median response of all randomized profiles is lower than the response obtained from the analyses of the median profile. These scattering effects are accounted for by decreasing the damping value of the deep soil layers in the randomized profiles by 15%. Due to this modification, the mean (log-average) damping value of deep soil layer changes from 0.60% to 0.51% and the median values of total kappa (k) coefficient of site is reduced by 0.005 sec.

2.5S.2.5.4 Site Response Analyses

The site response analysis performed for the STP 3 & 4 site is conducted using the program P-SHAKE (refer to Appendix 3C), which uses a procedure based on Random Vibration Theory (RVT) (References 2.5S.2-52 and 2.5S.2-53) with the following assumptions:

- Vertically-propagating shear waves are the dominant contributor to site response
- An equivalent-linear formulation of soil nonlinearity is appropriate for the characterization of site response

These are the same assumptions that are implemented in the SHAKE program (Reference 2.5S.2-54). With respect to RVT implementation, the major steps used in P-SHAKE are as follows:

(1) The input motion is provided in terms of acceleration response spectrum (ARS) and its associated spectral damping, instead of spectrum-compatible acceleration time histories. The input ARS is converted to acceleration power spectral density (PSD) using the RVT based procedure with the peak factor function.

(2) From the frequency domain solution of the soil profile (following SHAKE approach), the transfer function for shear strain in each layer is obtained and convolved with the power spectral density (PSD) of input motion to get the PSD and the maximum strain in each layer. The effective strain is obtained from the maximum strain and is used to obtain the new soil properties (soil shear modulus and damping) for the next iteration.

(3) The iterations are repeated until convergence is reached in all layers to the convergence limit set by the user.

(4) Once the final frequency domain solution is obtained, the acceleration response spectrum at each layer interface can be computed from the solution using an inverse process of obtaining PSD from the acceleration response spectrum.

The RVT site-response analysis requires the following additional parameters:

- <u>Strong-motion duration</u>. The RVT methodology requires this parameter, but results are not very sensitive to it. These are calculated from the mean magnitudes resulting from deaggregation. Table 2.3.1 in Reference 2.5S.2-58 provides strong motion duration values as a function of magnitude. Accordingly, strong motion durations were assigned for each of the cases considered (10^{-4} and 10^{-5} annual frequencies, HF and LF smooth spectra), presented in Table 2.5S.2-20.

- Effective strain ratio. A value of 0.65 is used. Effective strain ratio is defined as the ratio between the peak acceleration of earthquake time history and the equivalent harmonic wave going through the soil layers (Reference 2.5S.2-55).

Figure 2.5S.2-39 shows with thick red lines the logarithmic mean of site amplification factors at ground surface from the analysis of the 60 modified random profiles with the 10^{-4} LF input motion. As would be expected due to the large depth of sediments at the site, amplifications are largest at low frequencies (below 3 Hz) and small de-amplification occurs at high frequencies because of soil damping. The maximum strains in the soil column are low for this motion, and this is shown in Figure 2.5S.2-40, which plots the maximum strains versus depth that are calculated for the 60 profiles and their logarithmic mean (in red thick line). The logarithmic mean of maximum strains is less than 0.03%. The maximum strain calculated from the analyses of all profiles is 0.05% in the upper 600 feet (182 m) of soil. The maximum strains in the deep soil layer at depths below 600 feet (182 m) are very small and do not exceed value of 0.02%.

Figure 2.5S.2-41 and Figure 2.5S.2-42 show similar plots of amplification factors and maximum strains obtained from the analysis with 10^{-4} HF motion. The maximum strain results show that the soil column exhibits a lower level of straining under this earthquake with maximum strains being less than 0.025%. Figure 2.5S.2-43 through Figure 2.5S.2-46 show comparable plots of amplification factors and maximum strains from the analyses performed with the 10^{-5} input motion, both LF and HF. For this higher motion, larger maximum strains are observed, but the maximum logarithmic mean does not exceed 0.11%. From all of the 60 profiles, a maximum strain of 0.19% is calculated in the upper 600 feet (182 m) of soil. The maximum strain in the deep soil layers is very small, less than 0.06%.

Comparison of the profiles of logarithmic mean maximum strain in Figure 2.5S.2-47 clearly indicates that response of the site under the LF motions is stronger than under HF motions. Figure 2.5S.2-48 shows the logarithmic mean profiles for the strain-compatible damping that is a measure of energy dissipation in the soil profile during the shaking. Corresponding to the strains, a maximum damping value of 3.4% in the upper 600 feet (182 m) of soil is calculated for the analyses with the 10^{-5} LF motion. The strain compatible damping calculated for is the 10^{-4} LF motion small and does not exceed 1.9%. The small strain-compatible damping results in relatively small de-amplification of the site response at high frequencies.

A comparison of log-mean soil amplification factors at the ground surface level for LF and HF 10^{-4} and 10^{-5} input motions is shown in Figure 2.5S.2-49a. As shown in this figure, the amplifications at 10^{-4} level of input motion between the LF and HF input motions are about the same up to 7 Hz. De-amplification occurs at higher frequencies, larger than 10 Hz, followed by amplification of the peak ground acceleration at high frequencies (above 40 hz). The amplification due to 10^{-5} level of input motion follows the same trend compared to the amplification due to 10^{-4} motion indicating limited extent of soil nonlinearity in the soil column. The corresponding amplified ARS at ground surface are presented in Figure 2.5S.2-49b.

2.5S.2.6 Ground Motion Response Spectra

The following site-specific supplement addresses COL License Information Item 2.2.

The GMRS ground motion was developed starting from the 10^{-4} and 10^{-5} HF and LF rock UHRS shown in Figures 2.5S.2-33 and 2.5S.2-34. Site response was calculated for each of these rock input motions. Figure 2.5S.2-50 shows the resulting logarithmic mean spectra for surface conditions for each of these input rock motions; see Tables 2.5S.2-18 and 2.5S.2-19 for sampled numerical values of these rock response spectra. The broad-banded LF motion dominates the site response for the 10^{-4} rock input motion, but for 10^{-5} the HF rock motion indicates higher response in the frequency range 12.5 to 3.3 Hz. The envelope spectra for 10^{-4} and 10^{-5} were determined from these individual results, and these envelope spectra were smoothed with a running average filter to smooth out peaks and valleys that are not statistically significant. These envelope spectra are shown in Figure 2.5S.2-51; see Tables 2.5S.2-18 and 2.5S.2-19 for sampled numerical values of these rock response spectra.

This procedure corresponds to Approach 2A in NUREG/CR-6769 (Reference 2.5S.2-2), wherein the rock UHRS (for example, at 10^{-4}) is multiplied by a mean amplification factor at each frequency to estimate the 10^{-4} site UHRS.

The low-frequency character of the spectra in Figures 2.5S.2-33, 2.5S.2-34, and 2.5S.2-20 reflects the low-frequency amplification of the site. This is a deep soil site and there is a fundamental site resonance at about 0.6 Hz, with a dip in site response at about 0.7 Hz, and this dip occurs for all 60 of the site profiles that were used to characterize the site profile. As a result, there is a dip in the site spectra for 10^{-4} and 10^{-5} at 0.7 Hz that reflects the site characteristics.

The horizontal GMRS was developed from the horizontal UHRS using the approach described in ASCE/SEI Standard 43-05 (Reference 2.5S.2-56) and RG 1.208. The ASCE/SEI Standard 43-05 approach defines the GMRS using the site-specific UHRS, which is defined for Seismic Design Category SDC-5 at a mean 10^{-4} annual frequency of exceedance. The procedure for computing the GMRS is as follows.

For each spectral frequency at which the UHRS is defined, a slope factor AR is determined from:

$$A_R = SA(10^{-5})/SA(10^{-4}) \qquad \text{Equation 2.5S.2-8}$$

where $SA(10^{-4})$ is the spectral acceleration SA at a mean UHRS exceedance frequency of 10^{-4}/yr (and similarly for $SA(10^{-5})$). A Design Factor "DF" is defined based on A_R, which reflects the slope of the mean hazard curve between 10^{-4} and 10^{-5} mean annual frequencies of exceedance. The DF at each spectral frequency is given by:

$$DF = 0.6(A_R)^{0.80} \qquad \text{Equation 2.5S.2-9}$$

and

GMRS = max[SA(10^{-4}) x max(1, DF), 0.45 x SA(10^{-5})]   Equation 2.5S.2-10

The derivation of DF is described in detail in the Commentary to ASCE/SEI Standard 43-05 (Reference 2.5S.2-56) and in RG 1.208. Table 2.5S.2-21 shows the values of AR and DF calculated at each structural frequency and the resulting GMRS. The horizontal GMRS is plotted in Figure 2.5S.2-52. This horizontal GMRS is enveloped at all frequencies by the CSDRS, defined as the horizontal RG 1.60 spectrum anchored at a PGA of 0.30g.

A vertical GMRS was calculated by deriving vertical-to-horizontal (V/H) ratios and applying them to the horizontal 10^{-4} AND 10^{-5} UHRS. The V/H ratios were obtained by the applying the following steps described below.

For CEUS soil sites NUREG/CR-6728 (Reference 2.5S.2-46) suggests a methodology for estimating V/H using available empirical Western United States (WUS) ground motion attenuation relations for both soil and rock, horizontal and vertical motions, and ground motion modeling to develop transfer functions to translate WUS V/H estimates to CEUS V/H estimates. This methodology results in several significant trends in the derived ratios that depend on the frequency of the ground motion, the magnitude and distance of an earthquake, and the subsurface material properties at a site. Among these trends are: the tendency for V/H to increase with frequency, and (for soil sites) to increase with higher magnitudes and smaller distances in the high-frequency range, but to decrease with higher magnitude and smaller distances in the low-frequency range.

Using the attenuation relations of Reference 2.5S.2-57 for WUS soil V/H values, and using the controlling earthquake magnitudes and conservative values for distance for low- and broad-band frequency characterization of site-specific UHRS (for R>100 km and “overall” hazard, respectively, see Table 2.5S.2-17), V/H ratios have been developed for the STP 3 & 4 site. Figure 2.5S.2-53 shows all three magnitude V/H ratios at 93 mi (150km) distance. The specification of the distance of 150 km is based on the far-distance limit of the data used by Reference 2.5S.2-57 in their ground motion attenuation relations. In the high-frequencies, where V/H varies the most, V/H decreases with greater distance, so use of the distance of 150km, compared to the greater controlling distances in Table 2.5S.2-17, gives reasonable, if not conservative guidance on appropriate V/H for the project site. To account for the WUS-to-CEUS high-frequency transformation, discussed in EPRI (Reference 2.5S.2-12) and NUREG/CR-6728, these V/H ratios have been shifted toward higher frequencies. The value of this frequency shift (by a factor of 3.74) is derived by considering the V/H ratios presented in NUREG/CR-6728, and dividing the peak frequency for CEUS [~62.5Hz] by the peak frequency for WUS [~16.7Hz].

The V/H values from RG 1.60 are also shown in the Figure 2.5S.2-53. They have been adopted for the STP 3 & 4 site because they are conservative, acceptable, and simple. Figure 2.5S.2-54 plots the resulting vertical UHRS, calculated in this manner from the horizontal UHRS. The vertical GMRS was developed from the vertical UHRS in a manner identical to that used for the horizontal GMRS, and the vertical GMRS is also plotted in Figure 2.5S.2-54. Table 2.5S.2-22 lists the vertical UHRS, factors AR and

DF, and the vertical GMRS amplitudes. This vertical GMRS is enveloped at all frequencies by the vertical CSDRS, defined as the vertical RG 1.60 spectrum anchored at a PGA of 0.30g.

The Foundation Input Response Spectra (FIRS) are calculated using the same rock motions and the simulated (randomized) profiles for the full height soil column model used in calculating the GMRS, propagating the motion from bedrock to finished ground surface. The GMRS is calculated from the soil column responses at the finished ground surface level and the FIRS are generated at the foundation levels of the structures as “SHAKE Outcrop” responses. The FIRS for Category I structures are included in Appendices 3A and 3H.

2.5S.2.7 References

2.5S.2-1 “Probabilistic seismic hazard evaluation at nuclear plant sites in the central and eastern United States, resolution of the Charleston Earthquake issue,” EPRI Rept. 6395-D, Electric Power Research Institute (EPRI), April 1989.

2.5S.2-2 “Technical Basis for Revision of Regulatory Guidance on Design Ground Motions: Development of Hazard- and Risk-Consistent Seismic Spectra for Two Sites,” NUREG/CR-6769, Risk Engineering, Inc., U.S. Nuclear Regulatory Commission, 2001.

2.5S.2-3 “Seismic Hazard Methodology for the Central and Eastern United States,” Volume 1, Part 2: Methodology (Revision 1), EPRI NP-4726-A, Rev. 1, Electric Power Research Institute (EPRI), November 1988.

2.5S.2-4 “ANSS/CNSS Worldwide Earthquake Catalog files” [catsearch.27217.txt and ANSScatalogSearch(112806).pdf], Advanced National Seismic System [ANSS], 2006. Available at: http://www.ncedc.org/anss/catalog-search.html, accessed November 28, 2006.

2.5S.2-5 “International Seismological Centre [ISC] On-line Bulletin,” [ISC Regional Catalogue.pdf, SearchOutput.htm, and SearchOutput.out], International Seismological Centre (ISC). Available at http://www.isc.ac.uk, accessed November 28, 2006.

2.5S.2-6 “Seismicity of the United States, 1568-1989 (Revised),” U.S. Geological Survey Professional Paper 1527, Stover, C.W., and J.L. Coffman, 1993. Catalog files [NEIC_suse_031307search.htm, neic_suse_031307search.tif Search_SUSE.doc and SUSE.edb] downloaded March 13, 2007 and November 30, 2006 from the USGS website http://neic.usgs.gov/neis/epic/code_catalog.html.

2.5S.2-7 “United States earthquake data file: U.S. Geological Survey, Open-File Report 84-225,” 123 p. Stover, C.W., Reagor, G., and Algermissen, S.T., 1984. Catalog files [neic_ECM_031307search.tif, NEIC_ECM_031307search.htm, ECMSUS.stt and Search_ECMSUS.doc]