, this formation has been the source of Missouri's barite	45 - 175
			Derby-Doe Run	Thin to medium bedded dolomite alternating with thin bedded siltstone and shale		This formation is composed of dolomite layers that total about 150 feet. The lower of these layers are sandy; they then grade upward into thin-to-medium bedded dolomite interbedded with siltstones and shale. These beds are mostly tan to brown in color	135 - 325
			Davis	Interbedded siltstone, shale, sandstone, and dolomite. Fossiliferous near top		Alternating thin limestones and shales with presence of a green material called glauconite, composed of iron and silica, also presents some beds composed of flat disklike pebbles of limestone with rounded edges. These pebbles may have originated as polygon like bits of limy mud formed among the cracks of mud flats exposed to temporary drying	155 - 170
			Bonneterre	Light gray dolomite - fine to medium grained. Locally pure. Medium bedded		Gray limestone and dolomite. This rock is mostly fine grained and shaly but has some coarse zones. In areas where the igneous rock knobs or peaks were high enough to be out of the water during the earlier sea encroachment, these later beds lie directly upon the igneous rocks and contain sandy layers with some coarse fragments of the igneous rocks. In its exposed area, it is about 400 feet thick but has been found in drill holes to be over 1,500 feet	295 - 330
			Lamotte	Pink sandstone - fine to coarse grained. Cross bedded	180 - 300	Sandstone conglomerate composed mostly of quartz and feldspar grains with a mixture of larger fragments of the glassy igneous bottom rocks	130 - 385
Pre-Cambrian				Granite rocks - some intrusive or metamorphic rocks possible	?	Granite and rhyolite porphyry. Due to variations among the different parts of the magma, the result was a mass of igneous rocks of varying colors, some light to dark gray, some pink to red	?

REFERENCES:

- Modified from Figure 2.5-29 in Callaway Plant Unit 1 FSAR (AmerenUE, 2004)
- Gentile, 2004.

Figure 2.3.2-2. Site Stratigraphic Column for CEC (UniStar Nuclear Services, 2009).

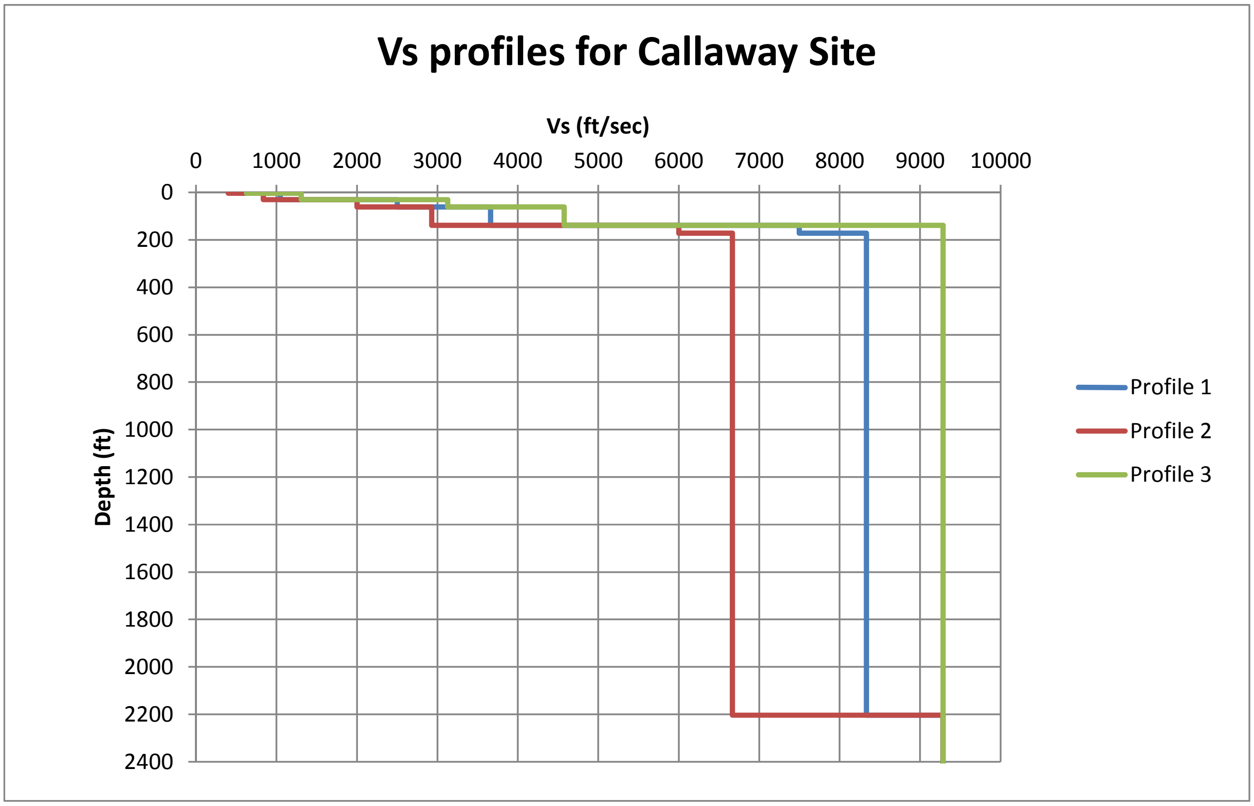


Figure 2.3.2-3. Shear-wave velocity profiles for CEC site

Table 2.3.2-1

Layer thicknesses, depths, and shear-wave velocities (Vs) for 3 profiles, CEC site

Profile 1			Profile 2			Profile 3		
Thickness (ft)	depth (ft)	Vs (ft/s)	Thickness (ft)	depth (ft)	Vs (ft/s)	Thickness (ft)	depth (ft)	Vs (ft/s)
	0	500		0	400		0	625
3.9	3.9	500	3.9	3.9	400	3.9	3.9	625
5.9	9.8	1045	5.9	9.8	836	5.9	9.8	1307
5.9	15.7	1045	5.9	15.7	836	5.9	15.7	1307
4.3	20.0	1045	4.3	20.0	836	4.3	20.0	1307
4.9	24.9	1045	4.9	24.9	836	4.9	24.9	1307
5.2	30.2	1045	5.2	30.2	836	5.2	30.2	1307
7.6	37.8	2502	7.6	37.8	2002	7.6	37.8	3127
7.6	45.4	2502	7.6	45.4	2002	7.6	45.4	3127
4.6	50.1	2502	4.6	50.1	2002	4.6	50.1	3127
3.0	53.1	2502	3.0	53.1	2002	3.0	53.1	3127
7.6	60.7	2502	7.6	60.7	2002	7.6	60.7	3127
9.7	70.4	3661	9.7	70.4	2929	9.7	70.4	4576
9.7	80.2	3661	9.7	80.2	2929	9.7	80.2	4576
9.7	89.9	3661	9.7	89.9	2929	9.7	89.9	4576
9.7	99.7	3661	9.7	99.7	2929	9.7	99.7	4576
9.8	109.4	3661	9.8	109.4	2929	9.8	109.4	4576
9.8	119.2	3661	9.8	119.2	2929	9.8	119.2	4576
9.8	129.0	3661	9.8	129.0	2929	9.8	129.0	4576
9.8	138.8	3661	9.8	138.8	2929	9.8	138.8	4576
16.4	155.2	7500	16.4	155.2	6000	16.4	155.2	9285
16.4	171.6	7500	16.4	171.6	6000	16.4	171.6	9285
26.1	197.7	8333	26.1	197.7	6667	26.1	197.7	9285
26.1	223.9	8333	26.1	223.9	6667	26.1	223.9	9285
26.1	250.0	8333	26.1	250.0	6667	26.1	250.0	9285
8.1	258.1	8333	8.1	258.1	6667	8.1	258.1	9285
48.4	306.5	8333	48.4	306.5	6667	48.4	306.5	9285
48.4	354.8	8333	48.4	354.8	6667	48.4	354.8	9285
48.4	403.2	8333	48.4	403.2	6667	48.4	403.2	9285
48.4	451.6	8333	48.4	451.6	6667	48.4	451.6	9285
48.4	500.0	8333	48.4	500.0	6667	48.4	500.0	9285
170.4	670.4	8333	170.4	670.4	6667	170.4	670.4	9285
170.4	840.8	8333	170.4	840.8	6667	170.4	840.8	9285
170.4	1011.2	8333	170.4	1011.2	6667	170.4	1011.2	9285
170.4	1181.5	8333	170.4	1181.5	6667	170.4	1181.5	9285

Profile 1			Profile 2			Profile 3		
Thickness (ft)	depth (ft)	Vs (ft/s)	Thickness (ft)	depth (ft)	Vs (ft/s)	Thickness (ft)	depth (ft)	Vs (ft/s)
170.4	1351.9	8333	170.4	1351.9	6667	170.4	1351.9	9285
170.4	1522.3	8333	170.4	1522.3	6667	170.4	1522.3	9285
170.4	1692.7	8333	170.4	1692.7	6667	170.4	1692.7	9285
170.4	1863.1	8333	170.4	1863.1	6667	170.4	1863.1	9285
170.4	2033.5	8333	170.4	2033.5	6667	170.4	2033.5	9285
170.4	2203.9	8333	170.4	2203.9	6667	170.4	2203.9	9285
3280.8	5484.7	9285	3280.8	5484.7	9285	3280.8	5484.7	9285

2.3.2.1 Shear Modulus and Damping Curves

No site-specific nonlinear dynamic material properties were available for the CEC for the soils and firm rock. The soil material over the upper 30.5 ft (9.3 m) was assumed to have behavior that could be modeled with either EPRI cohesionless soil or Peninsular Range G/G_{max} and hysteretic damping curves while the firm rock was assumed to reflect either EPRI firm rock curves or linear response (EPRI, 2013a). Consistent with the SPID (EPRI, 2013a), the EPRI soil and firm rock curves (model M1) were considered to be appropriate to represent the more nonlinear response likely to occur in the materials at this site. The Peninsular Range (PR) curves for soils combined with linear analysis for firm rock (model M2) (EPRI, 2013a) were assumed to represent an equally plausible more linear alternative response across loading level. For the linear analyses, the low strain damping from the EPRI rock curves were used as the constant damping values in the upper 500 ft.

2.3.2.2 Kappa

Base-case kappa estimates were determined using Section B-5.1.3.1 of the SPID (EPRI, 2013a) for a firm CEUS rock site. Kappa for a firm rock site with at least 3,000 ft (1 km) of sedimentary rock may be estimated from the average S-wave velocity over the upper 100 ft (V_{s100}) of the subsurface profile while for a site with less than 3,000 ft (1 km) of firm rock, kappa may be estimated with a Q_s of 40 below 500 ft combined with the low strain damping from the EPRI soil and rock curves and an additional kappa of 0.006s for the underlying hard rock. For the CEC site, with about 2,174 ft (663 m) of firm rock, the kappa estimates from the three profiles were 0.010 s, 0.014 s, and 0.003 s. Adding the additional kappa from the underlying hard basement rock produces total kappa values of 0.016 s, 0.020 s and 0.009 s. The range in kappa about the best estimate base-case value of 0.016 s (profile P1) was considered sufficient to adequately reflect epistemic uncertainty in low strain damping (kappa) for the profile. Additional epistemic uncertainty in profile damping (kappa) was considered to be accommodated at design loading levels by the multiple (2) sets of G/G_{max} and hysteretic damping curves for the soils and firm rock.

Table 2.3.2-2. Kappa Values and Weights Used for Site Response Analyses

Velocity Profile	Kappa(s)
P1	0.016
P2	0.020
P3	0.009
	Weights
P1	0.4
P2	0.3
P3	0.3
G/G_{max} and Hysteretic Damping Curves	
M1	0.5
M2	0.5

2.3.3 Randomization of Base Case Profiles

To account for the aleatory variability in dynamic material properties that is expected to occur across a site at the scale of a typical nuclear facility, variability in the assumed shear-wave velocity profiles has been incorporated in the site response calculations. For the CEC, random shear wave velocity profiles were developed from the base case profiles shown in Figure 2.3.2-1. Consistent with the discussion in Appendix B of the SPID (EPRI, 2013a), the velocity randomization procedure made use of random field models which describe the statistical correlation between layering and shear wave velocity. The default randomization parameters developed in Toro (1997) for USGS "A" site conditions were used for this site. Thirty random velocity profiles were generated for each base case profile. These random velocity profiles were generated using a natural log standard deviation of 0.25 over the upper 50 ft and 0.15 below that depth. As specified in the SPID (EPRI, 2013a), correlation of shear wave velocity between layers was modeled using the footprint correlation model. In the correlation model, a limit of +/- 2 standard deviations about the median value in each layer was assumed for the limits on random velocity fluctuations.

2.3.4 Input Spectra

Consistent with the guidance in Appendix B of the SPID (EPRI, 2013a), input Fourier amplitude spectra were defined for a single representative earthquake magnitude (**M** 6.5) using two different assumptions regarding the shape of the seismic source spectrum (single-corner and double-corner). A range of 11 different input amplitudes (median peak ground accelerations (PGA) ranging from 0.01 to 1.5 g) were used in the site response analyses. The characteristics of the seismic source and upper crustal attenuation properties assumed for the analysis of the CEC site were the same as those identified in Tables B-4, B-5, B-6 and B-7 of the SPID (EPRI, 2013a) as appropriate for typical CEUS site.

2.3.5 Methodology

To perform the site response analyses for the CEC site, a random vibration theory (RVT) approach was employed. This process utilizes a simple, efficient approach for computing site-specific amplification functions and is consistent with existing NRC guidance and the SPID (EPRI, 2013a). The guidance contained in Appendix B of the SPID (EPRI, 2013a) on incorporating epistemic uncertainty in shear-wave velocities, kappa, non-linear dynamic properties and source spectra for plants was followed for the CEC site.

2.3.6 Amplification Functions

The results of the site response analysis consist of amplification factors (5% damped pseudo absolute response spectra) which describe the amplification (or de-amplification) of hard reference rock motion as a function of frequency and input reference rock amplitude. The amplification factors are represented in terms of a median amplification value and an associated standard deviation (sigma) for each oscillator frequency and input rock amplitude. Consistent with the SPID (EPRI, 2013a) a minimum median amplification value of 0.5 was employed in the present analysis. Figure 2.3.6-1 illustrates the median and +/- 1 standard deviation in the predicted amplification factors developed for the eleven loading levels parameterized by the median reference (hard rock) peak acceleration (0.01g to 1.50g) for profile P1 and EPRI (EPRI, 2013a) rock G/G_{max} and hysteretic damping curves. The variability in the amplification factors results from variability in shear-wave velocity, depth to hard rock, and modulus reduction and hysteretic damping curves. To illustrate the effects of nonlinearity at the CEC firm rock site, Figure 2.3.6-2 shows the corresponding amplification factors developed with Peninsular Range G/G_{max} and hysteretic damping curves for soil combined with linear analysis for firm rock (model M2). Between the linear and nonlinear (equivalent-linear) analyses, Figure 2.3.6-1 and Figure 2.3.6-2 respectively show some differences at all loading levels and frequencies. Above about the 0.5g loading level, the differences increase especially at frequencies greater than about 1 Hz. Tabulated values of the amplification factors are provided in Appendix A.

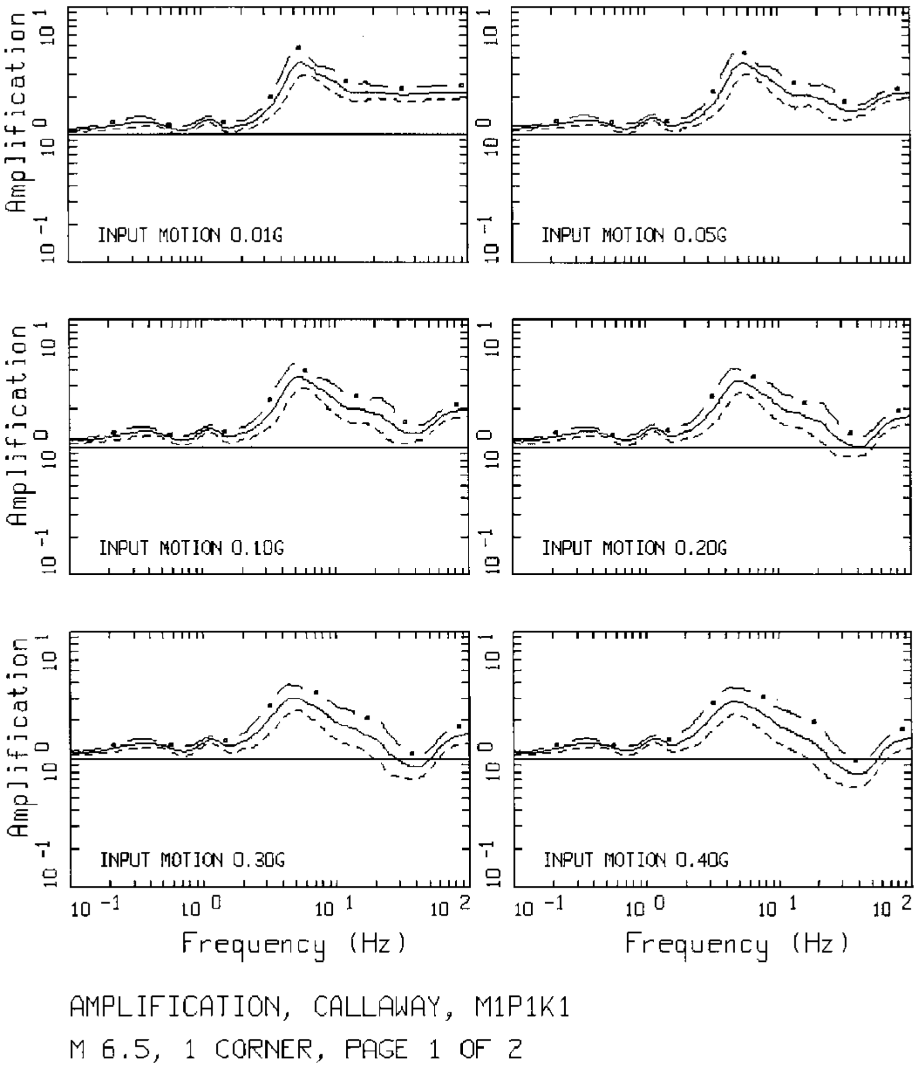
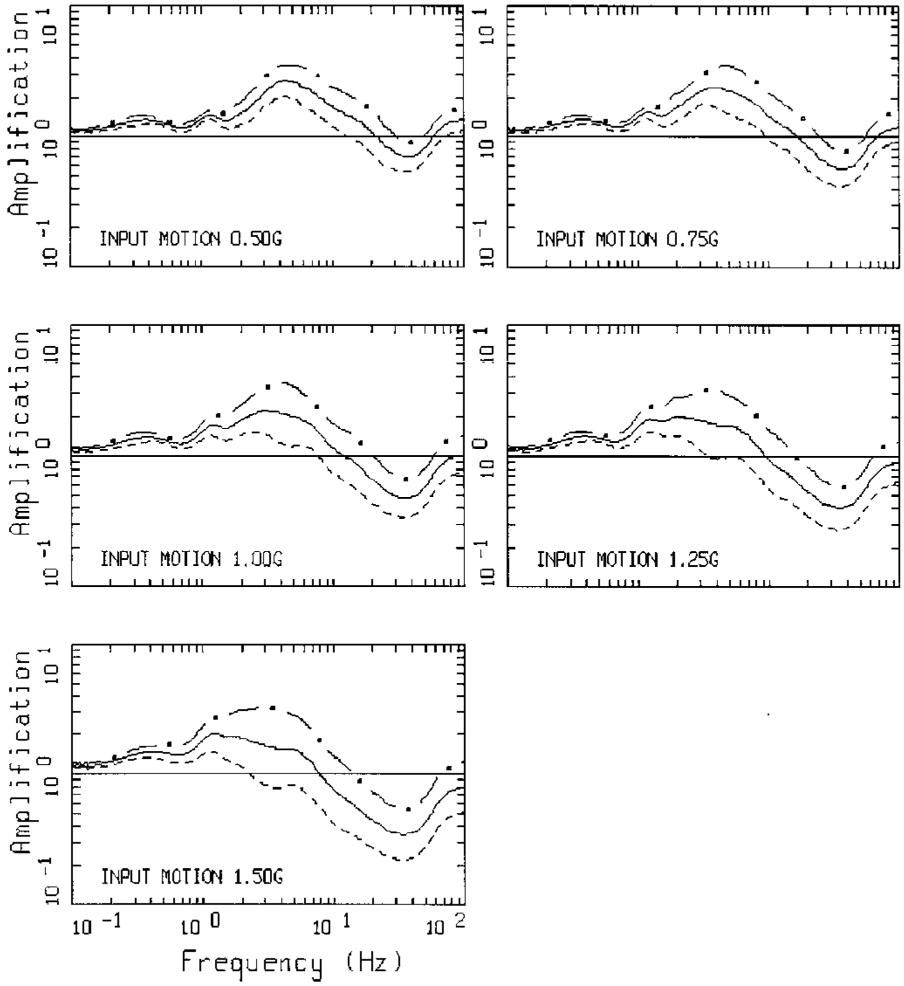


Figure 2.3.6-1. Example suite of amplification factors (5% damping pseudo absolute acceleration spectra) developed for the mean base-case profile (P1), EPRI rock modulus reduction and hysteretic damping curves (model M1), and base-case kappa (K1) at eleven loading levels of hard rock median peak acceleration values from 0.01g to 1.50g. M 6.5 and single-corner source model (EPRI, 2013a).



AMPLIFICATION, CALLAWAY, M1P1K1
M 6.5, 1 CORNER, PAGE 2 OF 2

Figure 2.3.6-1. (cont.)

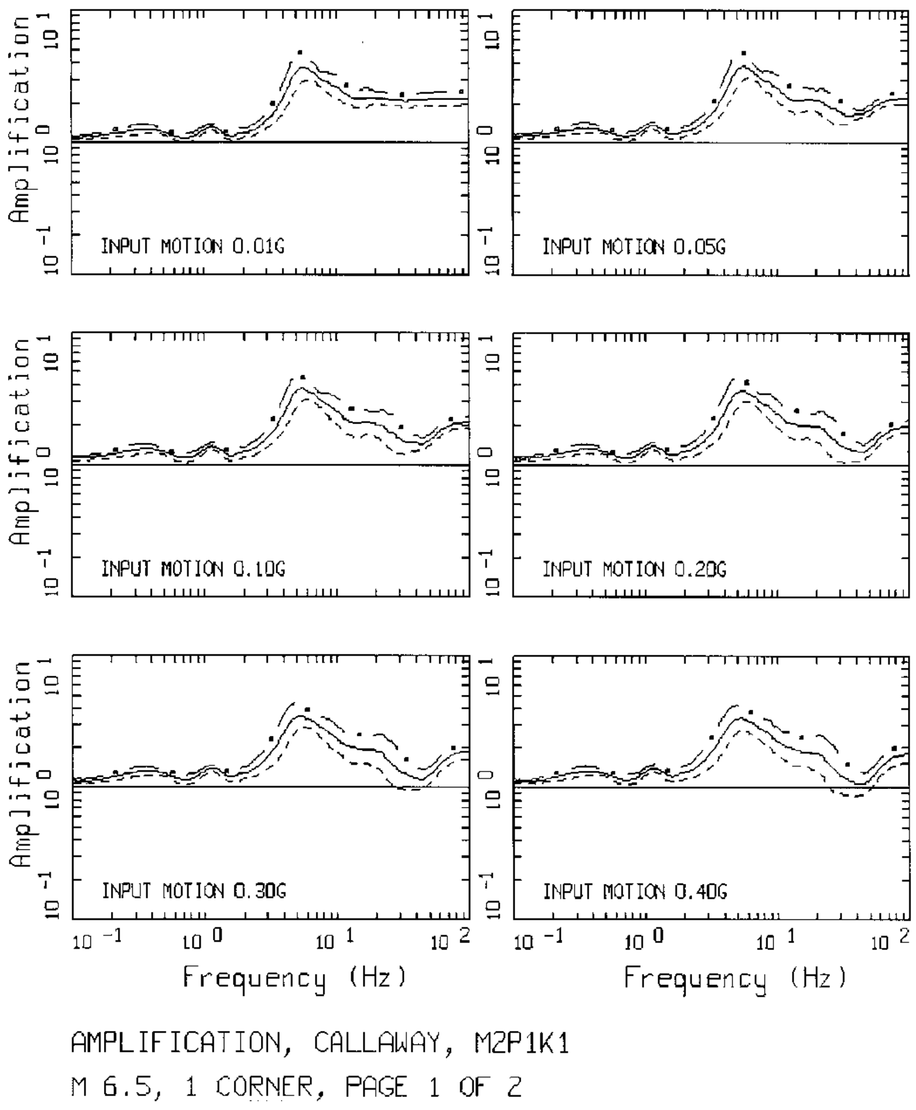


Figure 2.3.6-2. Example suite of amplification factors (5% damping pseudo absolute acceleration spectra) developed for the mean base-case profile (P1), linear site response (model M2), and base-case kappa (K1) at eleven loading levels of hard rock median peak acceleration values from 0.01g to 1.50g. M 6.5 and single-corner source model (EPRI, 2013a).

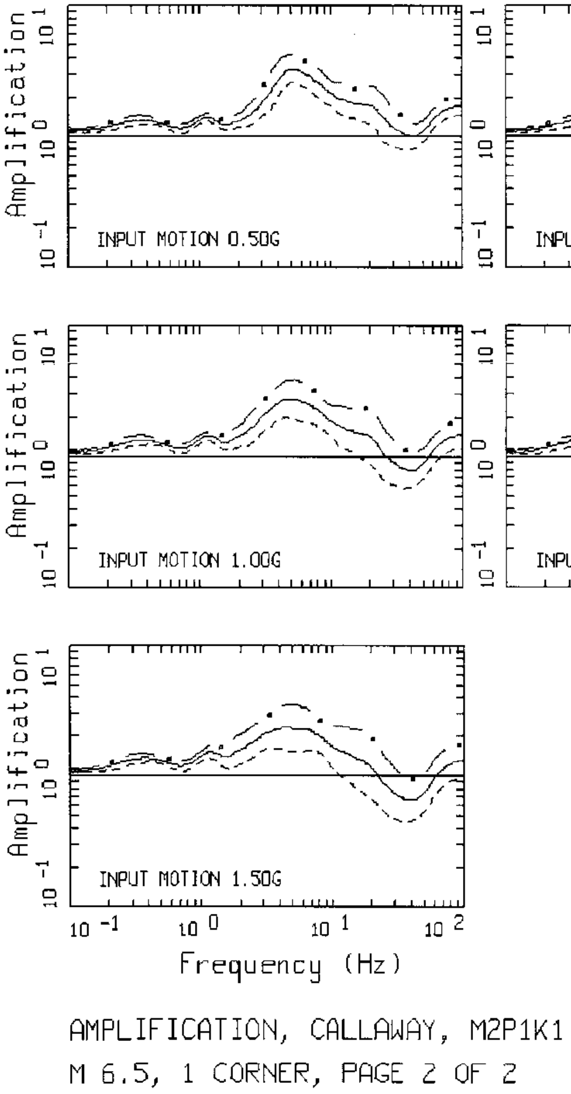


Figure 2.3.6-2. (cont.)

2.3.7 Control Point Seismic Hazard Curves

The procedure to develop probabilistic site-specific control point hazard curves used in the present analysis follows the methodology described in Section B-6.0 of the SPID (EPRI, 2013a). This procedure (referred to as Method 3) computes a site-specific control point hazard curve for a broad range of spectral accelerations given the site-specific bedrock hazard curve and site-specific estimates of soil or soft-rock response and associated uncertainties. This process is repeated for each of the seven spectral frequencies for which ground motion equations are available. The dynamic response of the materials below the control point was represented by the frequency- and amplitude-dependent amplification functions (median values and standard deviations) developed and described in the previous section. The resulting control point mean hazard curves for the CEC are shown in Figure 2.3.7-1 for the seven spectral frequencies for which ground motion equations are defined. Tabulated values of mean and fractile seismic hazard curves and site response amplification functions are provided in Appendix A.

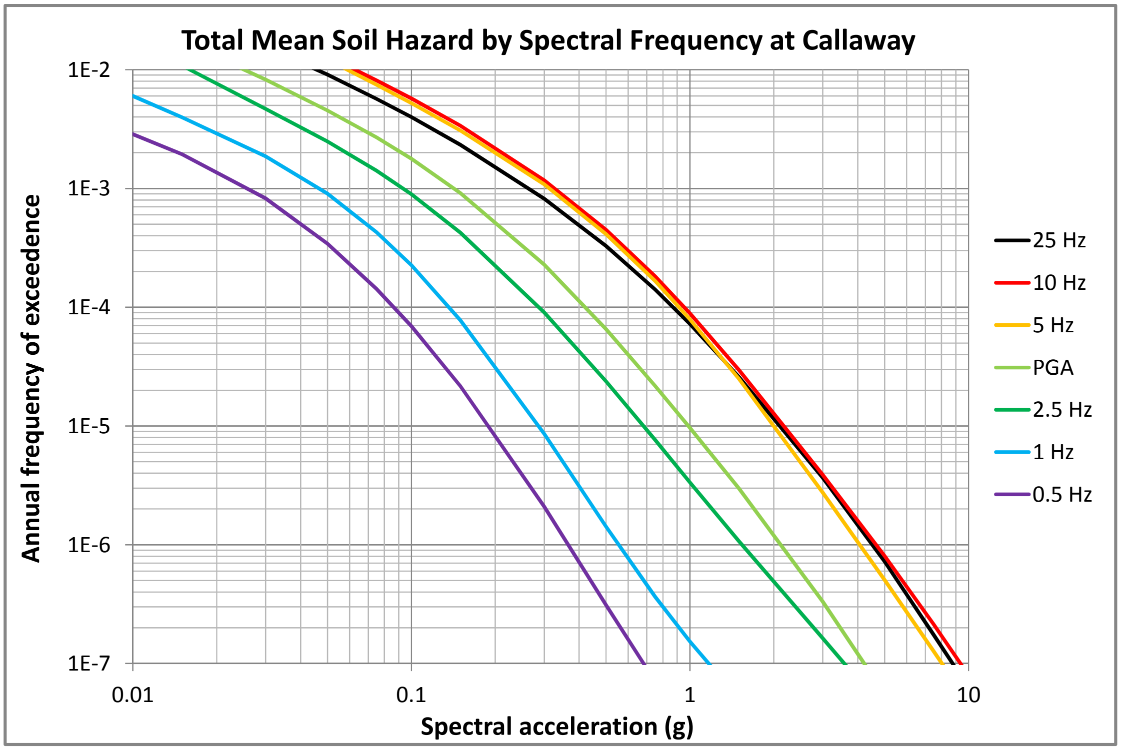


Figure 2.3.7-1. Control point mean hazard curves for spectral frequencies of 0.5, 1, 2.5, 5, 10, 25 and 100 Hz at CEC

2.4 Control Point Response Spectrum

The control point hazard curves described above have been used to develop uniform hazard response spectra (UHRS) and the ground motion response spectrum (GMRS). The UHRS were obtained through linear interpolation in log-log space to estimate the spectral acceleration at each spectral frequency for the

1E-4 and 1E-5 per year hazard levels. Table 2.4-1 shows the UHRS and GMRS accelerations for a range of spectral frequencies.

Table 2.4-1: UHRS and GMRS for Callaway.

Freq. (Hz)	10^{-4} UHRS (g)	10^{-5} UHRS (g)	GMRS (g)
100	4.20E-01	9.88E-01	5.00E-01
90	4.24E-01	1.00E+00	5.06E-01
80	4.30E-01	1.02E+00	5.15E-01
70	4.40E-01	1.05E+00	5.30E-01
60	4.61E-01	1.11E+00	5.57E-01
50	5.12E-01	1.23E+00	6.17E-01
40	6.17E-01	1.45E+00	7.34E-01
35	6.83E-01	1.60E+00	8.12E-01
30	7.68E-01	1.82E+00	9.20E-01
25	8.70E-01	2.10E+00	1.06E+00
20	9.16E-01	2.21E+00	1.11E+00
15	9.02E-01	2.18E+00	1.10E+00
12.5	9.10E-01	2.16E+00	1.09E+00
10	9.54E-01	2.17E+00	1.11E+00
9	9.90E-01	2.21E+00	1.13E+00
8	1.02E+00	2.24E+00	1.15E+00
7	1.03E+00	2.24E+00	1.15E+00
6	1.01E+00	2.19E+00	1.12E+00
5	9.14E-01	2.00E+00	1.02E+00
4	6.74E-01	1.55E+00	7.85E-01
3.5	5.29E-01	1.25E+00	6.32E-01
3	4.00E-01	9.59E-01	4.83E-01
2.5	2.87E-01	6.81E-01	3.44E-01
2	2.31E-01	5.32E-01	2.70E-01
1.5	1.70E-01	3.75E-01	1.92E-01
1.25	1.58E-01	3.39E-01	1.75E-01
1	1.36E-01	2.86E-01	1.48E-01
0.9	1.24E-01	2.61E-01	1.35E-01
0.8	1.12E-01	2.38E-01	1.23E-01
0.7	1.02E-01	2.19E-01	1.13E-01
0.6	9.47E-02	2.04E-01	1.05E-01
0.5	8.64E-02	1.89E-01	9.68E-02
0.4	6.91E-02	1.51E-01	7.75E-02
0.35	6.05E-02	1.32E-01	6.78E-02
0.3	5.18E-02	1.13E-01	5.81E-02
0.25	4.32E-02	9.44E-02	4.84E-02
0.2	3.45E-02	7.55E-02	3.87E-02
0.15	2.59E-02	5.66E-02	2.91E-02
0.125	2.16E-02	4.72E-02	2.42E-02
0.1	1.73E-02	3.77E-02	1.94E-02

The 1E-4 and 1E-5 UHRS are used to compute the GMRS at the control point and are shown in Figure 2.4-1.

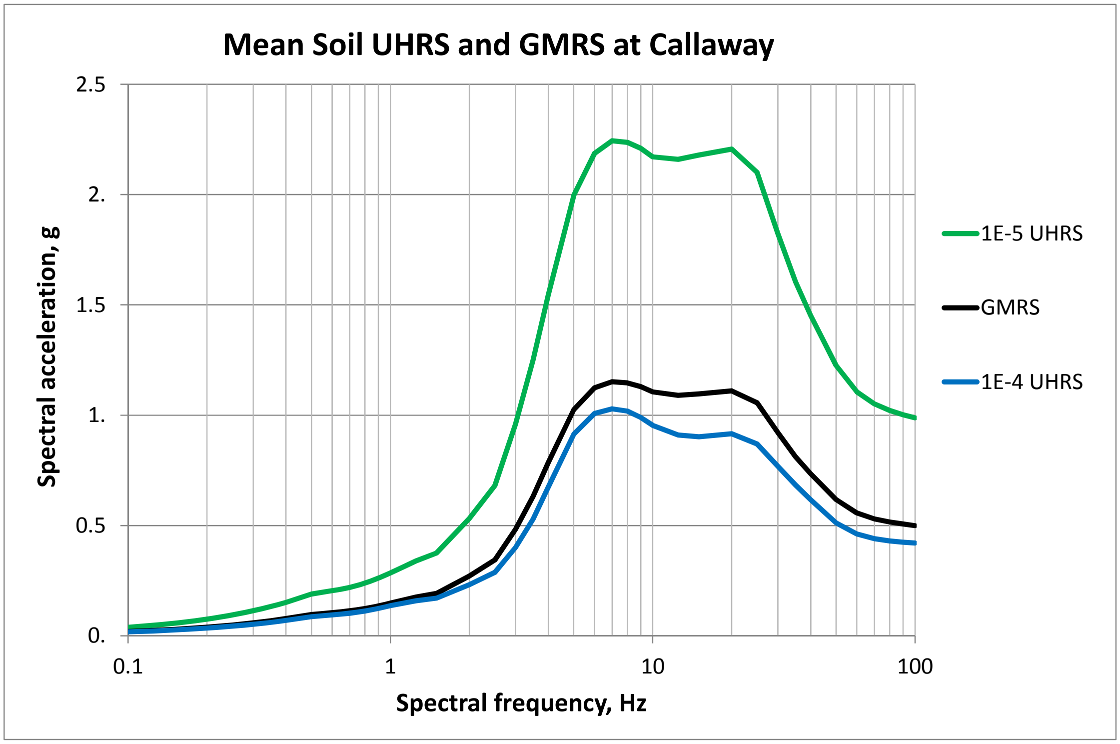


Figure 2.4-1: Plots of 1E-4 and 1E-5 uniform hazard spectra and GMRS at control point for CEC (5%-damped response spectra)

3 Plant Design Basis

The design basis for the CEC is identified in the Final Safety Analysis Report.

3.1 SSE Description of Spectral Shape

Refer to FSAR SA Sections 2.5 and 3.7 in addition to Section 3.7(B) of the Final Safety Analysis Report Standard Plant (FSAR SP) . The design event superseding all other considerations is taken as a recurrence of the New Madrid event 175 miles from the site. In order to provide an appropriate degree of conservatism, the SSE is defined as a horizontal ground acceleration at foundation level of 0.20g. This is equivalent to an intensity approaching MMI VIII at foundation level.

Due to the use of the SNUPPS standard design, the seismic responses of the major seismic Category I structures (containment, auxiliary/control, diesel generator, and fuel building) were originally generated for four sites (Callaway, Wolf Creek, Sterling, and Tyrone). The final geological and seismological design of the power block SSC is based on three sites (Callaway, Wolf Creek and Sterling) to ensure conservatism in the seismic design envelope. Certain items, whose final design was completed prior to the cancellation of Tyrone (the fourth site), are within the envelope for the four original sites. The site design response spectra in both the horizontal and vertical directions for the 0.20g SSE envelopes the SNUPPS sites and thus governs for both site-related non-power block and power block safety-related SSC.

The SSE is defined in terms of a PGA and a Regulatory Guide 1.60 design response spectral shape. The SSE is anchored to a 0.20g PGA. Table 3.1-1 and Figure 3.1-1 shows the spectral acceleration values as a function of frequency for the 5% damped horizontal SSE.

Table 3.1-1. SSE for CEC

Freq (Hz)	SA (g)
0.25	0.09
2.50	0.63
9.00	0.52
33.00	0.20
100.00	0.20

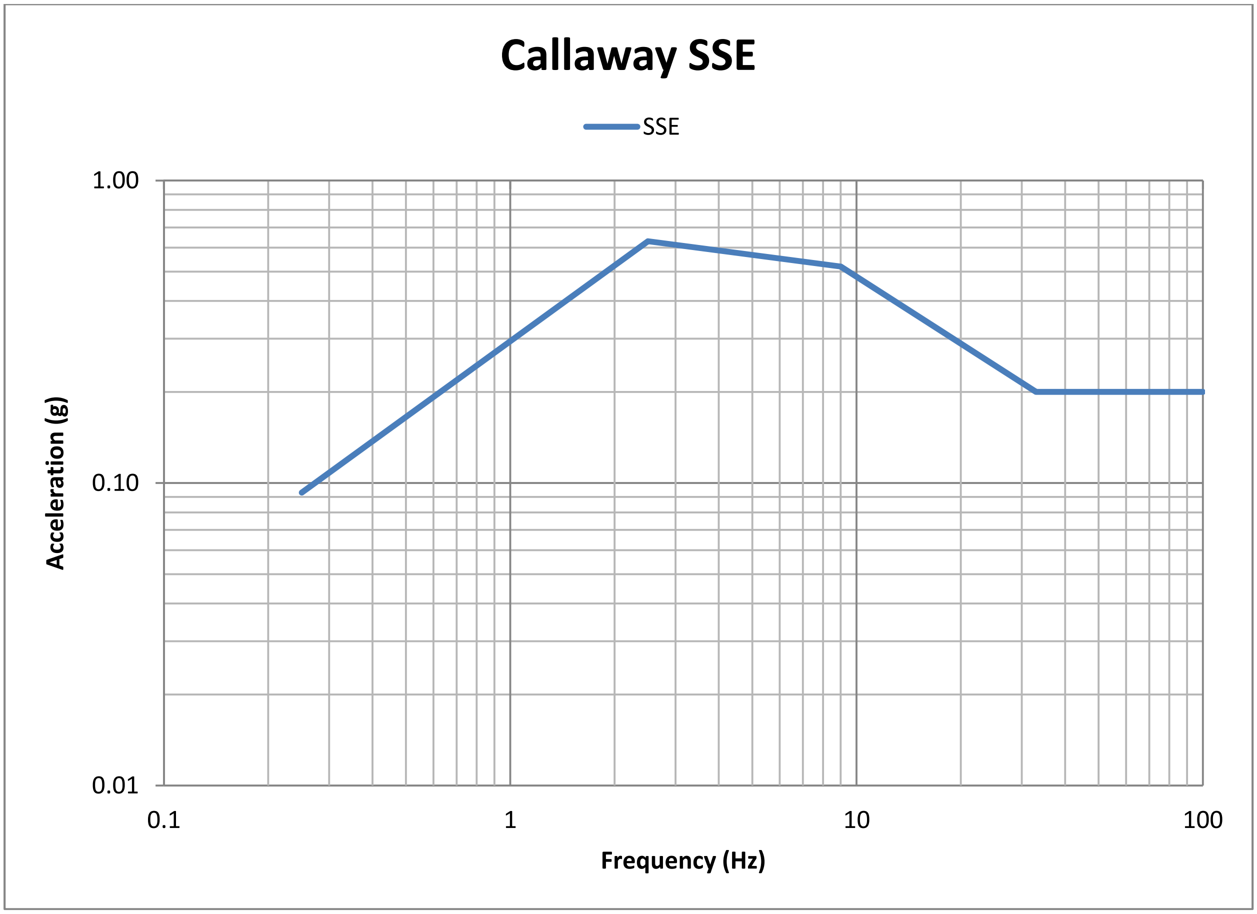


Figure 3.1-1: SSE for Callaway

3.2 Control Point Elevation

The SSE control point is defined at the free field at finish grade (Callaway Energy, 2014a).

Refer to FSAR Sections 3.7(B)-1. The CEC design response spectra are stated to be applied in the free field at finished grade.

4 Screening Evaluation

Following completion of the seismic hazard reevaluation, as requested in the 50.54(f) letter, a screening process is needed to determine if a seismic risk evaluation is needed. The horizontal GMRS determined from the hazard reevaluation is used to characterize the amplitude of the new seismic hazard at each of the nuclear power plant sites. The screening evaluation is based upon a comparison of the GMRS with the 5% damped horizontal SSE. In accordance with SPID Section 3, a screening evaluation was performed as described below.

4.1 Risk Evaluation Screening (1 to 10 Hz)

In the 1 to 10 Hz part of the response spectrum, the GMRS exceeds the SSE. Therefore, the CEC screens in for a risk evaluation.

4.2 High Frequency Screening (>10 Hz)

For a portion of the range above 10 Hz, the GMRS exceeds the SSE. Therefore, the CEC screens in for a high frequency confirmation (Relay Chatter).

4.3 Spent Fuel Pool Evaluation Screening (1 to 10 Hz)

In the 1 to 10 Hz part of the response spectrum, the GMRS exceeds the SSE. Therefore, the CEC screens in for a spent fuel pool evaluation.

5 Interim Actions

Based on the screening evaluation, the expedited seismic evaluation described in the Augumented Approach guidance (EPRI 2013c) will be performed as proposed in a letter to NRC dated April 9, 2013 (NEI 2013) and agreed to by NRC in a letter dated May 7, 2013 (USNRC 2013).

Consistent with NRC letter dated February 20, 2014 (USNRC 2014), the seismic hazard reevaluations presented herein are distinct from the current design and licensing bases of the CEC. Therefore, the results do not call into question the operability or functionality of SSCs and are not reportable pursuant to 10 CFR 50.72, "Immediate notification requirements for operating nuclear power reactors," and 10 CFR 50.73, "Licensee event report system.

The NRC letter also requests that licensees provide an interim evaluation or actions to demonstrate that the plant can cope with the reevaluated hazard while the expedited approach and risk evaluations are conducted. In response to that request, NEI letter dated March 12, 2014 (NEI, 2014), provides seismic core damage risk estimates using the updated seismic hazards for the operating nuclear plants in the Central and Eastern United States. These risk estimates continue to support the following conclusions of the NRC GI-199 Safety/Risk Assessment:

> 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 CEC is included in the March 12, 2014 risk estimates. Using the methodology described in the NEI letter, all plants were shown to be below 10^{-4}/year; thus, the above conclusions apply.

Callaway letter ULNRC-06065 (Callaway Energy, 2014b), dated January 14, 2014, documented the fully completed 2.3 Seismic Walkdown Program performed for the CEC. As a result of the walkdowns, it was reported to the NRC that there were no immediately implemented plant changes warranted as a result of the NTTF 2.3 Seismic Walkdown program. Resolutions of the Callaway Action Requests (CARs) for seismically insignificant unusual conditions and potentially adverse seismic conditions were identified in the CEC CAP. Current status and resolutions (where applicable and available) for CARs related to potentially adverse seismic conditions were noted in Attachment 1 of the letter referenced above.

6 Conclusions

In accordance with the 50.54(f) request for information, a seismic hazard and screening evaluation was performed for the CEC. A GMRS was developed solely for purpose of screening for additional evaluations in accordance with the SPID. Based on the results of the screening evaluation, the CEC screens in for risk evaluation, a Spent Fuel Pool evaluation, and a High Frequency Confirmation (Relay Chatter).

7 References

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Appendix A

Table A-1a. Mean and Fractile Seismic Hazard Curves for PGA at CEC

AMPS(g)	MEAN	0.05	0.16	0.50	0.84	0.95
0.0005	1.01E-01	7.34E-02	8.23E-02	9.93E-02	9.93E-02	9.93E-02
0.001	9.17E-02	5.91E-02	7.34E-02	9.24E-02	9.93E-02	9.93E-02
0.005	4.56E-02	1.95E-02	3.19E-02	4.43E-02	5.91E-02	7.45E-02
0.01	2.58E-02	1.02E-02	1.62E-02	2.42E-02	3.33E-02	5.05E-02
0.015	1.74E-02	6.64E-03	1.02E-02	1.60E-02	2.22E-02	3.84E-02
0.03	8.25E-03	2.68E-03	4.13E-03	7.03E-03	1.10E-02	2.19E-02
0.05	4.54E-03	1.04E-03	1.74E-03	3.63E-03	6.64E-03	1.31E-02
0.075	2.69E-03	4.07E-04	7.45E-04	1.90E-03	4.37E-03	8.35E-03
0.1	1.78E-03	1.95E-04	3.73E-04	1.07E-03	3.05E-03	6.17E-03
0.15	9.17E-04	6.45E-05	1.34E-04	4.25E-04	1.60E-03	3.68E-03
0.3	2.28E-04	1.05E-05	2.32E-05	8.35E-05	3.14E-04	9.79E-04
0.5	6.54E-05	2.84E-06	6.64E-06	2.49E-05	8.47E-05	2.32E-04
0.75	2.17E-05	8.98E-07	2.22E-06	8.98E-06	3.19E-05	7.34E-05
1.	9.66E-06	3.47E-07	9.37E-07	4.07E-06	1.55E-05	3.42E-05
1.5	2.97E-06	7.03E-08	2.29E-07	1.18E-06	5.20E-06	1.15E-05
3.	3.31E-07	2.29E-09	1.16E-08	9.37E-08	5.42E-07	1.42E-06
5.	5.53E-08	2.25E-10	8.98E-10	1.02E-08	8.12E-08	2.46E-07
7.5	1.21E-08	1.62E-10	2.01E-10	1.46E-09	1.51E-08	5.50E-08
10.	3.89E-09	1.32E-10	1.62E-10	4.19E-10	4.13E-09	1.77E-08

Table A-1b. Mean and Fractile Seismic Hazard Curves for 25 Hz at CEC

AMPS(g)	MEAN	0.05	0.16	0.50	0.84	0.95
0.0005	1.04E-01	7.77E-02	8.60E-02	9.93E-02	9.93E-02	9.93E-02
0.001	9.76E-02	7.03E-02	7.89E-02	9.79E-02	9.93E-02	9.93E-02
0.005	6.11E-02	3.28E-02	4.56E-02	6.09E-02	7.55E-02	8.98E-02
0.01	4.01E-02	1.90E-02	2.76E-02	3.90E-02	5.12E-02	6.83E-02
0.015	2.93E-02	1.31E-02	1.92E-02	2.76E-02	3.79E-02	5.50E-02
0.03	1.56E-02	6.26E-03	9.11E-03	1.40E-02	2.04E-02	3.37E-02
0.05	9.09E-03	3.05E-03	4.63E-03	7.89E-03	1.25E-02	2.07E-02
0.075	5.69E-03	1.44E-03	2.39E-03	4.77E-03	8.35E-03	1.36E-02
0.1	3.98E-03	7.66E-04	1.36E-03	3.19E-03	6.26E-03	1.02E-02
0.15	2.33E-03	2.84E-04	5.66E-04	1.62E-03	4.01E-03	6.83E-03
0.3	8.19E-04	4.50E-05	1.11E-04	3.95E-04	1.46E-03	3.19E-03
0.5	3.28E-04	1.23E-05	3.19E-05	1.27E-04	5.20E-04	1.38E-03
0.75	1.41E-04	4.63E-06	1.20E-05	5.12E-05	2.01E-04	5.58E-04
1.	7.23E-05	2.25E-06	6.00E-06	2.60E-05	1.02E-04	2.68E-04
1.5	2.58E-05	8.12E-07	2.22E-06	9.79E-06	3.90E-05	9.11E-05
3.	3.66E-06	1.36E-07	3.52E-07	1.53E-06	6.17E-06	1.42E-05
5.	7.20E-07	2.60E-08	6.93E-08	3.09E-07	1.23E-06	2.88E-06
7.5	1.75E-07	4.70E-09	1.42E-08	7.03E-08	3.09E-07	6.93E-07
10.	6.26E-08	1.13E-09	3.68E-09	2.25E-08	1.16E-07	2.49E-07

Table A-1c. Mean and Fractile Seismic Hazard Curves for 10 Hz at CEC

AMPS(g)	MEAN	0.05	0.16	0.50	0.84	0.95
0.0005	1.07E-01	8.12E-02	8.85E-02	9.93E-02	9.93E-02	9.93E-02
0.001	1.04E-01	7.77E-02	8.60E-02	9.93E-02	9.93E-02	9.93E-02
0.005	7.55E-02	4.90E-02	5.91E-02	7.55E-02	9.11E-02	9.93E-02
0.01	5.37E-02	3.01E-02	3.90E-02	5.35E-02	6.83E-02	7.89E-02
0.015	4.07E-02	2.10E-02	2.80E-02	4.01E-02	5.27E-02	6.36E-02
0.03	2.22E-02	1.04E-02	1.42E-02	2.13E-02	2.96E-02	3.90E-02
0.05	1.30E-02	5.58E-03	7.89E-03	1.21E-02	1.77E-02	2.42E-02
0.075	8.15E-03	3.14E-03	4.56E-03	7.45E-03	1.13E-02	1.60E-02
0.1	5.73E-03	1.92E-03	2.96E-03	5.12E-03	8.35E-03	1.18E-02
0.15	3.37E-03	8.60E-04	1.40E-03	2.84E-03	5.27E-03	7.77E-03
0.3	1.17E-03	1.55E-04	2.88E-04	7.66E-04	2.07E-03	3.63E-03
0.5	4.49E-04	3.73E-05	7.66E-05	2.29E-04	7.55E-04	1.67E-03
0.75	1.82E-04	1.16E-05	2.57E-05	8.35E-05	2.80E-04	6.93E-04
1.	8.90E-05	5.20E-06	1.16E-05	4.07E-05	1.31E-04	3.23E-04
1.5	2.95E-05	1.57E-06	3.79E-06	1.38E-05	4.50E-05	9.93E-05
3.	3.88E-06	1.49E-07	4.07E-07	1.77E-06	6.83E-06	1.40E-05
5.	8.05E-07	1.69E-08	5.50E-08	3.09E-07	1.44E-06	3.23E-06
7.5	2.15E-07	2.35E-09	9.24E-09	6.73E-08	3.73E-07	9.11E-07
10.	7.96E-08	5.75E-10	2.35E-09	2.04E-08	1.32E-07	3.52E-07

Table A-1d. Mean and Fractile Seismic Hazard Curves for 5 Hz at CEC

AMPS(g)	MEAN	0.05	0.16	0.50	0.84	0.95
0.0005	1.07E-01	8.12E-02	8.98E-02	9.93E-02	9.93E-02	9.93E-02
0.001	1.04E-01	7.77E-02	8.60E-02	9.93E-02	9.93E-02	9.93E-02
0.005	7.63E-02	4.63E-02	5.75E-02	7.55E-02	9.51E-02	9.93E-02
0.01	5.39E-02	2.76E-02	3.68E-02	5.35E-02	7.13E-02	8.23E-02
0.015	4.05E-02	1.90E-02	2.60E-02	3.95E-02	5.50E-02	6.64E-02
0.03	2.14E-02	8.98E-03	1.27E-02	2.01E-02	3.05E-02	3.79E-02
0.05	1.22E-02	4.83E-03	6.93E-03	1.13E-02	1.74E-02	2.22E-02
0.075	7.47E-03	2.68E-03	4.07E-03	6.93E-03	1.08E-02	1.40E-02
0.1	5.22E-03	1.67E-03	2.64E-03	4.83E-03	7.77E-03	1.02E-02
0.15	3.08E-03	7.66E-04	1.31E-03	2.72E-03	4.83E-03	6.64E-03
0.3	1.08E-03	1.53E-04	2.88E-04	7.45E-04	1.84E-03	3.19E-03
0.5	4.13E-04	3.84E-05	7.77E-05	2.19E-04	6.73E-04	1.51E-03
0.75	1.66E-04	1.20E-05	2.53E-05	7.55E-05	2.39E-04	6.64E-04
1.	7.93E-05	5.12E-06	1.11E-05	3.42E-05	1.08E-04	3.14E-04
1.5	2.49E-05	1.53E-06	3.42E-06	1.11E-05	3.42E-05	9.24E-05
3.	2.74E-06	1.62E-07	3.84E-07	1.42E-06	4.56E-06	9.51E-06
5.	5.03E-07	2.29E-08	6.00E-08	2.49E-07	8.98E-07	1.84E-06
7.5	1.27E-07	3.68E-09	1.10E-08	5.27E-08	2.22E-07	4.98E-07
10.	4.66E-08	9.51E-10	2.88E-09	1.60E-08	7.77E-08	1.92E-07

Table A-1e. Mean and Fractile Seismic Hazard Curves for 2.5 Hz at CEC

AMPS(g)	MEAN	0.05	0.16	0.50	0.84	0.95
0.0005	1.00E-01	7.34E-02	8.23E-02	9.93E-02	9.93E-02	9.93E-02
0.001	8.74E-02	5.91E-02	6.93E-02	8.72E-02	9.93E-02	9.93E-02
0.005	3.51E-02	1.67E-02	2.25E-02	3.37E-02	4.83E-02	5.83E-02
0.01	1.74E-02	7.66E-03	1.05E-02	1.62E-02	2.46E-02	3.05E-02
0.015	1.08E-02	4.56E-03	6.45E-03	1.01E-02	1.53E-02	1.92E-02
0.03	4.68E-03	1.55E-03	2.42E-03	4.37E-03	6.93E-03	8.85E-03
0.05	2.48E-03	5.58E-04	9.79E-04	2.16E-03	4.01E-03	5.50E-03
0.075	1.41E-03	2.10E-04	4.01E-04	1.07E-03	2.46E-03	3.79E-03
0.1	8.94E-04	9.65E-05	1.95E-04	5.75E-04	1.60E-03	2.76E-03
0.15	4.25E-04	2.88E-05	6.26E-05	2.07E-04	7.34E-04	1.62E-03
0.3	9.04E-05	3.09E-06	7.45E-06	2.72E-05	1.21E-04	4.01E-04
0.5	2.38E-05	5.83E-07	1.51E-06	6.17E-06	2.72E-05	9.37E-05
0.75	7.63E-06	1.57E-07	4.43E-07	2.04E-06	8.85E-06	2.64E-05
1.	3.35E-06	6.17E-08	1.92E-07	9.51E-07	4.25E-06	1.13E-05
1.5	1.07E-06	1.62E-08	5.75E-08	3.33E-07	1.55E-06	3.79E-06
3.	1.64E-07	1.40E-09	6.45E-09	4.83E-08	2.64E-07	6.83E-07
5.	4.00E-08	2.92E-10	1.15E-09	9.93E-09	6.26E-08	1.77E-07
7.5	1.20E-08	1.72E-10	3.33E-10	2.53E-09	1.77E-08	5.35E-08
10.	4.76E-09	1.62E-10	1.98E-10	9.51E-10	6.64E-09	2.13E-08

Table A-1f. Mean and Fractile Seismic Hazard Curves for 1 Hz at CEC

AMPS(g)	MEAN	0.05	0.16	0.50	0.84	0.95
0.0005	7.25E-02	4.01E-02	5.20E-02	7.23E-02	9.24E-02	9.93E-02
0.001	4.99E-02	2.25E-02	3.23E-02	4.98E-02	6.64E-02	7.89E-02
0.005	1.23E-02	4.70E-03	7.13E-03	1.16E-02	1.72E-02	2.22E-02
0.01	6.02E-03	2.04E-03	3.19E-03	5.58E-03	8.72E-03	1.15E-02
0.015	3.97E-03	1.08E-03	1.87E-03	3.63E-03	6.09E-03	8.00E-03
0.03	1.86E-03	2.68E-04	5.58E-04	1.51E-03	3.19E-03	4.63E-03
0.05	9.06E-04	7.13E-05	1.72E-04	6.09E-04	1.67E-03	2.76E-03
0.075	4.28E-04	2.10E-05	5.42E-05	2.29E-04	7.89E-04	1.51E-03
0.1	2.25E-04	8.12E-06	2.19E-05	1.01E-04	3.95E-04	8.60E-04
0.15	7.76E-05	1.92E-06	5.50E-06	2.72E-05	1.29E-04	3.19E-04
0.3	8.57E-06	1.32E-07	4.07E-07	2.25E-06	1.18E-05	3.63E-05
0.5	1.42E-06	1.44E-08	5.35E-08	3.37E-07	1.90E-06	5.83E-06
0.75	3.65E-07	2.19E-09	9.65E-09	7.55E-08	5.05E-07	1.55E-06
1.	1.53E-07	6.00E-10	2.72E-09	2.64E-08	2.04E-07	6.83E-07
1.5	5.03E-08	1.92E-10	5.05E-10	5.83E-09	6.00E-08	2.29E-07
3.	7.63E-09	1.36E-10	1.62E-10	4.98E-10	6.73E-09	3.33E-08
5.	1.62E-09	1.29E-10	1.53E-10	1.77E-10	1.18E-09	6.36E-09
7.5	4.13E-10	1.21E-10	1.32E-10	1.62E-10	3.28E-10	1.53E-09
10.	1.44E-10	1.21E-10	1.32E-10	1.62E-10	1.95E-10	5.75E-10

Table A-1g. Mean and Fractile Seismic Hazard Curves for 0.5 Hz at CEC

AMPS(g)	MEAN	0.05	0.16	0.50	0.84	0.95
0.0005	3.70E-02	1.84E-02	2.64E-02	3.57E-02	4.77E-02	5.66E-02
0.001	2.16E-02	9.79E-03	1.46E-02	2.04E-02	2.84E-02	3.63E-02
0.005	5.27E-03	1.79E-03	2.76E-03	4.83E-03	7.77E-03	1.02E-02
0.01	2.87E-03	5.83E-04	1.08E-03	2.53E-03	4.63E-03	6.36E-03
0.015	1.94E-03	2.49E-04	5.35E-04	1.57E-03	3.37E-03	4.90E-03
0.03	8.24E-04	4.13E-05	1.13E-04	4.90E-04	1.55E-03	2.72E-03
0.05	3.42E-04	8.23E-06	2.57E-05	1.44E-04	6.09E-04	1.36E-03
0.075	1.43E-04	1.98E-06	6.73E-06	4.37E-05	2.29E-04	6.45E-04
0.1	6.92E-05	6.83E-07	2.35E-06	1.69E-05	9.79E-05	3.23E-04
0.15	2.17E-05	1.38E-07	4.90E-07	3.84E-06	2.53E-05	1.01E-04
0.3	2.09E-06	6.73E-09	2.64E-08	2.42E-07	1.98E-06	8.98E-06
0.5	3.11E-07	6.09E-10	2.49E-09	2.64E-08	2.76E-07	1.31E-06
0.75	7.06E-08	1.82E-10	4.50E-10	4.19E-09	5.75E-08	3.05E-07
1.	2.67E-08	1.62E-10	2.04E-10	1.23E-09	1.84E-08	1.16E-07
1.5	7.57E-09	1.32E-10	1.62E-10	2.92E-10	3.79E-09	3.09E-08
3.	9.13E-10	1.21E-10	1.32E-10	1.62E-10	3.33E-10	2.72E-09
5.	1.65E-10	1.21E-10	1.32E-10	1.62E-10	1.72E-10	4.70E-10
7.5	3.71E-11	1.21E-10	1.32E-10	1.62E-10	1.72E-10	1.92E-10
10.	1.18E-11	1.21E-10	1.32E-10	1.62E-10	1.62E-10	1.72E-10

Table A-2. Amplification Functions for CEC

PGA	Median AF	Sigma ln(AF)	25 Hz	Median AF	Sigma ln(AF)	10 Hz	Median AF	Sigma ln(AF)	5 Hz	Median AF	Sigma ln(AF)
1.00E-02	2.44E+00	1.22E-01	1.30E-02	2.42E+00	1.49E-01	1.90E-02	2.86E+00	1.73E-01	2.09E-02	3.18E+00	2.66E-01
4.95E-02	2.42E+00	1.13E-01	1.02E-01	2.17E+00	2.70E-01	9.99E-02	2.77E+00	2.09E-01	8.24E-02	3.29E+00	2.52E-01
9.64E-02	2.28E+00	1.28E-01	2.13E-01	2.02E+00	3.03E-01	1.85E-01	2.67E+00	2.28E-01	1.44E-01	3.29E+00	2.51E-01
1.94E-01	2.09E+00	1.52E-01	4.43E-01	1.80E+00	3.31E-01	3.56E-01	2.51E+00	2.59E-01	2.65E-01	3.24E+00	2.50E-01
2.92E-01	1.96E+00	1.71E-01	6.76E-01	1.65E+00	3.50E-01	5.23E-01	2.38E+00	2.79E-01	3.84E-01	3.16E+00	2.65E-01
3.91E-01	1.85E+00	1.86E-01	9.09E-01	1.52E+00	3.62E-01	6.90E-01	2.27E+00	2.90E-01	5.02E-01	3.08E+00	2.76E-01
4.93E-01	1.75E+00	2.01E-01	1.15E+00	1.41E+00	3.73E-01	8.61E-01	2.17E+00	2.98E-01	6.22E-01	2.99E+00	2.93E-01
7.41E-01	1.57E+00	2.36E-01	1.73E+00	1.19E+00	3.93E-01	1.27E+00	1.96E+00	3.27E-01	9.13E-01	2.79E+00	3.41E-01
1.01E+00	1.43E+00	2.69E-01	2.36E+00	1.02E+00	4.11E-01	1.72E+00	1.78E+00	3.45E-01	1.22E+00	2.57E+00	3.97E-01
1.28E+00	1.31E+00	2.98E-01	3.01E+00	8.90E-01	4.27E-01	2.17E+00	1.63E+00	3.83E-01	1.54E+00	2.35E+00	4.32E-01
1.55E+00	1.21E+00	3.27E-01	3.63E+00	7.92E-01	4.40E-01	2.61E+00	1.50E+00	4.18E-01	1.85E+00	2.19E+00	4.72E-01
2.5 Hz	**Median AF**	**Sigma ln(AF)**	**1 Hz**	**Median AF**	**Sigma ln(AF)**	**0.5 Hz**	**Median AF**	**Sigma ln(AF)**			
2.18E-02	1.34E+00	1.38E-01	1.27E-02	1.30E+00	1.05E-01	8.25E-03	1.26E+00	7.53E-02			
7.05E-02	1.42E+00	1.55E-01	3.43E-02	1.34E+00	1.05E-01	1.96E-02	1.29E+00	7.51E-02			
1.18E-01	1.47E+00	1.71E-01	5.51E-02	1.35E+00	1.05E-01	3.02E-02	1.30E+00	7.55E-02			
2.12E-01	1.54E+00	2.02E-01	9.63E-02	1.38E+00	1.07E-01	5.11E-02	1.31E+00	7.70E-02			
3.04E-01	1.61E+00	2.26E-01	1.36E-01	1.40E+00	1.11E-01	7.10E-02	1.32E+00	7.85E-02			
3.94E-01	1.68E+00	2.41E-01	1.75E-01	1.42E+00	1.17E-01	9.06E-02	1.34E+00	7.90E-02			
4.86E-01	1.74E+00	2.53E-01	2.14E-01	1.45E+00	1.26E-01	1.10E-01	1.34E+00	7.93E-02			
7.09E-01	1.85E+00	2.88E-01	3.10E-01	1.51E+00	1.51E-01	1.58E-01	1.35E+00	8.07E-02			
9.47E-01	1.91E+00	3.57E-01	4.12E-01	1.55E+00	1.71E-01	2.09E-01	1.36E+00	8.36E-02			
1.19E+00	1.92E+00	4.13E-01	5.18E-01	1.59E+00	1.82E-01	2.62E-01	1.37E+00	8.71E-02			
1.43E+00	1.91E+00	4.31E-01	6.19E-01	1.61E+00	2.03E-01	3.12E-01	1.39E+00	1.03E-01			

Tables A2-b1 and A2-b2 are tabular versions of the typical amplification factors provided in Figures 2.3.6-1 and 2.3.6-2. Values are provided for two input motion levels at approximately 10-4 and 10-5 mean annual frequency of exceedance (EPRI, 2014). These factors are unverified and are provided for information only. The figures should be considered the governing information.

Table A2-b1. Median AFs and sigmas for Model 1, Profile 1, for 2 PGA levels.

M1P1K1	Rock PGA=0.292			M1P1K1	PGA=1.01		
Freq. (Hz)	Soil_SA	med. AF	sigma ln(AF)	Freq. (Hz)	Soil_SA	med. AF	sigma ln(AF)
100.0	0.463	1.583	0.165	100.0	1.044	1.038	0.323
87.1	0.465	1.546	0.166	87.1	1.046	1.006	0.323
75.9	0.468	1.482	0.168	75.9	1.048	0.951	0.324
66.1	0.473	1.361	0.170	66.1	1.052	0.853	0.325
57.5	0.482	1.172	0.175	57.5	1.058	0.709	0.326
50.1	0.498	1.001	0.183	50.1	1.067	0.585	0.329
43.7	0.524	0.890	0.195	43.7	1.083	0.503	0.333
38.0	0.564	0.875	0.215	38.0	1.107	0.475	0.340
33.1	0.616	0.909	0.246	33.1	1.146	0.473	0.348
28.8	0.668	0.991	0.293	28.8	1.197	0.503	0.361
25.1	0.738	1.092	0.344	25.1	1.269	0.538	0.391
21.9	0.833	1.303	0.368	21.9	1.359	0.616	0.415
19.1	0.916	1.459	0.359	19.1	1.470	0.687	0.425
16.6	0.931	1.553	0.312	16.6	1.604	0.792	0.445
14.5	0.945	1.657	0.289	14.5	1.726	0.904	0.468
12.6	0.970	1.755	0.307	12.6	1.805	0.984	0.456
11.0	0.978	1.822	0.297	11.0	1.897	1.072	0.438
9.5	1.019	1.994	0.305	9.5	2.009	1.202	0.436
8.3	1.058	2.251	0.303	8.3	2.149	1.408	0.425
7.2	1.083	2.469	0.279	7.2	2.286	1.613	0.417
6.3	1.106	2.690	0.251	6.3	2.382	1.805	0.441
5.5	1.145	2.924	0.227	5.5	2.417	1.933	0.488
4.8	1.151	3.014	0.230	4.8	2.444	2.013	0.537
4.2	1.065	2.881	0.278	4.2	2.456	2.101	0.540
3.6	0.886	2.469	0.285	3.6	2.431	2.150	0.491
3.2	0.700	2.074	0.266	3.2	2.313	2.186	0.418
2.8	0.563	1.762	0.244	2.8	2.162	2.166	0.356
2.4	0.451	1.534	0.211	2.4	1.892	2.065	0.317
2.1	0.375	1.405	0.156	2.1	1.596	1.926	0.273
1.8	0.315	1.319	0.142	1.8	1.312	1.780	0.246
1.6	0.258	1.249	0.108	1.6	1.042	1.640	0.224
1.4	0.233	1.317	0.093	1.4	0.902	1.658	0.214
1.2	0.221	1.420	0.070	1.2	0.813	1.708	0.186
1.0	0.194	1.383	0.062	1.0	0.684	1.603	0.155
0.91	0.160	1.254	0.071	0.91	0.544	1.412	0.127
0.79	0.134	1.167	0.080	0.79	0.443	1.283	0.105
0.69	0.117	1.150	0.082	0.69	0.378	1.241	0.090
0.60	0.105	1.185	0.068	0.60	0.332	1.260	0.072
0.52	0.094	1.243	0.051	0.52	0.291	1.310	0.056
0.46	0.082	1.299	0.052	0.46	0.250	1.359	0.059
0.10	0.003	1.132	0.029	0.10	0.009	1.149	0.036

Table A2-b2. Median AFs and sigmas for Model 2, Profile 1, for 2 PGA levels.

M2P1K1	PGA=0.292			M2P1K1	PGA=1.01		
Freq. (Hz)	Soil_SA	med. AF	sigma ln(AF)	Freq. (Hz)	Soil_SA	med. AF	sigma ln(AF)
100.0	0.548	1.875	0.125	100.0	1.495	1.487	0.233
87.1	0.552	1.836	0.127	87.1	1.504	1.446	0.235
75.9	0.558	1.766	0.129	75.9	1.516	1.375	0.239
66.1	0.568	1.634	0.133	66.1	1.536	1.245	0.245
57.5	0.586	1.426	0.139	57.5	1.571	1.053	0.256
50.1	0.620	1.246	0.149	50.1	1.633	0.896	0.272
43.7	0.672	1.140	0.172	43.7	1.723	0.800	0.292
38.0	0.760	1.179	0.223	38.0	1.865	0.800	0.327
33.1	0.843	1.243	0.266	33.1	2.050	0.847	0.373
28.8	0.920	1.365	0.332	28.8	2.226	0.935	0.410
25.1	1.042	1.542	0.365	25.1	2.503	1.061	0.464
21.9	1.155	1.806	0.327	21.9	2.873	1.302	0.483
19.1	1.179	1.878	0.267	19.1	3.128	1.461	0.470
16.6	1.146	1.911	0.229	16.6	3.066	1.514	0.419
14.5	1.113	1.951	0.253	14.5	3.039	1.592	0.379
12.6	1.113	2.015	0.265	12.6	3.057	1.667	0.361
11.0	1.150	2.142	0.234	11.0	3.131	1.770	0.313
9.5	1.232	2.411	0.242	9.5	3.270	1.956	0.263
8.3	1.265	2.693	0.220	8.3	3.350	2.195	0.258
7.2	1.283	2.925	0.174	7.2	3.372	2.380	0.298
6.3	1.328	3.230	0.161	6.3	3.401	2.577	0.336
5.5	1.361	3.478	0.187	5.5	3.371	2.697	0.342
4.8	1.286	3.365	0.262	4.8	3.318	2.733	0.327
4.2	1.058	2.863	0.317	4.2	3.104	2.655	0.304
3.6	0.808	2.252	0.299	3.6	2.720	2.406	0.293
3.2	0.617	1.829	0.234	3.2	2.251	2.127	0.278
2.8	0.500	1.566	0.177	2.8	1.844	1.847	0.279
2.4	0.410	1.392	0.152	2.4	1.479	1.614	0.263
2.1	0.349	1.307	0.109	2.1	1.216	1.467	0.207
1.8	0.298	1.249	0.112	1.8	1.006	1.365	0.176
1.6	0.248	1.199	0.086	1.6	0.815	1.282	0.130
1.4	0.227	1.279	0.083	1.4	0.731	1.343	0.103
1.2	0.217	1.391	0.066	1.2	0.686	1.442	0.080
1.0	0.191	1.361	0.061	1.0	0.597	1.400	0.073
0.91	0.158	1.239	0.072	0.91	0.489	1.269	0.078
0.79	0.133	1.157	0.081	0.79	0.408	1.180	0.083
0.69	0.117	1.143	0.083	0.69	0.354	1.162	0.083
0.60	0.105	1.179	0.069	0.60	0.315	1.195	0.069
0.52	0.093	1.239	0.051	0.52	0.279	1.253	0.052
0.46	0.081	1.296	0.053	0.46	0.241	1.308	0.054
0.10	0.003	1.130	0.031	0.10	0.008	1.123	0.030