10 CFR 50.54(f)

aps

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March 10, 2015

U.S. Nuclear Regulatory Commission
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Reference: NRC Letter, *Request for Information Pursuant to Title 10 of the Code of Federal Regulations 50.54(f) Regarding Recommendations 2.1, 2.3, and 9.3, of the Near-Term Task Force Review of Insights from the Fukushima Dai-ichi Accident*, dated March 12, 2012

Dear Sirs:

Subject: **Palo Verde Nuclear Generating Station (PVNGS)**
Units 1, 2, and 3
Docket Nos. STN 50-528, 50-529, and 50-530
Seismic Hazard and Screening Report

In accordance with the NRC request for information in the reference letter, enclosed is the *Seismic Hazard and Screening Report for Palo Verde Nuclear Generating Station Units 1, 2, and 3,* which documents the results of the seismic hazard evaluation performed for Arizona Public Service Company (APS).

The PVNGS structural design bounds the reevaluated seismic hazard ground motion response spectrum (GMRS), therefore, no further evaluations or interim actions are needed or required for the Near Term Task Force (NTTF) Recommendation 2.1 seismic review.

No commitments are being made to the NRC by this letter. Should you need further information regarding this submittal, please contact Thomas Weber, Department Leader, Regulatory Affairs, at (623) 393-5764.

I declare under penalty of perjury that the foregoing is true and correct.

Executed on 3/10/15
(Date)

Sincerely,

JJC/TNW/pjh

A010
NRR

Enclosure: *Seismic Hazard and Screening Report for the Palo Verde Nuclear Generating Station Units 1, 2, and 3,* March 2015

cc:	W. M. Dean	NRC Director Office of Nuclear Reactor Regulation
	M. L. Dapas	NRC Region IV Regional Administrator
	B. K. Singal	NRC NRR Project Manager for PVNGS
	M. M. Watford	NRC NRR Project Manager
	C. A. Peabody	NRC Senior Resident Inspector PVNGS
	N. J. DiFrancesco	NRC JLD Project Manager

SEISMIC HAZARD AND SCREENING REPORT

for the
PALO VERDE NUCLEAR GENERATING STATION
UNITS 1, 2, AND 3

REVISION 0
MARCH 2015

Contents

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 United States Nuclear Regulatory Commission (U.S.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 10 CFR 50.54(f) letter, *Request for Information Pursuant to Title 10 of the Code of Federal Regulations 50.54(f) Regarding Recommendations 2.1, 2.3, and 9.3, of the Near-Term Task Force Review of Insights from the Fukushima Dai-Ichi Accident,* (U.S.NRC, 2012a) that requests information to assure that these recommendations are addressed by all U.S. nuclear power plants. The 10 CFR 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 10 CFR 50.54(f) letter pertaining to NTTF Recommendation 2.1 for the Palo Verde Nuclear Generating Station (PVNGS), located in in Maricopa County, Arizona. In providing this information, Arizona Public Service Company (APS) 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, 2013). The Augmented Approach, Seismic Evaluation Guidance: *Augmented Approach for the Resolution of Fukushima Near-Term Task Force Recommendation 2.1: Seismic* (EPRI, 2013a), 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 PVNGS 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 is bounded by the design of Seismic Category 1 structures, systems and components.

In response to the 10 CFR 50.54(f) letter and following the guidance provided in the SPID (EPRI, 2013), a seismic hazard reevaluation for the PVNGS site was performed. For screening purposes, a Ground Motion Response Spectrum (GMRS) was developed.

Based on the results of the screening evaluation, the PVNGS Design Spectral Response Curve used for the design of Seismic Category 1 Structures, Systems and Components (SSCs) exceeds the GMRS curve in the 1 to 10 Hz frequency range and in the frequency range above 10 Hz; therefore, no further action is required for the NTTF Recommendation 2.1 seismic review.

2 Seismic Hazard Reevaluation

The plant description is provided in the PVNGS *Updated Final Safety Analysis Report* (UFSAR, Rev. 17). PVNGS is located in Maricopa County, Arizona, approximately 34 miles west of the nearest boundary of the city of Phoenix (UFSAR, Rev. 17 Section 2.5). The PVNGS site essentially consists of a relatively thin veneer of dense cohesionless soils, 30 to 60 feet in thickness, underlain by about 250 feet of stiff to hard clays. Cohesionless soils include layers and lenses of sands with some gravels, silty sands, clayey sands, and silts. A third general material type, granular backfill, was placed beneath and adjacent to some Seismic Category I structures.

The level of maximum vibratory ground motion that might occur at the site was determined by considering the largest earthquakes that might credibly occur in each of the following seismic zones:

- Seismic Zone A is the concentration of activity in the southwest quadrant from the site at distances beyond about 120 miles.
- Seismic Zone B is a roughly circular zone of epicenters about 80 miles in diameter and lying astride the Arizona-Sonora border.
- Seismic Zone C is a band of rather diffuse seismicity extending diagonally across Arizona from its northwest corner. Zone C corresponds to a transition zone between the Colorado Plateau to the northeast and the Sonoran Desert portion of the Basin and Range province to the southwest.
- The remainder of the region within 200 miles of the site has very sparse seismic activity and is termed Zone D. Seismic Zone D generally corresponds to the Sonora Desert portion of the Basin and Range province.
- Seismic Zone E is a band of seismicity trending northwestward across southern Nevada and into central Utah. This zone is about 100 miles wide and has been called the Southern Nevada Transverse Zone. Zone E was included because it bounds the site zone and separates the site zone from Nevada Basin and Range tectonics further to the north.

When attenuation of strong ground motions because of distance from the epicenter was considered, the most severe case at the site was found to be the postulated (hypothetical) occurrence of a Sonora-type (1887) earthquake located 72 miles from the site (Zone C). The 10 CFR Part 100, Appendix A site characterization safe shutdown earthquake (SSE) vibratory ground motion associated with this event was found to be conservatively represented by horizontal and vertical design response spectra normalized to 0.20g with the characteristics recommended in *NRC Regulatory Guide 1.60* (U.S.NRC, 1973) design spectra. These design spectra were judged to be a very conservative envelope of the level of ground shaking to be expected at the site due to an earthquake of magnitude 8.0 at a distance of 72 miles.

2.1 Regional and Local Geology

The PVNGS site is located in western Arizona near the city of Tonopah (Figure 1), within the Southern Basin and Range physiographic province. The region surrounding the site has a complex geologic history associated with three major phases of deformation along the western margin of the North American continent. These phases include (1) east-directed subduction of portions of the Farallon plate beneath the North American plate and subsequent orogenesis during Mesozoic and Cenozoic time, (2) multiple phases of Basin and Range extension from the Eocene to the late Miocene, and (3) a late Miocene to Recent phase of transform faulting and extension to accommodate oblique divergence between the Pacific and North American plates.

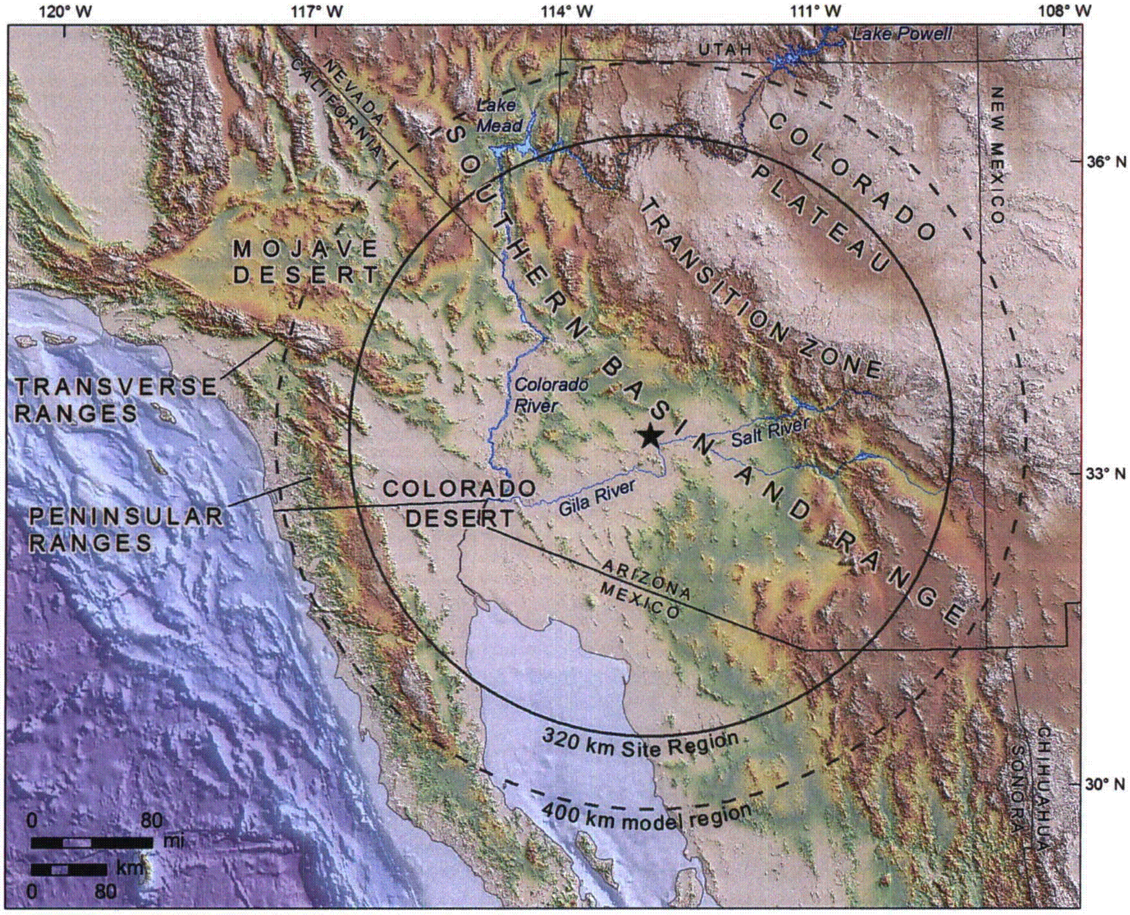

Figure 1. Physiographic provinces in the region surrounding the PVNGS site. Black star indicates the location of the PVNGS site. Source: (APS, 2015).

The Southern Basin and Range physiographic province is generally characterized by discontinuous northwest to east-northeast trending mountain ranges flanked by extensive bedrock pediments, with intervening sedimentary basins that can be as much as 30 km wide (Menges and Pearthree, 1989). This topography expresses post-Laramide epeirogenic extension, which comprises normal-fault-bounded grabens and half-grabens. Very few geologic slip rates are published for faults in this province, but available data indicate that Southern Basin and Range normal faults are characterized by very slow slip rates and long recurrence intervals (Pearthree et al., 1983).

Within the PVNGS Site Region (320-km radius), the Southern Basin and Range physiographic province is characterized by low rates of seismicity and low to moderate magnitude historical earthquakes. The sparse and diffuse pattern of earthquakes does not form lineaments coincident with known faults, and does not indicate the presence of unmapped faults. Beyond the Site Region the largest historical earthquake in the Southern Basin and Range physiographic province is the 1887 Sonoran earthquake. This moment magnitude (**M**) ~7.5 earthquake was located more than 400 km southeast of the PVNGS site (e.g., Suter and Contreras, 2002; Suter, 2006). The Northern Basin and Range Province in central and northern Nevada, well outside the Site Region, also has had several large, historical surface-rupturing earthquakes, including the 1915 **M**7.2 Pleasant Valley and 1954 **M**7.1 Fairview Peak earthquakes (e.g., Stover and Coffman, 1993).

The nearest mapped Quaternary fault to the PVNGS site is the Sand Tank fault, which lies about 60 km to the south-southwest. This fault is characterized by an approximately 2m high fault scarp on Pleistocene alluvium that extends for approximately 3.5 km. Demsey and Pearthree (Demsey and Pearthree 1990), however, speculate that the fault may extend for as much as 32 km based on tonal lineaments. Demsey and Pearthree's (1990) preferred interpretation is that this scarp formed during a single earthquake that occurred between about 8,000 and 20,000 years ago.

Major dextral strike-slip faults associated with the Pacific-North American plate boundary are located about 240 to 300 km west of the PVNGS site. These include the San Andreas, San Jacinto, Cerro Prieto, and other faults, all of which have high slip rates and have produced repeated moderate and large magnitude earthquakes in the Holocene Epoch. The closest of these faults is the San Andreas fault, which at its nearest point lies about 240 km west of the PVNGS site.

The geologic materials underlying Units 1, 2, and 3 at the PVNGS site include about 350 ft of basin sediments overlying bedrock. Basin sediments include stratigraphic subdivisions of sands, gravels, clays, silts, and fanglomerate. Bedrock consists of Miocene volcanic and interbedded sedimentary rocks. The basement complex comprises Precambrian granitic and metamorphic rocks and has been encountered at a depth of about 1,200 feet below the ground surface in the site area (UFSAR, Rev. 17). Section 2.3 of this report provides additional detail regarding the subsurface geologic materials at the PVNGS site.

2.2 Probabilistic Seismic Hazard Analysis

A Probabilistic Seismic Hazard Analysis (PSHA) was conducted for PVNGS using updated Seismic Source Characterization (SSC) and Ground Motion Characterization (GMC) models as primary inputs. The SSC model describes the future potential for earthquakes (e.g., magnitudes, locations, and rates) in the region surrounding the PVNGS site, and the GMC model describes the distribution of the ground motion as a function of earthquake magnitude, style of faulting, source-to-site geometry, and site conditions.

2.2.1 Overview of SSHAC Process

In accordance with 10 CFR 50.54(f) letter (U.S.NRC, 2012a), the SSC and GMC models were developed using Senior Seismic Hazard Analysis Committee (SSHAC) Level 3 procedures described in NUREG/CR-6372 (Budnitz et al., 1997), and the detailed implementation guidance provided in NUREG 2117 (U.S.NRC, 2012b). The goal of following the SSHAC Level 3 process is to provide reasonable regulatory assurance that the center, body, and range of the technically defensible interpretations have been adequately captured in the SSC and GMC models. Thus, the SSC and GMC studies were planned, conducted, and reviewed in strict compliance with the SSHAC Level 3 procedures.

The four main components of the SSHAC process are: (1) evaluation of data and methods; (2) integration of data and methods in model development; (3) documentation of the SSHAC process and modeling decisions; and (4) participatory peer review. The SSC and GMC models were developed by separate but parallel SSHAC Level 3 studies, and each underwent ongoing review by each model's respective Participatory Peer Review Panel (PPRP). Following review of the final reports, each PPRP issued a closure letter summarizing their perspective of the respective SSHAC Level 3 study. The letters describe the PPRP review process, the adequacy of the study in fulfilling the SSHAC Level 3 process of evaluation and integration, and the adequacy of documentation. The closure letter from the SSC PPRP is provided in Appendix B.

The closure letter from the GMC PPRP, for the SWUS GMC SSHAC revision 1 report, which is the foundation document for the PVNGS seismic hazard, is provided in Appendix C. Appendix C identifies PPRP reservations related "only to completeness of the documentation."

Appendix D provides the SWUS GMC Project letter "Transmittal of SWUS GMC SSHAC Level 3 Technical Report (Rev. 2)." This letter documents that the final GMC Models used in the PVNGS hazard evaluation did not change with respect to the Revision 1 report.

Appendix E reflects final PPRP endorsement of the SWUS GMC SSHAC revision 2 report, including resolution of all reservations identified in Appendix C PPRP closure letter for PVNGS.

2.2.2 Summary of Seismic Source Characterization (SSC) Model

This section summarizes the seismic source characterization (SSC) model developed for PVNGS (APS, 2015). Regulatory Guide (RG) 1.208 (U.S.NRC, 2007) recommends performing seismological investigations within a radius of 320 km of the site (i.e., the Site Region). The PVNGS SSC model region exceeds this recommendation, extending to 400 km in order to include major faults in southern California and northwestern Mexico. The PVNGS SSC model comprises area earthquake sources and fault earthquake sources. The area sources extend to 400 km from the PVNGS site (the "model region"). In general, the fault sources also are within 400 km of the PVNGS site, but some high slip-rate fault sources associated with the main Pacific-North American plate boundary extend beyond 400 km from the site.

Area sources are characterized with a defined geometry, seismogenic thickness, rate of earthquake occurrence, maximum earthquake magnitude (Mmax), and magnitude-frequency distribution function. In the PVNGS SSC there are two alternative depictions of area sources, the Two-Zone and Seismotectonic models (Figures 2 and 3). Future earthquakes in the area sources are modeled with rupture characteristics such as location, dip, and slip sense. The recurrence of future earthquakes in each area source is treated as a truncated exponential distribution (Gutenberg-Richter) with spatially variable parameters based on the smoothing of observed seismicity. The smoothing approach used is the penalized maximum likelihood approach that was implemented by the CEUS-SSC Project (EPRI et al., 2012). Activity rates and *b*-values were calculated for area sources using assumptions on spatial smoothing of parameters and on interpretations of historical earthquakes. This process resulted in activity rates (for $\mathbf{M}>5$) and *b*-values for each 0.25 degree cell, for each area source used in the hazard calculations.

Fault sources are planar sources of earthquakes that are attributed to well-defined, seismogenic or potentially seismogenic geologic faults or fault zones. The fault sources are characterized by their mapped location, geometry, depth, slip sense, slip rate, magnitude, and magnitude-frequency distribution function. The SSC model includes 168 fault sources (Figure 4). Hazard sensitivity analyses performed throughout the course of SSC model development and final hazard calculations indicate that a large number of the fault sources are not significant contributors to hazard at the site, because collectively 150 fault sources contribute less than 1% of the total reference rock fault hazard at 10 Hz and 1 Hz spectral frequencies. In keeping with the hazard-informed approach for developing the SSC model prescribed by the SSHAC process, this information was used to focus characterization efforts on those faults that matter most in terms of hazard at the site.

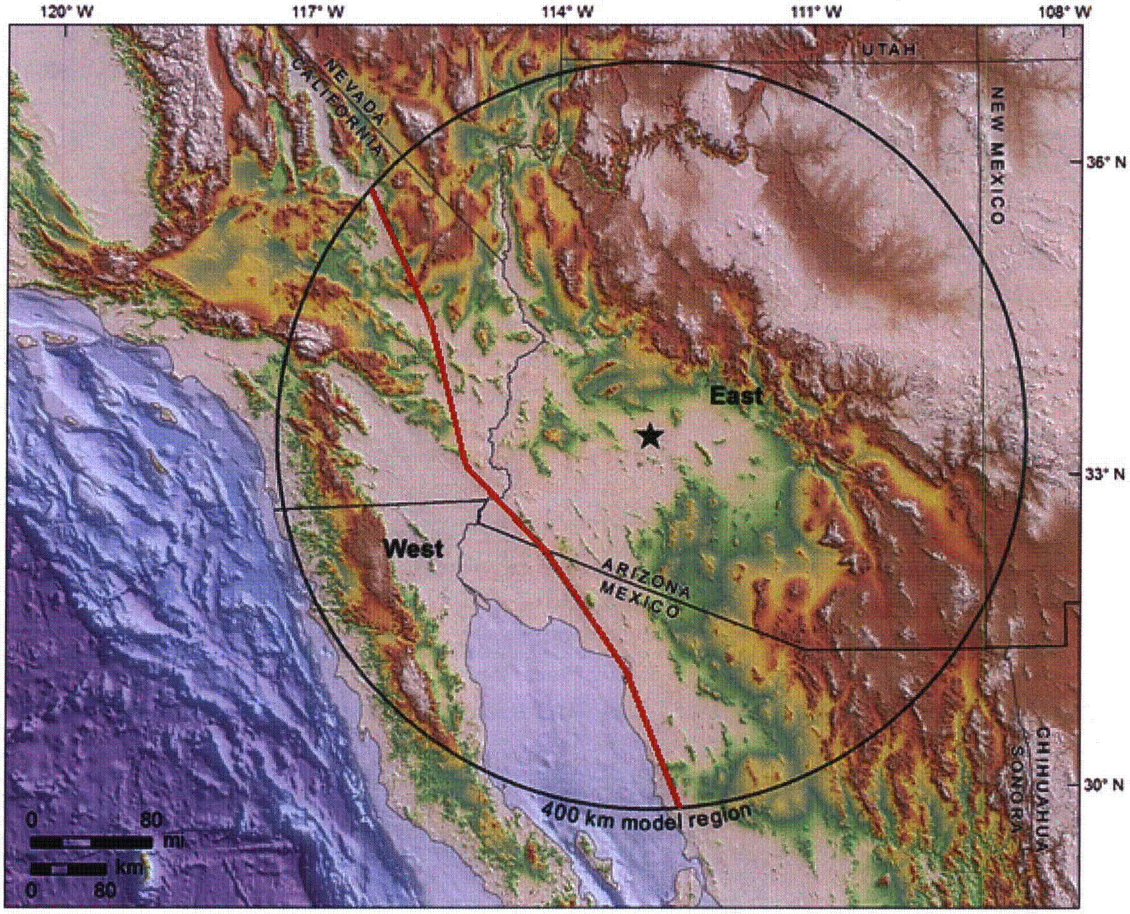

Figure 2. The Two-Zone model for area sources in the PVNGS SSC model. The West and East sources model future earthquakes based solely on broad characteristics related to plate tectonic setting. Black star indicates the location of the PVNGS site. Source: (APS, 2015).

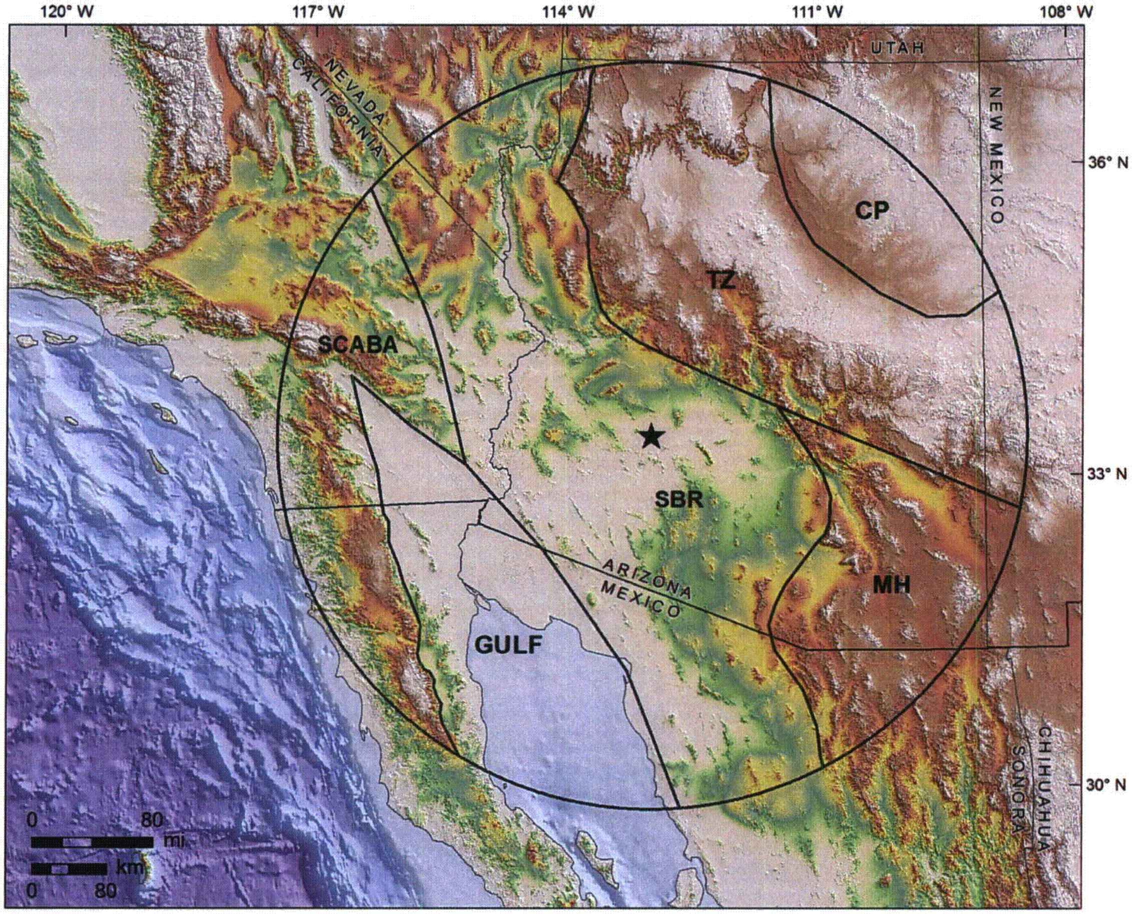

Figure 3. The Seismotectonic model for area sources in the PVNGS SSC model. Sources include Southern Basin and Range (SBR), Southern California and Baja California (SCABA), Gulf of California (GULF), Mexican Highlands (MH), Transition Zone (TZ), and Colorado Plateau (CP). Each source models future earthquakes based on variations in crustal behavior (interpreted from geophysical, seismological, and geological data) within each plate tectonic setting. Black star indicates the location of the PVNGS site. Source: (APS, 2015).

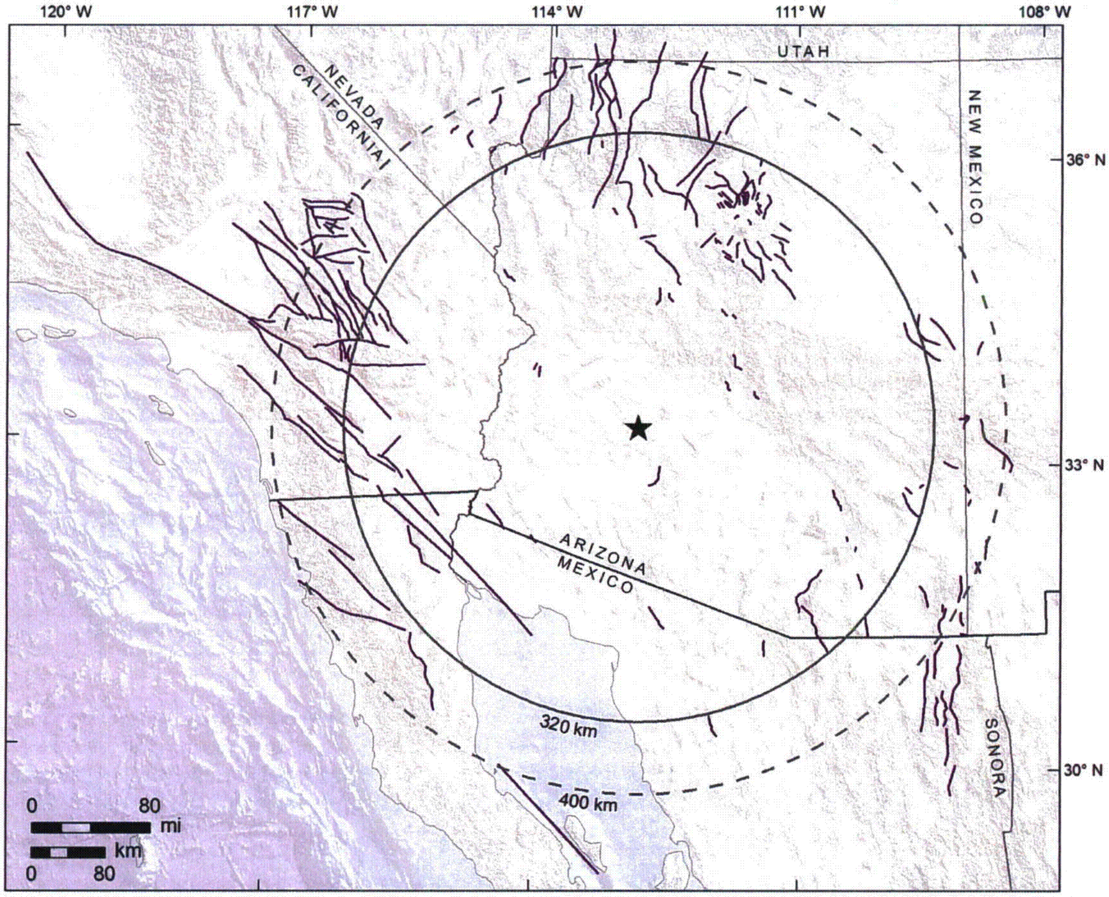

Figure 4. Fault sources in the PVNGS SSC model. Black star indicates the location of the PVNGS site. Source: APS (2015).

2.2.3 Summary of Ground Motion Characterization (GMC) Model

This section summarizes the ground motion model developed by the Southwestern U.S. (SWUS) Ground Motion Characterization (GMC) Project (GeoPentech, 2015), and the modification of the Ground Motion logic tree for use in the Probabilistic Seismic Hazard Analysis (PSHA) for PVNGS. The regional SWUS GMC Project developed site specific Ground Motion Prediction Equations (GMPEs) of the median ground motion and models of the standard deviation (sigma) for 5% damped pseudo-spectral acceleration. These site specific GMPEs were developed for use in the Diablo Canyon Power Plant (DCPP) and Palo Verde Nuclear Generating Station (PVNGS) PSHAs. The site specific aspects of the GMPEs were addressed by optimizing the GMPEs for the seismic sources that have significant contributions to the seismic hazard at each site (GeoPentech, 2015).

Two separate sets of GMPEs were developed by the SWUS GMC project for PVNGS. The first set of GMPEs estimate ground motion for earthquakes in the less active area east of the highly active zone associated with the main plate boundary in California and Baja California (designated herein the "Greater AZ" region, see the region labeled "east" in Figure 2). This set was optimized for predominantly normal faulting earthquakes with **M**5 to 7, at distances less than 50 km. The second set of GMPEs estimate ground motion for the distant, larger magnitude earthquakes in California and Mexico. This set of GMPEs was optimized for **M**7 to 8.5 earthquakes at large distances (greater than 200 km), and includes path-specific effects to capture the systematic differences in ground motion attenuation observed during California and Mexico earthquakes at sites in central Arizona, as compared to sites in California. Both sets of GMPEs were developed for a reference site condition with shear wave velocities of 760 m/s and average kappa of 0.041 seconds (GeoPentech, 2015). To make the SWUS GMPEs applicable to PVNGS rock conditions, response spectrum adjustment factors that convert ground motions from the reference rock conditions to the rock conditions at PVNGS were applied to the hazard calculations. See Section 2.3, Site Response Evaluation, for a further discussion of the response spectrum adjustment factors.

2.2.3.1 GMPEs for the Greater AZ Region

Figure 5 shows the SWUS GMC logic tree for the median ground motion for both area sources and faults in the Greater AZ region, which has the following three nodes: Distant Metric for Common Form, Base Model, and Directivity. One or more branches representing a single model (one-branch) or alternative models (multiple branches) were assigned to each node. The Distant Metric for the Common Form node had two branches. These were the "R_{RUP} based Common Form Model" branch, representing models that were based on closest distance from site to earthquake rupture (R_{RUP}) distance metric, and the "R_{JB} based Common Form Model" branch, representing models that were based on the Joyner-Boore distance (R_{JB}) metric. The GMC gave the "R_{RUP} based Common Form Model" branch a higher weight of 0.7 and the "R_{JB} based Common Form Model" branch a lower weight of 0.3. Both models were applicable to strike-slip (SS), normal (NML), and reverse (REV) fault mechanisms. Depending on the spectral period, the Base Model node had between 17 and 24 branches, with a non-uniform branch weight distribution. Each branch represented a unique set of model coefficients that were applied to the R_{RUP} and R_{JB} based Common Form Model. Only the Base Model branches downstream of the "R_{RUP} based Common Form Model" branch included coefficients that adjusted for hanging-wall effects. The Base Model branches were labeled "Model1," "Model2," "Model3," etc. The Directivity node had a single branch, the "NO" branch, which had a branch weight of 1.0, showing that directivity effects were not assigned to the GMPEs.

Figure 6 shows the SWUS GMC logic tree for the standard deviation in ground motion ("sigma") model for sources of the Greater AZ region, which had the following three nodes: Model, Epistemic Uncertainty, and Aleatory Distribution Form. Each node had one or more branches. The Model node had a single branch, "M-Dependent", which had a branch weight of 1.0 showing that magnitude-dependent effects influenced ground motion. The Epistemic Uncertainty node had three branches. These were the "High", "Central" and "Low" uncertainty branches, which had branch weights of 0.3, 0.55, and 0.15, respectively. The Aleatory Distribution Form node had two branches. These were the "Mixture Model" and "Normal" form branches, which had branch weights of 0.8 and 0.2, respectively.

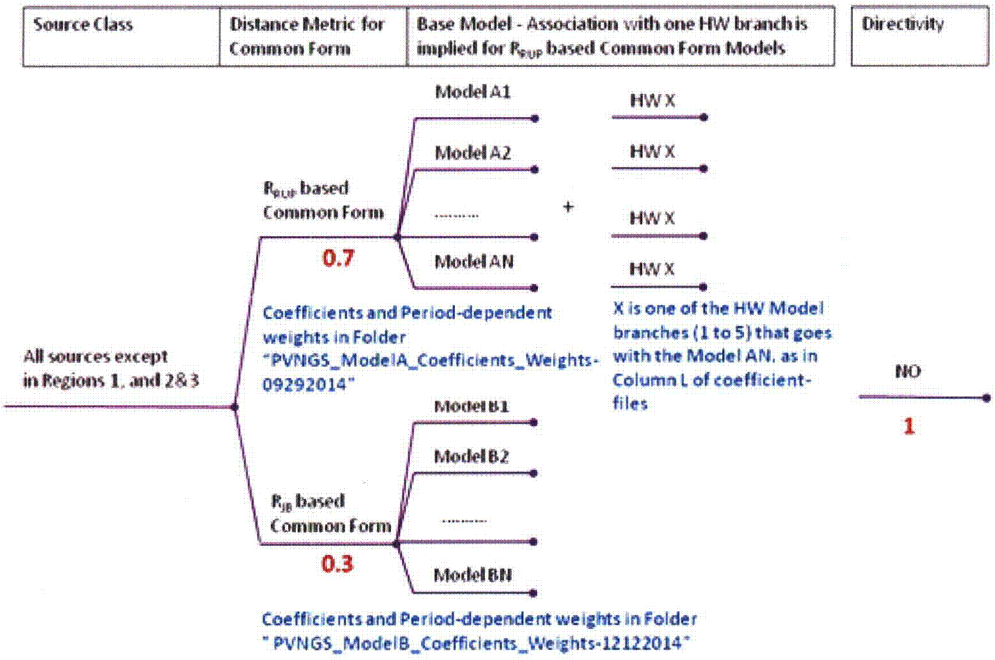

Figure 5. Logic tree for the SWUS GMC median model for faults and area sources in the Greater AZ region. Modified after GeoPentech's (GeoPentech, 2015) Figure 2-1 in Appendix C (Part I).

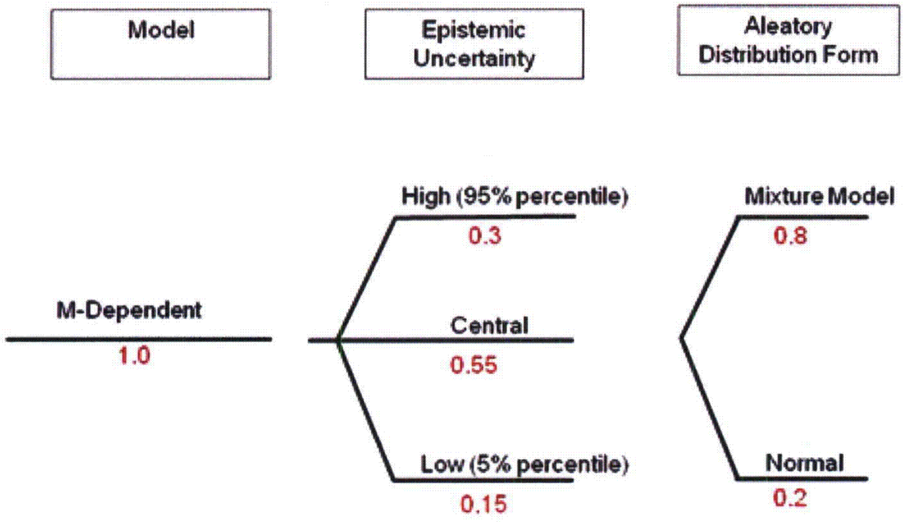

Figure 6. Logic tree for the SWUS GMC total sigma model for faults and area sources in the Greater AZ region. Modified after GeoPentech's (GeoPentech, 2015) Figure 4-1 in Appendix C (Part I).

2.2.3.2 GMPEs for California and Mexico

Figure 7 shows the SWUS GMC logic tree for the median ground motion model for faults and area sources in California and Mexico. This logic tree had the following five nodes: Median Model, Path Term approach, Additional M scaling uncertainty, Median Path Term, and Directivity. Each node had multiple branches representing alternative models. The Median Model node had five equally weighted branches, which were the Next Generation Attenuation-West 2 (NGA-W2) GMPEs, namely the Abrahamson et al. (Abrahamson et al., 2014), Boore et al. (Boore et al., 2014), Campbell and Bozorgnia (Campbell and Bozorgnia, 2014), Chiou and Youngs (Chiou and Youngs, 2014), and Idriss (Idriss, 2014) models. The Path Term approach node had two branches, the "YES" and "NO" path term branches, which had branch weights of 0.8 and 0.2, respectively. Three branches were assigned to the Additional M scaling uncertainty node, the "High," "Central," and "Low" uncertainty branches, which had branch weights of 0.2, 0.6, and 0.2, respectively. The Median Path Term node was only applicable for the "YES" path term branch and had three branches assigned to it. These were the "High," "Central," and "Low" uncertainty branches, which were assigned branch weights of 0.2, 0.6, and 0.2, respectively.

Figure 8 shows the SWUS GMC logic tree for the sigma model for sources in California and Mexico. One sigma model was developed for the "YES" path term approach branch of the median GMPE, and the second sigma model was developed for the "NO" path term branch. The sigma model logic tree is similar to the Greater AZ source logic tree, and has the following three nodes: Model, Epistemic Uncertainty, and Aleatory Distribution Form. The Model node has a single branch, "M-Dependent", which has a branch weight of 1.0 showing that magnitude dependent effects were attributed to the uncertainty in the ground motion. The Epistemic Uncertainty node has three branches. These are the "High", "Central" and "Low" uncertainty branches, with branch weights of 0.3, 0.55, and 0.15, respectively. The Aleatory Distribution Form node has two branches. These were the "Mixture Model" and "Normal" form branches, with branch weights of 0.8 and 0.2, respectively.

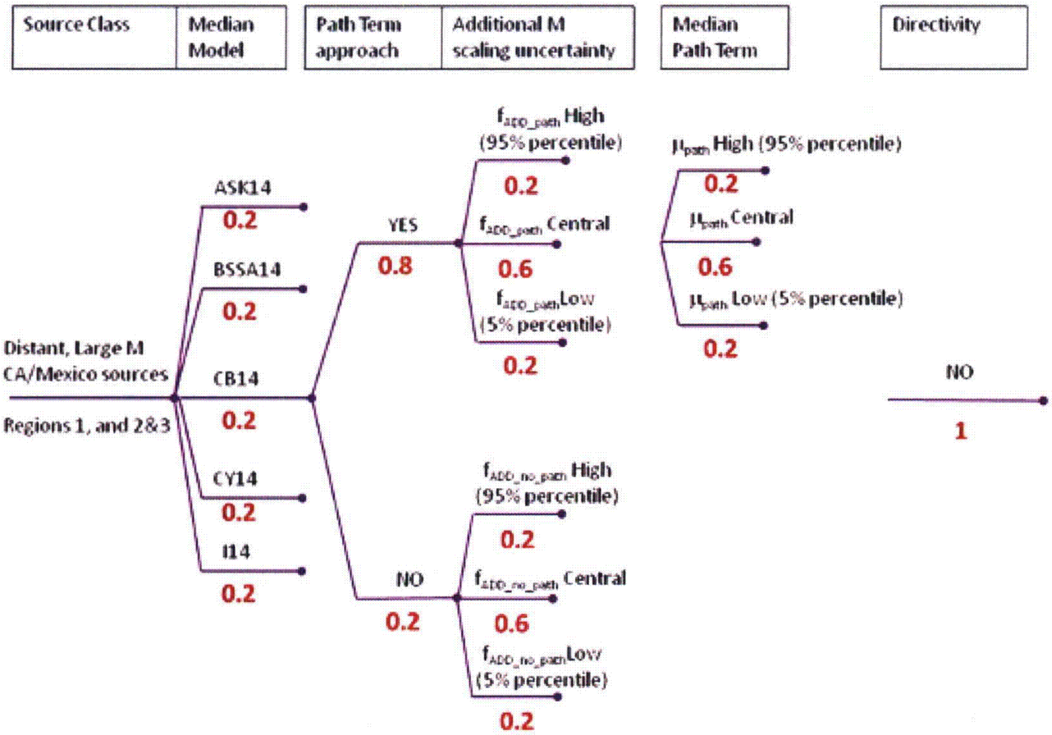

Figure 7. Logic tree for the SWUS GMC median model for faults and area sources in California and Mexico. Modified after GeoPentech's (GeoPentech, 2015) Figure 3-1 in Appendix C (Part I).

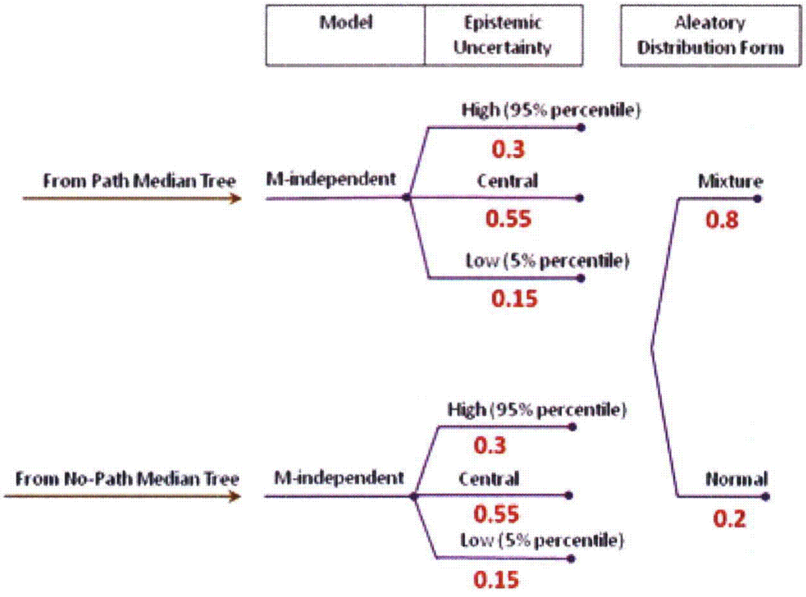

Figure 8. Logic tree for the SWUS GMC total sigma model for faults and area sources in California and Mexico. Modified after GeoPentech's (GeoPentech, 2015) Figure 5-1 in Appendix C (Part I).

2.2.3.3 GMPE Implementation

Several simplifications to the ground motion logic trees were made in the hazard calculations for PVNGS. For earthquakes in the Greater AZ region, the Distance Metric for the Common Form logic tree node (see Figure 5) was collapsed to the higher weighted R_{RUP} based Common Form Model branch. A hazard sensitivity study for this logic tree node showed that collapsing the branches to a single branch would have a minor impact on hazard (LCI, 2015a). For earthquakes in both the Greater AZ region and in California and Mexico, the Aleatory Distribution Form logic tree node (see Figures 6 and 8) was collapsed to the higher weighted Mixture Model branch. A hazard sensitivity study showed that collapsing the branches to the Mixture Model is conservative (LCI, 2015a).

Other important characteristics of the ground motion logic trees were modeled, such as the "YES/NO" path branches (see Figure 7) and the "High/Central/Low" epistemic uncertainty branches in the sigma model (see Figure 8).

2.2.4 Summary of PSHA Implementation

This section describes the probabilistic seismic hazard analysis (PSHA) implementation of site specific rock seismic hazard at the PVNGS site. Primary inputs to this PSHA are the PVNGS SSC model (APS, 2015) and the SWUS GMC model (GeoPentech, 2015).

Response spectrum adjustment factors (AF) that convert ground motions from reference rock conditions (shear wave velocities of 760 m/s) of the SWUS GMPEs to the site specific rock conditions at PVNGS were incorporated into the hazard calculations.

2.2.4.1 Methodology

As described in Section 2.2.2, the PVNGS SSC includes area sources and fault sources. There are two alternative zonation models for area sources. The first is the Two-Zone model, which includes the West and East area sources (Figure 2). The PVNGS site is located within the East source, thus the East source is designated a "host" source (it includes the site location). Second is the Seismotectonic model, which includes six area sources: Southern California and Baja California (SCABA), Gulf of California (GULF), Southern Basin and Range (SBR), Mexican Highlands (MH), Transition Zone (TZ), and Colorado Plateau (CP) (Figure 3). The PVNGS site is located within the SBR source, thus the SBR source is designated a "host" source.

A total of 168 fault sources were included in the PVNGS SSC (Figure 4). Of these, 150 fault sources were identified as being insignificant to the overall hazard at the site, since they collectively contributed less than 1% to the total reference rock fault hazard at 10 Hz and 1 Hz spectral frequencies (LCI, 2015a). As a result, these 150 faults were not considered in this analysis. The remaining 18 faults that were included in the soil hazard calculation are shown on Figure 9 and include the following:

- San Andreas Fault (SAF)
- Cerro Prieto Fault (CP)
- San Jacinto Fault (SJF)
- Laguna Salada Fault (LS)
- Elsinore Fault (ELF)
- Agua Blanca Fault (AB)
- Ballenas Transform Fault (BT)

- Pinto Mountain Fault (PMNT)
- Calico-Hidalgo Fault (CH)
- Sand Tank Fault (ST)
- Big Chino Little Chino Fault (BCLC)
- Blue Cut Fault (BC)
- Pisgah-Bullion Mountain-Mesquite Lake Fault (PBMML)
- Horseshoe Fault (HS)
- Williamson Valley Grabens Fault (WVG)
- Carefree Fault (CF)
- Algodones Fault (AG)
- Plomosa East Fault (PE)

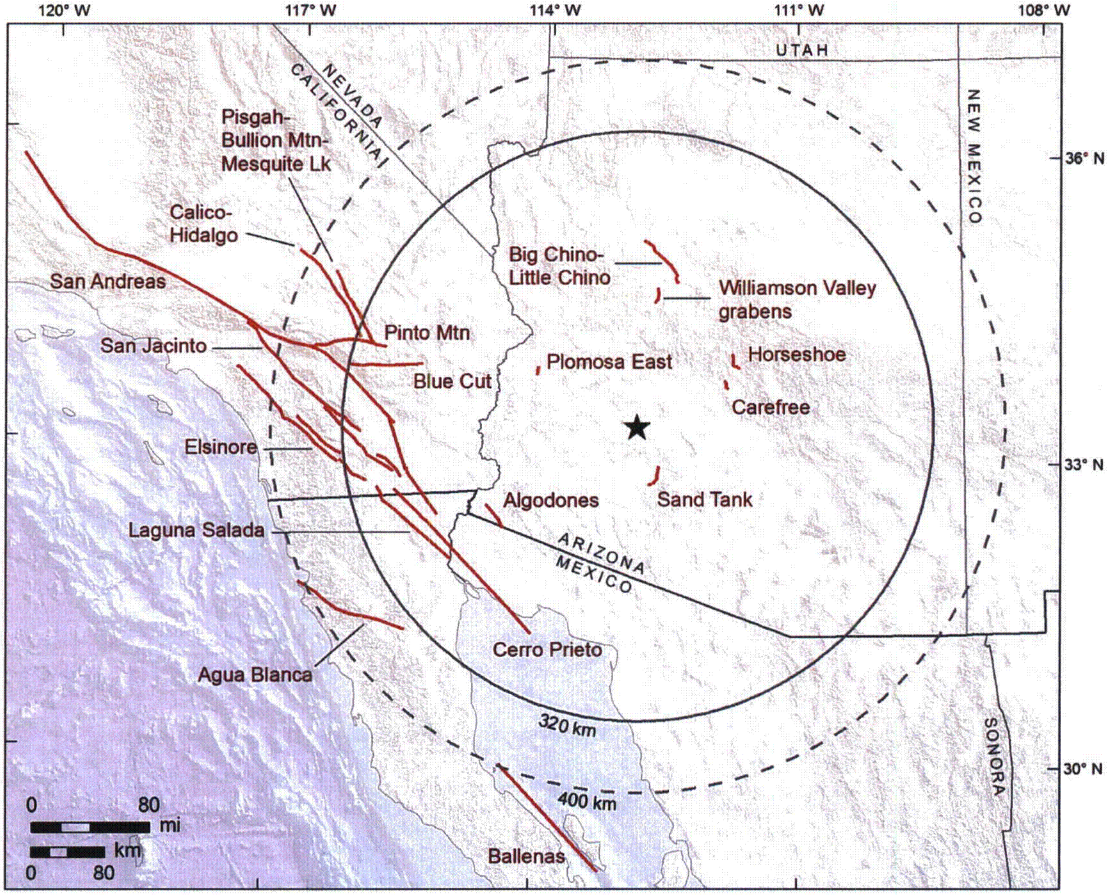

Figure 9. Final 18 fault sources included in PVNGS hazard calculations. Hazard insignificant faults (totaling 150) were excluded. Black star indicates the location of the PVNGS site. Source: (APS, 2015).

Two simplifications to the characterization of area seismic sources were made. The simplifications included (1) collapsing the rupture orientation branch to the central value, and (2) modeling fault dips as vertical.

For non-host sources, these simplifications were not expected to have an impact on the hazard because of the large distances between the non-host area sources and the site (Figures 2 and 3). Non-host area sources were minor contributors to the total 10^{-4} hazard at 1 Hz spectral acceleration (SA). This insensitivity of hazard to rupture orientation and fault dip for non-host sources was confirmed by performing a rupture orientation sensitivity using the SBR source (LCI, 2015a).

Ground motion for host sources *is* sensitive to dip and crustal thickness because of the smaller distance between nearby ruptures and the site. The difference in ground motion between the SSC fault dips and seismogenic thicknesses, and a vertical dip and single crustal thickness, was taken into account in the host sources by adjusting the ground motion for a vertical fault to the ground motion for a non-vertical fault with multiple down-dip widths. The adjustment was calibrated to achieve accurate hazards at mean annual frequencies of exceedence (MAFEs) of 10^{-4} and 10^{-6} (LCI, 2015a).

Ground motions were modeled for seven spectral frequencies (GeoPentech, 2015). The spectral frequencies were peak ground acceleration (PGA; equivalent to 100 Hz SA), 20 Hz SA, 10 Hz SA, 5 Hz SA, 2.5 Hz SA, 1 Hz SA, and 0.5 Hz SA. Seismic hazard was calculated for 20 ground motion amplitudes, which were 0.000001g, 0.0005g, 0.001g, 0.005g, 0.01g, 0.015g, 0.03g, 0.05g, 0.075g, 0.1g, 0.15g, 0.3g, 0.5g, 0.75g, 1.0g, 1.5g, 3.0g, 5.0g, 7.5g and 10.0g. All ground motion equations represented spectral accelerations at 5% of critical damping; as such, spectral amplitude results presented in this report represent spectral acceleration at 5% of critical damping.

2.2.5 Mean Site Specific Rock Hazard Curves for Major Contributing Sources

Figures 10 and 11 plot the mean site specific rock hazard for the PVNGS site for 10 Hz SA and 1 Hz SA. For both 10 Hz SA and 1 Hz SA, the area sources are the dominant contributors to hazard.

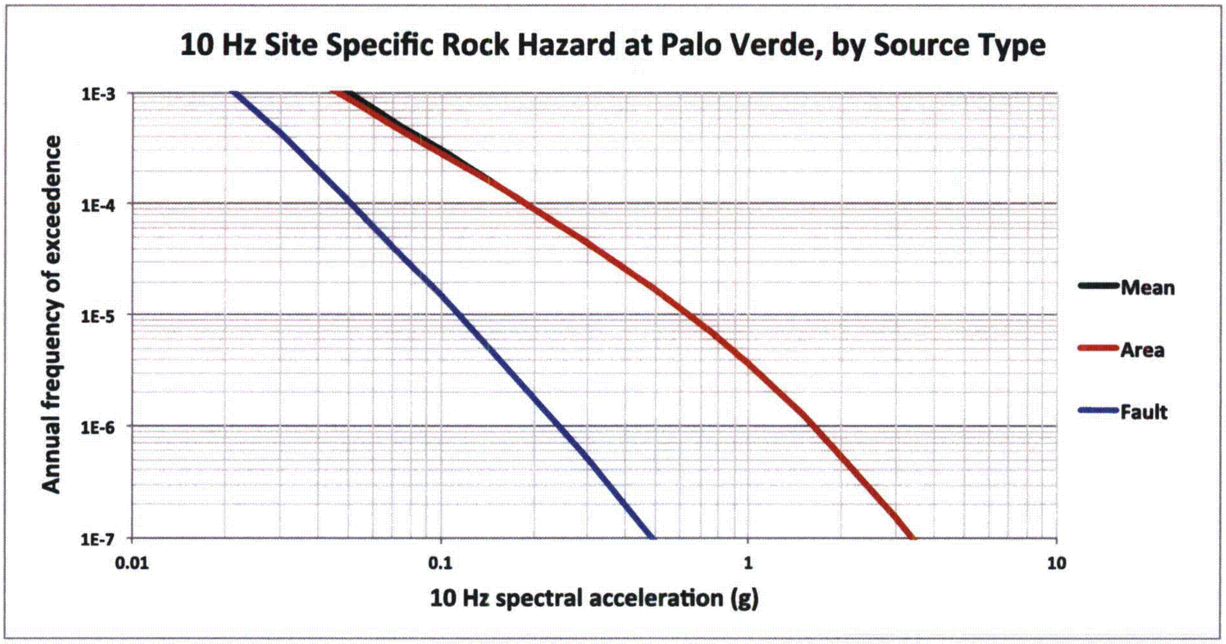

Figure 10. Site specific rock hazard curves showing total mean hazard and contributions from area sources and faults for 10 Hz SA. Note that the area source hazard and total mean hazard are almost identical. Source: Figure 1 from LCI (LCI, 2015c).

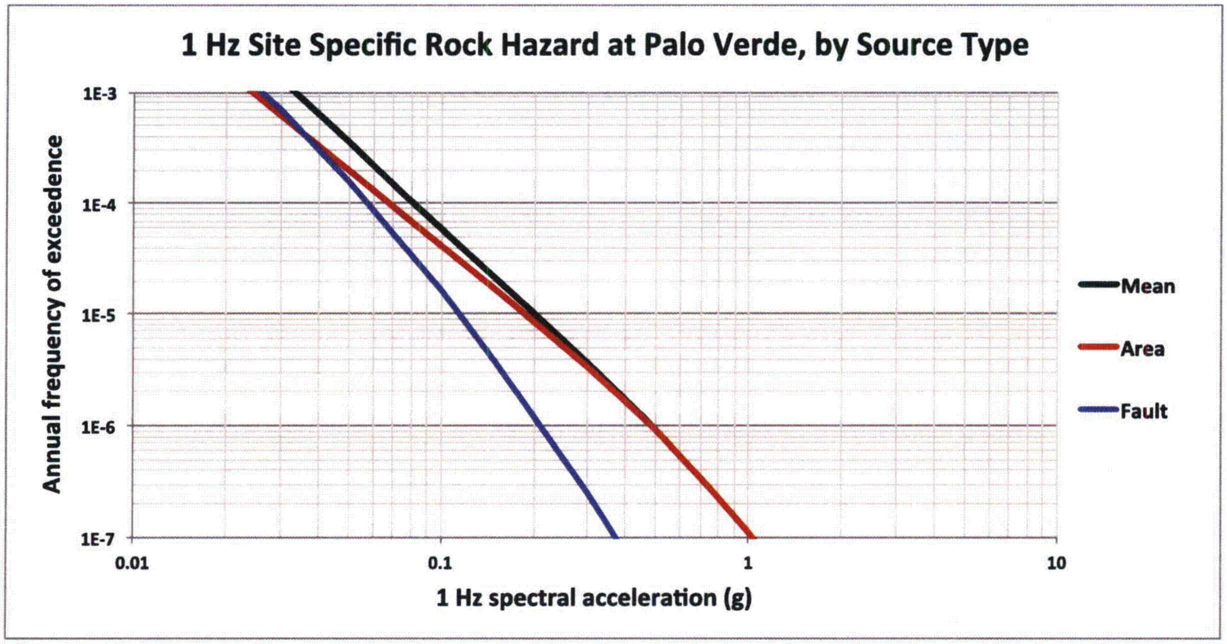

Figure 11. Site specific rock hazard curves showing total mean hazard and contributions from area sources and faults for 1 Hz SA. Source: Figure 2 from LCI (LCI, 2015c).

For area sources there are the Two-Zone[1] and Seismotectonic[2] models, and for faults there are California-Mexico[3] faults and Greater AZ[4] faults. Figures 12 and 13 plot the seismic source contributions to the total mean hazard from these groups for 10 Hz SA and 1 Hz SA. For 10 Hz SA, the Seismotectonic and Two-Zone models are the dominant contributors to hazard. For 1 Hz SA at 10^{-4} MAFE, the Seismotectonic and Two-Zone models and California-Mexico faults are the dominant contributors to hazard; at 10^{-5} MAFE and 10^{-6} MAFE, the Seismotectonic and Two-Zone models are the dominant contributors to hazard.

Contributions from individual Seismotectonic and Two-Zone model sources for 10 Hz SA and 1 Hz SA are plotted in Figures 14 and 15. For both 10 Hz SA and 1 Hz SA, the Seismotectonic model, host source SBR is the dominant contributor to total area source hazard. Contributions from individual faults for 10 Hz SA and 1 Hz SA are plotted in Figures 16 and 17. For both 10 Hz SA and 1 Hz SA, the San Andreas (SAF), Cerro Prieto (CP), and San Jacinto (SJF) faults are the primary fault contributors to total mean hazard.

Figures 18 and 19 show the total mean hazard and sensitivity of 10 Hz SA and 1 Hz SA site specific rock hazard to the SWUS R_{RUP} based Common Form Model ground motion equations used in the hazard calculation from the Greater AZ faults and Greater AZ area sources[5]. The key identifies individual equations as Models 1 through 31 (this follows the naming convention of GeoPentech 2015, which uses a discontinuous numbering system). The spread in hazard curves at 10 Hz SA is fairly small with the exception of Model 19 and Model 23. Note that in the SWUS GMC model, individual GMPEs are

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[1] The Two-Zone model comprises the East and West area sources.

[2] The Seismotectonic model comprises the SCABA, GULF, CP, TZ, MH, and SBR area sources.

[3] California-Mexico faults are the AG, SAF, CP, SJF, LS, ELF, AB, BT, PMNT, PBMML, BC, and CH faults.

[4] Greater AZ faults are the ST, BCLC, HS, WVG, CF, and PE faults.

[5] Greater AZ area sources are the East from the Two-Zone model, and the SBR, MH, TZ, and CP from the Seismotectonic model.

determined independently from frequency to frequency, so a particular GMPE number in Figure 18 does not correspond to that same GMPE number in Figure 19. Direct comparisons of the hazard curves between Figure 18 and 19 cannot be made because the GMPE numbers are not correlated.

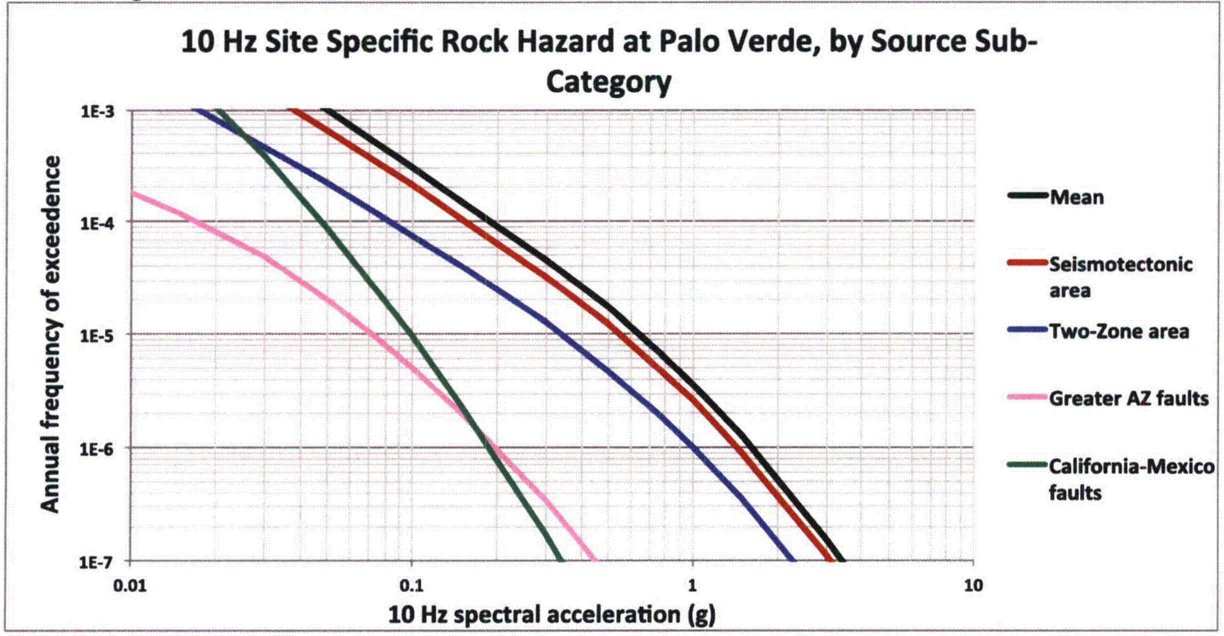

Figure 12. Site specific rock hazard curves showing total mean hazard and contributions from Seismotectonic and Two-Zone models, and from California-Mexico faults and Greater AZ faults for 10 Hz SA. Source: Figure 3 from LCI (LCI, 2015c).

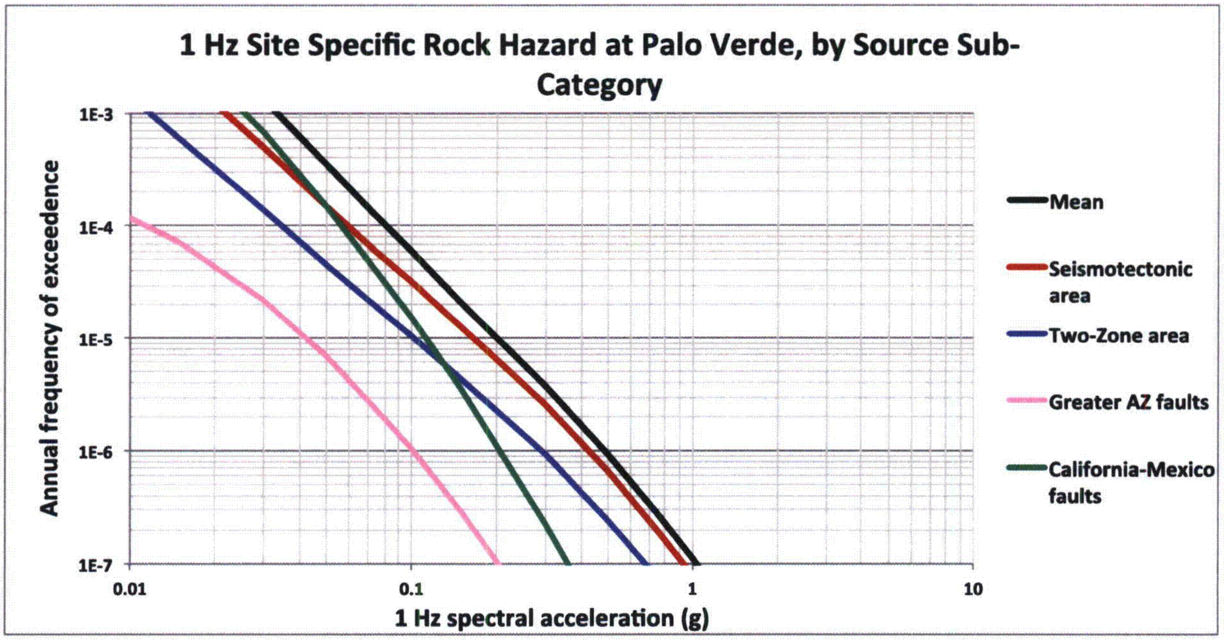

Figure 13. Site specific rock hazard curves showing total mean hazard and contributions from Seismotectonic and Two-Zone models, and from California-Mexico faults and Greater AZ faults for 1 Hz SA. Source: Figure 4 from LCI (LCI, 2015c).

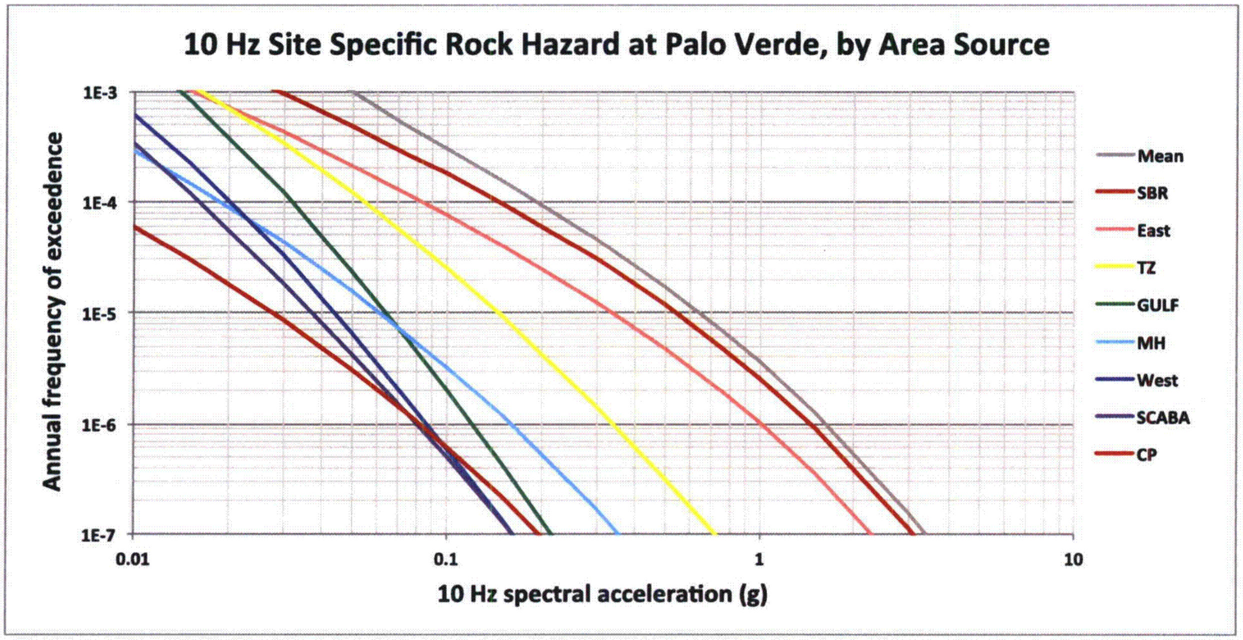

Figure 14. Site specific rock hazard curves showing total mean hazard and contributions from individual sources of the Seismotectonic and Two-Zone models for 10 Hz SA. Source: Figure 5 from LCI (LCI, 2015c).

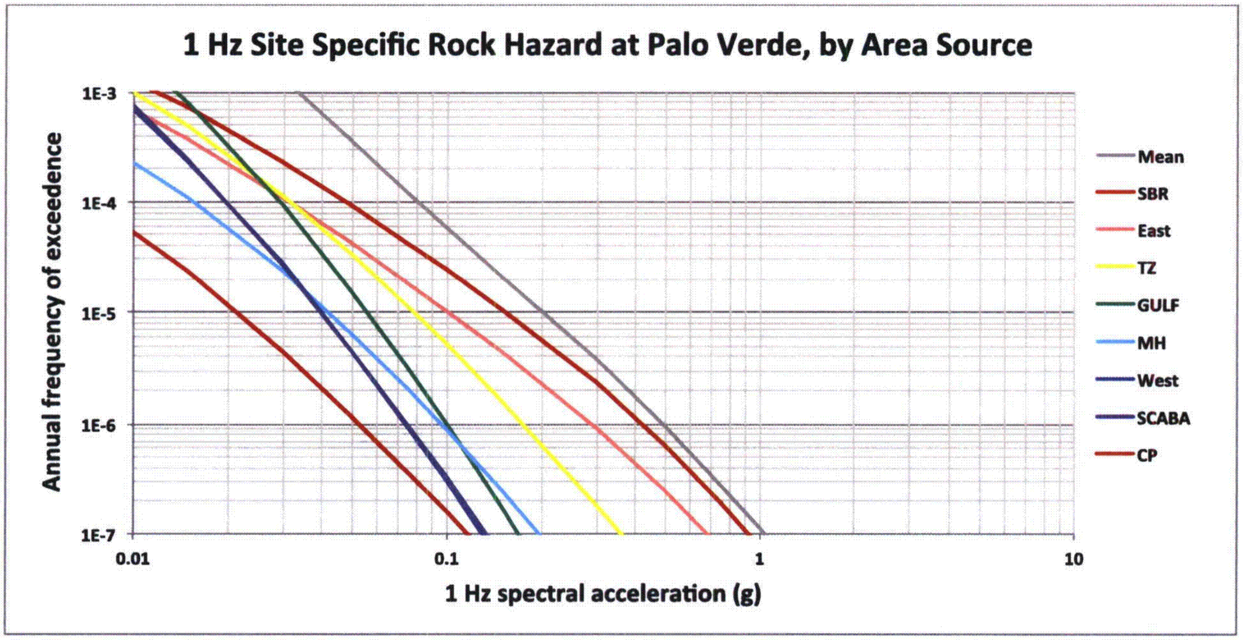

Figure 15. Site specific rock hazard curves showing total mean hazard and contributions from individual sources of the Seismotectonic and Two-Zone models for 1 Hz SA. Source: Figure 6 from LCI (LCI, 2015c).

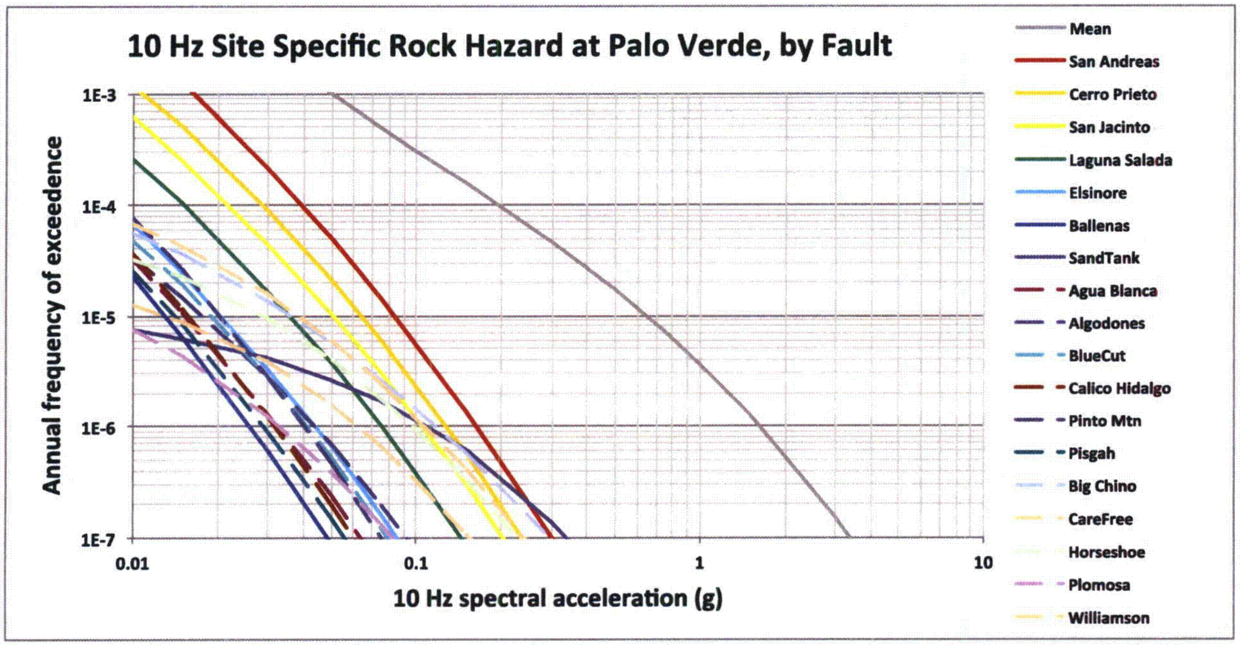

Figure 16. Site specific rock hazard curves showing total mean hazard and contributions from individual California-Mexico faults and Greater AZ faults for 10 Hz SA. Source: Figure 7 from LCI (LCI, 2015c).

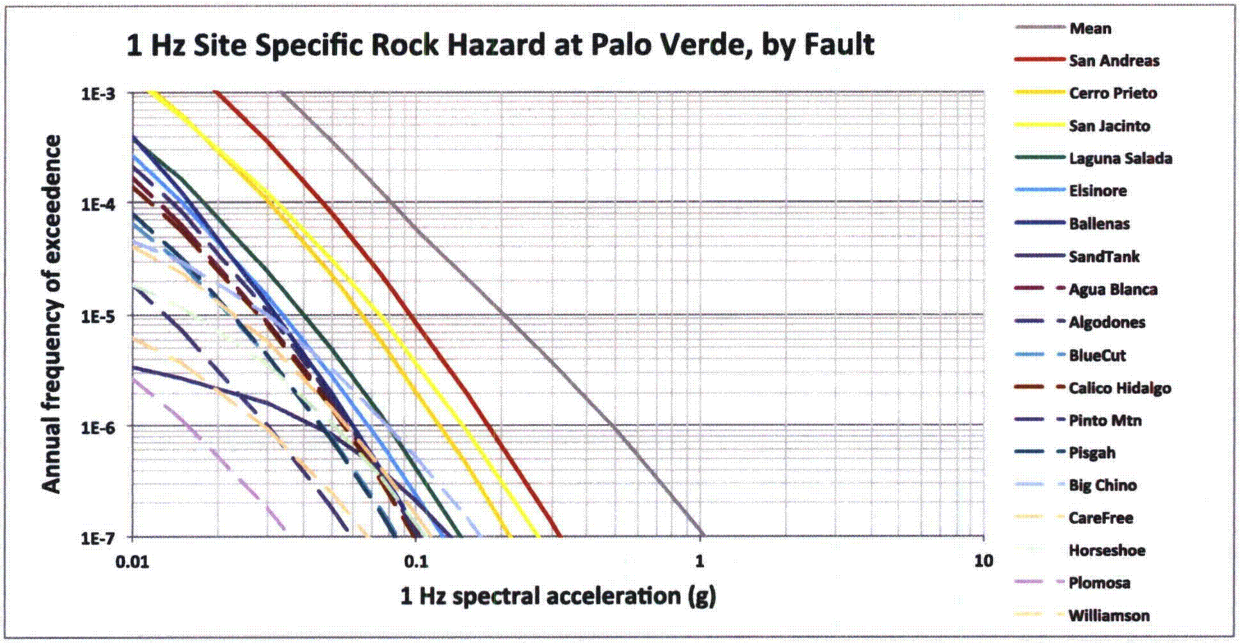

Figure 17. Site specific rock hazard curves showing total mean hazard and contributions from individual California-Mexico faults and Greater AZ faults for 1 Hz SA. Source: Figure 8 from LCI (LCI, 2015c).

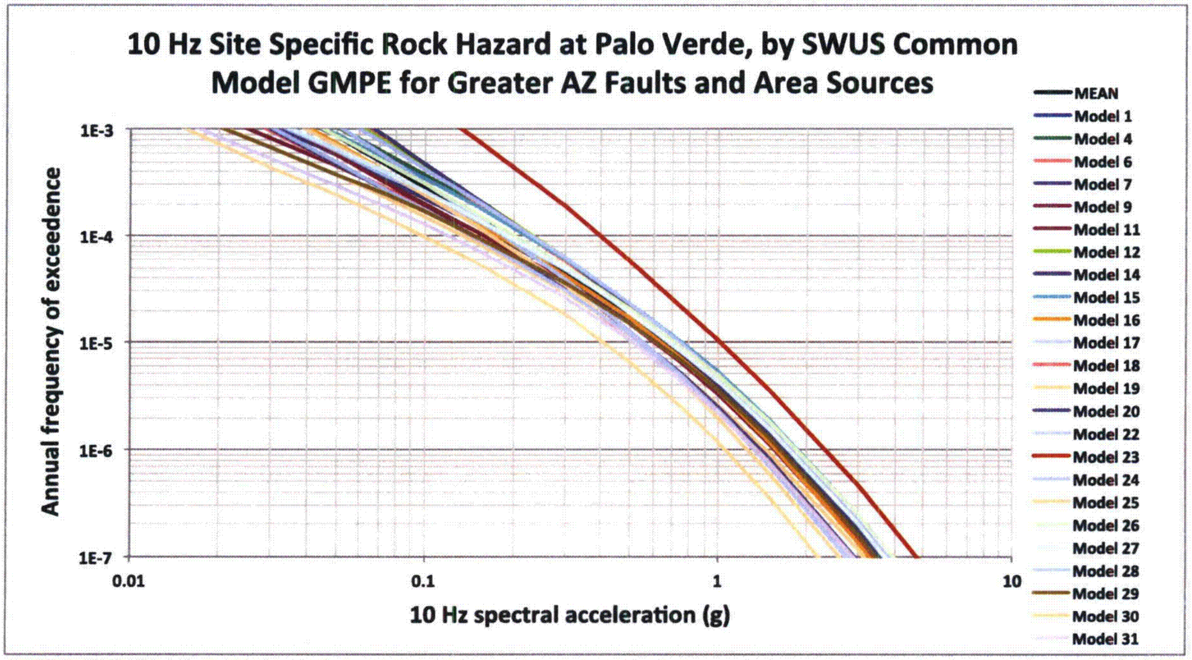

Figure 18. Sensitivity to the SWUS R_{rup} based Common Form model GMPEs from the Greater AZ faults and area sources for 10 Hz SA. Hazard curves do not include weights on each alternative. Source: Figure 16 from LCI (LCI, 2015c).

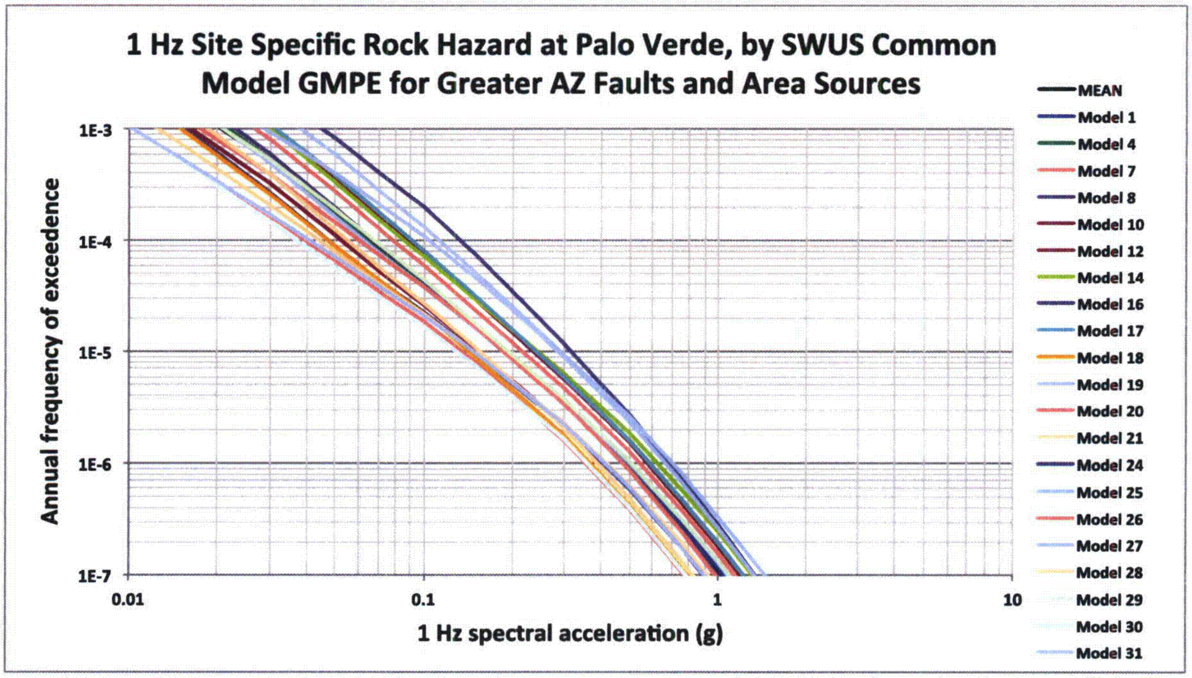

Figure 19. Sensitivity to the SWUS R_{rup} based Common Form model GMPEs from the Greater AZ faults and area sources for 1 Hz SA. Hazard curves do not include weights on each alternative. Source: Figure 17 from LCI (LCI, 2015c).

Figure 20 shows the total mean hazard and sensitivity of 1 Hz SA site specific rock hazard to the SWUS NGA-W2 GMPEs (which were modified for path approach and magnitude-scaling uncertainty). These GMPEs were used to calculate hazard from the California-Mexico faults and from area sources[6] in California and Mexico. The key in Figure 20 identifies individual GMPEs as follows: ASK is Abrahamson, Silva, and Kanai (Abrahamson et al., 2014), BSSA is Boore, Stewart, Seyhan, and Atkinson (Boore et al., 2014), CB is Campbell and Bozorgnia (Campbell and Bozorgnia, 2014), CY is Chiou and Youngs (Chiou and Youngs, 2014), and ID is Idriss (Idriss, 2014). At 1 Hz SA the ASK GMPE calculates the highest hazard and the ID GMPE calculates the lowest hazard. Figure 21 shows the total mean hazard and sensitivity of 1 Hz SA site specific rock hazard to the SWUS path approach modification to the NGA-W2 model ground motion equations used in the hazard calculations from the California-Mexico faults and area sources. For 1 Hz SA, the "YES" path approach gives a lower hazard than the "NO" path approach by a factor of 10 to 50.

Figures 22 and 23 show the total mean hazard and sensitivity of 10 Hz SA and 1 Hz SA site specific rock hazard to the sigma model epistemic branches used in the hazard calculation from the Greater AZ faults and area sources in the Greater AZ region. These figures show a moderate sensitivity to the sigma model. Figure 24 shows the total mean hazard and sensitivity of 1 Hz SA site specific rock hazard to the sigma model epistemic uncertainty branches used in the hazard calculation from the California-Mexico faults and area sources. This figure shows somewhat more sensitivity to the sigma model than Figure 23 shows for the Greater AZ faults and area sources in the Greater AZ region. Taken together, Figures 20 through 24 indicate that the sigma models "High" epistemic uncertainty branch produces the highest hazard.

Figures 25 and 26 show the sensitivity of the SBR source hazard at 10 Hz SA and 1 Hz SA to maximum magnitude. Figure 26 shows the 1 Hz SA SBR source hazard has a moderate sensitivity to the maximum magnitude. These figures show that the SBR source hazard has a larger sensitivity to the maximum magnitude at the lower frequencies than at the higher frequencies.

Figures 27 through 32 show the deaggregation of hazard by magnitude and distance for spectral accelerations corresponding to MAFEs of 10^{-4}, 10^{-5}, and 10^{-6}. Plots for each MAFE show the deaggregation of hazard for high (5 and 10 Hz SA) and low (1 and 2.5 Hz SA) spectral frequencies. For high frequencies, local small-magnitude earthquakes dominate at all MAFE levels. For low frequencies and a 10^{-4} MAFE, a bimodal distribution of local, small-magnitude earthquakes and distant, large-magnitude earthquakes are dominant contributors to seismic hazard. For low frequencies and a 10^{-5} MAFE, local, large-magnitude earthquakes dominate. The low frequency 10^{-6} MAFE hazard deaggregation plot shows that moderate magnitude earthquakes at close distances dominate the hazard. Table 1 summarizes the mean magnitude and mean distance results from the deaggregation of hazard. Note that magnitudes indicated in Table 1 are on the moment magnitude scale.

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[6] Area sources in California and Mexico are the West from the Two-Zone model, and SCABA, and GULF from the Seismotectonic model.

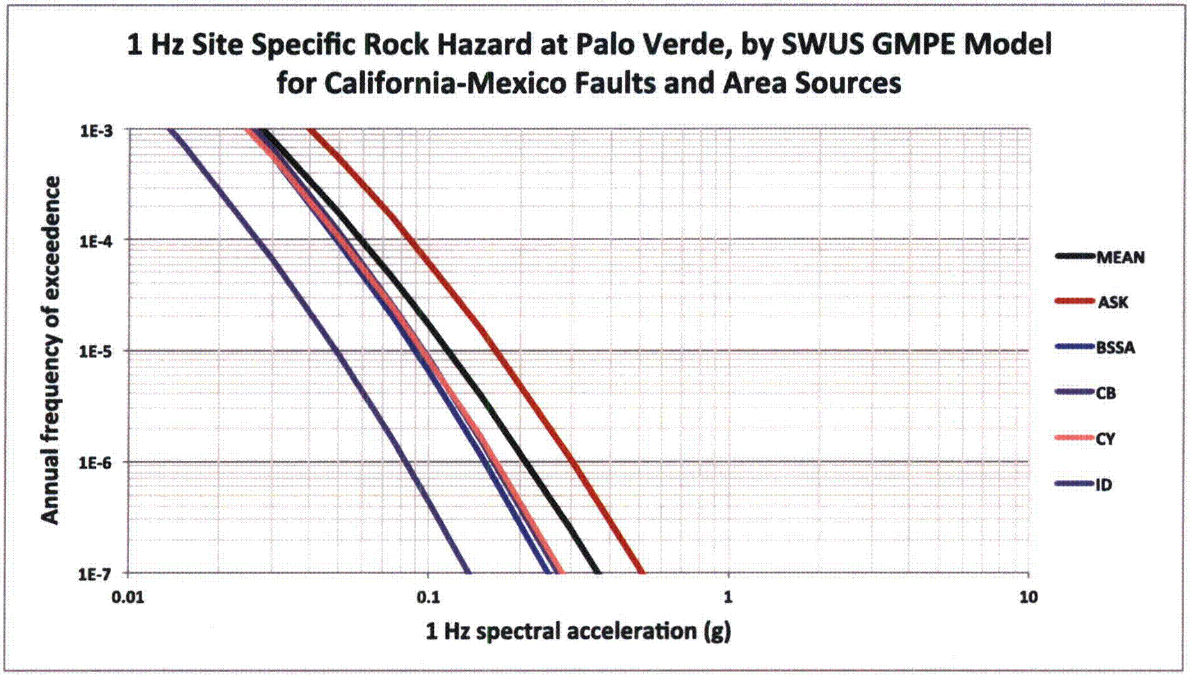


Figure 20. Sensitivity to the SWUS NGA-W2 GMPEs path approach for California-Mexico faults and area sources for 1 Hz SA. Hazard curves do not include weights on each alternative. Source: Figure 18 from LCI (LCI, 2015c).

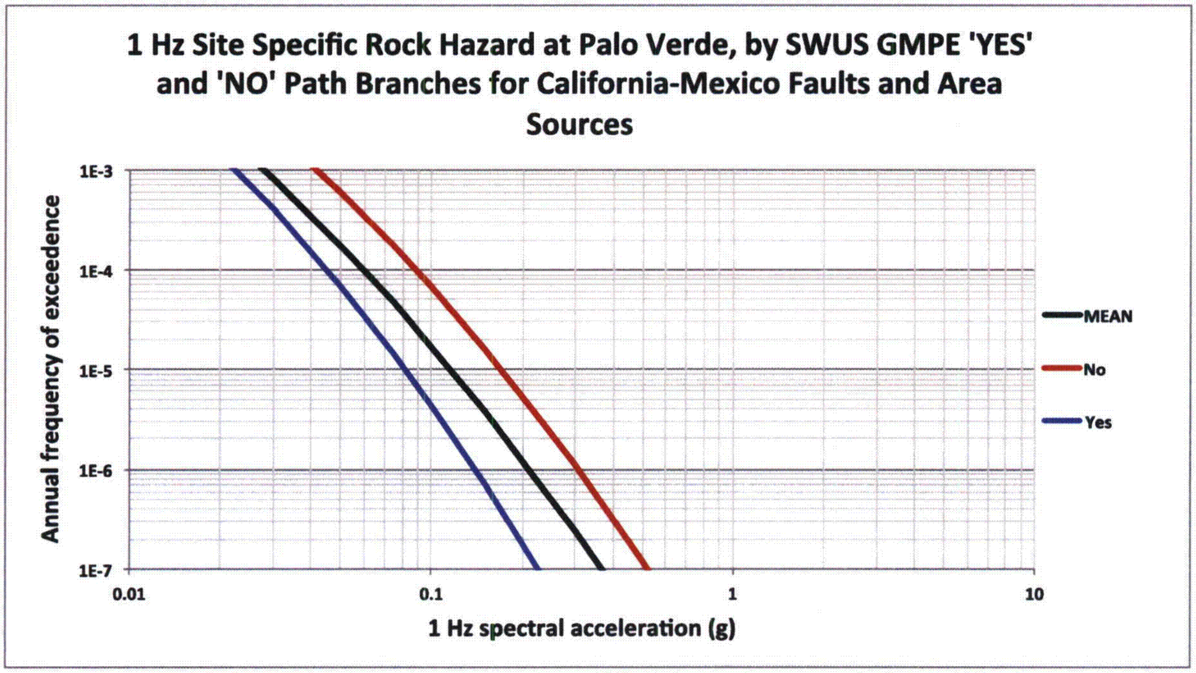


Figure 21. Sensitivity to the SWUS NGA-W2 modified for path approach for California-Mexico faults and area sources in California and Mexico for 1 Hz SA. Hazard curves do not include weights on each alternative. Source: Figure 19 from LCI (LCI, 2015c).

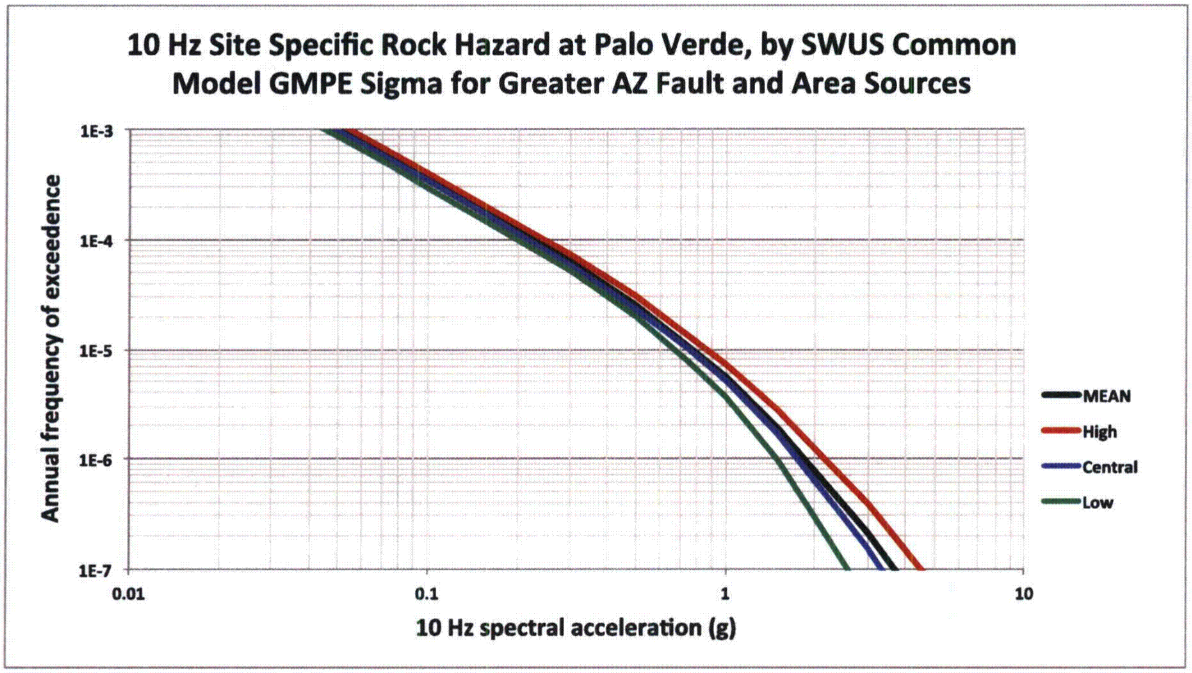


Figure 22. Sensitivity to the epistemic uncertainty in sigma model for faults and area sources in the Greater AZ region for 10 Hz SA. Hazard curves do not include weights on each alternative. Source: Figure 20 from LCI (LCI, 2015c).

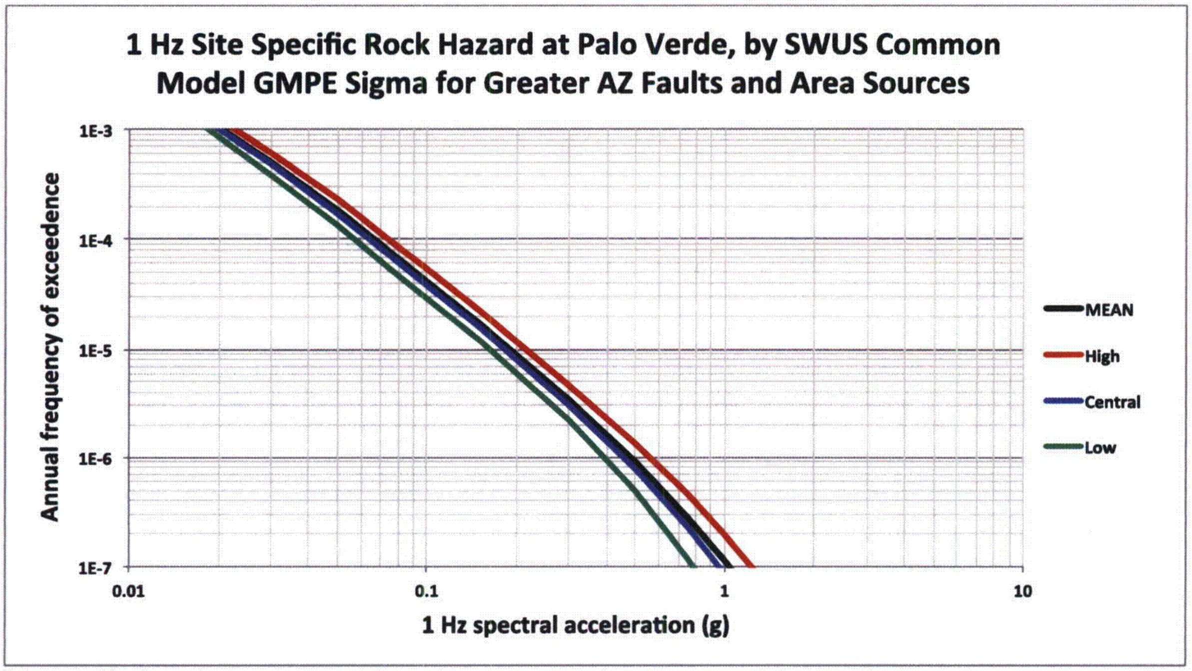


Figure 23. Sensitivity to the epistemic uncertainty in sigma model from faults and area sources in the Greater AZ region for 1 Hz SA. Hazard curves do not include weights on each alternative. Source: Figure 21 from LCI (LCI, 2015c).

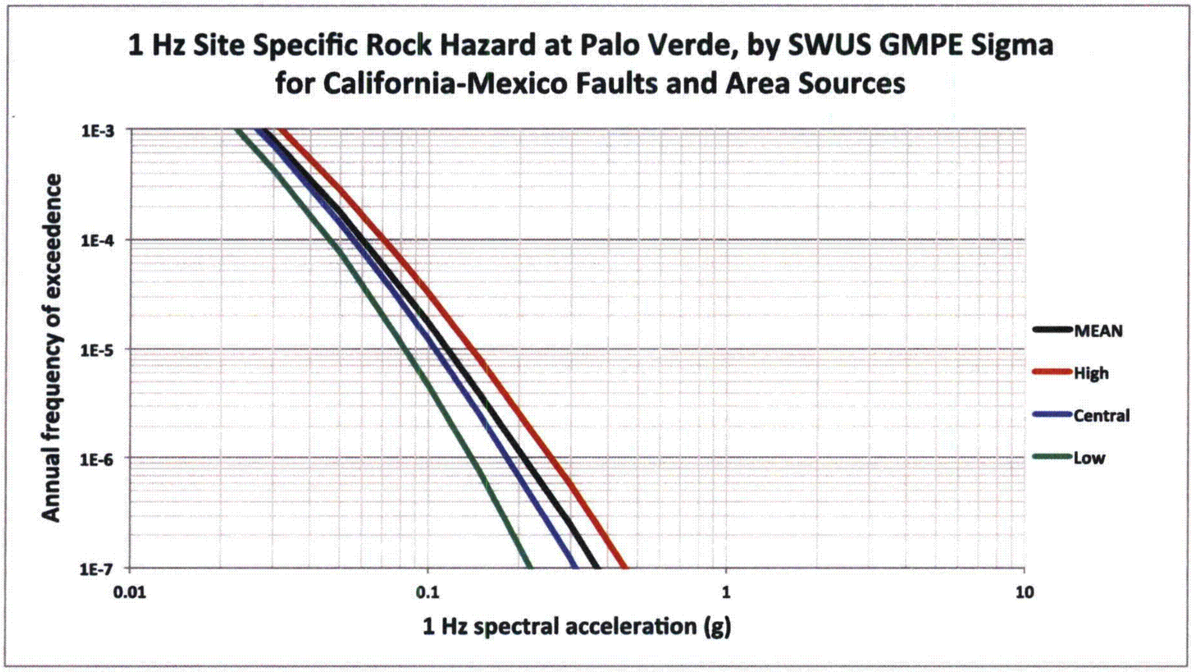


Figure 24. Sensitivity to the epistemic uncertainty in sigma model from California-Mexico faults and area sources for 1 Hz SA. Hazard curves do not include weights on each alternative. Source: Figure 22 from LCI (LCI, 2015c).

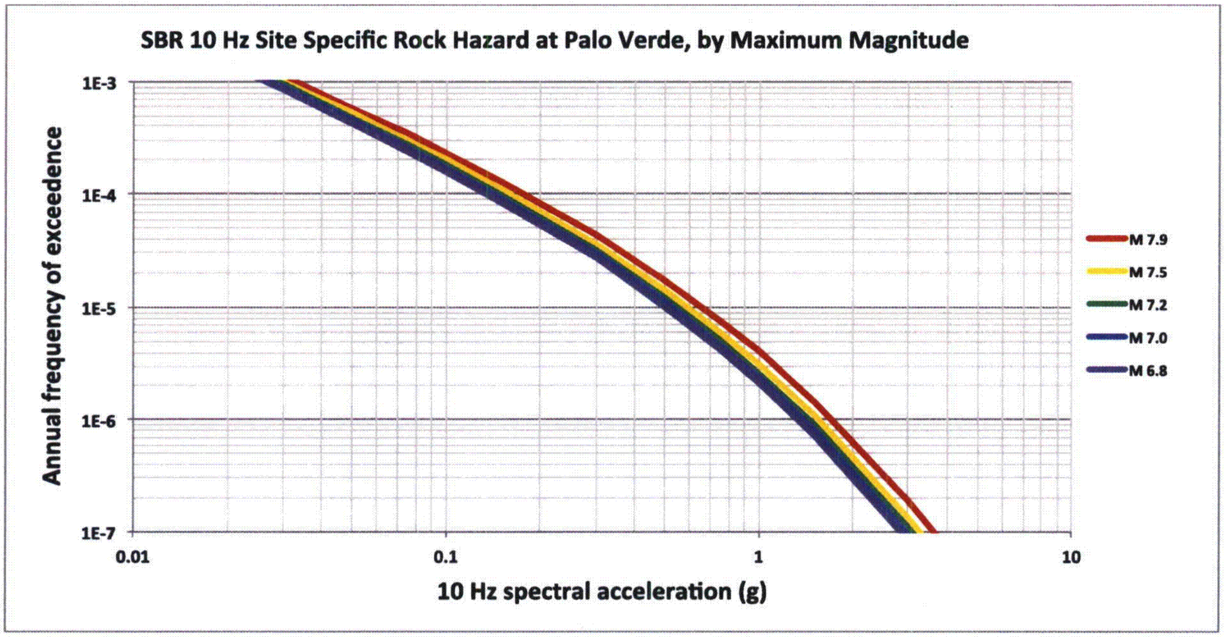


Figure 25. Sensitivity to maximum magnitude for the SBR source for 10 Hz SA. Hazard curves do not include weights on each alternative. Source: Figure 23 from LCI (LCI, 2015c).

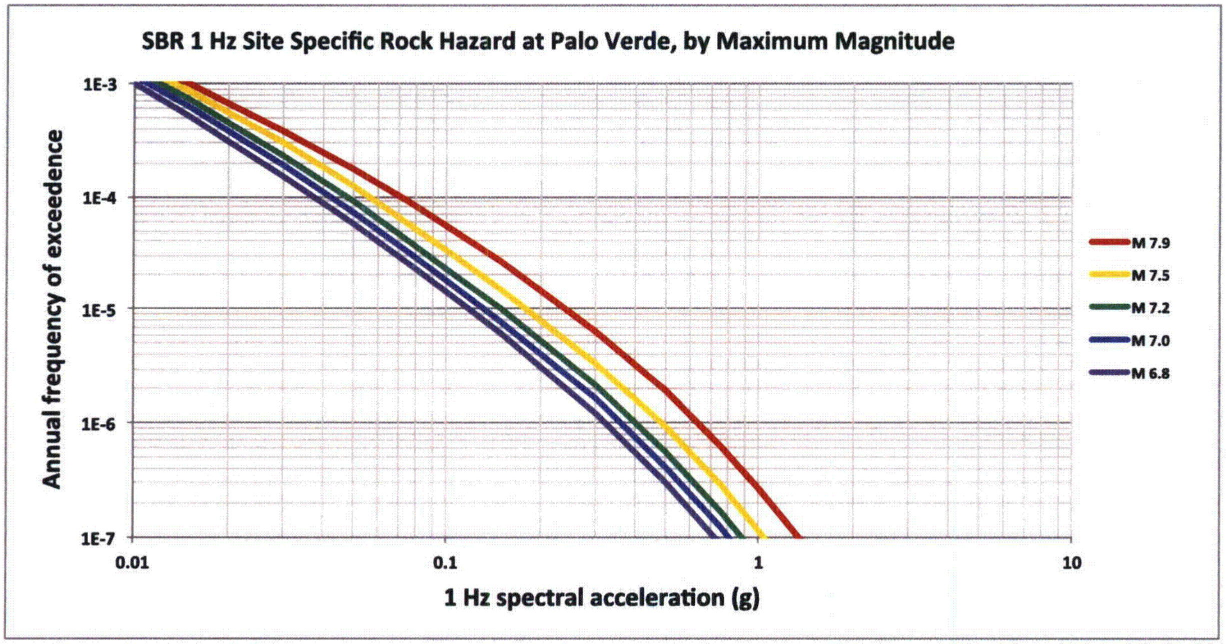


Figure 26. Sensitivity to maximum magnitude for the SBR source for 1 Hz SA. Hazard curves do not include weights on each alternative. Source: Figure 24 from LCI (LCI, 2015c).

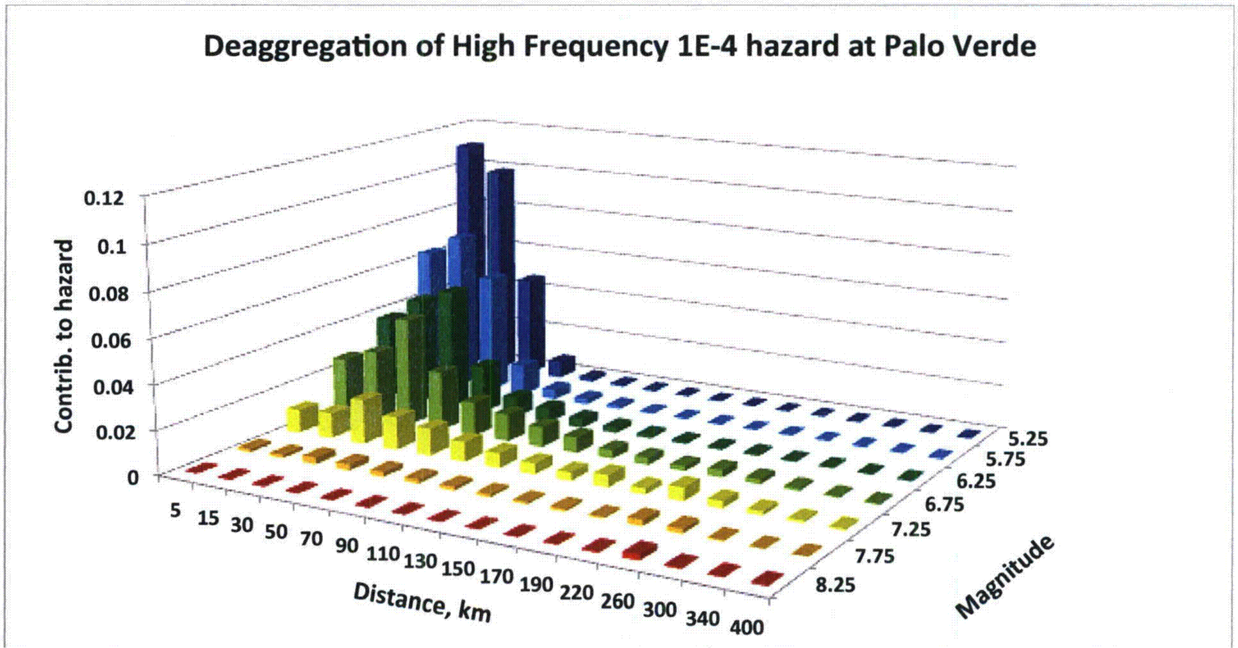


Figure 27. Deaggregation of site specific rock hazard for 10^{-4} MAFE at spectral frequencies of 5 and 10 Hz SA. Source: Figure 34 from LCI (LCI, 2015c).

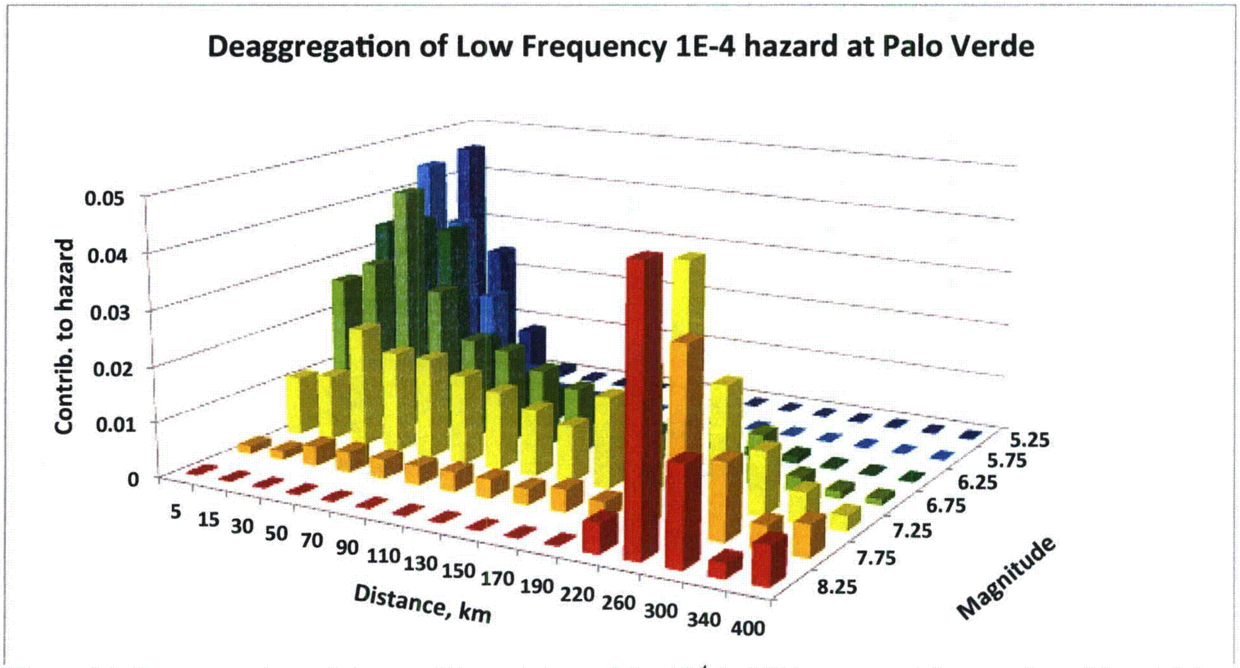


Figure 28. Deaggregation of site specific rock hazard for 10^{-4} MAFE at spectral frequencies of 1 and 2.5 Hz SA. Source: Figure 35 from LCI (LCI, 2015c).

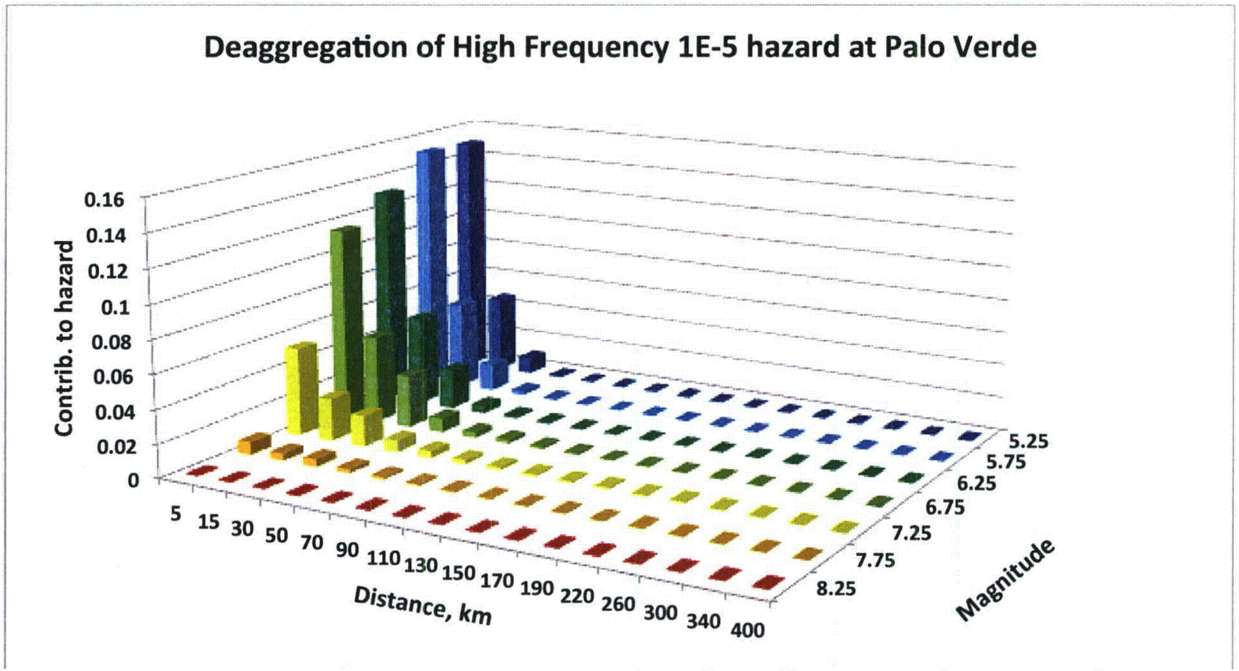


Figure 29. Deaggregation of site specific rock hazard for 10^{-5} MAFE at spectral frequencies of 5 and 10 Hz SA. Source: Figure 36 from LCI (LCI, 2015c).

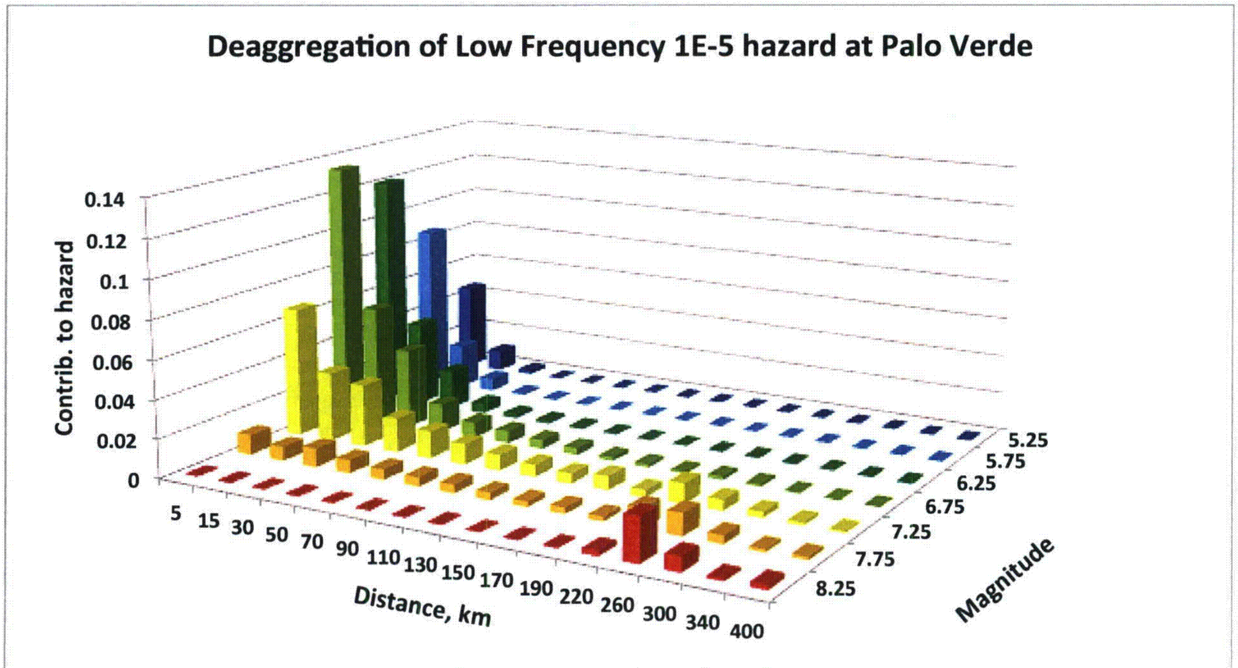


Figure 30. Deaggregation of site specific rock hazard for 10^{-5} MAFE at spectral frequencies of 1 and 2.5 Hz SA. Source: Figure 37 from LCI (LCI, 2015c).

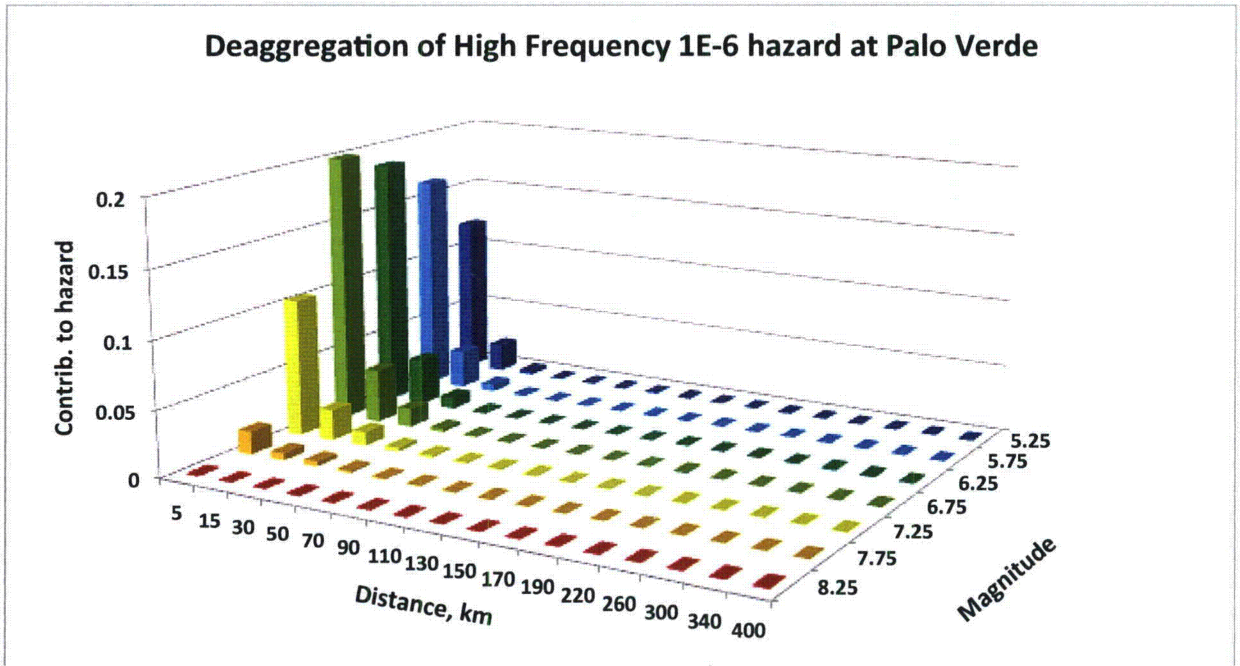


Figure 31. Deaggregation of site specific rock hazard for 10^{-6} MAFE at spectral frequencies of 5 and 10 Hz SA. Source: Figure 38 from LCI (LCI, 2015c).

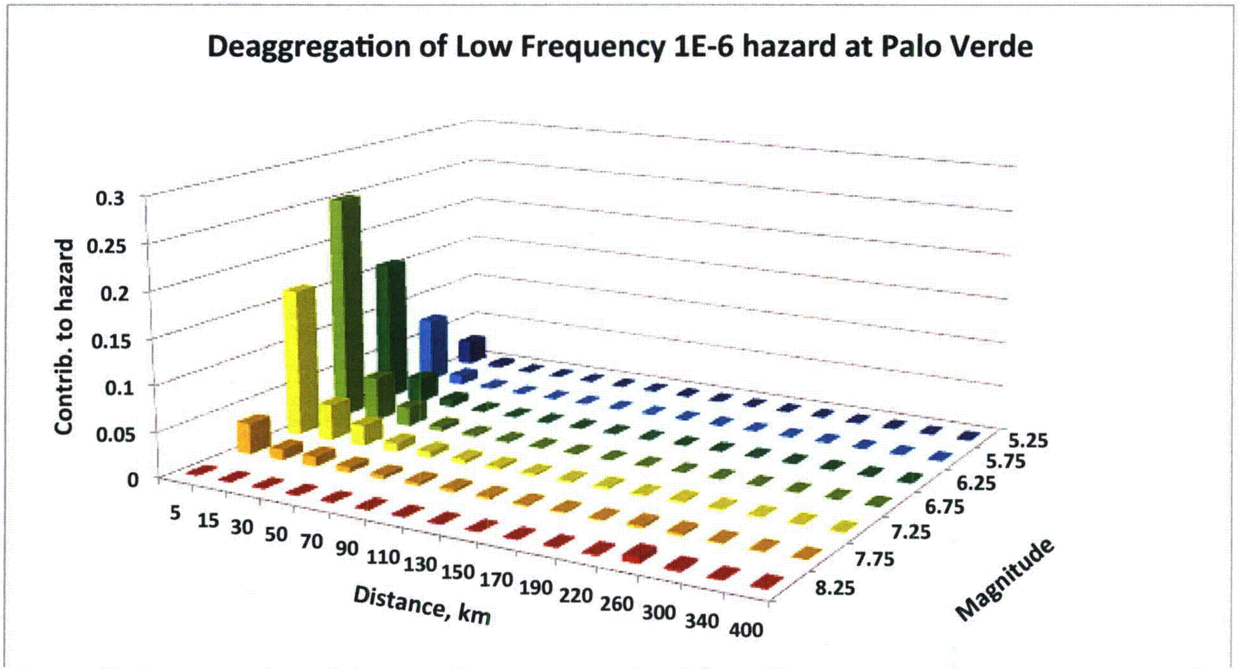


Figure 32. Deaggregation of site specific rock hazard for 10^{-6} MAFE at spectral frequencies of 1 and 2.5 Hz SA. Source: Figure 39 from LCI (LCI, 2015c).

Table 1. Deaggregation results for MAFE 10^{-4}, 10^{-5}, and 10^{-6} high and low frequencies.

	MAFE 10^{-4}		MAFE 10^{-5}		MAFE 10^{-6}	
	Magnitude	**Distance (km)**	**Magnitude**	**Distance (km)**	**Magnitude**	**Distance (km)**
High-Frequency	6.1	21	6.2	9	6.3	7
Low-Frequency	7.4*	210*	7.6*	200*	6.8	9

*M and R calculated for R > 100 km, because the contribution to hazard for R > 100 km is more than 5% of the total hazard (U.S.NRC, 2007). Source: Table 3 from LCI (LCI, 2015c).

2.2.6 Total Mean Seismic Site Specific Rock Hazard Curves

Figure 33 plots total mean hazard curves for the seven spectral frequencies at which hazard calculations were conducted. The individual hazard curves are also documented in tabular form in Table 2.

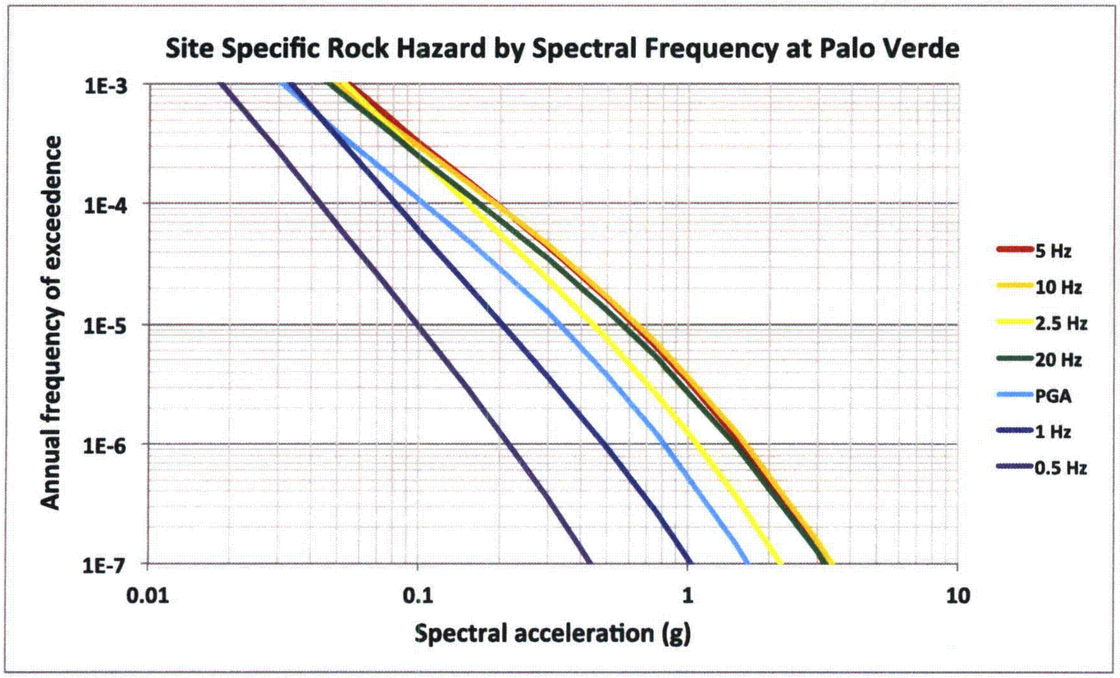


Figure 33. Total mean site specific rock hazard curves for seven spectral frequencies. Source: Figure 25 from LCI (LCI, 2015c).

Table 2. Total mean site specific rock hazard for seven spectral frequencies. Source: Table 2 from LCI (LCI, 2015c).

Spectral acceleration g	0.5 Hz	1 Hz	2.5 Hz	5 Hz	10 Hz	20 Hz	PGA
0.000001	1.60E+00	1.60E+00	1.60E+00	1.60E+00	1.59E+00	1.59E+00	1.59E+00
0.0005	3.07E-01	5.90E-01	8.87E-01	7.16E-01	5.39E-01	5.12E-01	4.80E-01
0.001	1.74E-01	3.50E-01	5.52E-01	4.35E-01	3.12E-01	2.95E-01	2.59E-01
0.005	1.94E-02	5.61E-02	1.03E-01	7.51E-02	4.87E-02	4.80E-02	3.27E-02
0.01	4.58E-03	1.62E-02	3.44E-02	2.47E-02	1.62E-02	1.64E-02	9.47E-03
0.015	1.73E-03	6.84E-03	1.59E-02	1.18E-02	7.99E-03	8.12E-03	4.29E-03
0.03	2.77E-04	1.31E-03	3.61E-03	3.14E-03	2.34E-03	2.27E-03	1.07E-03
0.05	6.63E-05	3.55E-04	1.14E-03	1.18E-03	9.66E-04	8.75E-04	3.97E-04
0.075	2.11E-05	1.23E-04	4.61E-04	5.53E-04	4.87E-04	4.15E-04	1.84E-04
0.1	9.38E-06	5.84E-05	2.45E-04	3.25E-04	3.01E-04	2.47E-04	1.07E-04
0.15	2.94E-06	2.09E-05	1.02E-04	1.56E-04	1.52E-04	1.20E-04	5.00E-05
0.3	3.54E-07	3.69E-06	2.34E-05	4.39E-05	4.54E-05	3.44E-05	1.23E-05
0.5	6.30E-08	9.37E-07	7.45E-06	1.62E-05	1.70E-05	1.28E-05	3.70E-06
0.75	1.43E-08	2.81E-07	2.74E-06	6.70E-06	7.15E-06	5.36E-06	1.24E-06
1	4.66E-09	1.11E-07	1.25E-06	3.35E-06	3.62E-06	2.73E-06	5.30E-07
1.5	8.68E-10	2.72E-08	3.72E-07	1.13E-06	1.26E-06	9.65E-07	1.43E-07
3	3.60E-11	1.87E-09	3.50E-08	1.29E-07	1.54E-07	1.25E-07	1.14E-08
5	2.61E-12	2.02E-10	4.86E-09	2.05E-08	2.64E-08	2.24E-08	1.39E-09
7.5	2.73E-13	2.92E-11	8.68E-10	4.14E-09	5.69E-09	5.05E-09	2.23E-10
10	4.99E-14	6.71E-12	2.34E-10	1.22E-09	1.78E-09	1.64E-09	5.55E-11

2.3 Site Response Evaluation

A site response analysis was performed for PVNGS following the guidance contained in Seismic Enclosure 1 of the 10 CFR 50.54(f) letter (U.S.NRC, 2012a) and in the Screening, Prioritization, and Implementation Details (SPID) (EPRI, 2013) for nuclear power plant sites that are not founded on hard rock (defined as 2.83 km/s).

2.3.1 Description of Subsurface Material

The subsurface material at PVNGS consists of about 350 ft of basin sediments overlying bedrock, with a crystalline basement complex at a depth of about 1,200 feet below the ground surface. Basin sediments include stratigraphic subdivisions of sands, gravels, clays, silts, and fanglomerate. Bedrock consists of Miocene volcanic and interbedded sedimentary rocks. The basement complex comprises Precambrian granitic and metamorphic rocks (UFSAR, Rev. 17). In the following site response analysis, these materials are divided into two representative site geologic profiles, a shallow site profile and deep site profile, that are separated at the bottom of the basin sediments.

2.3.2 Development of Base Case Profiles and Nonlinear Material Properties

Shallow Site Profile: The PVNGS shallow site profile (LCI, 2015d) was developed from detailed lithologic descriptions and natural gamma logs from UFSAR and PSAR documents to define stratigraphic horizons of similar composition and texture. Boring logs from beneath each of the three reactors are shown in Figure 34. A composite shallow stratigraphic profile (Figure 35) was created by averaging the thickness and properties of each correlative horizon. Mean layer depths and their variability as well as best-estimates of shear wave velocity (Vs) and unit weight are provided in Table 3. The control point elevation for this profile is defined at the ground surface.

Best-estimate values in Table 3 make up the base-case shallow site profile. These Vs values were estimated from suspension logs (LCI, 2015f), downhole and crosshole surveys from the UFSAR and Spectral Analysis of Surface Waves (SASW) surveys (LCI, 2015g). Epistemic uncertainty ($\sigma_{\ln Vs}$) was estimated for shear wave velocities in the base-case (BC) profile from the different measurements that were used to develop best-estimate values, and is provided for each layer in Table 3. Upper-range (UR) and lower-range (LR) profiles were developed by multiplying and dividing the BC profile by $\exp(1.28*\sigma_{\ln Vs})$, following guidance in the SPID to achieve 10th and 90th percentile values. BC, LR, and UR Vs profiles are provided in Figure 36 and Table 4. Note that the UR profile does not include a lithologic layer of fanglomerate to account for its possible non-existence.

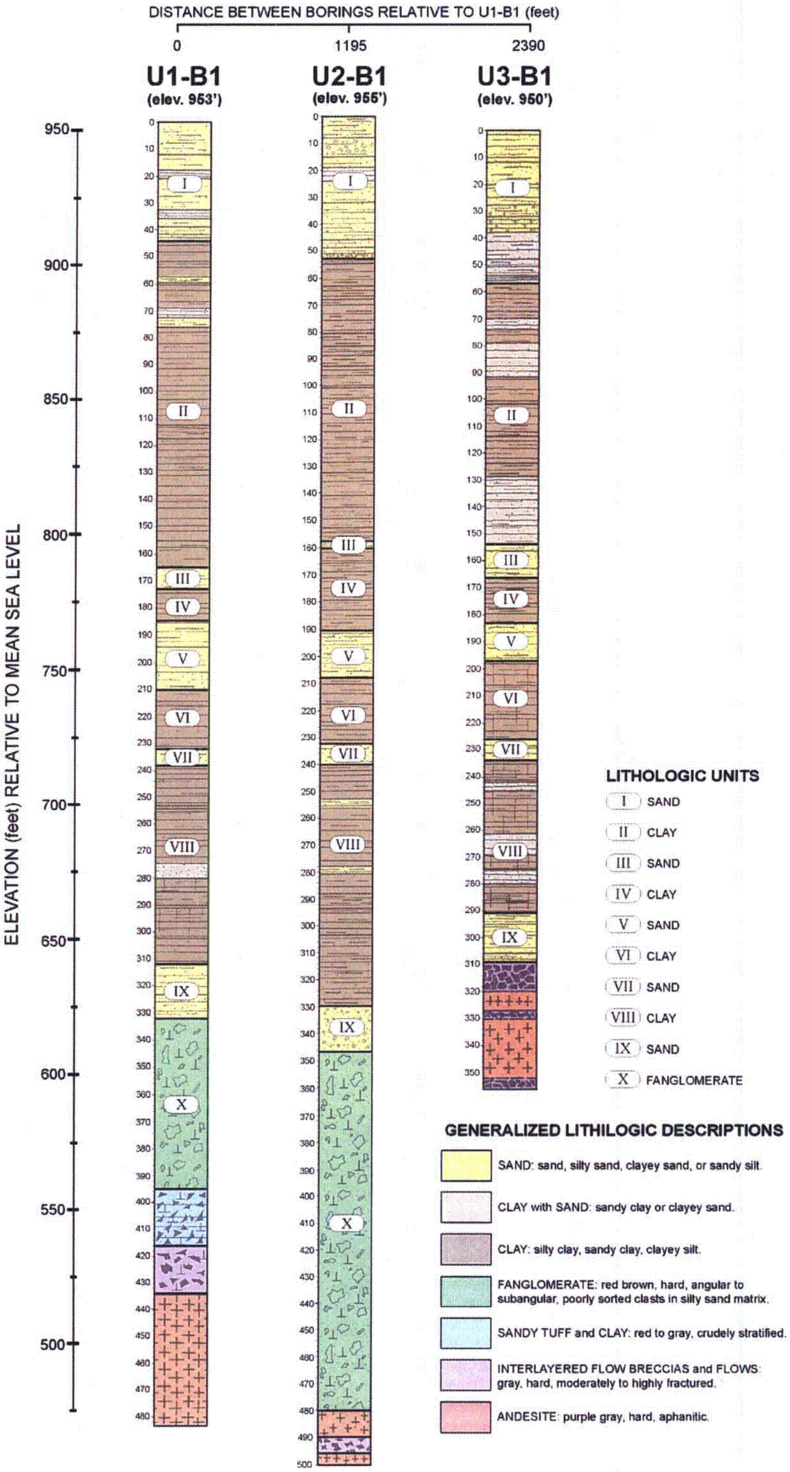
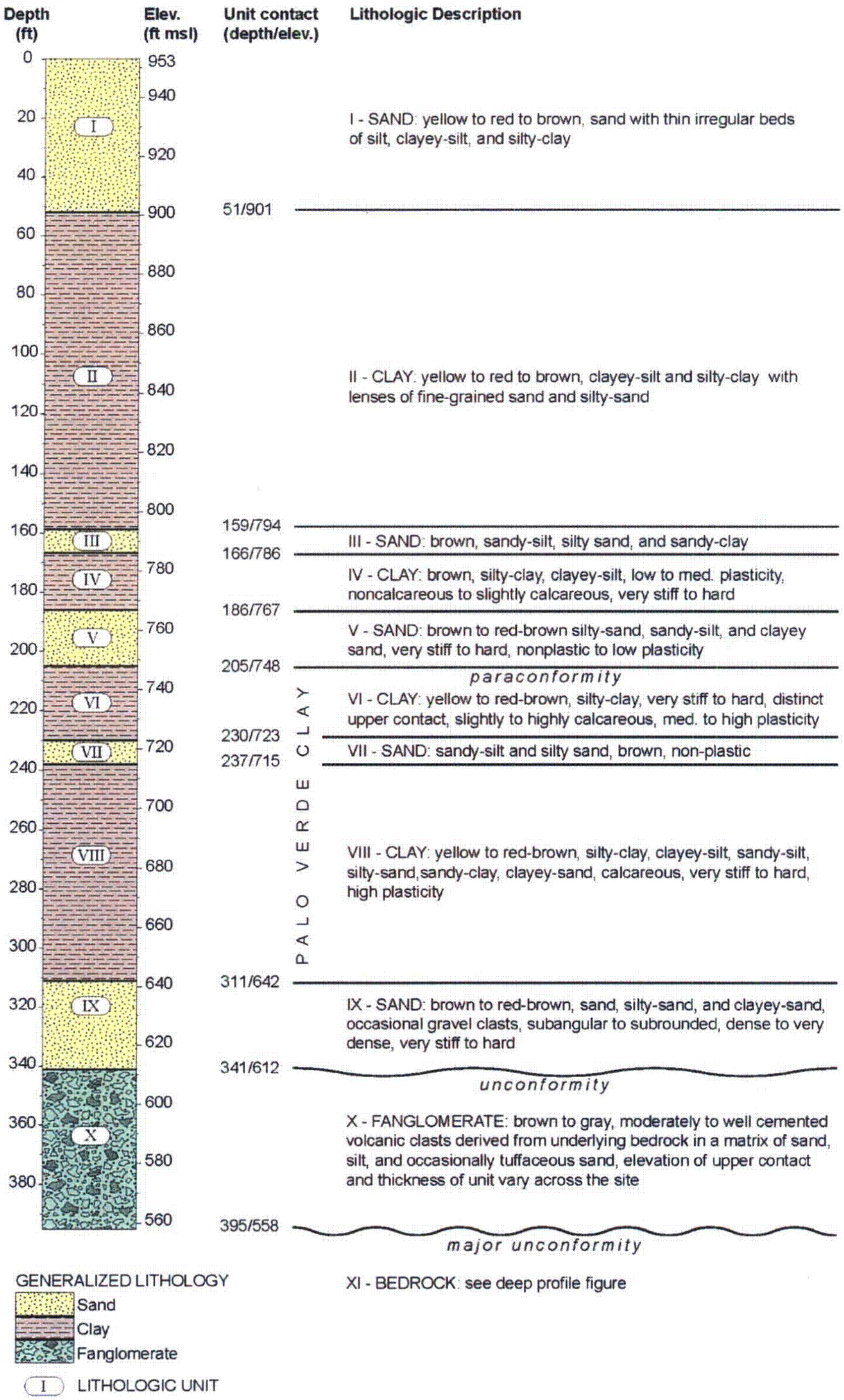


Figure 34. PVNGS Units 1, 2, and 3 generalized boring stratigraphy modified from Units 1, 2, and 3 B1 borings PSAR, Amendment 20. Lithologic units are identified with Roman numerals I-X. Source: Figure 2 from LCI (LCI, 2015d).



I - SAND: yellow to red to brown, sand with thin irregular beds of silt, clayey-silt, and silty-clay

51/901

II - CLAY: yellow to red to brown, clayey-silt and silty-clay with lenses of fine-grained sand and silty-sand

159/794

III - SAND: brown, sandy-silt, silty sand, and sandy-clay

166/786

IV - CLAY: brown, silty-clay, clayey-silt, low to med. plasticity, noncalcareous to slightly calcareous, very stiff to hard

186/767

V - SAND: brown to red-brown silty-sand, sandy-silt, and clayey sand, very stiff to hard, nonplastic to low plasticity

205/748

VI - CLAY: yellow to red-brown, silty-clay, very stiff to hard, distinct upper contact, slightly to highly calcareous, med. to high plasticity

230/723

VII - SAND: sandy-silt and silty sand, brown, non-plastic

237/715

VIII - CLAY: yellow to red-brown, silty-clay, clayey-silt, sandy-silt, silty-sand,sandy-clay, clayey-sand, calcareous, very stiff to hard, high plasticity

311/642

IX - SAND: brown to red-brown, sand, silty-sand, and clayey-sand, occasional gravel clasts, subangular to subrounded, dense to very dense, very stiff to hard

341/612

X - FANGLOMERATE: brown to gray, moderately to well cemented volcanic clasts derived from underlying bedrock in a matrix of sand, silt, and occasionally tuffaceous sand, elevation of upper contact and thickness of unit vary across the site

395/558

XI - BEDROCK: see deep profile figure

Figure 35. Shallow site stratigraphic column for the PVNGS site. Source: Figure 5 from LCI (LCI, 2015d).

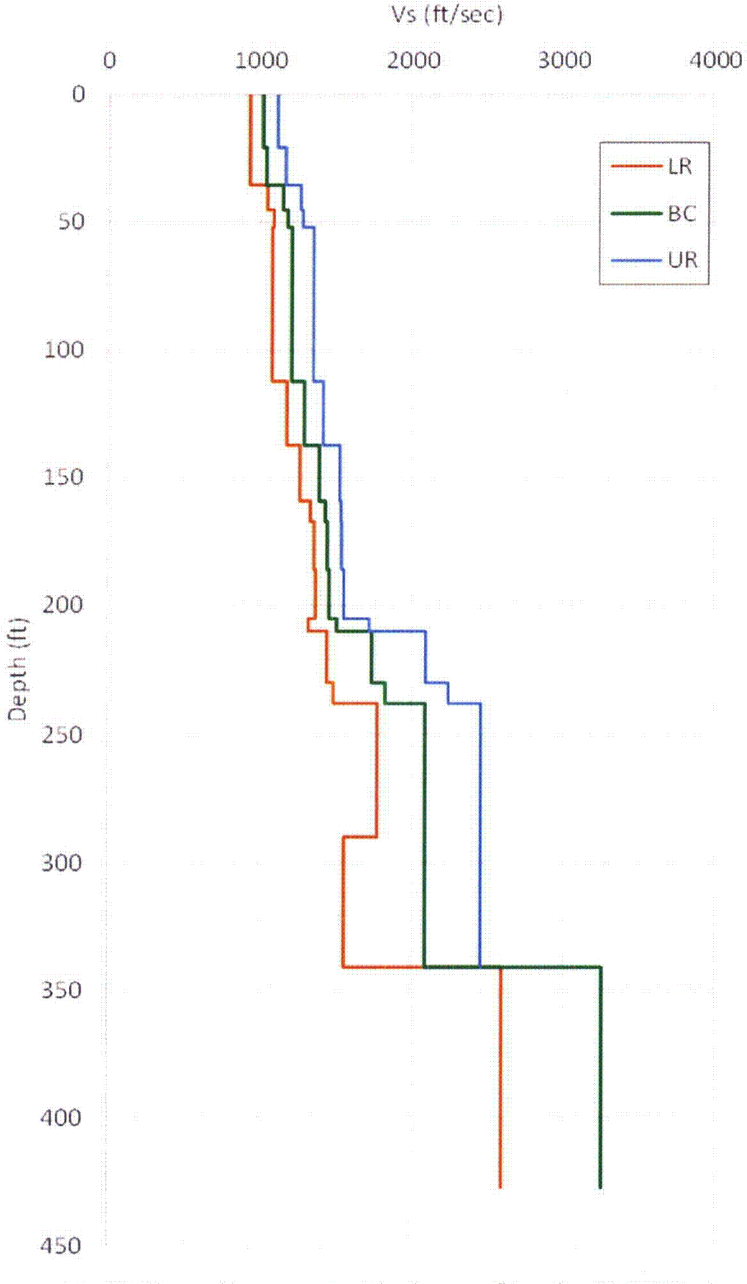


Figure 36. Shallow shear wave velocity profiles for PVNGS: base-case (BC), lower-range (LR), and upper-range (UR). Note that the UR profile ends at a depth of 340 ft. Source: Figure 32 from LCI (LCI, 2015d).

Table 3. Dynamic properties of shallow site profile. Source: Table 9 from LCI (LCI, 2015d).

Layer	Strati-graphic Unit	Generalized lithology	Depth (ft)	Thickness (ft)	Unit Weight (pcf)	Sigma Depth (ft)	Base Case Vs (ft/s)	sigma Vs (ln)	sigma Vs (ln) [SPID]
1	I	Sand	0	21	120	0.0	1017	0.070	0.23
2	I	Sand	21	14	120	3.2	1041	0.088	0.19
3	I	Sand	35	10	120	5.4	1150	0.075	0.17
4	I	Sand	45	7	120	6.9	1181	0.063	0.15
5	II	Clay	52	60	125[1]	8.0	1208	0.087	0.15
6	II	Clay	112	25	125[1]	3.5	1293	0.073	0.15
7	II	Clay	137	22	125[1]	4.3	1391	0.073	0.15
8	III	Sand	159	8	126[2]	5.0	1432	0.055	0.15
9	IV	Clay	167	19	125[1]	8.0	1446	0.049	0.15
10	V	Sand	186	19	126[2]	2.0	1459	0.050	0.15
11	VI	Clay	205	5	125[1]	5.0	1510	0.103	0.15
12	VI	Clay	210	20	125[1]	1.8	1742	0.145	0.15
13	VII	Sand	230	8	126[2]	2.0	1829	0.160	0.15
14	VIII	Clay	238	52	125[1]	1.0	2094	0.127	0.15
15	VIII	Clay	290	21	125[1]	15.9	2094	0.127	0.15
16	IX	Sand	311	30	130	17.0	2094	0.127	0.15
17	X	Fanglomerate	341	86	140	60.0	3262	0.176	0.15
Bed-rock	XI	Andesite/ basalt/ flow breccia/tuff	427	N/A[3]	140	83	4485	N/A[3]	N/A[3]

Notes:

[1] 125 pcf is the average unit weight of all clay units. The unit weights for all clay units are averaged for the sake of simplicity in the site response analysis.

[2] 126 pcf is the average unit weight of Sand Units III, V, and VII. The average is used for the sake of simplicity in the site response analysis.

[3] In the site response analysis for shallow profile, Unit XI is considered as the half space.

Table 4. Layer depths, thicknesses, and shear wave velocities (Vs) for lower-range (LR), base-case (BC), and upper-range (UR) profiles for the shallow site profile at PVNGS. Source: Table 10 from LCI (LCI, 2015d).

Layer	Depth (ft)	Thickness (ft)	Vs (ft/sec)		
			LR	BC	UR
1	0	21	929	1017	1113
2	21	15	930	1041	1165
3	35	10	1046	1150	1266
4	45	7	1090	1181	1280
5	52	60	1081	1208	1351
6	112	25	1178	1293	1419
7	137	22	1266	1391	1528
8	159	8	1334	1432	1536
9	167	19	1359	1446	1540
10	186	19	1369	1459	1555
11	205	5	1324	1510	1723
12	210	20	1448	1742	2098
13	230	8	1489	1829	2245
14	238	52	1780	2094	2462
15	290	21	1560	2094	2462
16	311	30	1560	2094	2462
17	341	86	2603	3262	N/A

Deep Site Profile: The PVNGS deep site profile was developed in LCI Calculation *Adjustment Factors from Reference Rock to Palo Verde Rock* (LCI, 2015b) and LCI (LCI, 2015d) from data presented in the UFSAR and Geological Society of America Bulletin *A seismic-refraction survey of crustal structure in central Arizona* (Warren, 1969) to model the bedrock and basement complex materials. There are no borings underneath the three units that reach the top of the basement complex, so the upper contact is estimated using a geologic cross-section from the UFSAR that shows the shallow and deep stratigraphy at the site (Figure 37). Mean layer depths and their variability as well as best-estimates of Vs and unit weight are provided in Table 5. The control point elevation for this profile is defined at the bottom of the shallow site profile.

Best-estimate values in Table 5 make up the base-case deep site profile. These Vs values were estimated from suspension (LCI, 2015f) for bedrock. Vs for the basement complex was determined using typical seismic wave velocities for granodiorite due to the absence of site specific data. Epistemic uncertainty was estimated for Vs in the BC profile using a logarithmic standard deviation of 0.35 as recommended by the SPID (EPRI, 2013).

Just like the shallow site profile, UR and LR Vs values were developed by multiplying and dividing the BC profile value by $\exp(1.28*\sigma_{\ln Vs})$, respectively. Uncertainty in the thickness of each layer was accounted for in the LR and UR deep site profiles. For the volcanics, this uncertainty was determined from boring logs as described in LCI (LCI, 2015d). For the upper basement layers, this uncertainty was taken as 10 percent of each respective mean thickness. The LR and UR profiles were constructed by pairing 90th percentile Vs with 10th percentile thickness (and vice versa) in order to maximize the variation in travel time, in a manner similar to what is done in EPRI (EPRI, 2013). The three resulting Vs profiles are shown in Figure 38 and Table 6.

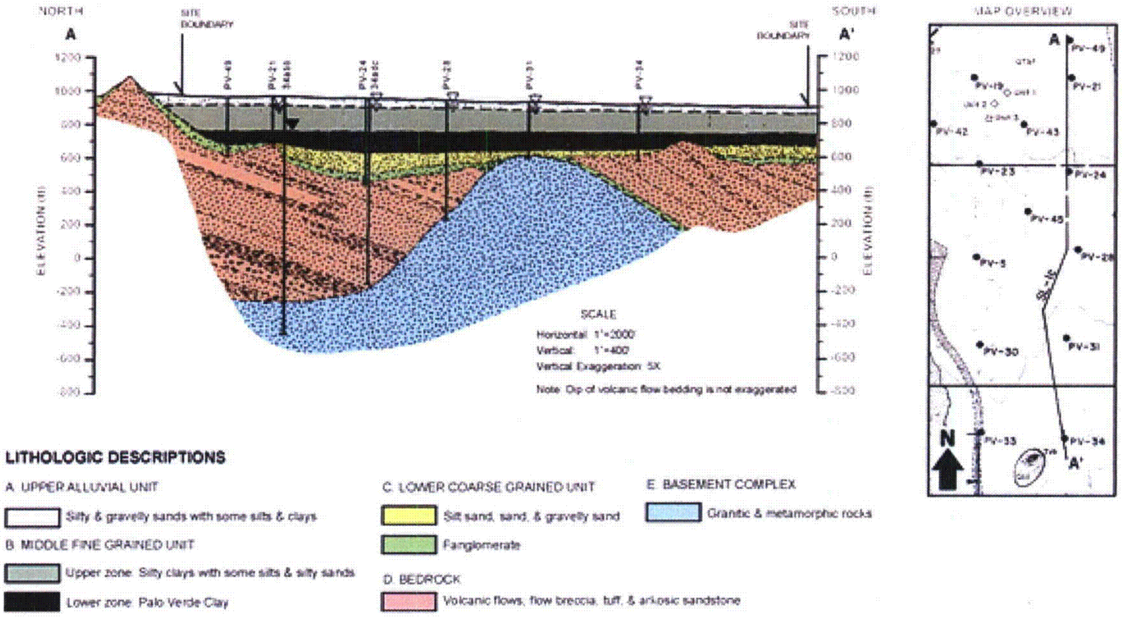


Figure 37. Geologic cross-section showing the shallow and deep stratigraphy at the PVNGS site; modified from UFSAR Figure 2.4-27. The map in plan view on the right shows the cross-section line, as noted by A-A'; map is modified from PSAR Figure 2.5-13. Note that Units 1-3 are west of the cross-section line, between borings PV-21 and PV-24. Source: Figure 8 from LCI (LCI, 2015d).

Table 5. Dynamic properties of deep site profile. Source: Table 16 from LCI (LCI, 2015d).

Strat. unit	**Generalized lithology**	**Depth to top of layer (ft)**	**Unit weight (pcf)**	**Mean Vs (ft/sec)**	**Mean Vp (ft/sec)**	**Vs Sigma (ln)**	**Poisson's Ratio**	**Elevation**				**Mean Thickness (ft)**	**Sigma, Thickness (ft)**
								Mean, Top (ft msl)	**Sigma, Top (ft)** [3]	**Range +, Top (ft msl)**	**Range -, Top (ft msl)**		
XI	Andesite/ basalt/ flow breccia/ tuff	395	140	4485	9863	0.35	0.370	558	83	641	475	808	145
XII	Weathered granodiorite/ meta-granite (top)	1203	146[1]	5438	10786	0.35	0.330	-250	N/A	N/A	N/A	20	10
XII	Weathered granodiorite/ meta-granite (middle)	1223	152[1]	7343	12632	0.35	0.245	-270	N/A	N/A	N/A	20	10
XII	Weathered granodiorite/ meta-granite (bottom)	1243	157[1]	9248	14477	0.35	0.155	-290	N/A	N/A	N/A	20	10
XII	Granodiorite/ meta-granite	1263	171[2]	10200	15400	0.35	0.109	-310	N/A	N/A	N/A	N/A	N/A

Notes:

[1] Unit weight for the weathered basement complex is determined from Vp.

[2] Unit weight for unweathered basement complex is determined from Warren (Warren, 1969).

[3] Sigma top is only calculated for Andesite XI for use in shallow site profile site response calculations. Sigma is calculated using top elevation contact of bedrock from Units 1-3 B1 boreholes (Figure 34).

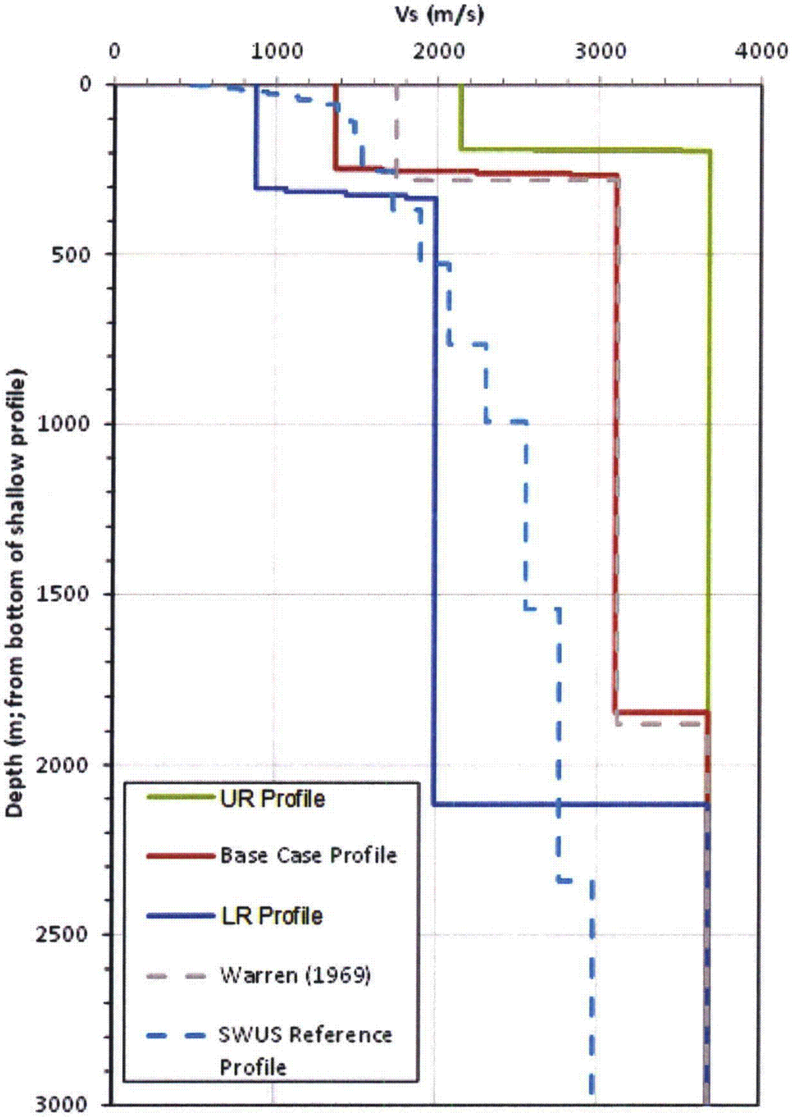


Figure 38. Deep shear wave velocity profiles for PVNGS. A depth of 0 corresponds to the bottom of the shallow profile (soils). Also shown are the Warren (Warren, 1969) and SWUS GMC (GeoPentech, 2015) profiles. Source: Figure 1 from LCI (LCI, 2015b).

Table 6. Lower-range (LR), base-case (BC), and upper-range (UR) profiles for the deep site profile at PVNGS. Source: LCI (LCI, 2015d).

Lower Range Profile (low velocities, thicker layers, base-case density); weight = 0.3		
Description	Thickness (m)	Vs (m/s)
Volcanic bedrock sequence	324.2	873.4
Basement (shallow; weathered top)	10.0	1,059.0
Basement (shallow; weathered middle)	10.0	1,430.0
Basement (shallow; weathered bottom)	10.0	1,800.9
Basement (shallow)	1,784.2	1,986.3
Basement (deep)	22,560.0	3,680.0

Base Case Profile (median Values all parameters); weight = 0.4		
Description	Thickness (m)	Vs (m/s)
Volcanic bedrock sequence	267.6	1,367.0
Basement (shallow; weathered top)	6.1	1,657.5
Basement (shallow; weathered middle)	6.1	2,238.1
Basement (shallow; weathered bottom)	6.1	2,818.8
Basement (shallow)	1,581.7	3,109.0
Basement (deep)	20,000.0	3,680.0

Upper Range Profile (high velocities, thinner layers, base case density); weight = 0.3		
Description	Thickness (m)	Vs (m/s)
Volcanic bedrock sequence	211.0	2,139.6
Basement (shallow; weathered top)	2.2	2,594.3
Basement (shallow; weathered middle)	2.2	3,503.1
Basement (shallow; weathered bottom)	2.2	3,680.0
Basement (shallow)	1,379.3	3,680.0
Basement (deep)	17,440.0	3,680.0

2.3.2.1 *Shear Modulus and Damping Curves*

Site specific nonlinear dynamic material properties were not available for PVNGS for the soils and firm rock that comprise the shallow site profile. The soil material over the shallow site profile was modeled with both the EPRI cohesionless soil (EPRI, 1993) and Peninsular Range (Silva et al., 1996) G/Gmax and hysteretic damping curves while the clay material was modeled using Vucetic and Dobry (Vucetic and Dobry, 1991) values. Consistent with the SPID (EPRI, 2013), the EPRI soil and Peninsular Range curves were considered to be equally appropriate to represent the more nonlinear response likely to occur in the materials at this site. Only Vucetic and Dobry (Vucetic and Dobry, 1991) curves were used to model the nonlinear response of the clay layers. The generic degradation curves of Vucetic and Dobry (Vucetic and Dobry, 1991) were developed with a wide range of clay data and are judged to be the best equivalent-linear material model available. Table 7 summarizes the alternative material properties applied to each layer.

Table 7. Degradation curves for each stratigraphic unit at PVNGS. Source: Table 14 from LCI (LCI 2015d).

Layer	Stratigraphic Unit	Generalized lithology	Depth (ft)	Thickness (ft)	Degradation Curves (Alternative 1)	Degradation Curves (Alternative 2)
1	I	Sand	0	21	EPRI Soil 0-20 ft	Peninsular Curves 0-50 ft
2	I	Sand	21	14	EPRI Soil 20-50 ft	Peninsular Curves 0-50 ft
3	I	Sand	35	10	EPRI Soil 20-50 ft	Peninsular Curves 0-50 ft
4	I	Sand	45	7	EPRI Soil 20-50 ft	Peninsular Curves 0-50 ft
5	II	Clay	52	60	Vucetic and Dobry (1991)-PI=30	Vucetic and Dobry (1991)-PI=30
6	II	Clay	112	25	Vucetic and Dobry (1991)-PI=30	Vucetic and Dobry (1991)-PI=30
7	II	Clay	137	22	Vucetic and Dobry (1991)-PI=30	Vucetic and Dobry (1991)-PI=30
8	III	Sand	159	8	EPRI Soil 120-250 ft	Peninsular Curves 51-500 ft
9	IV	Clay	167	19	Vucetic and Dobry (1991)-PI=30	Vucetic and Dobry (1991)-PI=30
10	V	Sand	186	19	EPRI Soil 120-250 ft	Peninsular Curves 51-500 ft
11	VI	Clay	205	5	Vucetic and Dobry (1991)-PI=30	Vucetic and Dobry (1991)-PI=30
12	VI	Clay	210	20	Vucetic and Dobry (1991)-PI=30	Vucetic and Dobry (1991)-PI=30
13	VII	Sand	230	8	EPRI Soil 120-250 ft	Peninsular Curves 51-500 ft
14	VIII	Clay	238	52	Vucetic and Dobry (1991)-PI=30	Vucetic and Dobry (1991)-PI=30
15	VIII	Clay	290	21	Vucetic and Dobry (1991)-PI=30	Vucetic and Dobry (1991)-PI=30
16	IX	Sand	311	30	EPRI Soil 250-500 ft	Peninsular Curves 51-500 ft
17	X	Fanglomerate	341	86	EPRI Soil 250-500 ft	Peninsular Curves 51-500 ft

Shear modulus and damping curves were not required for the deep site profile. Strains will remain low in such firm materials at the depths represented by this profile, so it is not necessary to model nonlinear behavior.

2.3.2.2 Kappa

Adjustment factors were developed in LCI (LCI, 2015b) to convert ground motions from the reference rock associated with the GMPEs from the SWUS GMC (GeoPentech, 2015) to site specific rock conditions at PVNGS corresponding to the deep site profile described above. These Vs-kappa[7] adjustments consist of two parts. The first part accounts for impedance differences. This part can be calculated using the Quarter-wavelength approach (Boore and Joyner, 1997; Boore, 2003, 2013) and affects all frequencies. The second part accounts for the differences in kappa. It has an exponential form and affects mainly the high frequencies. The net adjustment factor (in Fourier-amplitude space) is the ratio of the target filter (for site specific rock) divided by the host filter (for reference rock). Multiple values of this factor were calculated to account for uncertainty in the inputs.

The host kappa value for SWUS GMPEs was taken as 0.041 sec (GeoPentech, 2015), and the target kappa value at PVNGS was taken as 0.033 sec with a logarithmic standard deviation of 0.5 (GeoPentech, 2015). The BC target kappa value is 0.033 sec, and the associated uncertainty was used to derive the 10th and 90th percentiles for a LR and UR value, respectively. The BC, LR, and UR target kappas were combined with each of the BC, LR, and UR deep site profiles in LCI (LCI, 2015d) to get nine sets of adjustment factors (Table A-1 in Appendix A and Figure 39). The weights applied to the {BC, LR, UR} kappa alternatives and {BC, LR, UR} Vs profile alternatives were each {0.4, 0.3, 0.3}, respectively. The resulting combined weights for the nine sets of adjustment factors are provided in Table A-1 in Appendix A.

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[7] Vs is the shear wave velocity; kappa is a quantity that represents the anelastic attenuation in the upper crust. In the nomenclature of Anderson and Hough (Anderson and Hough, 1984), the kappa used in this calculation corresponds to kappa-zero, as it captures attenuation effects in the upper crust, rather than whole-path attenuation.

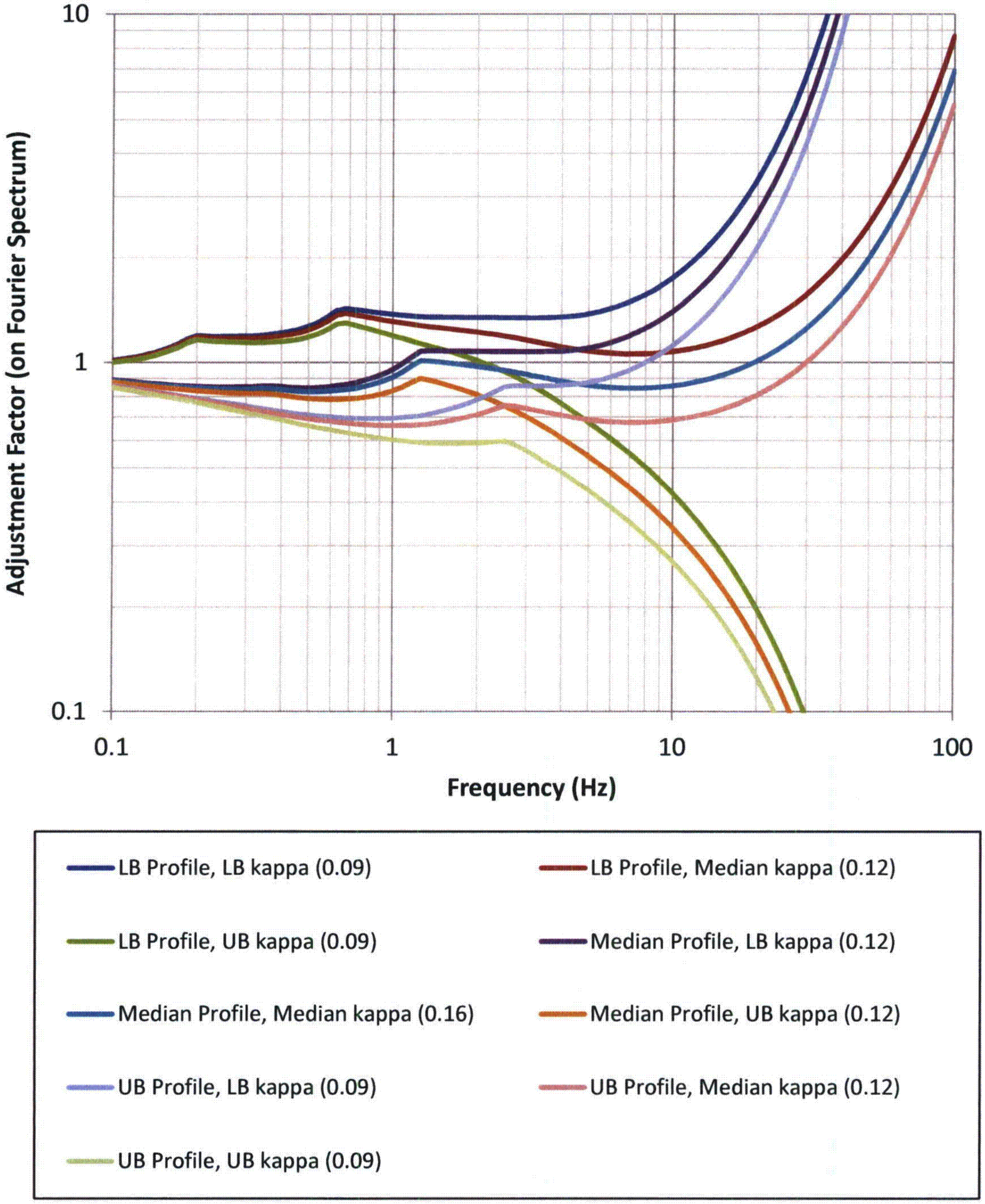


Figure 39. Adjustment factors to convert ground motions from SWUS reference rock to PVNGS rock conditions. Although some of these adjustment factors become very large at high frequencies (as a result of the kappa adjustments), the SWUS GMC (GeoPentech, 2015) rock motions have zero or no energy at these frequencies (say, above 20 Hz). Therefore, the effect on spectral accelerations is expected to be much smaller than the effect shown here. Source: Figure 2 from LCI (LCI, 2015b).

2.3.3 Randomization of Shear Wave Velocity Profiles

Randomization of each profile (BC, LR, UR) was performed to account for aleatory variability of the assigned properties across the site at the scale of a typical nuclear facility. The following properties were randomized:

- *Shear wave velocity in each layer.* SPID (EPRI, 2013) guidance was followed. Aleatory variability of shear wave velocities (Vs) in each layer was modeled in a depth-dependent manner using the logarithmic standard deviations provided in Table 3. For all layers, shear wave velocities were truncated to +/-2 $\sigma_{\ln Vs}$. Correlation of Vs between adjacent layers was also modeled according to Toro (Toro, 1995) using USGS site class "A" parameters (which are for hard rock). Note that the depth used to determine variability and correlation corresponds to the middle of each layer.
- *Material properties.* SPID guidance was followed. Realizations were truncated at +/-2 $\sigma_{\ln}$ for both G/G_{max} and damping curves.
- *Profile layer depths and thicknesses.* Depth to the top of each layer was modeled using a Normal distribution. The mean and standard deviation used for this model were the values provided in Table 3. Each realization of depth to the top of a given layer was limited to +/-2σ.
- *Depth to bedrock.* Depth to the bedrock was modeled using a Normal distribution. The mean and standard deviation used for this model were the values provided in Table 3. Each realization of depth to the top of bedrock was limited to +/-2σ.
- *Kappa.* Kappa was modified per Section 2.3.2.2 to adjust SWUS GMPEs to site specific PVNGS rock conditions.

Sixty random velocity profiles were generated for each combination of profile (BC, LR, and UR), material model (EPRI or Peninsular values), input spectrum (Refer to Section 2.3.4), and set of adjustment factors (Refer to Section 2.3.2.2).

2.3.4 Input Spectra

Input control motions were obtained using previously calculated reference-rock hazard for PVNGS (LCI, 2105a). Both the high-frequency (HF; derived from hazard at 5 Hz and 10 Hz spectral frequencies) and low-frequency (LF; derived from hazard at 1 Hz and 2.5 Hz spectral frequencies) spectra from LCI (LCI, 2015a) at mean annual frequencies of exceedence (MAFEs) of 10^{-4}, 10^{-5}, and 10^{-6} were scaled to 11 different PGA amplitudes between 0.01 g and 1.5 g (for a total of 22 input control motions) following guidance from the SPID. The 11 PGA amplitudes are approximately equally spaced (logarithmically) within that range. The HF or LF spectrum with the nearest PGA value to each amplitude was scaled to that amplitude. The resulting scaled HF motions are provided in Table A-2 of Appendix A, and scaled LF motions are provided in Table A-3 of Appendix A.

Input response spectra were converted to Fourier amplitude spectra (FAS) using inverse random vibration theory (IRVT; e.g., Rathje et al., 2005). IRVT requires an estimate of ground motion duration for each input control motion, which was calculated according to the method in Rathje et al. (2005). This duration calculation requires mean deaggregated magnitudes (M) and distances (R) for each HF and LF spectrum (from LCI, 2015a and provided in Table 8) as well as stress drop and crustal velocity values. Values for stress-drop (100 bars) and crustal velocity (3,500 m/s) for the PVNGS region were obtained from general western United States values provided in Al Atik et al. (Al Atik et al., 2014). The calculated durations are listed in Table 8.

Figure 40 shows the IRVT-derived FAS corresponding to the HF input response spectrum at a MAFE of 10^{-4} before and after the host kappa value was enforced. Removal of the high frequency content from the FAS by enforcing kappa results in an IRVT-derived response spectrum slightly different from the input target spectrum, however this deviation is not expected to have a significant effect on site response calculations. Kappa was enforced at about 10 Hz where the slope of the FAS obtained from the IRVT process is very close to the host kappa value. These results are representative of the other input control motions.

Table 8. Deaggregated magnitudes and distances for reference rock and associated durations. Source: LCI (LCI, 2015a).

Motion	Magnitude (M_w)	Distance (km)	Duration (sec)
10^{-4} Low Freq.	7.5	210	26.3
10^{-4} High Freq.	6.1	18	4.06
10^{-5} Low Freq.	7.6	200	27.7
10^{-5} High Freq.	6.2	8.0	3.94
10^{-6} Low Freq.	6.8	8.0	7.46
10^{-6} High Freq.	6.4	6.0	4.76

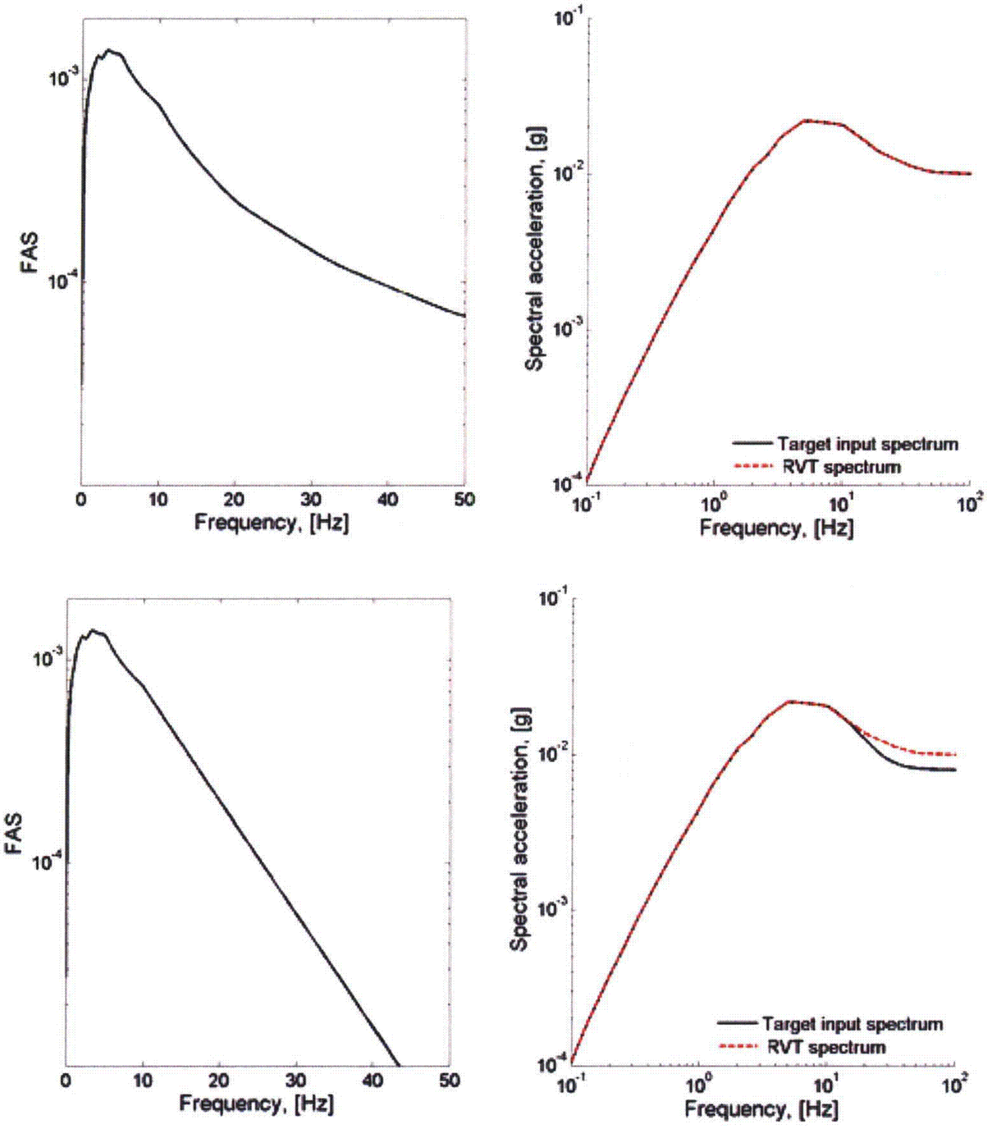


Figure 40. IRVT-derived FAS and its corresponding RVT-derived response spectrum for the 10^{-4} hazard level HF input control motion before (top figures) and after (bottom figures) host-kappa value of 0.041 sec is enforced. Source: Figure 43 from LCI (LCI, 2015d).

2.3.5 *Methodology*

A random vibration theory (RVT) approach was employed to perform the site response analyses for the PVNGS site. This process utilizes a simple, efficient approach for computing site specific amplification functions and is consistent with SPID (EPRI, 2013) guidance. For the BC, LR, and UR shallow site profiles, site amplification factors (SAF) are developed for seven spectral frequencies (0.5 Hz SA, 1.0 Hz SA, 2.5 Hz SA, 5.0 Hz SA, 10 Hz SA, 20 Hz SA, and 100 Hz SA or PGA) over the range of spectral amplitudes represented by the input control motions (refer to Section 2.3.4). Each set of SAF incorporates the various types of variability in profile and material properties described above, as well as uncertainty in kappa and deep shear wave velocities as represented by the nine sets of adjustment factors in Fourier amplitude space. To include the deep site profile effect on SAF, the IRVT-derived input FAS was multiplied by the set of Vs-kappa adjustment factors from Section 2.3.2.2 prior to using that input spectrum to drive the shallow site profile.

2.3.6 Amplification Functions

The results of the site response analysis consist of SAF for 5% damped pseudo-absolute response spectra that describe the amplification (or de-amplification) of 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 log standard deviation for each oscillator frequency and input rock amplitude. A minimum median amplification value of 0.5 was employed in the present analysis, consistent with SPID guidance (EPRI, 2013). Figures 41a through 41f illustrate (using the BC velocity profile) the median and +/- 1 standard deviation in the predicted surface spectra and amplification factors developed for the HF and LF loading levels corresponding to MAFEs of 10^{-4}, 10^{-5}, and 10^{-6} parameterized by reference rock spectral amplitudes (0.01g to 1.50g) for the BC and EPRI soil G/Gmax and hysteretic damping curves. The variability in the amplification factors results from variability in shear wave velocity, depth to hard rock, modulus reduction curves, hysteretic damping curves, and application of the nine Fourier adjustment functions to account for uncertainty in kappa and the deep site Vs profile. To illustrate the effects of nonlinearity at PVNGS, Figures 42a through 42c show the final amplification factors developed with all combinations of the varied parameters for each of the three profiles (base-case, lower-range, and upper-range). Note that all required weighted combinations of the resulting SAF were performed in linear (SAF) space as opposed to log (ln[SAF]) space.

Figures 42a through 42c show differences at all loading levels and frequencies. Values of median SAF and their variability at spectral frequencies of 0.5 Hz SA, 1.0 Hz SA, 2.5 Hz SA, 5.0 Hz SA, 10 Hz SA, 20 Hz SA, and PGA over a range of amplitudes are provided in Appendix A Tables A-4, A-5, and A-6 for the BC, LR, and UR velocity profiles.

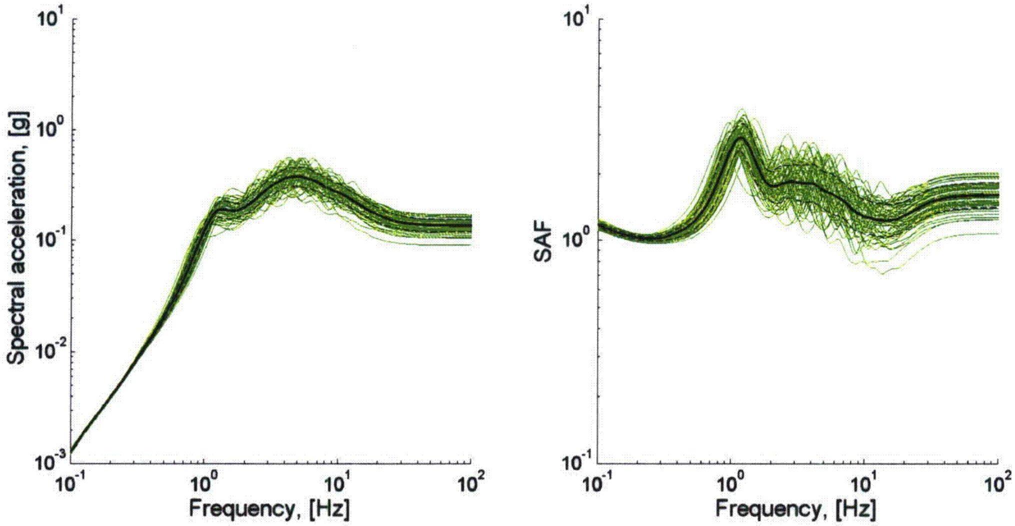


Figure 41a. PVNGS BC surface response spectra and SAF for 10^{-4} HF input motion using the EPRI soil material model and a single reference rock to local rock adjustment function. Green lines are spectra for 60 individual randomized profiles. Median (black solid line) and $\pm 1\sigma_{\ln}$ (black dashed lines) are also shown. Source: Figure 46 from LCI (LCI, 2015d).

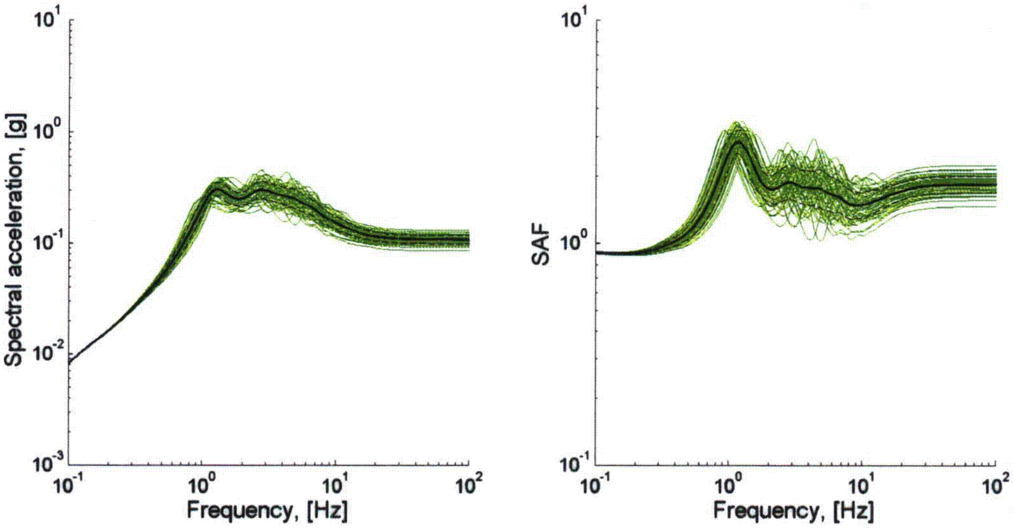


Figure 41b. PVNGS BC surface response spectra and SAF for 10^{-4} LF input motion using the EPRI soil material model, and a single reference rock to local rock adjustment function. Green lines are spectra for 60 individual randomized profiles. Median (black solid line) and $\pm 1\sigma_{\ln}$ (black dashed lines) are also shown. Source: Figure 47 from LCI (LCI, 2015d).

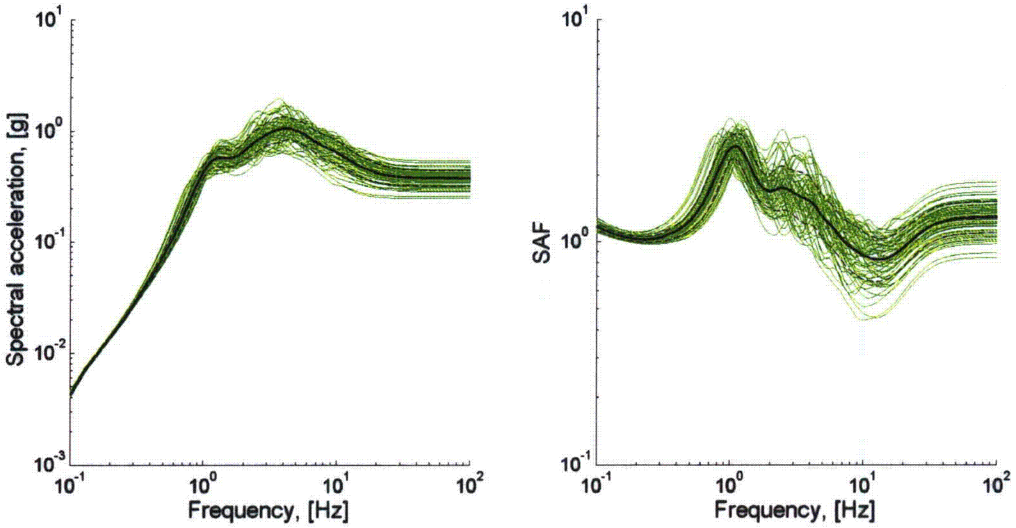


Figure 41c. PVNGS BC surface response spectra and SAF for 10^{-5} HF input motion using the EPRI soil material model and a single reference rock to local rock adjustment function. Green lines are spectra for 60 individual randomized profiles. Median (black solid line) and $\pm 1\sigma_{\ln}$ (black dashed lines) are also shown. Source: Figure 48 from LCI (LCI, 2015d).

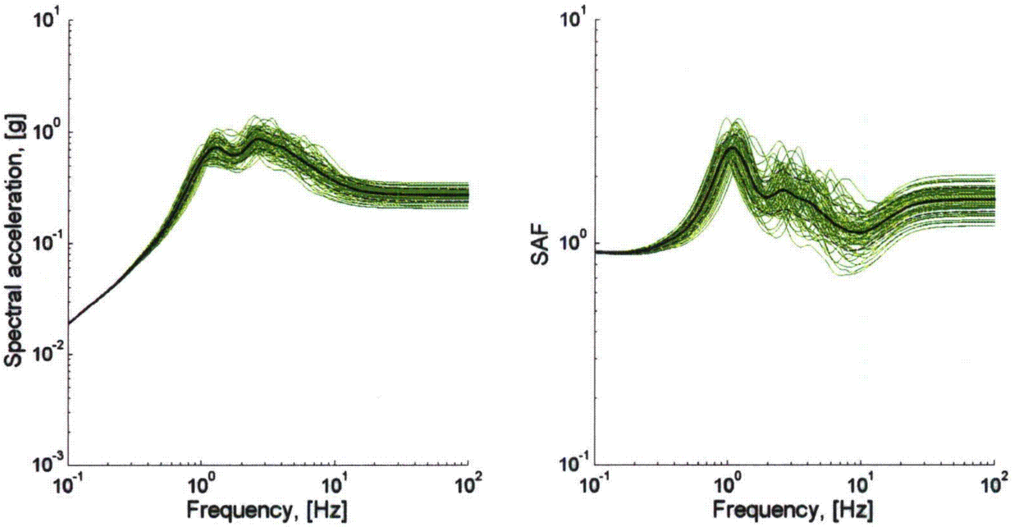


Figure 41d. PVNGS BC surface response spectra and SAF for 10^{-5} LF input motion using the EPRI soil material model, and a single reference rock to local rock adjustment function. Green lines are spectra for 60 individual randomized profiles. Median (black solid line) and $\pm 1\sigma_{\ln}$ (black dashed lines) are also shown. Source: Figure 49 from LCI (LCI, 2015d).

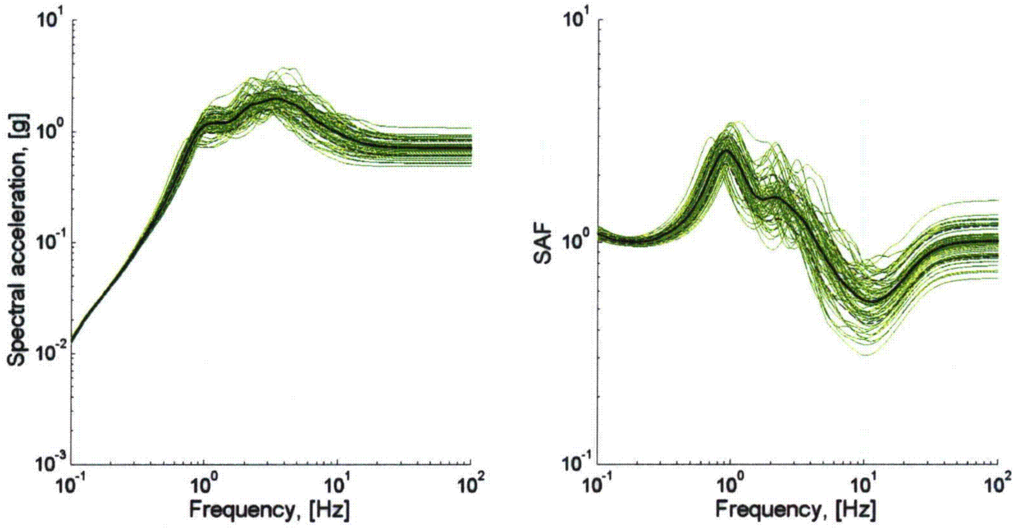


Figure 41e. PVNGS BC surface response spectra and SAF for 10^{-6} HF input motion using the EPRI soil material model and a single reference rock to local rock adjustment function. Green lines are spectra for 60 individual randomized profiles. Median (black solid line) and $\pm 1\sigma_{\ln}$ (black dashed lines) are also shown. Source: Figure 50 from LCI (LCI, 2015d).

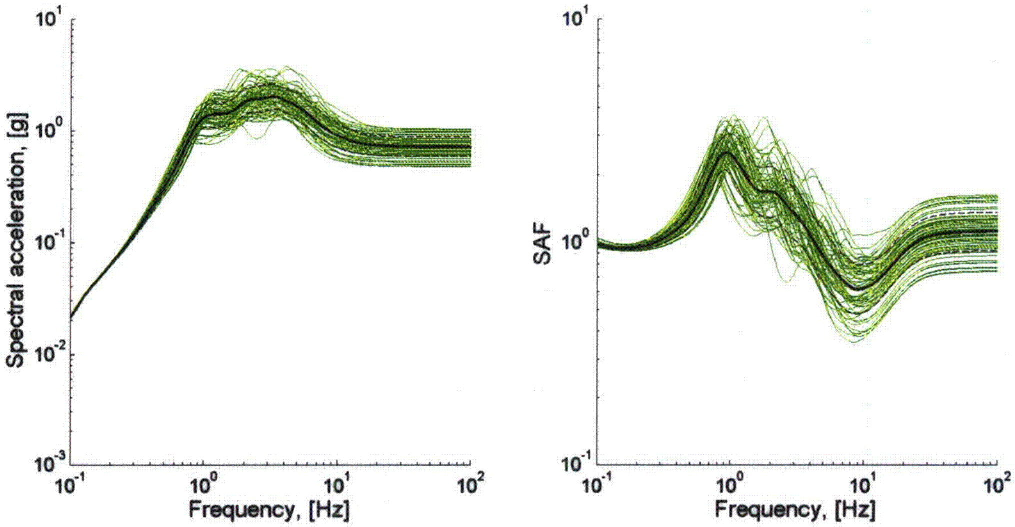


Figure 41f. PVNGS BC surface response spectra and SAF for 10^{-6} LF input motion using the EPRI soil material model, and a single reference rock to local rock adjustment function. Green lines are spectra for 60 individual randomized profiles. Median (black solid line) and $\pm 1\sigma_{\ln}$ (black dashed lines) are also shown. Source: Figure 51 from LCI (LCI, 2015d).

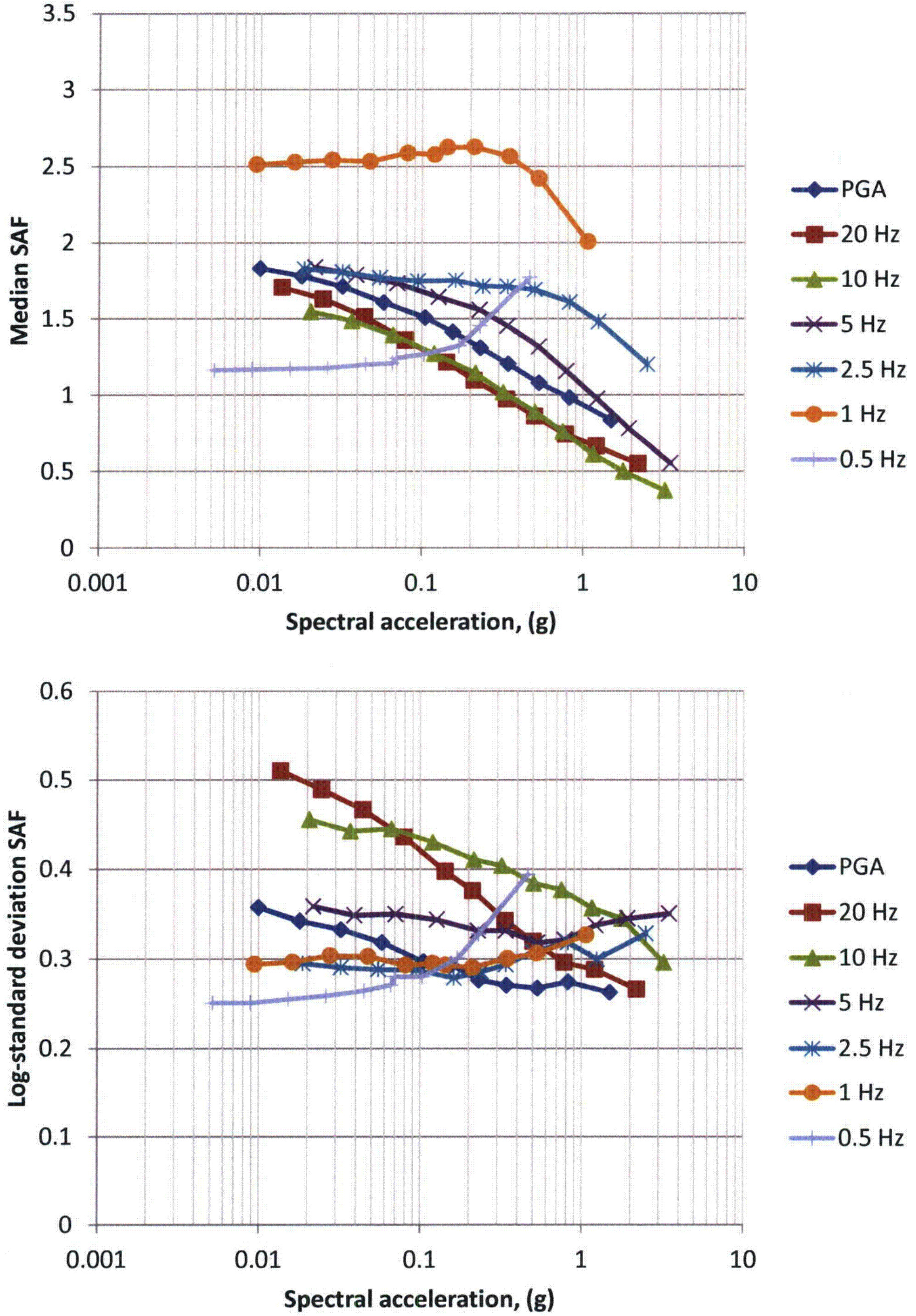
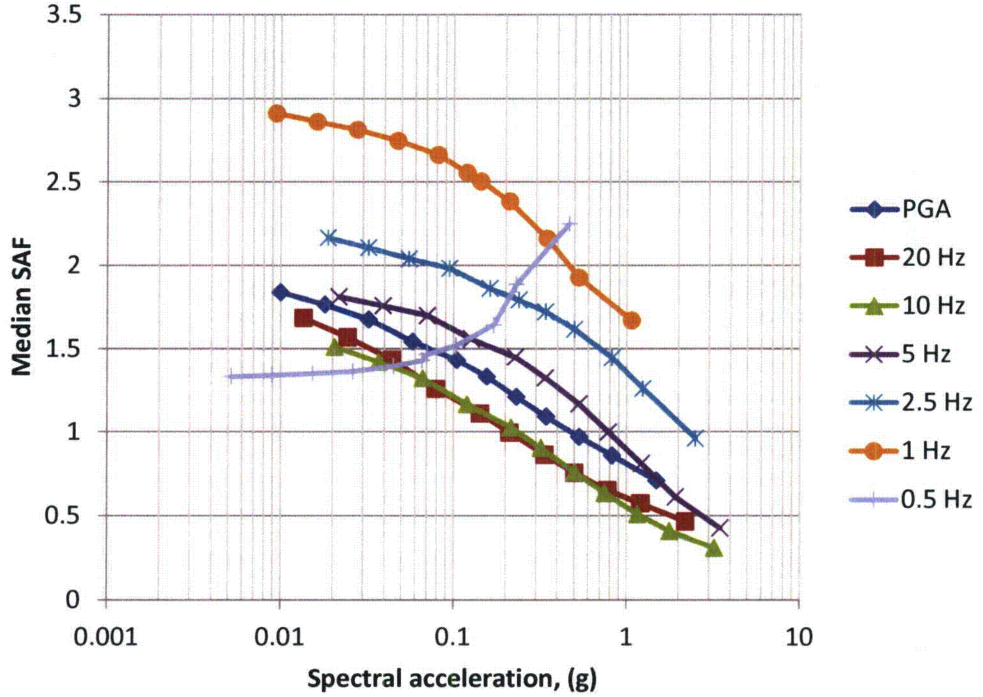


Figure 42a. PVNGS BC profile median amplification factors and log standard deviation as a function of spectral acceleration. Source: Figure 55 from LCI (LCI, 2015d).



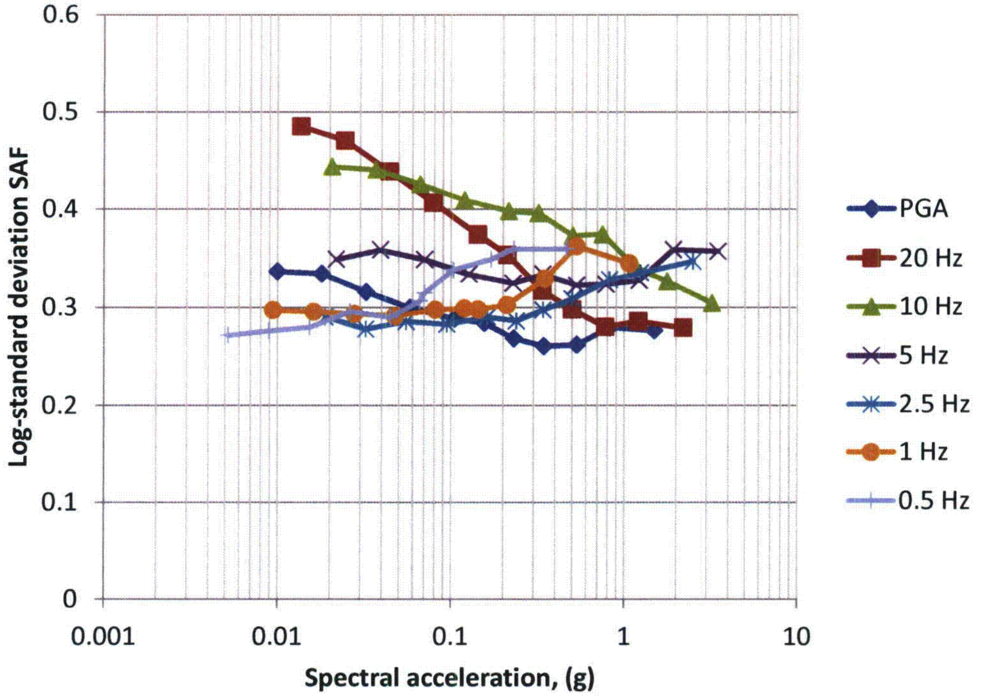


Figure 42b. PVNGS LR profile median amplification factors and log standard deviation as a function of spectral acceleration. Source: Figure 56 from LCI (LCI, 2015d).

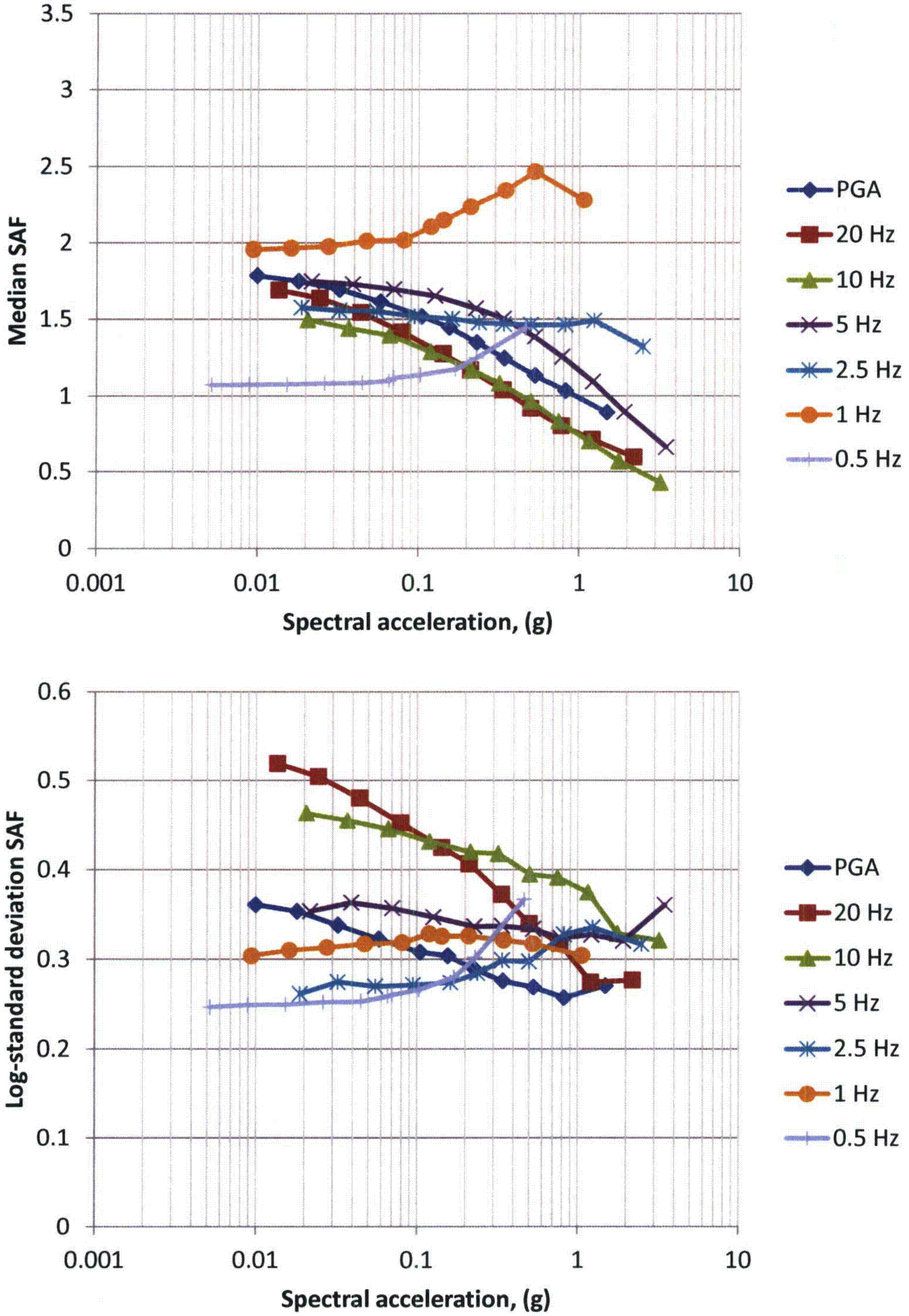


Figure 42c. PVNGS UR profile median amplification factors and log standard deviation as a function of spectral acceleration. Source: Figure 57 from LCI (LCI, 2015d).

2.4 Soil Hazard and Ground Motion Response Spectrum (GMRS) Calculations

2.4.1 Background

The subject analyses calculate the soil hazard at the PVNGS site using: (1) the 2015 PVNGS seismic sources (Section 2.1); (2) the 2015 SWUS GMPEs (Section 2.2); and (3) site specific amplification factors (Section 2.3). For the purposes of these analyses, the "PVNGS site" control point was chosen as Unit 2/free-field elevation (LCI, 2015d, S&A, 2015, and Section 3.2). The site specific amplification factors (Section 2.3) that convert ground motions from reference rock (shear wave velocity of 760 m/s) to PVNGS soil were applied in the these calculations. The soil seismic hazard analysis conformed to the requirements of the SPID (EPRI, 2013) and the results can be used for the seismic evaluation and screening of nuclear plant structures, systems, and components.

2.4.2 Methodology

The methodology for seismic hazard calculations is well established in the technical literature (e.g., McGuire, 2004). The calculation of soil hazard was implemented with Approach 3 (REI, 2001).

Ground motions were modeled for seven spectral frequencies (Section 2.2.4.1). The spectral frequencies were PGA (equivalent to 100 Hz spectral acceleration), 20 Hz spectral acceleration (SA), 10 Hz SA, 5 Hz SA, 2.5 Hz SA, 1 Hz SA, and 0.5 Hz SA. Seismic hazard was calculated for 20 ground motion amplitudes, which were 0.000001g, 0.0005g, 0.001g, 0.005g, 0.01g, 0.015g, 0.03g, 0.05g, 0.075g, 0.1g, 0.15g, 0.3g, 0.5g, 0.75g, 1.0g, 1.5g, 3.0g, 5.0g, 7.5g and 10.0g. All ground motion equations represented spectral acceleration at 5% of critical damping, so results presented in this report represent spectral acceleration at 5% of critical damping.

Steps used in calculating the mean soil horizontal GMRS were as follows.

1. The seismic hazard (annual frequency of exceedance) representing ground motion at the top of the soil column was calculated using the inputs described in Sections 2.2 and 2.3, for the seven spectral frequencies indicated above.
2. Spectral amplitudes corresponding to 10^{-4}, 10^{-5}, and 10^{-6} annual frequencies of exceedence were determined by log-log interpolation of the total mean hazard curves at the seven spectral frequencies indicated above.
3. Uniform hazard response spectra (UHRS) for 10^{-4}, 10^{-5}, and 10^{-6} annual frequencies of exceedence were calculated by anchoring mean spectral shapes determined from site amplification calculations (Section 2.3) to the spectral amplitudes calculated in step 2 above. These mean spectral shapes were calculated using site amplification calculations for amplitudes, magnitudes, and distances consistent with 10^{-4}, 10^{-5}, and 10^{-6} annual frequencies of exceedence. For spectral frequencies below 0.5 Hz, 1/T scaling was assumed (where T is spectral period). This is consistent with requirements for seismic building codes (e.g., Building Seismic Safety Council, 2009). This step gave smooth UHRS for spectral frequencies between 100 Hz and 0.1 Hz.
4. The GMRS was calculated at each spectral frequency from the UHRS at that frequency derived in step 3 above. The following equations (U.S.NRC, 2007) were used to calculate the GMRS values:

$$\text{Amplitude Ratio } A_R = \frac{10^{-5}\,\text{UHRS}}{10^{-4}\,\text{UHRS}}$$

$$\text{Design Factor DF} = \max(1, 0.6 \times A_R^{0.8})$$

$$\text{GMRS} = \max(10^{-4}\,\text{UHRS} \times \text{DF}, 0.45 \times 10^{-5}\,\text{UHRS})$$

These steps resulted in horizontal UHRS and GMRS applicable at the top of soil (free-field) for the PVNGS site.

2.4.3 Results

The 10^{-4}, 10^{-5}, and 10^{-6} UHRS for the seven spectral frequencies for which hazards were calculated are shown in Table 9.

Table 9. Mean 10^{-4}, 10^{-5}, and 10^{-6} UHRS. Source: Table 1 from LCI (LCI, 2015e)

UHRS acceleration, g			
Spectral frequency	**10^{-4}**	**10^{-5}**	**10^{-6}**
0.5 Hz	0.0613	0.146	0.364
1.0 Hz	0.226	0.553	1.29
2.5 Hz	0.297	0.806	1.82
5.0 Hz	0.371	0.956	1.80
10 Hz	0.275	0.659	1.23
20 Hz	0.207	0.491	0.930
PGA	0.170	0.429	0.860

Figure 43 plots mean total soil hazard curves for the seven spectral frequencies (PGA, 20 Hz SA, 10 Hz SA, 5 Hz SA, 2.5 Hz SA, 1 Hz SA, and 0.5 Hz SA) at which hazard calculations were conducted. The individual hazard curves are also documented in tabular form in Table 10. The relative relationship among soil hazard curves is typical for nuclear plant sites in the U.S.

Figure 44 plots 10^{-4}, 10^{-5}, and 10^{-6} horizontal UHRS and GMRS. The individual 10^{-4}, 10^{-5}, and 10^{-6} horizontal UHRS and GMRS are also documented in tabular form in Table 11.

Figures 45 and 46 show fractile soil hazard curves for 10 Hz SA and 1 Hz SA, respectively. The fractile soil hazard curves indicate a range in hazard of a factor of about 4 between the 0.84 and 0.16 fractile for 10 Hz SA and a factor of about 7 for 1 Hz. The fractile range reflects the consistency in ground motion among GMPEs controlling the hazard at 10 Hz SA and 1 Hz SA.

The sensitivity of soil hazard to the three velocity profiles (Base-Case, Lower-Range, and Upper-Range) used in the site response analysis (Section 2.3) are plotted in Figures 47 and 48 for 10 Hz SA and 1 Hz SA, respectively. Figure 47 shows that the Upper-Range profile produces the highest hazard curve at 10 Hz SA, and the Lower-Range profile produces the lowest hazard curve. This is consistent with the Upper-Range profile being stiffer and shallower than either the Base-Case or the Lower-Range profiles. A stiffer, shallower profile produces more high frequency response, and the stiff material remains almost linear at high amplitudes. Figure 48 shows that for 1 Hz SA, the Lower-Range profile produces the highest hazard at low amplitudes (SA less than 0.2g) but produces the lowest hazard at high amplitudes (SA greater than 0.8g). This is consistent with the Lower-Range profile being softer and deeper than either the Base-Case and Upper-Range profiles. A softer, deeper profile results in more low-frequency response at low amplitudes, but non-linear effects in soft materials reduce the response at high amplitudes.

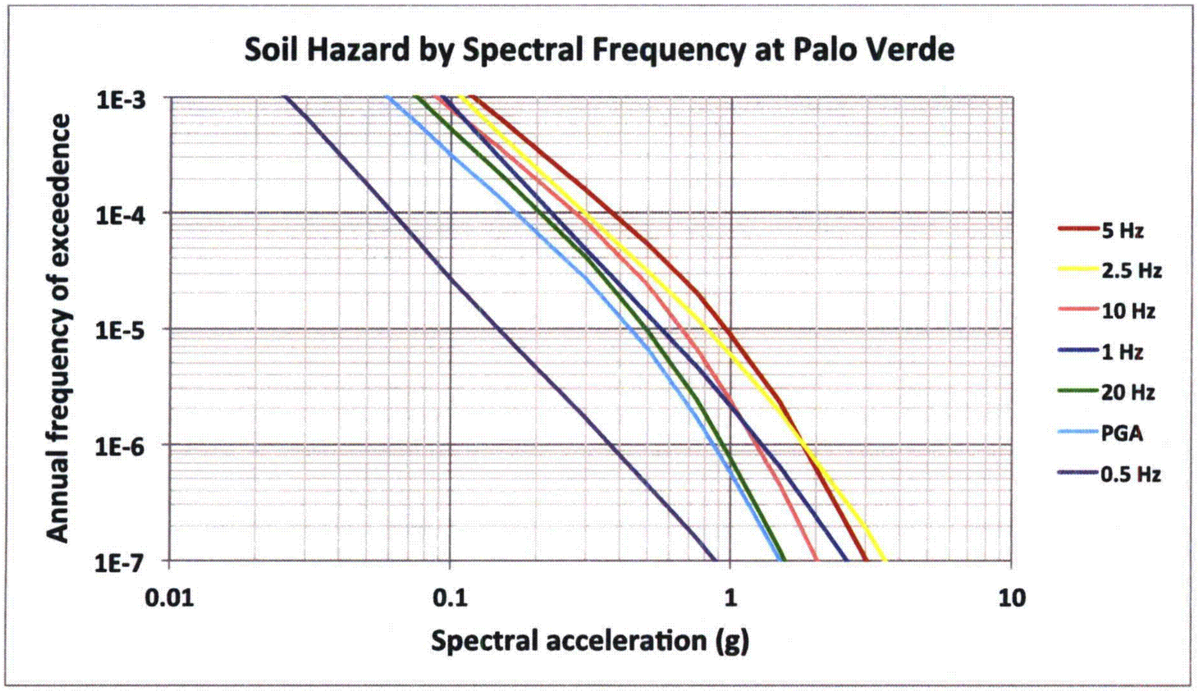


Figure 43. Total mean soil hazard curves for seven spectral frequencies. Source: Figure 1 from LCI (LCI, 2015e).

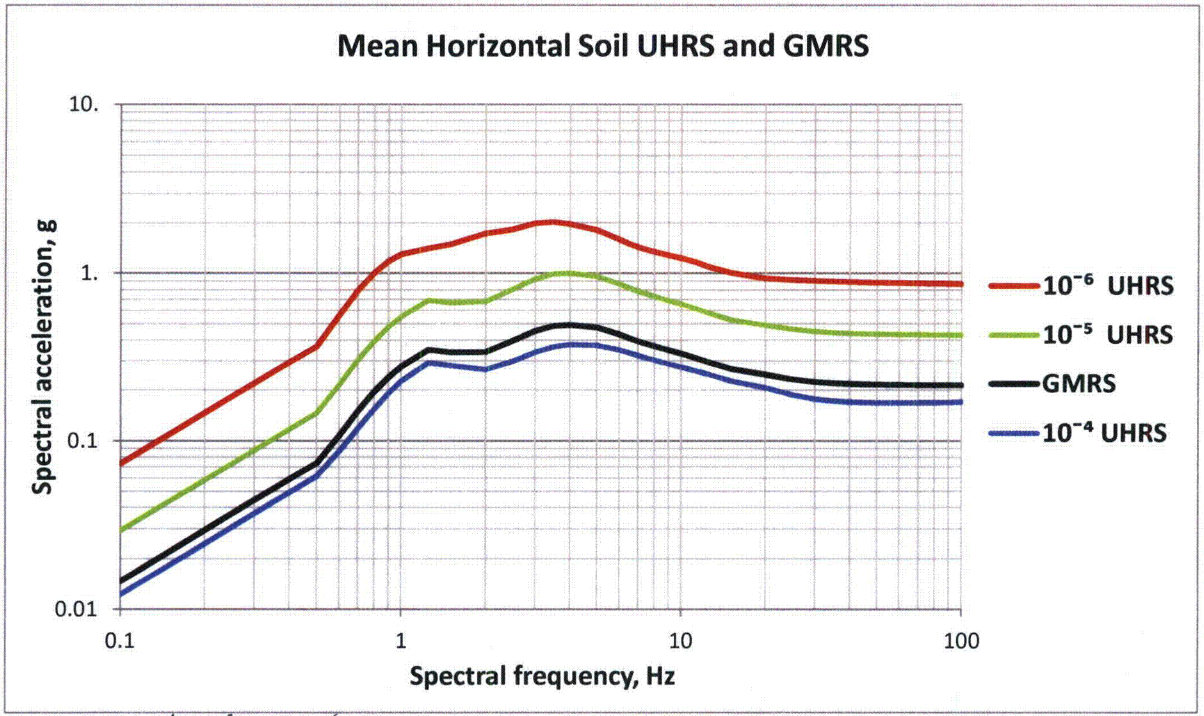


Figure 44. 10^{-4}, 10^{-5}, and 10^{-6} mean horizontal soil UHRS and GMRS. Source: Figure 2 from LCI (LCI, 2015e).

Table 10. Total mean soil hazard for seven spectral frequencies. Source: Table 2 from LCI (LCI, 2015e).

Spectral acceleration g	0.5 Hz	1 Hz	2.5 Hz	5 Hz	10 Hz	20 Hz	PGA
0.000001	1.60E+00	1.60E+00	1.60E+00	1.60E+00	1.60E+00	1.60E+00	1.60E+00
0.0005	3.80E-01	1.05E+00	1.21E+00	1.05E+00	7.86E-01	7.33E-01	7.74E-01
0.001	2.25E-01	7.17E-01	8.90E-01	7.56E-01	5.16E-01	4.68E-01	4.81E-01
0.005	3.31E-02	1.99E-01	2.43E-01	2.02E-01	1.14E-01	1.00E-01	9.18E-02
0.01	9.05E-03	8.83E-02	1.07E-01	8.77E-02	4.53E-02	3.98E-02	3.31E-02
0.015	3.71E-03	4.85E-02	5.95E-02	4.85E-02	2.42E-02	2.12E-02	1.63E-02
0.03	6.73E-04	1.37E-02	1.74E-02	1.48E-02	7.35E-03	6.23E-03	4.18E-03
0.05	1.73E-04	4.54E-03	6.00E-03	5.63E-03	2.90E-03	2.29E-03	1.42E-03
0.075	5.79E-05	1.73E-03	2.40E-03	2.54E-03	1.36E-03	9.88E-04	5.94E-04
0.1	2.69E-05	8.39E-04	1.23E-03	1.43E-03	7.88E-04	5.32E-04	3.20E-04
0.15	9.34E-06	2.93E-04	4.77E-04	6.37E-04	3.58E-04	2.17E-04	1.33E-04
0.3	1.63E-06	4.78E-05	9.75E-05	1.57E-04	8.34E-05	4.10E-05	2.69E-05
0.5	4.48E-07	1.30E-05	3.08E-05	5.29E-05	2.32E-05	9.51E-06	6.53E-06
0.75	1.55E-07	4.58E-06	1.20E-05	1.98E-05	6.73E-06	2.34E-06	1.69E-06
1	7.07E-08	2.11E-06	5.85E-06	8.81E-06	2.40E-06	7.48E-07	5.63E-07
1.5	2.22E-08	6.40E-07	1.90E-06	2.24E-06	4.46E-07	1.23E-07	1.00E-07
3	2.60E-09	6.07E-08	1.88E-07	1.06E-07	1.47E-08	3.46E-09	3.38E-09
5	4.61E-10	8.43E-09	2.52E-08	6.52E-09	8.70E-10	1.71E-10	1.90E-10
7.5	1.05E-10	1.54E-09	4.36E-09	5.33E-10	8.23E-11	1.23E-11	1.49E-11
10	3.48E-11	4.28E-10	1.16E-09	7.70E-11	1.49E-11	1.67E-12	2.12E-12

Table 11. Mean Soil Horizontal UHRS and GMRS for Palo Verde. Source: Table 3 from LCI (LCI, 2015e)

Freq, Hz	10^{-4} UHRS (g)	10^{-5} UHRS (g)	10^{-6} UHRS (g)	GMRS (g)
100	1.70E-01	4.29E-01	8.60E-01	2.14E-01
90	1.69E-01	4.30E-01	8.63E-01	2.14E-01
80	1.69E-01	4.30E-01	8.66E-01	2.14E-01
70	1.68E-01	4.31E-01	8.69E-01	2.14E-01
60	1.68E-01	4.33E-01	8.73E-01	2.15E-01
50	1.68E-01	4.35E-01	8.78E-01	2.16E-01
40	1.70E-01	4.39E-01	8.86E-01	2.18E-01
35	1.72E-01	4.43E-01	8.91E-01	2.20E-01
30	1.77E-01	4.50E-01	8.98E-01	2.24E-01
25	1.87E-01	4.64E-01	9.11E-01	2.32E-01
20	2.07E-01	4.91E-01	9.30E-01	2.48E-01
15	2.27E-01	5.29E-01	1.01E+00	2.68E-01
12.5	2.49E-01	5.81E-01	1.09E+00	2.94E-01
10	2.75E-01	6.59E-01	1.23E+00	3.32E-01
9	2.86E-01	6.89E-01	1.28E+00	3.47E-01
8	3.02E-01	7.27E-01	1.34E+00	3.66E-01
7	3.22E-01	7.84E-01	1.43E+00	3.94E-01
6	3.48E-01	8.64E-01	1.59E+00	4.32E-01
5	3.71E-01	9.56E-01	1.80E+00	4.75E-01
4	3.75E-01	9.99E-01	1.96E+00	4.93E-01
3.5	3.63E-01	9.92E-01	2.02E+00	4.87E-01
3	3.37E-01	9.23E-01	1.98E+00	4.53E-01
2.5	2.97E-01	8.06E-01	1.82E+00	3.96E-01
2	2.65E-01	6.82E-01	1.72E+00	3.39E-01
1.5	2.80E-01	6.68E-01	1.48E+00	3.37E-01
1.25	2.91E-01	6.92E-01	1.40E+00	3.49E-01
1	2.26E-01	5.53E-01	1.29E+00	2.77E-01
0.9	1.91E-01	4.79E-01	1.17E+00	2.39E-01
0.8	1.54E-01	3.93E-01	9.97E-01	1.96E-01
0.7	1.18E-01	3.02E-01	7.82E-01	1.50E-01
0.6	8.61E-02	2.14E-01	5.58E-01	1.07E-01
0.5	6.13E-02	1.46E-01	3.64E-01	7.36E-02
0.4	4.90E-02	1.17E-01	2.91E-01	5.89E-02
0.35	4.29E-02	1.02E-01	2.55E-01	5.15E-02
0.3	3.68E-02	8.76E-02	2.18E-01	4.42E-02
0.25	3.07E-02	7.30E-02	1.82E-01	3.68E-02
0.2	2.45E-02	5.84E-02	1.46E-01	2.95E-02
0.15	1.84E-02	4.38E-02	1.09E-01	2.21E-02
0.125	1.53E-02	3.65E-02	9.10E-02	1.84E-02
0.1	1.23E-02	2.92E-02	7.28E-02	1.47E-02

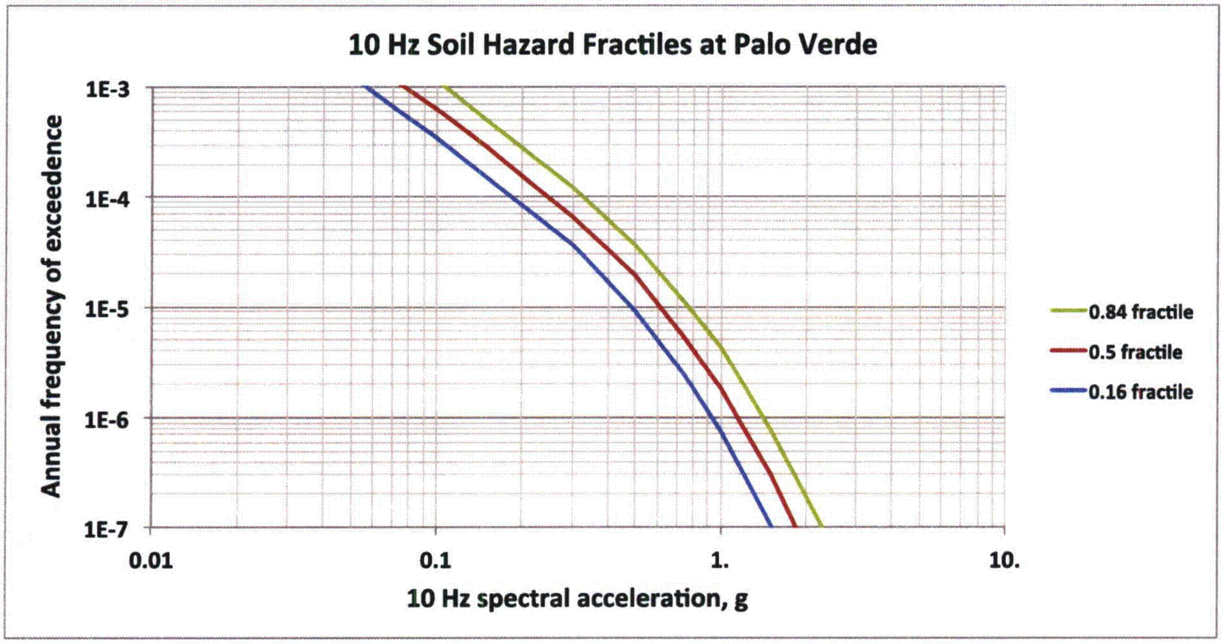


Figure 45. Fractile soil hazard curves for 10 Hz SA. Source: Figure 5 from LCI (LCI, 2015e).

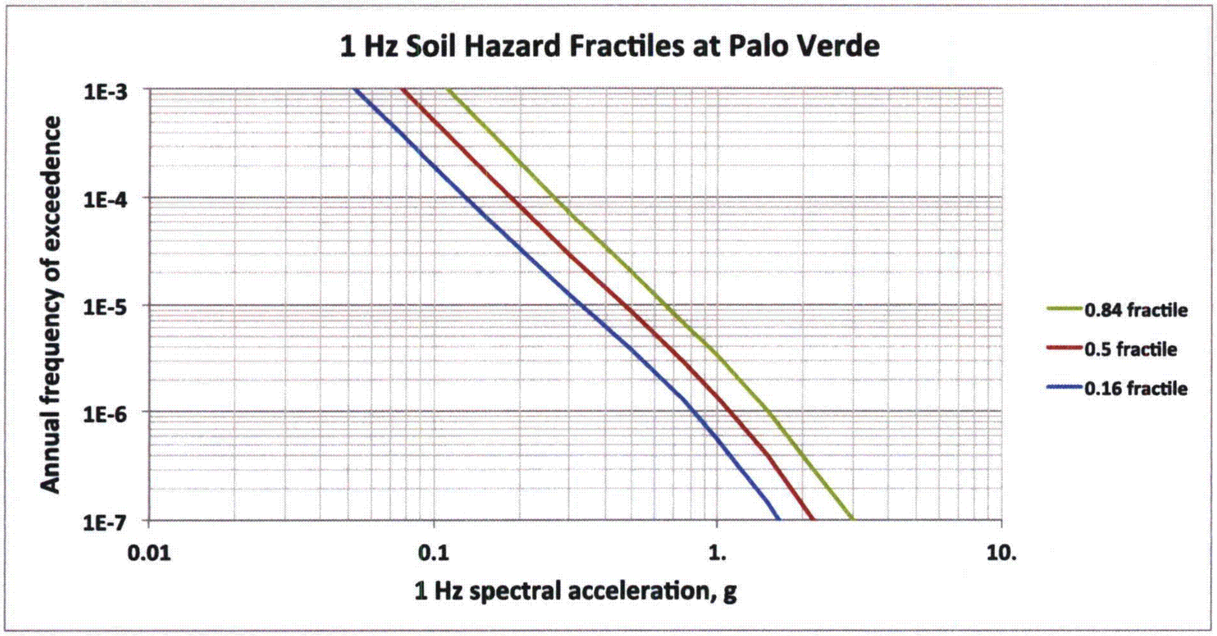


Figure 46. Fractile soil hazard curves for 1 Hz SA. Source: Figure 6 from LCI (LCI, 2015e).

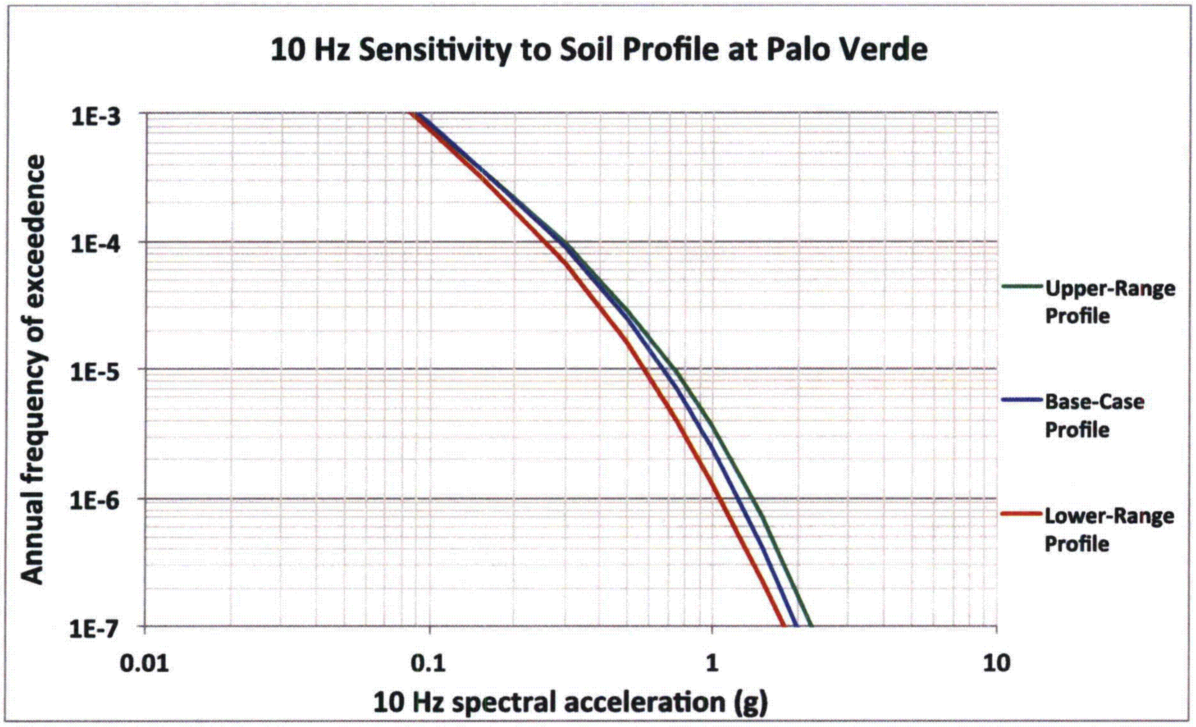


Figure 47. Sensitivity to the BC, UR, and LR velocity profiles described in Section 2.3 for 10 Hz SA (curves are not weighted by profile weights). Source: Figure 7 from LCI (LCI, 2015e).

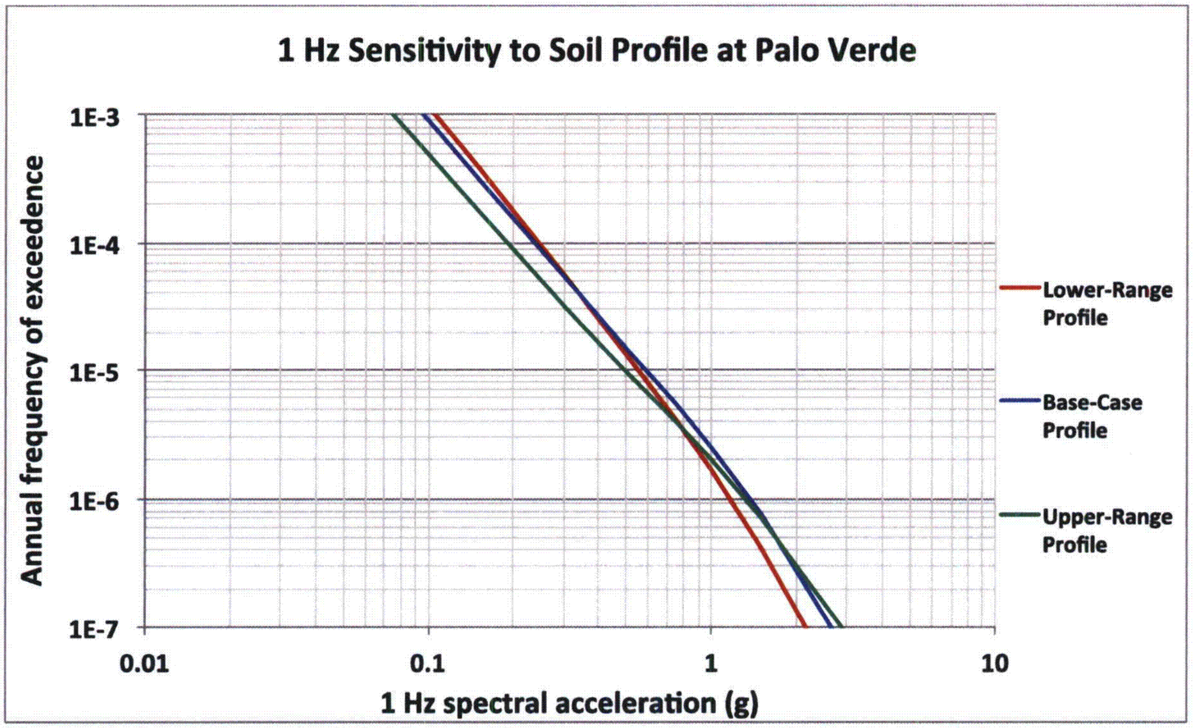


Figure 48. Sensitivity to the BC, UR, and LR velocity profiles described in Section 2.3 for 1 Hz SA (curves are not weighted by profile weights). Source: Figure 8 from LCI (LCI, 2015e).

3 Plant Design Basis

The PVNGS design basis is identified in the Updated Final Safety Analysis Report (UFSAR, Rev. 17, Sections 2.5 and 3.7).

3.1 SSE Description of Spectral Shape

The 10 CFR 100 Appendix A site characterization SSE was established in UFSAR Section 2.5 as peak ground acceleration (PGA) of 20% gravity (0.20g). The seismic analysis of all Seismic Category 1 structures was performed utilizing a Design Spectral Response Curve anchored at a PGA value of 0.25g. A PGA of 0.25g thus constitutes the design value for PVNGS, which bounds the 0.20g site characterization SSE (licensing basis).

For PVNGS Unit 1, 2, and 3 the design earthquake is defined in terms of a PGA and a Regulatory Guide 1.60 design response spectral shape. Table 12 and Figure 49 shows the spectral acceleration values as a function of frequency for the 5% damped horizontal Design Specteral Response Curve.

Table 12. PVNGS Unit 1, 2, and 3 0.25g PGA horizontal design spectral response curve, 5% damping.

Freq (Hz)	SA (g)
0.25	0.12
2.50	0.78
9.00	0.65
33.00	0.25
100.00	0.25

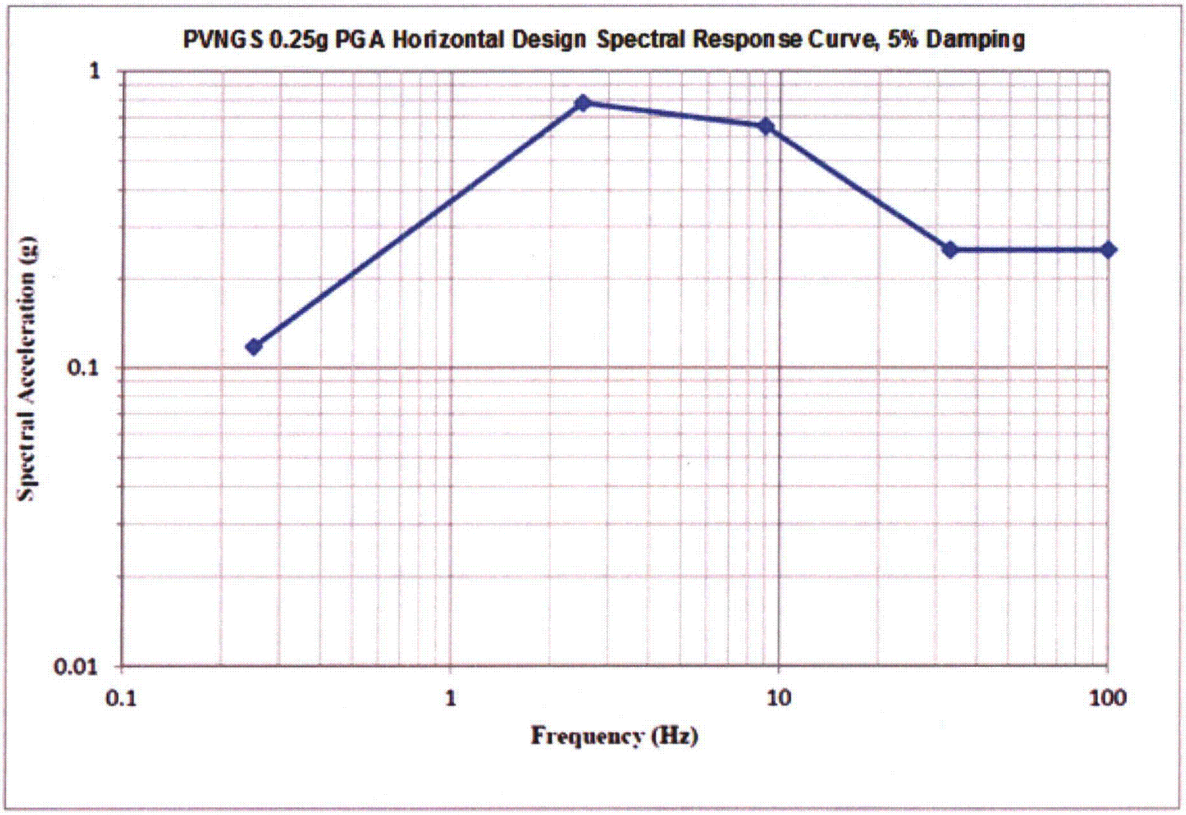


Figure 49. PVNGS Unit 1, 2, and 3 0.25g PGA horizontal design spectral response curve, 5% damping. Source: (S&A, 2015a)

3.2 Control Point Elevation

UFSAR Section 2.5.2.6 defines the site characterization SSE vibratory ground motion, which is essentially based on free-field surface motions, as applicable to the grade level of the plant.

The 0.25g design level of acceleration and the associated design spectral response curve are applied to both the plant grade and the foundation level for the purpose of structural design and soil-structure interaction analyses. Additional discussion pertaining to the control point elevation can be found in S&A project report (S&A, 2015).

The control point, which is representative of Unit 1, 2, and 3, is therefore defined as Unit 2/free-field (plant grade, foundation) level.

4 Screening Evaluation

Following completion of the seismic hazard reevaluation, as requested in the 10 CFR 50.54(f) letter, a screening process was performed to determine if a seismic risk evaluation was needed. The horizontal GMRS determined from the hazard reevaluation was used to characterize the amplitude of the new seismic hazard at PVNGS. The screening evaluation was based upon a comparison of the GMRS with the 5% damped horizontal Design Spectral Response Curve. Figure 50 shows a comparison between the plant design and the site GMRS that was calculated for Unit 2 as described in Section 2.4 above. In accordance with SPID Section 3, a screening evaluation was performed as described below.

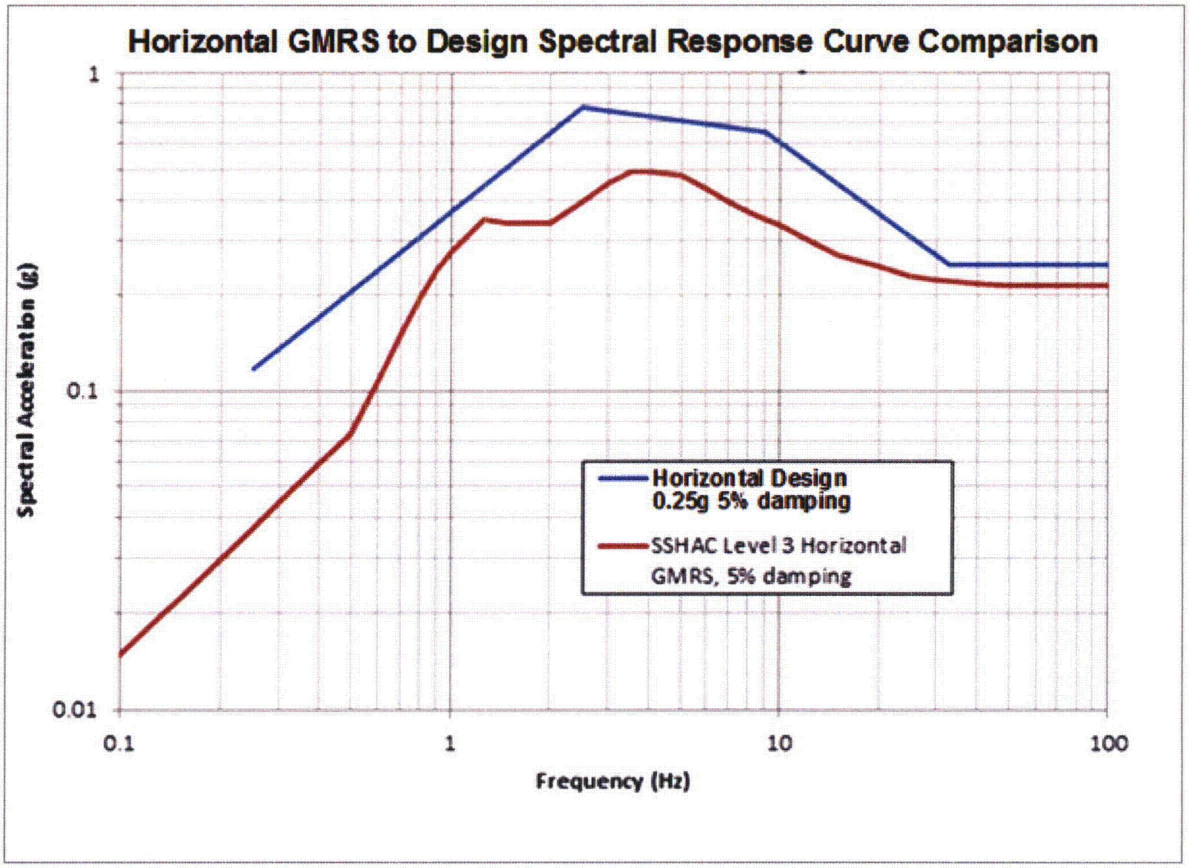


Figure 50. PVNGS Unit 1, 2, and 3 horizontal GMRS to design spectral response curve comparison. Source: (S&A, 2015a).

4.1 Risk Evaluation Screening (1 to 10 Hz)

The Design Spectral Response Curve used for the design of Seismic Category 1 Structures, Systems and Components (SSCs) exceeds the GMRS response curve in the frequency range of 1 to 10 Hz.

Consistent with the guidance provided in the 10 CFR 50.54(f) letter (U.S.NRC, 2012a), APS is therefore not required to perform a Seismic Risk Evaluation for the PVNGS site.

4.2 *High Frequency Screening (>10 Hz)*

The Design Spectral Response Curve used for the design of Seismic Category 1 Structures, Systems and Components (SSCs) also exceeds the GMRS response curve in the frequency range above 10 Hz.

Consistent with the guidance provided in the 10 CFR 50.54(f) letter (U.S.NRC, 2012a), APS is therefore not required to perform the High Frequency Confirmation for the PVNGS site.

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

The Design Spectral Response Curve used for the design of Seismic Category 1 Structures, Systems and Components (SSCs) exceeds the GMRS response curve in the frequency range of 1 to 10 Hz.

Consistent with the guidance provided in the 10 CFR 50.54(f) letter (U.S.NRC, 2012a), APS is therefore not required to perform a spent fuel pool evaluation for the PVNGS site.

5 Interim Actions

PVNGS fully meets the criteria discussed in the SPID (EPRI, 2013) for screening out.

Interim actions are not, therefore, needed or required for the PVNGS site.

6 Conclusions

In accordance with the 10 CFR 50.54(f) request for information, a seismic hazard and screening evaluation was performed for the PVNGS site. A GMRS was developed for purpose of screening for additional evaluations in accordance with the SPID. Based on the results of the PVNGS screening evaluation, no further action is required for the NTTF Recommendation 2.1 seismic review.

7 References

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Appendix A. Tabulated Data

Table A-1. Fourier adjustment factors from reference rock conditions to local rock conditions and their weights. Source: Table 1 from LCI (LCI, 2015b).

	SWUS to PVNGS Adjustment Factor (Fourier-amplitude Space)								
Abbrev:	**TF1**	**TF2**	**TF3**	**TF4**	**TF5**	**TF6**	**TF7**	**TF8**	**TF9**
Freq. (Hz)	**LB Profile, LB kappa (0.09)**	**LB Profile, Median kappa (0.12)**	**LB Profile, UB kappa (0.09)**	**Median Profile, LB kappa (0.12)**	**Median Profile, Median kappa (0.16)**	**Median Profile, UB kappa (0.12)**	**UB Profile, LB kappa (0.09)**	**UB Profile, Median kappa (0.12)**	**UB Profile, UB kappa (0.09)**
0.1000	1.0136	1.0086	0.9993	0.8916	0.8873	0.8790	0.8598	0.8556	0.8477
0.1080	1.0218	1.0165	1.0063	0.8871	0.8824	0.8736	0.8528	0.8483	0.8398
0.1166	1.0313	1.0255	1.0144	0.8821	0.8771	0.8676	0.8451	0.8403	0.8312
0.1259	1.0424	1.0360	1.0240	0.8766	0.8712	0.8611	0.8367	0.8316	0.8219
0.1359	1.0574	1.0504	1.0372	0.8721	0.8663	0.8554	0.8291	0.8236	0.8132
0.1468	1.0768	1.0691	1.0546	0.8684	0.8622	0.8505	0.8219	0.8160	0.8050
0.1585	1.0999	1.0914	1.0754	0.8643	0.8576	0.8451	0.8140	0.8077	0.7959
0.1711	1.1279	1.1185	1.1009	0.8597	0.8526	0.8391	0.8054	0.7987	0.7861
0.1848	1.1660	1.1555	1.1358	0.8571	0.8493	0.8349	0.7981	0.7910	0.7775
0.1995	1.1927	1.1811	1.1594	0.8549	0.8466	0.8310	0.7910	0.7833	0.7689
0.2154	1.1895	1.1770	1.1536	0.8524	0.8435	0.8268	0.7830	0.7748	0.7594
0.2326	1.1852	1.1718	1.1467	0.8496	0.8400	0.8220	0.7742	0.7654	0.7491
0.2512	1.1856	1.1711	1.1441	0.8501	0.8397	0.8203	0.7678	0.7584	0.7409
0.2712	1.1867	1.1710	1.1419	0.8511	0.8398	0.8189	0.7612	0.7511	0.7324
0.2929	1.1878	1.1709	1.1395	0.8522	0.8400	0.8175	0.7538	0.7431	0.7231
0.3162	1.1890	1.1707	1.1368	0.8533	0.8402	0.8159	0.7456	0.7341	0.7128
0.3415	1.1950	1.1752	1.1385	0.8580	0.8438	0.8174	0.7393	0.7271	0.7043
0.3687	1.2037	1.1821	1.1423	0.8578	0.8425	0.8141	0.7334	0.7203	0.6960
0.3981	1.2136	1.1902	1.1469	0.8537	0.8372	0.8068	0.7268	0.7128	0.6869
0.4299	1.2251	1.1996	1.1526	0.8490	0.8313	0.7987	0.7193	0.7043	0.6768
0.4642	1.2429	1.2149	1.1636	0.8464	0.8274	0.7924	0.7133	0.6973	0.6678
0.5012	1.2688	1.2380	1.1817	0.8466	0.8260	0.7884	0.7092	0.6920	0.6605
0.5412	1.3013	1.2673	1.2051	0.8474	0.8252	0.7847	0.7046	0.6861	0.6525
0.5843	1.3476	1.3096	1.2403	0.8521	0.8281	0.7843	0.7014	0.6816	0.6455
0.6310	1.4077	1.3648	1.2871	0.8586	0.8325	0.7851	0.6987	0.6774	0.6388
0.6813	1.4269	1.3801	1.2954	0.8659	0.8375	0.7861	0.6956	0.6728	0.6315
0.7356	1.4146	1.3645	1.2744	0.8755	0.8445	0.7887	0.6931	0.6686	0.6244
0.7943	1.4047	1.3511	1.2549	0.8901	0.8561	0.7952	0.6929	0.6665	0.6191
0.8577	1.3940	1.3366	1.2342	0.9073	0.8699	0.8033	0.6928	0.6643	0.6134
0.9261	1.3821	1.3207	1.2118	0.9275	0.8863	0.8132	0.6926	0.6619	0.6073
1.0000	1.3731	1.3074	1.1914	0.9546	0.9089	0.8283	0.6943	0.6611	0.6024
1.0798	1.3666	1.2962	1.1724	0.9900	0.9390	0.8494	0.6980	0.6620	0.5988
1.1659	1.3594	1.2839	1.1520	1.0338	0.9764	0.8762	0.7019	0.6629	0.5948

Table A-1. Fourier adjustment factors from reference rock conditions to local rock conditions and their weights. Source: Table 1 from LCI (LCI, 2015b).

	SWUS to PVNGS Adjustment Factor (Fourier-amplitude Space)								
Abbrev:	**TF1**	**TF2**	**TF3**	**TF4**	**TF5**	**TF6**	**TF7**	**TF8**	**TF9**
Freq. (Hz)	**LB Profile, LB kappa (0.09)**	**LB Profile, Median kappa (0.12)**	**LB Profile, UB kappa (0.09)**	**Median Profile, LB kappa (0.12)**	**Median Profile, Median kappa (0.16)**	**Median Profile, UB kappa (0.12)**	**UB Profile, LB kappa (0.09)**	**UB Profile, Median kappa (0.12)**	**UB Profile, UB kappa (0.09)**
1.2589	1.3512	1.2703	1.1300	1.0758	1.0114	0.8998	0.7062	0.6639	0.5906
1.3594	1.3483	1.2614	1.1117	1.0777	1.0082	0.8886	0.7142	0.6681	0.5888
1.4678	1.3478	1.2543	1.0943	1.0773	1.0026	0.8747	0.7246	0.6743	0.5883
1.5849	1.3471	1.2464	1.0757	1.0767	0.9963	0.8598	0.7364	0.6813	0.5880
1.7113	1.3460	1.2378	1.0557	1.0759	0.9894	0.8439	0.7496	0.6893	0.5879
1.8478	1.3446	1.2282	1.0344	1.0748	0.9817	0.8268	0.7645	0.6984	0.5882
1.9953	1.3435	1.2184	1.0121	1.0739	0.9739	0.8090	0.7821	0.7093	0.5892
2.1544	1.3435	1.2089	0.9895	1.0739	0.9663	0.7909	0.8033	0.7228	0.5916
2.3263	1.3431	1.1984	0.9654	1.0735	0.9579	0.7716	0.8280	0.7387	0.5951
2.5119	1.3424	1.1869	0.9398	1.0730	0.9487	0.7512	0.8522	0.7535	0.5966
2.7123	1.3421	1.1751	0.9132	1.0728	0.9392	0.7300	0.8575	0.7508	0.5835
2.9286	1.3413	1.1620	0.8851	1.0721	0.9288	0.7075	0.8570	0.7424	0.5655
3.1623	1.3399	1.1476	0.8553	1.0710	0.9173	0.6837	0.8561	0.7332	0.5465
3.4145	1.3419	1.1351	0.8264	1.0726	0.9073	0.6606	0.8573	0.7252	0.5280
3.6869	1.3434	1.1213	0.7960	1.0738	0.8963	0.6362	0.8583	0.7164	0.5086
3.9811	1.3451	1.1067	0.7644	1.0751	0.8846	0.6110	0.8594	0.7070	0.4884
4.2987	1.3525	1.0956	0.7347	1.0811	0.8757	0.5873	0.8641	0.7000	0.4694
4.6416	1.3605	1.0837	0.7040	1.0874	0.8662	0.5627	0.8692	0.6924	0.4498
5.0119	1.3751	1.0756	0.6751	1.0991	0.8598	0.5396	0.8785	0.6872	0.4313
5.4117	1.3923	1.0680	0.6458	1.1129	0.8536	0.5162	0.8895	0.6823	0.4126
5.8434	1.4148	1.0625	0.6173	1.1309	0.8493	0.4934	0.9039	0.6788	0.3944
6.3096	1.4430	1.0592	0.5892	1.1534	0.8466	0.4710	0.9219	0.6767	0.3765
6.8129	1.4746	1.0560	0.5606	1.1787	0.8441	0.4481	0.9421	0.6747	0.3582
7.3564	1.5156	1.0569	0.5334	1.2114	0.8448	0.4264	0.9683	0.6752	0.3408
7.9433	1.5606	1.0574	0.5054	1.2474	0.8452	0.4039	0.9971	0.6756	0.3229
8.5770	1.6136	1.0599	0.4776	1.2898	0.8472	0.3817	1.0310	0.6772	0.3051
9.2612	1.6782	1.0659	0.4507	1.3414	0.8520	0.3603	1.0722	0.6810	0.2880
10.0000	1.7503	1.0722	0.4233	1.3990	0.8570	0.3383	1.1183	0.6850	0.2704
10.7978	1.8346	1.0808	0.3962	1.4664	0.8639	0.3167	1.1721	0.6905	0.2531
11.6591	1.9374	1.0941	0.3702	1.5486	0.8746	0.2959	1.2378	0.6990	0.2365
12.5893	2.0549	1.1088	0.3441	1.6425	0.8863	0.2750	1.3129	0.7084	0.2199
13.5936	2.1894	1.1246	0.3179	1.7500	0.8989	0.2541	1.3988	0.7185	0.2031
14.6780	2.3499	1.1446	0.2926	1.8783	0.9149	0.2338	1.5014	0.7313	0.1869
15.8489	2.5422	1.1692	0.2680	2.0321	0.9346	0.2142	1.6243	0.7470	0.1712

Table A-1. Fourier adjustment factors from reference rock conditions to local rock conditions and their weights. Source: Table 1 from LCI (LCI, 2015b).

	SWUS to PVNGS Adjustment Factor (Fourier-amplitude Space)								
Abbrev:	TF1	TF2	TF3	TF4	TF5	TF6	TF7	TF8	TF9
Freq. (Hz)	LB Profile, LB kappa (0.09)	LB Profile, Median kappa (0.12)	LB Profile, UB kappa (0.09)	Median Profile, LB kappa (0.12)	Median Profile, Median kappa (0.16)	Median Profile, UB kappa (0.12)	UB Profile, LB kappa (0.09)	UB Profile, Median kappa (0.12)	UB Profile, UB kappa (0.09)
17.1133	2.7672	1.1962	0.2438	2.2119	0.9562	0.1949	1.7680	0.7643	0.1558
18.4785	3.0319	1.2258	0.2201	2.4235	0.9798	0.1759	1.9371	0.7832	0.1406
19.9526	3.3536	1.2614	0.1975	2.6806	1.0083	0.1578	2.1427	0.8059	0.1262
21.5443	3.7485	1.3041	0.1761	2.9963	1.0424	0.1407	2.3950	0.8332	0.1125
23.2631	4.2270	1.3518	0.1556	3.3787	1.0805	0.1244	2.7006	0.8637	0.0994
25.1189	4.8118	1.4050	0.1361	3.8461	1.1231	0.1088	3.0743	0.8977	0.0869
27.1227	5.5426	1.4671	0.1179	4.4303	1.1727	0.0943	3.5412	0.9373	0.0754
29.2864	6.4784	1.5422	0.1014	5.1783	1.2327	0.0811	4.1391	0.9853	0.0648
31.6228	7.6667	1.6277	0.0861	6.1281	1.3010	0.0688	4.8983	1.0399	0.0550
34.1455	9.1952	1.7252	0.0722	7.3499	1.3789	0.0577	5.8748	1.1022	0.0461
36.8695	11.1888	1.8369	0.0597	8.9434	1.4682	0.0477	7.1486	1.1736	0.0381
39.8107	13.8284	1.9655	0.0486	11.0533	1.5710	0.0388	8.8350	1.2557	0.0310
42.9866	17.3805	2.1143	0.0389	13.8925	1.6900	0.0311	11.1045	1.3508	0.0249
46.4159	22.2896	2.2920	0.0307	17.8164	1.8320	0.0245	14.2409	1.4644	0.0196
50.1187	29.2648	2.5099	0.0238	23.3918	2.0062	0.0190	18.6974	1.6036	0.0152
54.1170	39.2659	2.7684	0.0181	31.3858	2.2128	0.0145	25.0872	1.7687	0.0116
58.4341	53.9344	3.0774	0.0135	43.1106	2.4598	0.0108	34.4589	1.9662	0.0086
63.0957	75.9811	3.4500	0.0098	60.7328	2.7576	0.0078	48.5447	2.2042	0.0063
68.1292	110.005	3.9029	0.0069	87.9283	3.1197	0.0055	70.2824	2.4936	0.0044
73.5642	164.031	4.4589	0.0048	131.113	3.5641	0.0038	104.800	2.8488	0.0031
79.4328	252.802	5.1544	0.0032	202.069	4.1200	0.0026	161.517	3.2932	0.0020
85.7696	404.226	6.0417	0.0021	323.104	4.8292	0.0017	258.262	3.8601	0.0013
92.6119	671.328	7.1753	0.0013	536.603	5.7353	0.0010	428.915	4.5843	0.0008
100.0000	1160.96	8.6394	0.0008	927.980	6.9056	0.0006	741.749	5.5197	0.0005

Table A-2. Scaled HF input control motions. Source: LCI (LCI, 2015a).

Freq. (Hz)	HF 1 (g)	HF 2 (g)	HF 3 (g)	HF 4 (g)	HF 5 (g)	HF 6 (g)	HF 7 (g)	HF 8 (g)	HF 9 (g)	HF 10 (g)	HF 11 (g)
100	1.00E-02	1.80E-02	3.24E-02	5.83E-02	1.05E-01	1.56E-01	2.31E-01	3.44E-01	5.33E-01	8.27E-01	1.50E+00
90	1.00E-02	1.81E-02	3.25E-02	5.85E-02	1.05E-01	1.56E-01	2.33E-01	3.46E-01	5.37E-01	8.33E-01	1.51E+00
80	1.01E-02	1.81E-02	3.27E-02	5.88E-02	1.06E-01	1.57E-01	2.35E-01	3.48E-01	5.40E-01	8.40E-01	1.52E+00
70	1.01E-02	1.82E-02	3.28E-02	5.91E-02	1.06E-01	1.58E-01	2.36E-01	3.51E-01	5.45E-01	8.48E-01	1.54E+00
60	1.02E-02	1.83E-02	3.30E-02	5.94E-02	1.07E-01	1.59E-01	2.39E-01	3.54E-01	5.50E-01	8.57E-01	1.55E+00
50	1.03E-02	1.85E-02	3.32E-02	5.98E-02	1.08E-01	1.60E-01	2.41E-01	3.58E-01	5.56E-01	8.68E-01	1.57E+00
40	1.08E-02	1.94E-02	3.50E-02	6.30E-02	1.13E-01	1.68E-01	2.57E-01	3.82E-01	5.92E-01	9.22E-01	1.67E+00
33	1.13E-02	2.03E-02	3.66E-02	6.58E-02	1.18E-01	1.76E-01	2.72E-01	4.04E-01	6.26E-01	9.71E-01	1.76E+00
30	1.17E-02	2.11E-02	3.79E-02	6.82E-02	1.23E-01	1.82E-01	2.83E-01	4.21E-01	6.53E-01	1.01E+00	1.84E+00
25	1.25E-02	2.26E-02	4.06E-02	7.31E-02	1.31E-01	1.95E-01	3.07E-01	4.55E-01	7.06E-01	1.10E+00	1.99E+00
20	1.36E-02	2.45E-02	4.41E-02	7.94E-02	1.43E-01	2.12E-01	3.38E-01	5.02E-01	7.78E-01	1.21E+00	2.20E+00
15	1.61E-02	2.90E-02	5.22E-02	9.40E-02	1.69E-01	2.51E-01	4.00E-01	5.95E-01	9.22E-01	1.43E+00	2.59E+00
13	1.75E-02	3.16E-02	5.68E-02	1.02E-01	1.84E-01	2.73E-01	4.36E-01	6.47E-01	1.00E+00	1.55E+00	2.81E+00
10	2.05E-02	3.70E-02	6.66E-02	1.20E-01	2.16E-01	3.20E-01	5.04E-01	7.49E-01	1.16E+00	1.78E+00	3.22E+00
9	2.08E-02	3.74E-02	6.73E-02	1.21E-01	2.18E-01	3.24E-01	5.10E-01	7.57E-01	1.17E+00	1.80E+00	3.27E+00
8	2.10E-02	3.78E-02	6.81E-02	1.23E-01	2.21E-01	3.27E-01	5.16E-01	7.67E-01	1.19E+00	1.83E+00	3.33E+00
7	2.13E-02	3.83E-02	6.90E-02	1.24E-01	2.23E-01	3.32E-01	5.24E-01	7.78E-01	1.21E+00	1.87E+00	3.39E+00
6	2.15E-02	3.88E-02	6.98E-02	1.26E-01	2.26E-01	3.36E-01	5.28E-01	7.84E-01	1.22E+00	1.90E+00	3.44E+00
5	2.18E-02	3.92E-02	7.06E-02	1.27E-01	2.29E-01	3.40E-01	5.31E-01	7.89E-01	1.22E+00	1.93E+00	3.50E+00
4	1.91E-02	3.44E-02	6.19E-02	1.11E-01	2.01E-01	2.98E-01	4.67E-01	6.94E-01	1.08E+00	1.71E+00	3.10E+00
3.3	1.71E-02	3.07E-02	5.53E-02	9.96E-02	1.79E-01	2.66E-01	4.18E-01	6.21E-01	9.64E-01	1.54E+00	2.80E+00
3	1.55E-02	2.78E-02	5.01E-02	9.02E-02	1.62E-01	2.41E-01	3.79E-01	5.63E-01	8.73E-01	1.40E+00	2.55E+00
2.5	1.28E-02	2.31E-02	4.15E-02	7.47E-02	1.34E-01	2.00E-01	3.14E-01	4.66E-01	7.22E-01	1.17E+00	2.13E+00
2	1.09E-02	1.96E-02	3.54E-02	6.36E-02	1.15E-01	1.70E-01	2.64E-01	3.93E-01	6.09E-01	1.02E+00	1.84E+00
1.5	7.78E-03	1.40E-02	2.52E-02	4.53E-02	8.16E-02	1.21E-01	1.90E-01	2.82E-01	4.38E-01	7.41E-01	1.34E+00
1.3	6.57E-03	1.18E-02	2.13E-02	3.83E-02	6.90E-02	1.02E-01	1.61E-01	2.40E-01	3.72E-01	6.34E-01	1.15E+00
1	4.45E-03	8.01E-03	1.44E-02	2.59E-02	4.67E-02	6.93E-02	1.10E-01	1.64E-01	2.54E-01	4.57E-01	8.28E-01
0.9	3.85E-03	6.94E-03	1.25E-02	2.25E-02	4.04E-02	6.01E-02	9.51E-02	1.41E-01	2.19E-01	3.94E-01	7.15E-01
0.8	3.28E-03	5.91E-03	1.06E-02	1.91E-02	3.44E-02	5.11E-02	8.05E-02	1.20E-01	1.85E-01	3.34E-01	6.07E-01

Table A-2. Scaled HF input control motions. Source: LCI (LCI, 2015a).

Freq. (Hz)	**HF 1 (g)**	**HF 2 (g)**	**HF 3 (g)**	**HF 4 (g)**	**HF 5 (g)**	**HF 6 (g)**	**HF 7 (g)**	**HF 8 (g)**	**HF 9 (g)**	**HF 10 (g)**	**HF 11 (g)**
0.7	2.74E-03	4.92E-03	8.86E-03	1.60E-02	2.87E-02	4.26E-02	6.67E-02	9.90E-02	1.54E-01	2.78E-01	5.04E-01
0.6	2.19E-03	3.93E-03	7.08E-03	1.27E-02	2.29E-02	3.41E-02	5.28E-02	7.84E-02	1.22E-01	2.20E-01	4.00E-01
0.5	1.66E-03	3.00E-03	5.39E-03	9.71E-03	1.75E-02	2.59E-02	3.97E-02	5.90E-02	9.15E-02	1.67E-01	3.02E-01
0.4	1.18E-03	2.12E-03	3.81E-03	6.86E-03	1.23E-02	1.83E-02	2.80E-02	4.16E-02	6.46E-02	1.20E-01	2.18E-01
0.33	8.71E-04	1.57E-03	2.82E-03	5.08E-03	9.14E-03	1.36E-02	2.08E-02	3.08E-02	4.78E-02	9.05E-02	1.64E-01
0.3	7.38E-04	1.33E-03	2.39E-03	4.30E-03	7.75E-03	1.15E-02	1.77E-02	2.62E-02	4.07E-02	7.78E-02	1.41E-01
0.25	5.37E-04	9.67E-04	1.74E-03	3.13E-03	5.64E-03	8.38E-03	1.30E-02	1.93E-02	2.99E-02	5.82E-02	1.06E-01
0.2	3.73E-04	6.71E-04	1.21E-03	2.17E-03	3.91E-03	5.81E-03	9.10E-03	1.35E-02	2.10E-02	4.17E-02	7.56E-02
0.15	2.25E-04	4.06E-04	7.30E-04	1.31E-03	2.36E-03	3.51E-03	5.58E-03	8.29E-03	1.29E-02	2.63E-02	4.78E-02
0.13	1.75E-04	3.16E-04	5.68E-04	1.02E-03	1.84E-03	2.73E-03	4.38E-03	6.50E-03	1.01E-02	2.10E-02	3.80E-02
0.1	1.02E-04	1.84E-04	3.32E-04	5.97E-04	1.07E-03	1.60E-03	2.44E-03	3.62E-03	5.61E-03	1.19E-02	2.15E-02

Table A-3. Scaled LF input control motions. Source: LCI (LCI, 2015a).

Freq. (Hz)	LF 1 (g)	LF 2 (g)	LF 3 (g)	LF 4 (g)	LF 5 (g)	LF 6 (g)	LF 7 (g)	LF 8 (g)	LF 9 (g)	LF 10 (g)	LF 11 (g)
100	1.00E-02	1.71E-02	2.94E-02	5.03E-02	8.63E-02	1.27E-01	1.86E-01	2.73E-01	4.51E-01	7.44E-01	1.50E+00
90	1.00E-02	1.72E-02	2.94E-02	5.04E-02	8.63E-02	1.27E-01	1.86E-01	2.73E-01	4.51E-01	7.52E-01	1.52E+00
80	1.00E-02	1.72E-02	2.94E-02	5.04E-02	8.64E-02	1.27E-01	1.86E-01	2.74E-01	4.52E-01	7.61E-01	1.53E+00
70	1.00E-02	1.72E-02	2.94E-02	5.05E-02	8.65E-02	1.27E-01	1.87E-01	2.74E-01	4.52E-01	7.71E-01	1.55E+00
60	1.00E-02	1.72E-02	2.95E-02	5.05E-02	8.66E-02	1.27E-01	1.87E-01	2.74E-01	4.53E-01	7.83E-01	1.58E+00
50	1.01E-02	1.72E-02	2.95E-02	5.06E-02	8.67E-02	1.27E-01	1.87E-01	2.75E-01	4.53E-01	7.97E-01	1.61E+00
40	1.03E-02	1.76E-02	3.02E-02	5.18E-02	8.89E-02	1.30E-01	1.92E-01	2.82E-01	4.65E-01	8.30E-01	1.67E+00
33	1.05E-02	1.80E-02	3.09E-02	5.29E-02	9.07E-02	1.33E-01	1.96E-01	2.88E-01	4.76E-01	8.60E-01	1.73E+00
30	1.06E-02	1.82E-02	3.12E-02	5.35E-02	9.17E-02	1.35E-01	1.99E-01	2.92E-01	4.82E-01	8.98E-01	1.81E+00
25	1.09E-02	1.86E-02	3.19E-02	5.47E-02	9.37E-02	1.38E-01	2.04E-01	2.99E-01	4.94E-01	9.73E-01	1.96E+00
20	1.11E-02	1.91E-02	3.27E-02	5.61E-02	9.61E-02	1.41E-01	2.10E-01	3.08E-01	5.08E-01	1.07E+00	2.17E+00
15	1.20E-02	2.06E-02	3.54E-02	6.06E-02	1.04E-01	1.53E-01	2.28E-01	3.34E-01	5.52E-01	1.28E+00	2.58E+00
13	1.25E-02	2.15E-02	3.68E-02	6.30E-02	1.08E-01	1.59E-01	2.37E-01	3.48E-01	5.74E-01	1.39E+00	2.81E+00
10	1.35E-02	2.32E-02	3.98E-02	6.82E-02	1.17E-01	1.72E-01	2.56E-01	3.75E-01	6.19E-01	1.63E+00	3.29E+00
9	1.39E-02	2.37E-02	4.07E-02	6.97E-02	1.20E-01	1.76E-01	2.61E-01	3.83E-01	6.33E-01	1.68E+00	3.38E+00
8	1.42E-02	2.44E-02	4.18E-02	7.16E-02	1.23E-01	1.80E-01	2.67E-01	3.93E-01	6.48E-01	1.73E+00	3.49E+00
7	1.46E-02	2.51E-02	4.30E-02	7.37E-02	1.26E-01	1.85E-01	2.75E-01	4.03E-01	6.66E-01	1.79E+00	3.61E+00
6	1.54E-02	2.64E-02	4.52E-02	7.74E-02	1.33E-01	1.95E-01	2.87E-01	4.22E-01	6.96E-01	1.85E+00	3.73E+00
5	1.64E-02	2.81E-02	4.82E-02	8.26E-02	1.42E-01	2.08E-01	3.04E-01	4.47E-01	7.38E-01	1.92E+00	3.88E+00
4	1.75E-02	2.99E-02	5.13E-02	8.79E-02	1.51E-01	2.21E-01	3.21E-01	4.72E-01	7.78E-01	1.74E+00	3.50E+00
3.3	1.82E-02	3.12E-02	5.35E-02	9.17E-02	1.57E-01	2.31E-01	3.33E-01	4.89E-01	8.06E-01	1.60E+00	3.22E+00
3	1.84E-02	3.16E-02	5.41E-02	9.27E-02	1.59E-01	2.33E-01	3.35E-01	4.92E-01	8.13E-01	1.47E+00	2.96E+00
2.5	1.88E-02	3.23E-02	5.53E-02	9.48E-02	1.62E-01	2.38E-01	3.40E-01	5.00E-01	8.25E-01	1.24E+00	2.51E+00
2	1.66E-02	2.84E-02	4.86E-02	8.34E-02	1.43E-01	2.10E-01	2.75E-01	4.04E-01	6.67E-01	1.07E+00	2.15E+00
1.5	1.42E-02	2.44E-02	4.18E-02	7.16E-02	1.23E-01	1.80E-01	2.32E-01	3.41E-01	5.63E-01	8.12E-01	1.64E+00
1.3	1.32E-02	2.26E-02	3.87E-02	6.64E-02	1.14E-01	1.67E-01	2.13E-01	3.13E-01	5.17E-01	7.10E-01	1.43E+00
1	9.46E-03	1.62E-02	2.78E-02	4.76E-02	8.16E-02	1.20E-01	1.44E-01	2.11E-01	3.49E-01	5.30E-01	1.07E+00
0.9	8.69E-03	1.49E-02	2.55E-02	4.37E-02	7.50E-02	1.10E-01	1.30E-01	1.90E-01	3.14E-01	4.62E-01	9.31E-01
0.8	7.90E-03	1.35E-02	2.32E-02	3.98E-02	6.82E-02	1.00E-01	1.16E-01	1.70E-01	2.80E-01	3.96E-01	7.99E-01
0.7	7.10E-03	1.22E-02	2.08E-02	3.57E-02	6.12E-02	8.99E-02	1.01E-01	1.49E-01	2.46E-01	3.33E-01	6.71E-01

Table A-3. Scaled LF input control motions. Source: LCI (LCI, 2015a).

Freq. (Hz)	LF 1 (g)	LF 2 (g)	LF 3 (g)	LF 4 (g)	LF 5 (g)	LF 6 (g)	LF 7 (g)	LF 8 (g)	LF 9 (g)	LF 10 (g)	LF 11 (g)
0.6	6.18E-03	1.06E-02	1.81E-02	3.11E-02	5.33E-02	7.83E-02	8.60E-02	1.26E-01	2.08E-01	2.80E-01	5.64E-01
0.5	5.21E-03	8.93E-03	1.53E-02	2.62E-02	4.50E-02	6.60E-02	7.03E-02	1.03E-01	1.70E-01	2.31E-01	4.66E-01
0.4	4.19E-03	7.19E-03	1.23E-02	2.11E-02	3.62E-02	5.31E-02	5.66E-02	8.31E-02	1.37E-01	1.71E-01	3.44E-01
0.33	3.47E-03	5.96E-03	1.02E-02	1.75E-02	3.00E-02	4.40E-02	4.69E-02	6.89E-02	1.14E-01	1.32E-01	2.66E-01
0.3	3.15E-03	5.40E-03	9.25E-03	1.58E-02	2.72E-02	3.99E-02	4.25E-02	6.24E-02	1.03E-01	1.15E-01	2.33E-01
0.25	2.61E-03	4.47E-03	7.66E-03	1.31E-02	2.25E-02	3.30E-02	3.52E-02	5.16E-02	8.52E-02	8.96E-02	1.81E-01
0.2	2.08E-03	3.57E-03	6.12E-03	1.05E-02	1.80E-02	2.64E-02	2.81E-02	4.13E-02	6.82E-02	6.71E-02	1.35E-01
0.15	1.59E-03	2.73E-03	4.67E-03	8.01E-03	1.37E-02	2.01E-02	2.15E-02	3.15E-02	5.20E-02	4.48E-02	9.03E-02
0.13	1.39E-03	2.38E-03	4.08E-03	7.00E-03	1.20E-02	1.76E-02	1.88E-02	2.75E-02	4.55E-02	3.66E-02	7.39E-02
0.1	1.04E-03	1.79E-03	3.06E-03	5.25E-03	8.99E-03	1.32E-02	1.41E-02	2.07E-02	3.41E-02	2.14E-02	4.32E-02

Table A-4. SAFs and uncertainty for seven spectral frequencies at associated reference rock amplitudes for PVNGS base-case profile. Source: Table 22 from LCI (LCI, 2015d).

Low Frequency								
0.5 Hz			**1 Hz**			**2.5 Hz**		
Amp. (g)	Median SAF	$\sigma_{\ln(SAF)}$	Amp. (g)	Median SAF	$\sigma_{\ln(SAF)}$	Amp. (g)	Median SAF	$\sigma_{\ln(SAF)}$
5.21E-03	1.16E+00	2.50E-01	9.46E-03	2.51E+00	2.94E-01	1.88E-02	1.83E+00	2.95E-01
8.93E-03	1.17E+00	2.50E-01	1.62E-02	2.53E+00	2.96E-01	3.23E-02	1.81E+00	2.90E-01
1.53E-02	1.17E+00	2.54E-01	2.78E-02	2.54E+00	3.04E-01	5.53E-02	1.77E+00	2.88E-01
2.62E-02	1.18E+00	2.58E-01	4.76E-02	2.53E+00	3.03E-01	9.48E-02	1.75E+00	2.87E-01
4.50E-02	1.20E+00	2.64E-01	8.16E-02	2.59E+00	2.93E-01	1.62E-01	1.75E+00	2.78E-01
6.60E-02	1.21E+00	2.70E-01	1.20E-01	2.58E+00	2.95E-01	2.38E-01	1.71E+00	2.85E-01
7.03E-02	1.24E+00	2.80E-01	1.44E-01	2.63E+00	2.93E-01	3.40E-01	1.71E+00	2.93E-01
1.03E-01	1.27E+00	2.79E-01	2.11E-01	2.63E+00	2.90E-01	5.00E-01	1.69E+00	3.08E-01
1.70E-01	1.32E+00	3.01E-01	3.49E-01	2.57E+00	3.01E-01	8.25E-01	1.61E+00	3.19E-01
2.31E-01	1.45E+00	3.28E-01	5.30E-01	2.42E+00	3.06E-01	1.24E+00	1.48E+00	3.00E-01
4.66E-01	1.77E+00	3.94E-01	1.07E+00	2.01E+00	3.27E-01	2.51E+00	1.20E+00	3.29E-01

High Frequency											
5 Hz			**10 Hz**			**20 Hz**			**PGA**		
Amp. (g)	Median SAF	$\sigma_{\ln(SAF)}$	Amp. (g)	Median SAF	$\sigma_{\ln(SAF)}$	Amp. (g)	Median SAF	$\sigma_{\ln(SAF)}$	Amp. (g)	Median SAF	$\sigma_{\ln(SAF)}$
2.18E-02	1.84E+00	3.58E-01	2.05E-02	1.55E+00	4.56E-01	1.36E-02	1.71E+00	5.10E-01	1.00E-02	1.83E+00	3.57E-01
3.92E-02	1.79E+00	3.49E-01	3.70E-02	1.49E+00	4.43E-01	2.45E-02	1.63E+00	4.89E-01	1.80E-02	1.78E+00	3.42E-01
7.06E-02	1.73E+00	3.50E-01	6.66E-02	1.39E+00	4.45E-01	4.41E-02	1.51E+00	4.67E-01	3.24E-02	1.71E+00	3.33E-01
1.27E-01	1.64E+00	3.44E-01	1.20E-01	1.27E+00	4.30E-01	7.94E-02	1.36E+00	4.36E-01	5.83E-02	1.61E+00	3.18E-01
2.29E-01	1.56E+00	3.32E-01	2.16E-01	1.14E+00	4.11E-01	1.43E-01	1.22E+00	3.97E-01	1.05E-01	1.51E+00	2.97E-01
3.40E-01	1.45E+00	3.32E-01	3.20E-01	1.02E+00	4.04E-01	2.12E-01	1.10E+00	3.76E-01	1.56E-01	1.41E+00	2.93E-01
5.31E-01	1.32E+00	3.18E-01	5.04E-01	8.87E-01	3.84E-01	3.38E-01	9.72E-01	3.43E-01	2.31E-01	1.31E+00	2.76E-01
7.89E-01	1.16E+00	3.21E-01	7.49E-01	7.57E-01	3.77E-01	5.02E-01	8.59E-01	3.20E-01	3.44E-01	1.20E+00	2.70E-01
1.22E+00	9.75E-01	3.38E-01	1.16E+00	6.09E-01	3.57E-01	7.78E-01	7.40E-01	2.96E-01	5.33E-01	1.08E+00	2.67E-01
1.93E+00	7.77E-01	3.45E-01	1.78E+00	4.99E-01	3.45E-01	1.21E+00	6.62E-01	2.88E-01	8.27E-01	9.81E-01	2.74E-01
3.50E+00	5.51E-01	3.50E-01	3.22E+00	3.78E-01	2.96E-01	2.20E+00	5.49E-01	2.65E-01	1.50E+00	8.32E-01	2.62E-01

Table A-5. SAFs and uncertainty for seven spectral frequencies at associated reference rock amplitudes for PVNGS lower-range profile. Source: Table 23 from LCI (LCI, 2015d).

Low Frequency								
0.5 Hz			**1 Hz**			**2.5 Hz**		
Amp. (g)	Median SAF	$\sigma_{\ln(SAF)}$	Amp. (g)	Median SAF	$\sigma_{\ln(SAF)}$	Amp. (g)	Median SAF	$\sigma_{\ln(SAF)}$
5.21E-03	1.33E+00	2.71E-01	9.46E-03	2.91E+00	2.97E-01	1.88E-02	2.17E+00	2.90E-01
8.93E-03	1.34E+00	2.76E-01	1.62E-02	2.86E+00	2.95E-01	3.23E-02	2.11E+00	2.78E-01
1.53E-02	1.35E+00	2.79E-01	2.78E-02	2.81E+00	2.93E-01	5.53E-02	2.04E+00	2.86E-01
2.62E-02	1.36E+00	2.96E-01	4.76E-02	2.75E+00	2.91E-01	9.48E-02	1.98E+00	2.83E-01
4.50E-02	1.39E+00	2.90E-01	8.16E-02	2.66E+00	2.98E-01	1.62E-01	1.86E+00	2.90E-01
6.60E-02	1.43E+00	3.07E-01	1.20E-01	2.55E+00	2.99E-01	2.38E-01	1.79E+00	2.86E-01
7.03E-02	1.47E+00	3.15E-01	1.44E-01	2.50E+00	2.98E-01	3.40E-01	1.72E+00	2.98E-01
1.03E-01	1.52E+00	3.39E-01	2.11E-01	2.38E+00	3.03E-01	5.00E-01	1.62E+00	3.09E-01
1.70E-01	1.64E+00	3.50E-01	3.49E-01	2.16E+00	3.29E-01	8.25E-01	1.45E+00	3.29E-01
2.31E-01	1.89E+00	3.60E-01	5.30E-01	1.92E+00	3.62E-01	1.24E+00	1.26E+00	3.36E-01
4.66E-01	2.25E+00	3.60E-01	1.07E+00	1.67E+00	3.45E-01	2.51E+00	9.61E-01	3.47E-01

High Frequency											
5 Hz			**10 Hz**			**20 Hz**			**PGA**		
Amp. (g)	Median SAF	$\sigma_{\ln(SAF)}$	Amp. (g)	Median SAF	$\sigma_{\ln(SAF)}$	Amp. (g)	Median SAF	$\sigma_{\ln(SAF)}$	Amp. (g)	Median SAF	$\sigma_{\ln(SAF)}$
2.18E-02	1.81E+00	3.49E-01	2.05E-02	1.51E+00	4.44E-01	1.36E-02	1.68E+00	4.85E-01	1.00E-02	1.84E+00	3.37E-01
3.92E-02	1.76E+00	3.59E-01	3.70E-02	1.42E+00	4.40E-01	2.45E-02	1.57E+00	4.71E-01	1.80E-02	1.76E+00	3.35E-01
7.06E-02	1.70E+00	3.49E-01	6.66E-02	1.32E+00	4.25E-01	4.41E-02	1.44E+00	4.39E-01	3.24E-02	1.67E+00	3.16E-01
1.27E-01	1.56E+00	3.34E-01	1.20E-01	1.17E+00	4.09E-01	7.94E-02	1.26E+00	4.06E-01	5.83E-02	1.54E+00	3.00E-01
2.29E-01	1.45E+00	3.25E-01	2.16E-01	1.03E+00	3.98E-01	1.43E-01	1.11E+00	3.74E-01	1.05E-01	1.43E+00	2.88E-01
3.40E-01	1.32E+00	3.34E-01	3.20E-01	9.04E-01	3.96E-01	2.12E-01	9.96E-01	3.54E-01	1.56E-01	1.33E+00	2.84E-01
5.31E-01	1.17E+00	3.23E-01	5.04E-01	7.58E-01	3.73E-01	3.38E-01	8.63E-01	3.17E-01	2.31E-01	1.21E+00	2.68E-01
7.89E-01	9.98E-01	3.24E-01	7.49E-01	6.35E-01	3.75E-01	5.02E-01	7.56E-01	2.98E-01	3.44E-01	1.09E+00	2.61E-01
1.22E+00	8.11E-01	3.28E-01	1.16E+00	5.09E-01	3.41E-01	7.78E-01	6.51E-01	2.80E-01	5.33E-01	9.70E-01	2.62E-01
1.93E+00	6.10E-01	3.59E-01	1.78E+00	4.08E-01	3.27E-01	1.21E+00	5.71E-01	2.86E-01	8.27E-01	8.59E-01	2.80E-01
3.50E+00	4.25E-01	3.58E-01	3.22E+00	3.08E-01	3.05E-01	2.20E+00	4.65E-01	2.79E-01	1.50E+00	7.09E-01	2.76E-01

Table A-6. SAFs and uncertainty for seven spectral frequencies at associated reference rock amplitudes for PVNGS upper-range profile. Source: Table 24 from LCI (LCI, 2015d).

Low Frequency								
0.5 Hz			**1 Hz**			**2.5 Hz**		
Amp. (g)	Median SAF	$\sigma_{\ln(SAF)}$	Amp. (g)	Median SAF	$\sigma_{\ln(SAF)}$	Amp. (g)	Median SAF	$\sigma_{\ln(SAF)}$
5.21E-03	1.07E+00	2.46E-01	9.46E-03	1.95E+00	3.04E-01	1.88E-02	1.58E+00	2.61E-01
8.93E-03	1.07E+00	2.49E-01	1.62E-02	1.96E+00	3.10E-01	3.23E-02	1.56E+00	2.74E-01
1.53E-02	1.08E+00	2.49E-01	2.78E-02	1.97E+00	3.13E-01	5.53E-02	1.55E+00	2.70E-01
2.62E-02	1.08E+00	2.52E-01	4.76E-02	2.01E+00	3.17E-01	9.48E-02	1.52E+00	2.71E-01
4.50E-02	1.09E+00	2.52E-01	8.16E-02	2.02E+00	3.18E-01	1.62E-01	1.50E+00	2.74E-01
6.60E-02	1.10E+00	2.58E-01	1.20E-01	2.10E+00	3.28E-01	2.38E-01	1.48E+00	2.84E-01
7.03E-02	1.12E+00	2.60E-01	1.44E-01	2.15E+00	3.26E-01	3.40E-01	1.47E+00	2.99E-01
1.03E-01	1.14E+00	2.66E-01	2.11E-01	2.24E+00	3.26E-01	5.00E-01	1.46E+00	2.97E-01
1.70E-01	1.17E+00	2.79E-01	3.49E-01	2.34E+00	3.21E-01	8.25E-01	1.46E+00	3.27E-01
2.31E-01	1.25E+00	3.01E-01	5.30E-01	2.47E+00	3.17E-01	1.24E+00	1.49E+00	3.35E-01
4.66E-01	1.44E+00	3.67E-01	1.07E+00	2.28E+00	3.04E-01	2.51E+00	1.32E+00	3.17E-01

High Frequency											
5 Hz			**10 Hz**			**20 Hz**			**PGA**		
Amp. (g)	Median SAF	$\sigma_{\ln(SAF)}$	Amp. (g)	Median SAF	$\sigma_{\ln(SAF)}$	Amp. (g)	Median SAF	$\sigma_{\ln(SAF)}$	Amp. (g)	Median SAF	$\sigma_{\ln(SAF)}$
2.18E-02	1.75E+00	3.53E-01	2.05E-02	1.49E+00	4.63E-01	1.36E-02	1.69E+00	5.19E-01	1.00E-02	1.79E+00	3.61E-01
3.92E-02	1.73E+00	3.63E-01	3.70E-02	1.44E+00	4.55E-01	2.45E-02	1.64E+00	5.04E-01	1.80E-02	1.75E+00	3.53E-01
7.06E-02	1.70E+00	3.57E-01	6.66E-02	1.39E+00	4.45E-01	4.41E-02	1.54E+00	4.80E-01	3.24E-02	1.70E+00	3.38E-01
1.27E-01	1.65E+00	3.47E-01	1.20E-01	1.29E+00	4.32E-01	7.94E-02	1.42E+00	4.52E-01	5.83E-02	1.61E+00	3.22E-01
2.29E-01	1.57E+00	3.36E-01	2.16E-01	1.17E+00	4.20E-01	1.43E-01	1.27E+00	4.25E-01	1.05E-01	1.52E+00	3.08E-01
3.40E-01	1.50E+00	3.37E-01	3.20E-01	1.08E+00	4.18E-01	2.12E-01	1.17E+00	4.06E-01	1.56E-01	1.45E+00	3.04E-01
5.31E-01	1.38E+00	3.34E-01	5.04E-01	9.64E-01	3.95E-01	3.38E-01	1.04E+00	3.72E-01	2.31E-01	1.35E+00	2.88E-01
7.89E-01	1.25E+00	3.23E-01	7.49E-01	8.30E-01	3.91E-01	5.02E-01	9.17E-01	3.39E-01	3.44E-01	1.25E+00	2.75E-01
1.22E+00	1.09E+00	3.27E-01	1.16E+00	6.98E-01	3.75E-01	7.78E-01	8.02E-01	3.17E-01	5.33E-01	1.13E+00	2.69E-01
1.93E+00	8.95E-01	3.20E-01	1.78E+00	5.68E-01	3.28E-01	1.21E+00	7.11E-01	2.74E-01	8.27E-01	1.03E+00	2.57E-01
3.50E+00	6.59E-01	3.60E-01	3.22E+00	4.31E-01	3.21E-01	2.20E+00	5.94E-01	2.76E-01	1.50E+00	8.90E-01	2.70E-01

Appendix B SSC PPRP Endorsement Letter

This appendix provides the Participatory Peer Review Panel Closure Letter from (APS, 2015).

February 26, 2015

Dr. Ross Hartleb
LCI Project Manager, Palo Verde Nuclear Generating Station (PVNGS) Seismic Hazard Evaluation Project
Lettis Consultants International, Inc.
27441 Tourney Road, Suite 220
Valencia, CA 91355

Subject: PVNGS SSHAC Level 3 Seismic Source Characterization

Dear Dr. Hartleb:

On March 12, 2012, the U.S. Nuclear Regulatory Commission (NRC) issued a request for information pursuant to 10CFR50.54(f), requiring that all operating nuclear plants in the U.S. perform a site-specific Probabilistic Seismic Hazard Analysis (PSHA) and develop a Ground Motion Response Spectrum (GMRS) in accordance with Regulatory Guide 1.208 for comparison to the plant license Safe Shutdown Earthquake (SSE) ground motion. Licensees are required to re-evaluate the seismic hazard using present-day NRC regulatory criteria and guidance. For plants in the western U.S., including the PVNGS, the directive requires that the site-specific PSHA be performed using the Senior Seismic Hazard Analysis Committee (SSHAC[1], [2]) Level 3 process to develop the Seismic Source Characterization (SSC) model.

In accordance with the requirements for a SSHAC Level 3 study, the PVNGS SSC Participatory Peer Review Panel ("PPRP") is pleased to issue this PPRP Closure Letter containing our findings with respect to the PVNGS SSC Project. The PPRP was actively engaged in the review of all phases and activities of the Project's implementation. These phases included development of the Project Plan, planning and execution of the Technical Integration (TI) Team's evaluation and integration activities, and review of the TI Team's documentation of the SSC model. These phases are at the core of the SSHAC process.

In accordance with NRC guidance for SSHAC projects, the role of the PPRP is to conduct a review of both the *process* followed and the *technical assessments* made by the TI Team. Accordingly, this letter documents the activities that the PPRP has carried out to perform its review of the adequacy of the process followed, and its findings regarding the technical adequacy of the SSC.

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[1] Budnitz, R.J., G. Apostolakis, D.M. Boore, L.S. Cluff, K.L. Coppersmith, C.A. Cornell, and P.A. Morris (1997). *Recommendations for Probabilistic Seismic Hazard Analysis: Guidance on Uncertainty and the Use of Experts (known as the "Senior Seismic Hazard Analysis Committee Report", or "SSHAC Guideline")*, NUREG/CR-6372, U.S. Nuclear Regulatory Commission, TIC; 235076, Washington, D.C.
[2] USNRC (2012). *Practical Implementation Guidelines for SSHAC Level 3 and 4 Hazard Studies*, NUREG-2117, U.S. Nuclear Regulatory Commission, Washington, D.C.

PPRP Activities for the SSC Peer Review

The fundamental idea of a participatory peer review process entails the continual review of a project from its start to its completion. Thus, proper participatory peer review requires adequate opportunities during the conduct of the project for the PPRP to understand the data being used, the analyses performed, the TI Team's evaluations and integration of the technical bases for its assessments, and the completeness and clarity of the documentation. Participatory peer review also involves occasions for the PPRP to provide its reviews and comments in written form during the conduct of the project, such that their observations and recommendations can be considered by the TI Team in a timely manner prior to the completion of the project. Written comments by the PPRP serve to document the review process and provide part of the formal record documenting that all aspects of the SSHAC process have been satisfactorily conducted.

The activities of the PPRP for the PVNGS SSC are summarized in the table below, which includes written reviews during the various stages of the project. These activities directly addressed the conduct of the PVNGS SSC and the development of the SSC Report.

Date	PPRP Activity
January 21, 2013	SSC Kickoff Meeting ("Workshop 0"); PPRP members attended in person as observers
January 23, 2013	PPRP submitted review comments on the Project Plan via email
April 9-11, 2013	SSC Workshop No. 1: Significant Issues and Data Needs; PPRP members attended in person as observers
April 24, 2013	PPRP submitted written review comments on Kick-off Meeting
June 5, 2013	PPRP submitted written review comments on Workshop 1
July 10, 2013	TI working meeting No. 4: PPRP members Savage and Machette attend portion of TI working meeting by phone as observers
August 27-28, 2013	TI working meeting No. 5: PPRP member Rockwell attends portion of TI working meeting by phone as observer
September 24-26, 2013	SSC Workshop No. 2: Alternative Interpretations; PPRP members attended in person as observers
October 23, 2013	PPRP submitted written review comments on Workshop No. 2
February 4-6, 2014	Field Review of Geologic Mapping: PPRP members attended in person as observers
March 24, 2014	PPRP submitted written review comments of Field Review of Geologic Mapping
April 23-25, 2014	SSC Workshop No. 3: Preliminary Model and Hazard Feedback: PPRP members attended in person as active participants

Date	PPRP Activity
May 5, 2014	PPRP submitted written review comments on Workshop 3
June 18, 2014	Update on SSC Activities; PPRP members attended via webinar as observers
July 10-11, 2014	SSC Final Briefing; PPRP members attended in person
August 1, 2014	Update on SSC Activities; PPRP representatives attended via webinar as observers
January 12, 2015	Submittal of review comments on SSC Report, transmittal 1 &2
January 17, 2015	Submittal of review comments on SSC Report, transmittal 3
January 19-22, 2015	Submittal of PPRP written review comments on SSC Report transmittals 1-3 and on TI Team's responses to PPRP written review comments
February 17-19, 2015	Submittal of PPRP written review comments on PVNGS SSC Draft Report transmittal 4 and on TI Team's responses to PPRP written review comments
February 19-25, 2015	Teleconference call to resolve remaining issues with SSC Draft Report (2/19) and review of TI Team's responses to teleconference call issues
February 26, 2015	Submittal of PVNGS SSC PPRP Closure Letter

The activities listed above are those that directly addressed the conduct of the PVNGS SSC and the development of the PVNGS SSC Report. The PPRP has concluded that its ongoing review and feedback interactions with the TI Team during the conduct of the PVNGS SSC Project activities fully met the expectations for a SSHAC Level 3 study. From the presentation of the plans for conducting the PVNGS SSC at the start of the project to the completion of the PVNGS SSC Report, the TI Team provided multiple and effective communications with the PPRP. Webinars and written communications allowed the PPRP to fully understand the technical support for the TI Team's assessments. The TI Team provided written responses to PPRP comments documenting that all comments had been adequately considered during the conduct of the work and the compilation of its documentation.

SSHAC *Technical* Review

The role of the PPRP in the review of the technical aspects of the project is specified in NUREG-2117 (USNRC, 2012) as follows:

> "The PPRP fulfills two parallel roles, the first being technical review. This means that the PPRP is charged with ensuring that the full range of data, models, and methods have been duly considered in the assessment and also that all technical decisions are adequately justified and documented.

> The responsibility of the PPRP is to provide clear and timely feedback to the TI/TFI and project manager to ensure that any technical or process deficiencies are identified at the earliest possible stage so that they can be corrected. More commonly, the PPRP provides its perspectives and advice regarding the manner in which ongoing activities can be improved or carried out more effectively. In terms of technical review, a key responsibility of the PPRP is to highlight any data, models or proponents that have not been considered. Beyond completeness, it is not the responsibility of the PPRP to judge the weighting of the logic trees in detail, but rather to judge the justification provided for the models included or excluded, and for the weights applied to the logic-tree branches."

Consistent with this USNRC guidance, the PPRP reviewed at multiple times during the project the TI Team's analyses and evaluations of data, models, and methods. These reviews included conference calls, post-workshop meetings, written comments, and the review of drafts of the SSC Report. Through these reviews, the PPRP communicated feedback to the TI Team regarding data and approaches that did not appear to have been considered, suggestions for methods being used within the technical community, and recommendations for ways that the documentation could be improved to include more discussion of the technical bases for the assessments.

Examples of PPRP feedback regarding technical aspects of the project can be found in the written comments provided following workshops and field trips and during the review of the draft final report. The TI Team was responsive to the questions, comments, and suggestions made by the PPRP relative to the technical aspects of the project. Therefore, the PPRP concludes that the technical aspects of the project have been adequately addressed.

SSHAC *Process* Review

As explained in NUREG-2117 (USNRC, 2012), the SSHAC process consists of two important activities, described as follows:

> "The fundamental goal of a SSHAC process is to carry out properly and document completely the activities of evaluation and integration, defined as:
>
> - *Evaluation*: The consideration of the complete set of data, models, and methods proposed by the larger technical community that are relevant to the hazard analysis.
> - *Integration*: Representing the center, body, and range of technically defensible interpretations in light of the evaluation process (i.e., informed by the assessment of existing data, models, and methods)."

These activities are essential to any SSHAC Level study and to both new models and refinements to existing models (such as the PVNGS SSC).

During the *Evaluation* phase of the PVNGS SSC, the TI Team considered new data, models, and methods that have become available in the technical community since the previous PVNGS PSHA projects were completed in 1993 and 2012. In particular, the TI Team incorporated new earthquake occurrence models and carried out additional geologic mapping. The PPRP concluded that the TI Team conducted a satisfactory evaluation process and that this process has been sufficiently documented in the SSC report.

During the *Integration* phase of the project, an updated SSC model was developed for purposes of the PVNGS PSHA. SSHAC guidelines require that the technical bases for the SSC model be documented thoroughly in the SSC report. The SSC document demonstrates the consideration by the TI Team of the existence of seismic-source data and models that have become available since the previous PVNGS SSC model was developed.

During the entire course of the PVNGS Project, The TI Team maintained close coordination with the SWUS ground-motion characterization project to assure that the PVNGS SSC will connect seamlessly with the GMC model.

Based on the review of the *Evaluation* and *Integration* activities conducted by the TI Team, as well as the documentation of these activities in the SSC report, the PPRP concludes that the SSHAC level 3 process has been adequately conducted.

Conclusion

Based on its review of the PVNGS SSC, the PPRP concludes that the process and technical aspects of the analysis fully meet accepted guidance and current expectations for a SSHAC Level 3 study.

We appreciate the opportunity to provide our review of the project.

Sincerely,

PVNGS SSC PPRP Members

William U. Savage, Chair	Michael N. Machette	Thomas K. Rockwell
	Michael Machette	Thomas Rockwell

Appendix C GMC PPRP Endorsement Letter

This appendix provides the Participatory Peer Review Panel Closure Letter from (GeoPentech, 2015).

February 24, 2015

Dr. Carola Di Alessandro
SWUS Project Manager
GeoPentech, Inc.
525 N. Cabrillo Park Drive, Suite 280
Santa Ana, CA 92701

Subject: Participatory Peer Review Panel Closure Letter, Southwest United States Ground Motion Characterization Level 3 SSHAC Project

Dear Dr. Di Alessandro:

The Participatory Peer Review Panel (PPRP, also referred to herein as the "Panel") for the Southwest United States (SWUS) Ground Motion Characterization (GMC) Project is pleased to issue this PPRP Closure Letter. Herein we describe our participation in the SWUS GMC SSHAC Level 3 project and present our findings. Pursuant to the guidelines for a SSHAC Level 3 study (NUREG/CR-6372; NUREG-2117), the PPRP was engaged at all stages of the project, including review of the final Project Plan, Workshop agendas and participant lists; the planning of the evaluation and model integration activities; and review of the project documentation. Throughout the project, the Panel reviewed and provided regular feedback on both the process followed, and the technical assessments made, by the Technical Integrator (TI) Team. By this letter the Panel documents the activities it has performed in the course of its review, its assessment of the process followed relative to SSHAC Level 3 expectations, and its assessment of the technical rationale underlying the GMC model.

PPRP Activities in Support of the SWUS GMC Review

In a SSHAC Level 3 study, the PPRP fulfills two roles. The first is that of technical review, in which the Panel ensures that the full range of data, models and methods are considered and that technical decisions and judgments are adequately justified and documented. The second is that of process review, under which the Panel ensures that the study maintains conformity with the SSHAC Level 3 guidelines. To fulfill these roles, the Panel requires adequate opportunities to gain understanding of the data being used, the analyses being performed, the TI Team's evaluations of data and models, and the technical justifications for the TI Team's model decisions. The table below summarizes the formal project activities in which the Panel participated. Fulfilling these roles also requires the Panel to provide regular feedback to the TI Team during the course of the project. In addition to verbal feedback during Working Meetings and Workshops, the Panel provided written comments and recommendations at key stages of the project. Those written submittals are also noted in the table.

Date	PPRP Activity
June 21, 2012	Working Meeting #1 (Planning). All PPRP members attended.
July 18, 2012	Working Meeting #2 (Planning). All PPRP members attended.
August 27, 2012	Kick-off Meeting. All PPRP members attended.
September 17, 2012	PPRP submittal of written comments on the Project Plan.
October 8, 2012	Working Meeting #3. PPRP representatives attended as observers.
November 3, 2012	PPRP submittal of written comments on revised Project Plan.
November 29, 2012	PPRP submittal of PPRP endorsement letter for Project Plan.
December 10, 2012	Working Meeting #4. PPRP representatives attended as observers.
February 11, 2013	Working Meeting #5. PPRP representatives attended as observers.
March 19-21, 2013	Workshop #1: Critical issues and Data Needs. All PPRP members attended as observers. The PPRP provided verbal feedback to the TI Team at the end of each day of the Workshop
April 12, 2013	Working Meeting #6. PPRP representatives attended as observers.
April 21, 2013	PPRP submittal of written comments on Workshop #1.
May 23, 2013	Working Meeting #7. PPRP representatives attended as observers.
June 24, 2013	Working Meeting #8. PPRP representatives attended as observers.
July 16, 2013	Working Meeting #9. PPRP representatives attended as observers.
August 21, 2013	Working Meeting #10. PPRP representatives attended as observers.
October 2, 2013	Working Meeting #11. PPRP representatives attended as observers.
October 15, 2013	Working Meeting #12. PPRP representatives attended as observers.
October 22-24, 2013	Workshop #2: Proponent Models and Alternative Interpretations. All PPRP members attended as observers. The PPRP provided verbal feedback to the TI Team at the end of each day of the Workshop.
November 26, 2013	Working Meeting #13. PPRP representatives attended as observers.
December 3, 2013	PPRP submittal of written comments on Workshop #2.
January 2, 2014	Working Meeting #14. PPRP representatives attended as observers.
January 28-29, 2014	Special Working Meeting. All PPRP members attended as observers.
March 3, 2014	Working Meeting #15. PPRP representatives attended as observers.
March 10-12, 2014	Workshop #3: Preliminary GMC Models and Hazard Feedback. All PPRP members attended as participants. The PPRP provided verbal feedback to the TI Team at the end of each day of the Workshop.
March 24, 2014	Working Meeting #16. PPRP representatives attended as observers.
April 21, 2014	PPRP submittal of written comments on Workshop #3.
May 14, 2014	PPRP Closure Pre-Briefing. All PPRP members attended as participants.
July 17-18, 2014	PPRP Closure Briefing. All PPRP members attended as participants.
December 13, 2014	Submittal No. 1 of PPRP written review comments on SWUS GMC Report: Comments on SWUS GMC Report Rev.0, Chapters 7, 10, 11, 12, 13, and Appendices L, M, N, and R.
December 16, 2014	Teleconference, PPRP and TI Team, to discuss the PPRP written review comments, Submittal No. 1.
January 5, 2015	Submittal No. 2 of PPRP written review comments on SWUS GMC Report: Comments on SWUS GMC Report Rev.0, Chapters 6, 8, 9, 14, and Appendices H, I, J, K, O, and Q.
January 7, 2015	Teleconference, PPRP and TI Team, to discuss the PPRP written review comments, Submittal No. 2.
January 26, 2015	Teleconference, PPRP and TI Team, to discuss the main modifications introduced in SWUS GMC Report Draft Rev.1.
February 9, 2015	Teleconference, PPRP and TI Team, to discuss observations from PPRP partial review of SWUS GMC Report Draft Rev.1.
February 16, 2015	Teleconference, PPRP and Project Manager to discuss project completion schedule.
February 20, 2015	Submittal No. 3 of PPRP written review comments on SWUS GMC Report: Comments on SWUS GMC Report Draft Rev.1.

The PPRP finds that the level of ongoing review it was able to undertake, and the opportunities afforded the PPRP to provide feedback to the TI Team, met the expectations for a SSHAC Level 3 study. Interactions with the TI Team provided ample opportunity for the Panel to gain an understanding of the technical bases for the TI Team's evaluations. The Panel also was given adequate opportunity to query the TI Team, especially in Workshop #3 and in the Pre-Closure Briefing and Closure Briefing, to assess the justification provided for their model decisions. The TI Team provided written responses to each formal PPRP submittal, and in nearly every case the PPRP and TI Team subsequently discussed the comments and replies in a conference call or Working Meeting.

SSHAC Process Review

NUREG-2117 describes the goal of a SSHAC process as being "to carry out properly and document completely the activities of evaluation and integration, defined as:

> Evaluation: The consideration of the complete set of data, models and methods proposed by the larger technical community that are relevant to the hazard analysis.
> Integration: Representing the center, body, and range of technically defensible interpretations in light of the evaluation process (i.e., informed by the assessment of existing data, models, and methods)."

During the *Evaluation* activities, the TI Team considered new data, models and methods that have been introduced within the technical community since the previous seismic hazard studies were conducted for nuclear power plants in California and Arizona. The Team evaluated newly available ground motion databases, ground motion prediction equations (GMPEs), and ground motion simulation techniques. Notably, the TI Team evaluated methods for the representation of non-Gaussian aleatory variability, as well as newly available methods for the visualization and characterization of epistemic uncertainty in ground motion prediction.

The PPRP finds that the TI Team's evaluation was consistent with the expectations for a SSHAC Level 3 study, and, apart from the specific reservation noted at the end of this section, was adequately documented.

The *Integration* phase entails thoroughly documenting the technical bases for all elements of the GMC model, to provide assurance that the center, body and range of technically defensible interpretations have been captured. The TI Team used a new statistical technique to generate a suite of representative models for median ground motion prediction that collectively represent the epistemic uncertainty in ground motion more broadly than do the published GMPEs alone. This technique is combined with a new method to select and weight the predictions of the expanded suite of models. The TI Team's method for assigning weights is based on consideration of appropriate data sets and numerical simulations, with adequate justification. The TI Team's model for aleatory variability and weighting of alternative aleatory models is also adequately justified.

The PPRP finds that the TI Team's GMC model integration is consistent with the expectations of a SSHAC Level 3 project, and, apart from the specific reservation noted in the next paragraph, was adequately documented.

The PPRP's reservation with respect to the documentation of the evaluation and integration phases of the study is based on the TI Team's inability to produce a final report based on the last set of comments from the Panel (Submittal No. 3, February 20, 2015) that were intended to improve the completeness and clarity of the documentation. The TI Team was unable to revise the report in time for this letter to be issued in order to meet contractual obligations to provide written documentation to the utilities. The TI Team did provide written responses to the Panel's comments and assured the Panel in writing that the final version of the report would take these comments into account.

SSHAC Technical Review

NUREG-2117 describes the PPRP's technical review role as follows:

> "The PPRP fulfills two parallel roles, the first being technical review. This means that the PPRP is charged with ensuring that the full range of data, models, and methods have been duly considered in the assessment and also that all technical decisions are adequately justified and documented.
>
> The responsibility of the PPRP is to provide clear and timely feedback to the TI/TFI and project manager to ensure that any technical or process deficiencies are identified at the earliest possible stage so that they can be corrected. More commonly, the PPRP provides its perspectives and advice regarding the manner in which ongoing activities can be improved or carried out more effectively. In terms of technical review, a key responsibility of the PPRP is to highlight any data, models or proponents that have not been considered. Beyond completeness, it is not within the remit of the PPRP to judge the weighting of the logic-trees in detail but rather to judge the justification provided for the models included or excluded, and for the weights applied to the logic-tree branches."

As summarized in the table above, the PPRP reviewed the TI Team's evaluations of data, models and methods on multiple occasions, and through various means, including written communications, in-person meetings, teleconferences, and review of the project report. The Panel was given adequate opportunity to question the TI Team concerning details of their analysis, and provided feedback verbally and in writing. The TI Team was responsive to the technical input from the Panel. The TI Team's responses included evaluating additional data sets suggested by the Panel, undertaking additional analyses to address specific Panel technical questions or concerns, and examining and assessing alternative technical approaches suggested by the Panel.

The PPRP therefore concludes that it has been afforded an adequate basis for technical assessment of the TI Team's evaluations and model integration and finds that the project meets technical expectations for a SSHAC Level 3 study.

Conclusion

On the basis of its review of the SWUS GMC project, the PPRP finds that the project meets, with respect to both process and technical standards, the expectations for a SSHAC Level 3 study, with the reservation cited above. That reservation relates only to completeness of the documentation, which the TI Team has assured in writing will be rectified in the final report.

Sincerely,

Steven M Day
Steven M. Day
Chair, PPRP

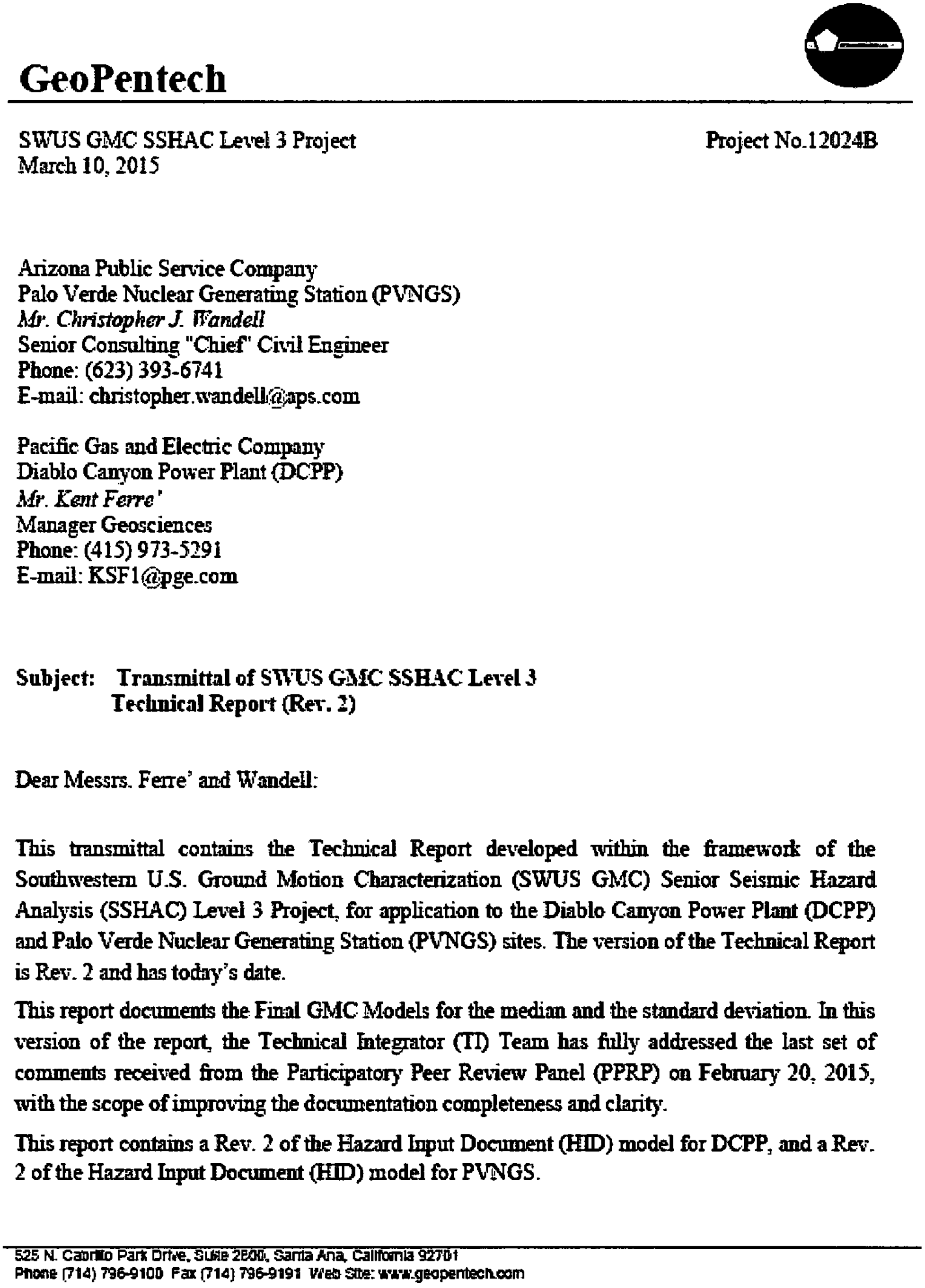
Kenneth W. Campbell
Kenneth W. Campbell
Member, PPRP

Brian Chiou
Brian Chiou
Member, PPRP

Thomas Rockwell
Thomas K. Rockwell
Member, PPRP

Appendix D SWUS GMC Project Transmittal Letter

This appendix provides the SWUS GMC Project letter *Transmittal of SWUS GMC SSHAC Level 3 Technical Report (Rev. 2)* from GeoPentech.



GeoPentech

SWUS GMC SSHAC Level 3 Project
March 10, 2015

Project No.12024B

Arizona Public Service Company
Palo Verde Nuclear Generating Station (PVNGS)
Mr. Christopher J. Wandell
Senior Consulting "Chief" Civil Engineer
Phone: (623) 393-6741
E-mail: christopher.wandell@aps.com

Pacific Gas and Electric Company
Diablo Canyon Power Plant (DCPP)
Mr. Kent Ferre'
Manager Geosciences
Phone: (415) 973-5291
E-mail: KSF1@pge.com

**Subject: Transmittal of SWUS GMC SSHAC Level 3
Technical Report (Rev. 2)**

Dear Messrs. Ferre' and Wandell:

This transmittal contains the Technical Report developed within the framework of the Southwestern U.S. Ground Motion Characterization (SWUS GMC) Senior Seismic Hazard Analysis (SSHAC) Level 3 Project, for application to the Diablo Canyon Power Plant (DCPP) and Palo Verde Nuclear Generating Station (PVNGS) sites. The version of the Technical Report is Rev. 2 and has today's date.

This report documents the Final GMC Models for the median and the standard deviation. In this version of the report, the Technical Integrator (TI) Team has fully addressed the last set of comments received from the Participatory Peer Review Panel (PPRP) on February 20, 2015, with the scope of improving the documentation completeness and clarity.

This report contains a Rev. 2 of the Hazard Input Document (HID) model for DCPP, and a Rev. 2 of the Hazard Input Document (HID) model for PVNGS.

525 N. Cabrillo Park Drive, Suite 2800, Santa Ana, California 92701
Phone (714) 796-9100 Fax (714) 796-9191 Web Site: www.geopentech.com

The final GMC Models for application to DCPP and PVNGS did not change with respect to the Rev. 1 Technical Report. Specifically, in the current Rev. 2 Technical Report, the HID (Rev. 2) model for PVNGS is identical to the HID (Rev. 2) model for PVNGS included in the Rev. 1 Technical Report. Also, the HID (Rev. 2) model for DCPP is identical to the HID (Rev. 1) model for DCPP included in the Rev. 1 Technical Report.

If you have any question, or need more information, please do not hesitate to contact us. On behalf of the Technical Integration (TI) Team and the other SWUS GMC SSHAC Level 3 Project participants, we thank Arizona Public Service and Pacific Gas and Electric Company for the support and cooperation.

Sincerely,

GeoPentech

Carola Di Alessandro
Project Manager

John A. Barneich
Principal

CC:
PVNGS Project Technical Integrator: Robin McGuire
PVNGS Hazard Analysts: Melanie Walling and Gabriel Toro
PVNGS SSC SSHAC Level 3 Project Manager: Ross Hartleb
SWUS GMC TI Team Lead: Norm Abrahamson

Appendix E GMC PPRP Endorsement Letter Revision 2

This appendix provides the March 10, 2015, Participatory Peer Review Panel Closure Letter.

March 10, 2015

Dr. Carola Di Alessandro
SWUS Project Manager
GeoPentech, Inc.
525 N. Cabrillo Park Drive, Suite 280
Santa Ana, CA 92701

Subject: Participatory Peer Review Panel Closure Letter, Southwest United States Ground Motion Characterization Level 3 SSHAC Project

Dear Dr. Di Alessandro:

The Participatory Peer Review Panel (PPRP, also referred to herein as the "Panel") for the Southwest United States (SWUS) Ground Motion Characterization (GMC) Project is pleased to issue this PPRP Closure Letter. Herein we describe our participation in the SWUS GMC SSHAC Level 3 project and present our findings. Pursuant to the guidelines for a SSHAC Level 3 study (NUREG/CR-6372; NUREG-2117), the PPRP was engaged at all stages of the project, including review of the final Project Plan, Workshop agendas and participant lists; the planning of the evaluation and model integration activities; and review of the project documentation. Throughout the project, the Panel reviewed and provided regular feedback on both the process followed, and the technical assessments made, by the Technical Integrator (TI) Team. By this letter the Panel documents the activities it has performed in the course of its review, its assessment of the process followed relative to SSHAC Level 3 expectations, and its assessment of the technical rationale underlying the GMC model.

The PPRP issued a previous letter dated February 24, 2015. In that letter, the Panel noted that there were limitations in the completeness and clarity of the project documentation. Those limitations were noted as exceptions to the Panel's finding that the project successfully met SSHAC Level 3 expectations. Since that time, the TI Team has produced a final report, designated Rev2, addressing the final set of comments from the Panel (PPRP Submittal No. 3, February 20, 2015). The Panel has reviewed Rev2 (including a short addendum supplied to the PPRP in draft form on March 9 which the TI Team has assured in writing will be incorporated in the final version) and finds that all material concerns have been adequately addressed and are now closed, apart from one remaining exception that will be described at the end of the SSHAC Process Review section below. Two GMC models were developed for application to Diablo Canyon Power Plant (DCPP) and Palo Verde Nuclear Generating Station (PVNGS), respectively. The exception applies only to the GMC model for DCPP, and is not relevant to the case of PVNGS.

PPRP Activities in Support of the SWUS GMC Review

In a SSHAC Level 3 study, the PPRP fulfills two roles. The first is that of technical review, in which the Panel ensures that the full range of data, models and methods are considered and that technical decisions and judgments are adequately justified and documented. The second is that of process review, under which the Panel ensures that the study maintains conformity with the SSHAC Level 3 guidelines. To fulfill these roles, the Panel requires adequate opportunities to gain understanding of the data being used, the analyses being performed, the TI Team's evaluations of data and models, and the technical justifications for the TI Team's model decisions. The table below summarizes the formal project activities in which the Panel participated. Fulfilling these roles also requires the Panel to provide regular feedback to the TI Team during the course of the project. In addition to verbal feedback during Working Meetings and Workshops, the Panel provided written comments and recommendations at key stages of the project. Those written submittals are also noted in the table.

Date	PPRP Activity
June 21, 2012	Working Meeting #1 (Planning). All PPRP members attended.
July 18, 2012	Working Meeting #2 (Planning). All PPRP members attended.
August 27, 2012	Kick-off Meeting. All PPRP members attended.
September 17, 2012	PPRP submittal of written comments on the Project Plan.
October 8, 2012	Working Meeting #3. PPRP representatives attended as observers.
November 3, 2012	PPRP submittal of written comments on revised Project Plan.
November 29, 2012	PPRP submittal of PPRP endorsement letter for Project Plan.
December 10, 2012	Working Meeting #4. PPRP representatives attended as observers.
February 11, 2013	Working Meeting #5. PPRP representatives attended as observers.
March 19-21, 2013	Workshop #1: Critical issues and Data Needs. All PPRP members attended as observers. The PPRP provided verbal feedback to the TI Team at the end of each day of the Workshop
April 12, 2013	Working Meeting #6. PPRP representatives attended as observers.
April 21, 2013	PPRP submittal of written comments on Workshop #1.
May 23, 2013	Working Meeting #7. PPRP representatives attended as observers.
June 24, 2013	Working Meeting #8. PPRP representatives attended as observers.
July 16, 2013	Working Meeting #9. PPRP representatives attended as observers.
August 21, 2013	Working Meeting #10. PPRP representatives attended as observers.
October 2, 2013	Working Meeting #11. PPRP representatives attended as observers.
October 15, 2013	Working Meeting #12. PPRP representatives attended as observers.
October 22-24, 2013	Workshop #2: Proponent Models and Alternative Interpretations. All PPRP members attended as observers. The PPRP provided verbal feedback to the TI Team at the end of each day of the Workshop.
November 26, 2013	Working Meeting #13. PPRP representatives attended as observers.
December 3, 2013	PPRP submittal of written comments on Workshop #2.
January 2, 2014	Working Meeting #14. PPRP representatives attended as observers.
January 28-29, 2014	Special Working Meeting. All PPRP members attended as observers.
March 3, 2014	Working Meeting #15. PPRP representatives attended as observers.
March 10-12, 2014	Workshop #3: Preliminary GMC Models and Hazard Feedback. All PPRP members attended as participants. The PPRP provided verbal feedback to the TI Team at the end of each day of the Workshop.
March 24, 2014	Working Meeting #16. PPRP representatives attended as observers.
April 21, 2014	PPRP submittal of written comments on Workshop #3.

May 14, 2014	PPRP Closure Pre-Briefing. All PPRP members attended as participants.
July 17-18, 2014	PPRP Closure Briefing. All PPRP members attended as participants.
December 13, 2014	Submittal No. 1 of PPRP written review comments on SWUS GMC Report: Comments on SWUS GMC Report Rev.0, Chapters 7, 10, 11, 12, 13, and Appendices L, M, N, and R.
December 16, 2014	Teleconference, PPRP and TI Team, to discuss the PPRP written review comments, Submittal No. 1.
January 5, 2015	Submittal No. 2 of PPRP written review comments on SWUS GMC Report: Comments on SWUS GMC Report Rev.0, Chapters 6, 8, 9, 14, and Appendices H, I, J, K, O, and Q.
January 7, 2015	Teleconference, PPRP and TI Team, to discuss the PPRP written review comments, Submittal No. 2.
January 26, 2015	Teleconference, PPRP and TI Team, to discuss the main modifications introduced in SWUS GMC Report Draft Rev.1.
February 9, 2015	Teleconference, PPRP and TI Team, to discuss observations from PPRP partial review of SWUS GMC Report Draft Rev.1.
February 16, 2015	Teleconference, PPRP and Project Manager to discuss project completion schedule.
February 20, 2015	Submittal No. 3 of PPRP written review comments on SWUS GMC Report: Comments on SWUS GMC Report Draft Rev.1.
February 24, 2015	Submittal of Closure Letter based on Draft Rev.1

The PPRP finds that the level of ongoing review it was able to undertake, and the opportunities afforded the PPRP to provide feedback to the TI Team, met the expectations for a SSHAC Level 3 study. Interactions with the TI Team provided ample opportunity for the Panel to gain an understanding of the technical bases for the TI Team's evaluations. The Panel also was given adequate opportunity to query the TI Team, especially in Workshop #3 and in the Pre-Closure Briefing and Closure Briefing, to assess the justification provided for their model decisions. The TI Team provided written responses to each formal PPRP submittal, and in nearly every case the PPRP and TI Team subsequently discussed the comments and replies in a conference call or Working Meeting.

SSHAC Process Review

NUREG-2117 describes the goal of a SSHAC process as being “to carry out properly and document completely the activities of evaluation and integration, defined as:

> Evaluation: The consideration of the complete set of data, models and methods proposed by the larger technical community that are relevant to the hazard analysis.
> Integration: Representing the center, body, and range of technically defensible interpretations in light of the evaluation process (i.e., informed by the assessment of existing data, models, and methods).”

During the *Evaluation* activities, the TI Team considered new data, models and methods that have been introduced within the technical community since the previous seismic hazard studies were conducted for nuclear power plants in California and Arizona. The

Team evaluated newly available ground motion databases, ground motion prediction equations (GMPEs), and ground motion simulation techniques. Notably, the TI Team evaluated methods for the representation of non-Gaussian aleatory variability, as well as newly available methods for the visualization and characterization of epistemic uncertainty in ground motion prediction.

The PPRP finds that the TI Team's evaluation and the documentation thereof are consistent with the expectations for a SSHAC Level 3 study, apart from the specific reservation noted at the end of this section.

The *Integration* phase entails thoroughly documenting the technical bases for all elements of the GMC model, to provide assurance that the center, body and range of technically defensible interpretations have been captured. The TI Team used a new statistical technique to generate a suite of representative models for median ground motion prediction that collectively represent the epistemic uncertainty in ground motion more broadly than do the published GMPEs alone. This technique is combined with a new method to select and weight the predictions of the expanded suite of models. The TI Team's method for assigning weights is based on consideration of appropriate data sets and numerical simulations, with adequate justification. The TI Team's model for aleatory variability and weighting of alternative aleatory models is also adequately justified.

The PPRP finds that the TI Team's GMC model integration and the documentation thereof are consistent with the expectations of a SSHAC Level 3 project, apart from the specific reservation noted in the next paragraph.

The Panel finds that the TI Team's evaluation of directivity models has limitations. The TI Team make use of a simplified directivity model to save computational time, and the final report adequately describes that model, how it is used, and some of its limitations. However, because the simplified model is unpublished, it is also necessary for the TI Team to document that the simplified model is appropriate for the purpose for which it is applied, in the sense that it gives results that are essentially consistent with the published and peer-reviewed model that it is intended to approximate. The final report (in the March 9 addendum) documents the performance of the simplified model through comparison with results from a hazard calculation that uses the full, published directivity model. At hazard levels of 10^{-4} and above, the full model calculation confirms the conclusion obtained using the simplified model. At hazard levels below 10^{-4}, however, the difference in calculated hazard between the full model and the simplified model increases with decreasing hazard level. This increasing trend has not been satisfactorily explained, has not been explored beyond the single fault case provided in the March 9 addendum, and has not been quantified in terms of impact on equal-hazard spectra at hazard levels of 10^{-5} and lower. Because the key rationale for the zero weighting of the directivity branch in the GMC model for periods longer than 0.5 s (the period range where the directivity effect applies) is the weak sensitivity of hazard to the directivity effect calculated using the simplified model, the PPRP finds that this weighting lacks sufficient technical justification.

SSHAC Technical Review

NUREG-2117 describes the PPRP's technical review role as follows:

> "The PPRP fulfills two parallel roles, the first being technical review. This means that the PPRP is charged with ensuring that the full range of data, models, and methods have been duly considered in the assessment and also that all technical decisions are adequately justified and documented.
>
> The responsibility of the PPRP is to provide clear and timely feedback to the TI/TFI and project manager to ensure that any technical or process deficiencies are identified at the earliest possible stage so that they can be corrected. More commonly, the PPRP provides its perspectives and advice regarding the manner in which ongoing activities can be improved or carried out more effectively. In terms of technical review, a key responsibility of the PPRP is to highlight any data, models or proponents that have not been considered. Beyond completeness, it is not within the remit of the PPRP to judge the weighting of the logic-trees in detail but rather to judge the justification provided for the models included or excluded, and for the weights applied to the logic-tree branches."

As summarized in the table above, the PPRP reviewed the TI Team's evaluations of data, models and methods on multiple occasions, and through various means, including written communications, in-person meetings, teleconferences, and review of the project report. The Panel was given adequate opportunity to question the TI Team concerning details of their analysis, and provided feedback verbally and in writing. The TI Team was responsive to the technical input from the Panel. The TI Team's responses included evaluating additional data sets suggested by the Panel, undertaking additional analyses to address specific Panel technical questions or concerns, and examining and assessing alternative technical approaches suggested by the Panel.

The PPRP therefore concludes that it has been afforded an adequate basis for technical assessment of the TI Team's evaluations and model integration. As noted above in the final paragraph of the SSHAC Process Review section, the evaluation of directivity effects has been inadequate and may constitute a technical limitation of the study. Apart from that reservation, the PPRP finds that the project meets technical expectations for a SSHAC Level 3 study.

Conclusion

On the basis of its review of the SWUS GMC project, the PPRP finds that the project meets, with respect to both process and technical standards, the expectations for a

SSHAC Level 3 study, with the reservation cited above. That reservation pertains specifically to application of the directivity component of the GMC model to the DCPP site.

Sincerely,

Steven M Day
Steven M. Day
Chair, PPRP

Kenneth W. Campbell
Kenneth W. Campbell
Member, PPRP

Brian Chiou
Brian Chiou
Member, PPRP

Thomas Rockwell
Thomas K. Rockwell
Member, PPRP