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102-07096-MLL/TNW/PJH
August 6, 2015

U.S. Nuclear Regulatory Commission
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Reference: APS Letter 102-07010, *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*, dated March 10, 2015

Dear Sirs:

Subject: **Palo Verde Nuclear Generating Station (PVNGS)**
Units 1, 2, and 3
Docket Nos. STN 50-528, 50-529, and 50-530
Response to Request for Additional Information Associated with Seismic Hazard and Screening Report

The reference letter submitted 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).

This letter responds to an NRC email request, dated June 24, 2015, regarding the Seismic Hazard and Screening Report. Enclosure 1 provides the response to the Request for Additional Information.

Enclosure 2 provides a replacement for page 46 of 97 to the PVNGS Seismic Hazard and Screening Report. This change corrects an administrative error in report section 2.3.3 by replacing the phrase 'site class "A" parameters' with 'site class "C" parameters' and deleting the parenthetical phrase "(which are for hard rock)." This report correction is consistent with the supporting hazard calculation which was performed using 'site class "C" parameters.' This administrative error has been entered into the PVNGS corrective action program.

No commitments are being made to the NRC by this letter.

Should you need further information regarding this letter, please contact Thomas Weber, Department Leader, Regulatory Affairs, at (623) 393-5764.

A001
NRR

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

Executed on August 6, 2015
(Date)

Sincerely,

Maria Lacal

MLL/TNW/PJH/af

Enclosures:
1. Response to Request for Additional Information Associated with Seismic Hazard and Screening Report
2. Seismic Hazard and Screening Report, Replacement Page 46 of 97

cc:	W. M. Dean	NRC Director Office of Nuclear Reactor Regulation
	M. L. Dapas	NRC Region IV Regional Administrator
	M. M. Watford	NRC NRR Project Manager
	C. A. Peabody	NRC Senior Resident Inspector PVNGS
	N. J. DiFrancesco	NRC JLD Project Manager
	F. G. Vega	NRR/JLD/PPSD/HMB Project Manager

ENCLOSURE 1

Response to Request for Additional Information Associated with Seismic Hazard and Screening Report

Request for Additional Information

The southwestern United States (SWUS) Ground Motion Characterization (GMC) project used the partially non-ergodic sigma model, which implies the use of a single station sigma model. For the partially non-ergodic approach, the site term ($\delta S2S_s$) is assumed to be known and as such its standard deviation (φ_{S2S}) is excluded from the single station sigma model. Use of the single station sigma approach assumes that the epistemic uncertainty for the site term is captured by the epistemic uncertainty in the Vs-kappa correction and the uncertainty in the site amplification factor. Section 2.3.6 of the Seismic Hazard and Screening Report for Palo Verde Nuclear Generating Station Units 1, 2, and 3, states that "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 the kappa and the deep site Vs profile."

In order for the staff to better understand how the uncertainty in the site term is captured for the Palo Verde site; please provide a more detailed description, including all equations used for the total standard deviation of the site amplification factor. As part of the response, describe how the various epistemic and aleatory portions are combined to determine the total amplification factor uncertainty. In addition, provide a justification for including the epistemic uncertainty associated with the Vs-kappa correction as part of the uncertainty in the site amplification factor rather than as part of the logic tree for the median ground motion models and whether this decision impacts the final control point hazard curves and GMRS.

APS Response:

1.0 Calculation of site amplification factors

The methodology used to develop site amplification factors (SAFs) in the Seismic Hazard and Screening Report for the Palo Verde Nuclear Generating Station Units 1, 2, and 3 (Reference 1) is presented here. This methodology follows the guidelines and recommendations of the Seismic Evaluation Guidance Screening, Prioritization and Implementation Details (SPID; Reference 2).

Site amplification at Palo Verde Nuclear Generating Station (PVNGS) was determined using random vibration theory (RVT)-based, one-dimensional, equivalent-linear techniques to calculate the site-specific dynamic response of vertically propagating shear waves in a horizontally layered medium. This approach has been widely studied in the engineering literature (References 3 through 6) and has been found to give accurate estimates of the dynamic response of a soil column subjected to earthquake ground motions. Within this approach, input response spectra are converted to Fourier amplitude spectra (FAS) through inverse RVT (IRVT; e.g., Reference 6).

The SAFs for PVNGS were determined for a range of spectral frequencies and intensity of ground motion. They incorporate both epistemic and aleatory uncertainty within the

shallow site profile developed in Sections 2.3.1 through 2.3.3 of Reference 1, as recommended by the SPID (further discussion of epistemic and aleatory uncertainty is provided below). The SAFs also account for the Vs-kappa correction (i.e., the conversion of ground motions from reference rock conditions to site-specific rock conditions, and the associated uncertainty) by applying the Fourier adjustment factors (FAFs) shown in Figure 39 of Reference 1. SAFs were calculated by taking the ratio of a surface response spectrum to the input reference rock response spectrum. Note that the FAFs were applied to each input control motion to convert reference-rock spectra to local-rock spectra prior to calculating site response.

For each combination of input parameters described below (specifically, each combination of median shear wave velocity (Vs) profile, shear modulus and degradation models, and FAF as discussed in Section 2.0), a set of 60 randomized profiles was generated. The mean and standard deviation of the SAFs resulting from the set of randomized profiles were then calculated for the randomized suite of profiles at seven spectral frequencies: 0.5 Hz, 1.0 Hz, 2.5 Hz, 5.0 Hz, 10 Hz, 20 Hz, and 100 Hz (peak ground acceleration, PGA). Input control motions were divided into low-frequency (LF) components and high-frequency (HF) components. Therefore, SAF values were derived for 0.5 Hz, 1.0 Hz, and 2.5 Hz using only the site amplification results of the LF input control motions, and for 5.0 Hz, 10 Hz, 20 Hz, and PGA using only the site amplification results of the HF input control motions.

Means and standard deviations of SAF computed above from each set of 60 generated profiles must be weighted and combined to reduce the number of different sets of SAF for each frequency and input amplitude. Combined weighted values were calculated using

$$\overline{SAF}_{wt} = \sum_{\text{all } i} w_i \overline{SAF_i} \qquad \text{Equation 1}$$

$$\sigma_{wt}^2 = \sum_{\text{all } i} w_i \left[(\overline{SAF_i} - \overline{SAF}_{wt})^2 + \sigma_{SAF,i}^2 \right] \qquad \text{Equation 2}$$

where i is the index of an alternative determination of SAF (i.e., one of the combinations of median Vs profile, shear modulus and degradation models, and FAF as discussed below), w_i is the weight of alternative i, $\overline{SAF_i}$ is the mean SAF of alternative i, $\sigma_{SAF,i}^2$ is the variance of SAF for alternative i (representing aleatory uncertainty among the 60 randomized profiles), $\overline{SAF}_{wt}$ is the weighted mean SAF, and σ_{wt}^2 is the weighted variance of SAF.

Once all SAFs were combined using equations 1 and 2, the weighted logarithmic variance and median were calculated (assuming a lognormal distribution) by

$$\sigma_{\ln SAF,wt}^2 = \ln\left(\frac{\sigma_{wt}^2}{\overline{SAF}_{wt}^{\,2}} + 1 \right) \qquad \text{Equation 3}$$

$$\widetilde{SAF}_{wt} = \overline{SAF}_{wt} \exp\left(-\frac{1}{2}\sigma^2_{\ln SAF,wt}\right) \qquad \text{Equation 4}$$

where $\sigma^2_{\ln SAF,wt}$ is the weighted variance of $\ln[SAF]$ and $\widetilde{SAF}_{wt}$ is the weighted median of SAF. After the calculation of $\widetilde{SAF}_{wt}$ using Equation 4, a lower limit of 0.5 was enforced for median SAF as recommended by the SPID. Use of Equations 1 through 4 (in terms of SAF) instead of the Equations in Section B.6.0 of the SPID (in terms of ln[SAF]) makes the results more sensitive to the upper tails of the distribution of the SAF.

2.0 Characterization of epistemic and aleatory uncertainty in site amplification calculations

This section describes how epistemic and aleatory uncertainty were characterized for inputs to the site response calculations in Reference 1. In general, epistemic uncertainty was incorporated through alternative models, about which aleatory uncertainty was incorporated through randomization of 60 independent Vs profiles and shear modulus degradation and damping curves. Details are presented below.

Note that the characterization described below incorporates data from recent site-specific investigations (spectral analysis of surface waves and suspension logging data), as well as from earlier data in the PVNGS Units 1, 2, and 3 UFSAR and PSAR (References 7 and 8). This data, combined with values from the SPID, yield a robust characterization of the site response of the PVNGS site and its associated uncertainty.

<u>Shear wave velocity profile</u>
Epistemic uncertainty in Vs was incorporated per the SPID using the base-case, lower-range, and upper-range median Vs profiles described in Section 2.3.2 of Reference 1.

Aleatory uncertainty of Vs in each layer was modeled in a depth-dependent manner according to Section 2.3.3 of Reference 1 and the SPID. This was captured in the generation of the 60 profiles by randomly assigning Vs to a given layer according to its median value (as defined by the base-case, lower-range, or upper-range value) and range (as characterized by the depth-dependent model).

<u>Material property models (shear modulus degradation and damping versus strain)</u>
The equivalent-linear site amplification calculation requires input curves for shear modulus degradation and damping versus strain. Epistemic uncertainty was incorporated using two alternative models for each layer in the base-case, lower-range, and upper-range Vs profiles. As described in Section 2.3.2.1 of Reference 1, the soil material over the shallow site profile was modeled with both the EPRI cohesionless soil (Reference 9) and Peninsular Range (Reference 10) shear modulus degradation and damping models while the clay material was modeled using Vucetic and Dobry (Reference 11) values. A given model was randomized within the generation of a set of 60 profiles to account for

aleatory uncertainty, and the two soil models were equally weighted following guidance from the SPID.

Profile Layer Randomization
Aleatory uncertainty in the depth to the top of each layer was modeled using a Normal distribution. The mean and standard deviation used for this model were developed in Reference 1. Depth to the top of each layer was randomized within the generation of a set of 60 profiles.

Depth to Bedrock
Aleatory uncertainty in depth to the bedrock was modeled using a Normal distribution. The mean and standard deviation used for this model were developed in Reference 1. Depth to the top of bedrock was randomized within the generation of a set of 60 profiles.

Fourier Adjustment Factors
The nine FAFs from reference rock conditions to site-specific rock conditions and their weights are provided in Reference 1. These FAFs account for uncertainty in the site kappa value as well as the deep-profile Vs. As noted above, the nine FAFs were applied to each input control motion prior to calculating site response. This was done separately to each combination of the base-case, lower-range, and upper-range Vs profiles with each of the shear modulus degradation and damping models. In this manner, the uncertainty in the FAFs could be captured as part of the aleatory uncertainty in the hazard calculations by combining the SAFs resulting from the nine FAFs using Equations 1 and 2. Further discussion of how the FAFs are incorporated into the SAFs is provided below.

Input Control Motions
Input control motions for site response calculations are described in Section 2.3.4 of Reference 1. HF and LF spectra were scaled to a range of 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.

Host Kappa
When HF input control motions were converted to FAS using IRVT, a host kappa value was enforced to control high frequency decay of the input control motions. This value is specified by Reference 12 as 0.041 seconds and was not randomized further. Aleatory and epistemic uncertainty in the host kappa are already captured as part of the aleatory and epistemic uncertainty in the reference rock Ground Motion Prediction Equations (GMPEs).

3.0 Justification for inclusion of uncertainty associated with Vs-kappa correction (and represented by nine alternative FAFs) as part of uncertainty in amplification factors

For computational efficiency, three sets of SAF medians and logarithmic standard deviations were used to compute the hazard at PVNGS. These three sets of SAF represent the base-case, lower-range, and upper-range Vs profiles. The remaining variability,

associated with the 60 randomized profiles, the nine FAFs (which represent epistemic uncertainty in the Vs-kappa correction), and the two sets of shear modulus degradation and damping models, is treated as aleatory variability in the hazard calculations. As part of the Approach 3 (Reference 13) seismic hazard calculations, this aleatory variability is combined with the aleatory variability in the reference rock GMPEs (from Reference 12), and taken into account in the calculation of exceedance probabilities.

The benefit of this approach is that it requires three logic-tree branches for site amplification (instead of 3x9x2=54 branches if one considered all combinations of median profile, deep-profile FAF, and shear modulus degradation and damping models). Although the uncertainty in the Vs-kappa correction is generally considered to represent epistemic uncertainty, the mean hazard curve is not affected by treating this uncertainty as aleatory. This is the case because the calculation of the mean hazard (weighted summation of the hazard over all logic-tree branches) and the hazard integration (for a specific branch) are both linear operations. Therefore, the calculated control point mean hazard curves are not affected if the weighted summation over FAFs is moved from the logic tree into the hazard integral and absorbed into the calculation of soil amplification (provided that Approach 3 of Reference 13 is used). As a result, the ground motion response spectra (GMRS) (which is based on mean hazard) is accurately calculated.

4.0 References

1. Arizona Public Service (2015). *Seismic Hazard and Screening Report for the Palo Verde Nuclear Generating Station Units 1, 2, and 3,* Revision 0, ADAMS Accession No. ML15076A073, dated March 10, 2015.
2. EPRI (2013). *Seismic Evaluation Guidance: Screening, Prioritization and Implementation Details (SPID) for the Resolution of Fukushima Near-Term Task Force Recommendation 2.1: Seismic*, EPRI, Palo Alto, CA, 1025287, dated February 2013.
3. Stepp, J. C., Silva, W. J., Seed, H. B., Idriss, I. M., McGuire, R.K., and Schneider, J. (1991). *Site response evaluations based upon generic soil profiles using random vibration methodology*, Proc., 4th Int. Conf. on Seismic Zonation, Vol. 4, EERI, Stanford, Calif., pp. 739–746.
4. Schneider, J. F., Silva, W. J., Chiou, S. J., and Stepp, J. C. (1991). *Estimation of ground motion at close distances using the band-limited white-noise model*, Proc., 4th Int. Conf. on Seismic Zonation, Vol. 4, EERI, Stanford, Calif., pp. 187–194.
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7. PVNGS (2014). *Palo Verde Nuclear Generating Station (PVNGS) Units 1, 2, and 3: Updated Final Safety Analysis Report (UFSAR)*, Revision 17.
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11. Vucetic, M., and Dobry, R. (1991). *Effects of Soil Plasticity on Cyclic Response," Journal of Geotechnical Engineering, ASCE*, v.117(1), pp. 89-107, dated January 1, 1991.
12. GeoPentech (2015). *Southwestern United States Ground Motion Characterization SSHAC Level 3 Technical Report*, Revision 1, dated February 2015.
13. Risk Engineering, Inc. (2001). *Technical basis for revision of regulatory guidance on design ground motions: hazard- and risk-consistent ground motion spectra guidelines*, U.S. Nuclear Regulatory Commission Report, NUREG/CR-6728, dated October 2001.

ENCLOSURE 2

Seismic Hazard and Screening Report
for the
Palo Verde Nuclear Generating Station
Units 1, 2, and 3

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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 σlnVs. Correlation of Vs between adjacent layers was also modeled according to Toro (Toro, 1995) using USGS site class "C" parameters. 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 σln for both G/Gmax 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.