REVISED RESPONSE TO REQUEST FOR ADDITIONAL INFORMATION

APR1400 Design Certification

Korea Electric Power Corporation / Korea Hydro & Nuclear Power Co., LTD

Docket No. 52-046

RAI No.: **182-8160**

SRP Section: **03.07.01 – Seismic Design Parameters**

Application Section: **3.7.1**

Date of RAI Issue: **08/31/2015**

Question No. 03.07.01-1

10 CFR 50 Appendix S requires that the safety functions of structures, systems, and components (SSCs) must be assured during and after the vibratory ground motion associated with the safe shutdown earthquake (SSE) ground motion through design, testing, or qualification methods. In accordance with 10 CFR 50 Appendix S, the staff reviewed the adequacy of the target power spectral density (PSD) functions used to demonstrate that the synthetic acceleration time histories used for seismic analysis of the SSCs have sufficient power over the frequency range of interest.

The DCD states that the development of synthetic acceleration time histories for the certified seismic design response spectra (CSDRS) and the hard rock high frequency (HRHF) response spectra (RS) is consistent with the SRP 3.7.1 Option 1 Approach 1 criteria, which include a provision of assessing the power sufficiency of the synthetic acceleration time histories in the frequency range of interest. This assessment needs to compare the PSDs estimated for the time histories with target PSD functions compatible with the design RS (DRS). DCD Sections 3.7.1.1.2 and 3.7.1.1.3; technical report APR1400-E-S-NR-14001-P, Rev. 0, “Seismic Design Bases;” and technical report APR1400-E-S-NR-14004-P, Rev. 1, “Evaluation of Effects of HRHF Response Spectra on SSCs,” provide information on the development of the target PSD functions to be compatible with the corresponding DRS. The staff reviewed the submitted documents and determined that the information requested below is needed in order to determine the acceptability of the target PSD.

a) Identification of the NUREG/CR-5347 time history simulation method

The above-referred documents indicate that the time history simulation method described in NUREG/CR-5347 was used to develop target PSD functions. The staff could not find the term “time history simulation method” in NUREG/CR-5347 and it is not clear to the staff whether it refers to the procedure utilizing Equations (7), (8), and (9) of Appendix B of NUREG/CR-5347. Therefore, the applicant is requested to clearly identify the time history simulation method.

In addition, the method presented in the two technical reports, APR1400-E-S-NR-14001-P, Rev. 0 and technical report APR1400-E-S-NR-14004-P, Rev. 1, utilizes the computer code SIMQKE to generate 30 artificial time histories based on random phasing. Each time history is developed to match the 2% damped DRS. The average of the PSD functions of these 30 resultant time histories is used to define the target PSD. In this process, it is not clear to the staff where and how the time history simulation method is used. As such, the applicant is requested to explain how the time history simulation method was used in the process and update the HRHF report as appropriate, since it is incorporated by reference (IBR).

b) Target PSD for the horizontal CSDRS below 9 Hz

Section 3.7.1.1.2 of the DCD and Section 3.2.4 of APR1400-E-S-NR-14001-P, Rev. 0, indicate that for frequencies lower than 9 Hz, the target PSD for the CSDRS in the horizontal direction is the same as that described in the SRP 3.7.1, Appendix A; while for frequencies between 9 Hz and 50 Hz, the target PSD was developed using 30 simulated time histories which match individually the 2% damped RS. Since a PSD function does not have a frequency-by-frequency independent relationship with the response spectra, the target PSD below 9 Hz was technically not determined appropriately. It appears to the staff that the target PSD based on the 30 time histories is applicable to the entire frequency range and there is no obvious need to use any part of the target PSD described in Appendix A of SRP 3.7.1. The applicant is requested to utilize the target PSD function based on the 30 simulated time histories or justify the hybrid approach that involves the target PSD provided in Appendix A of SRP 3.7.1 below 9 Hz.

c) Target PSD for the Vertical CSDRS

DCD Section 3.7.1.1.2 describes that the target PSD for the vertical CSDRS was developed using a one-time scaling method, in which the horizontal target PSD provided in Appendix A of SRP 3.7.1 was scaled for one time (without iterations) by a frequency-dependent scaling factor. This scaling factor was calculated as the squared, frequency-by-frequency ratio of the vertical CSDRS to the RG 1.60 horizontal RS. This approach would be acceptable if the two RS are very close; however, the vertical CSDRS is not close to the RG 1.60 horizontal RS. In fact, had the one-time scaling method been adequate, it could have been used for the development of the target PSD functions for the APR1400 horizontal CSDRS and the HRHF RS so that there would be no need to generate 30 time histories for each RS. Therefore, the applicant is requested to demonstrate that the one-time scaling method produced an adequate approximation of the target PSD for the vertical CSDRS or redevelop the target PSD based on an appropriate method (e.g., the simulation method used for the HRHF RS and the horizontal CSDRS).

d) Magnitude of Target PSD Functions

Figure 3-11 of APR1400-E-S-NR-14001-P, Rev. 0, “Seismic Design Bases” shows the smoothed ensemble-mean PSD and the piece-wise log-log linear PSD from the 30 time histories, and Figure 3-12 shows the target PSD and the minimum required PSD. Both figures are for the horizontal CSDRS anchored at 0.3 g. However, the PSD functions shown in Figure 3-11 differ significantly from Figure 3-12 (and other PSD figures after Figure 3-12). The applicant is requested to justify this difference.

e) Upper limit of 80 Hz for HRHF Target PSD

Technical report APR1400-E-S-NR-14004-P, Rev. 1 states that the APR1400 HRHF RS-compatible target PSDs were developed in the frequency range of 0.3 Hz to 80 Hz. It is understood that 0.3 Hz is consistent with Appendices A and B of SRP 3.7.1; however, the report does not provide a basis for the choice of 80 Hz. It is recently recognized during the development of Appendix B of SRP 3.7.1 Rev. 4 that the upper bound frequency in the PSD assessment should be consistent with the DRS shape. For a DRS with a zero period acceleration (ZPA) frequency, the ZPA frequency can be used as the upper bound frequency for the development of the target PSD. However, the horizontal and vertical HRHF DRS do not exhibit a definitive ZPA (zero period acceleration) frequency. As such, the applicant is requested to justify the use of 80 Hz as the upper bound frequency for the development of target PSDs.

Response – (Rev.1)

(a) The reference to NUREG/CR-5347 in technical reports APR1400-E-S-NR-14001-P/NP, Rev. 0, "Seismic Design Bases"; and APR1400-E-S-NR-14004-P/NP, Rev. 1, "Evaluation of Effects of HRHF Response Spectra on SSCs", refers to Equations (7), (8), and (9) of Appendix B of NUREG/CR-5347 for generation of an acceleration time history with its time history PSD function compatible with the 2%-damped RG 1.60 response spectrum for the horizontal component of motion, even though the term "time history simulation method" is not explicitly mentioned in this NUREG reference.

As mentioned above, Equations (7), (8), and (9) of Appendix B of NUREG/CR-5347 are for generation of an acceleration time history with its time-history PSD function compatible with the 2%-damped RG 1.60 response spectrum for the horizontal component of motion. The target PSD function compatible with the 2%-damped RG 1.60 response spectrum for the horizontal motion is given in Appendix B of NUREG/CR-5347.

It is noted that, in using Equation (7), (8), and (9) to generate an acceleration time history compatible with the RG 1.60 compatible target PSD given in Appendix B of NUREG/CR-5347, the generation of such a time history involves a random phase angle, Φk, in Equation (8). The random phase angle is uniformly distributed between 0 and 2π. Thus, in principle, an ensemble of such time histories can be generated, each of which has the same target PSD but a different phase angle that is randomly sampled between 0 and 2π. Calculations of the time-history PSDs for the ensemble of time histories so generated can be made, and the average of the time-history PSDs so calculated for the time-history ensemble will return back to the target PSD given in Appendix B of NUREG/CR-5347.

For the APR1400 standard plant DC project, since target PSD functions compatible with the APR1400 CSDRS and HRHF-RS are not available, they need be developed. The development of such target PSD functions follows the steps as described below.

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DCD Section 3.7.1.1.2,Technical eports APR1400-E-S-NR-14001-P/NP, Rev. 0 and APR1400-E-S-NR-14004-P/NP, Rev. 1 will be updated, as appropriate, to incorporate the explanation of the time history simulation method, as described above.

(b) A PSD function is related to the response spectrum (RS), frequency-by-frequency, approximately by a "PSD-to-RS peak factor". Since the APR1400 CSDRS below 9 Hz is the same as the RG 1.60 spectra anchored to the peak acceleration of 0.3g, the target PSD function for the RG 1.60 horizontal spectra anchored to the peak acceleration of 0.3g is adopted directly as the target PSD for the APR1400 horizontal CSDRS. Below 9 Hz, the target PSD function based on the 30 simulated horizontal CSDRS compatible time histories, as shown in Figure 3-11 of APR1400-E-S-NR-14001-P/NP, Rev. 0, is closely matched the target PSD function for the RG 1.60 horizontal response spectra, as shown in Figure 3-12 of APR1400-E-S-NR-14001-P/NP, Rev. 0. Therefore, the target PSD function for the RG 1.60 horizontal response spectra below 9 Hz is adopted as the target PSD function for the CSDRS, which is then combined with the target PSD function developed from the 30 simulated time histories for frequencies higher than 9 Hz, to form the target PSD function for the APR1400 horizontal CSDRS. The adopted target PSD function is closely matched as compared to the target PSD function developed from the 30 simulated time histories for the frequency range below 9 Hz.

DCD Section 3.7.1.1.2 will be updated as described above.

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(d) A PSD function is plotted in the unit of power (in^2/sec^4) per unit frequency. If the frequency is in Hz (cycle/sec) unit, then the PSD unit is ($in^2/sec^4/Hz$). If the frequency is in rps (radian per sec) unit, then the PSD unit is ($in^2/sec^4/rps$). Since $\omega = 2\pi f$, where f is frequency in Hz and ω is frequency in rps. Thus, the PSD value in the unit of ($in^2/sec^4/Hz$) unit is equal to 2π times the PSD value in the unit of ($in^2/sec^4/rps$), i.e., ($in^2/sec^4/Hz$) = ($in^2/sec^4/rps$) $\div 2\pi$.

The PSD in Figure 3-11 is plotted in the unit of ($in^2/sec^4/Hz$). The PSD in Figure 3-12 (and other PSD figures after Figure 3-12) is plotted in the unit of ($in^2/sec^4/rps$). The PSD in Figure 3-12 multiplied by a factor of 2π will give the numerical value of the PSD in the same unit of PSD in Figure 3-11. The use of the unit of ($in^2/sec^4/Hz$) is convenient for comparison with the target PSD compatible with the target PSD for the RG 1.60 horizontal spectra. The use of the unit of ($in^2/sec^4/rps$) is convenient for checking compatibility with the time history PSD, which is computed from the Fourier spectrum in the frequency unit of rps.

Figure 3-11 of Technical Report APR1400-E-S-NR-14001-P/NP, Rev. 0 will be revised to reflect the response.

(e) The 5%-damped horizontal and vertical HRHF design response spectra are developed up to 100 Hz. The HRHF DRS developed from the EPRI report TR-1023389, "Evaluation of Seismic Hazards at Central and Eastern US Nuclear Power Sites", Electric Power Research Institute, June 2011, are 5%-damped response spectra. For development of HRHF DRS for damping ratio values other than 5% (2, 3, 5, 7, and 10%), the response spectral ratios for the CEUS rock sites given in Table 1 of Appendix C of SRP 3.7.1 Rev. 3 are used. Such spectral ratios as presented in Table 1 of Appendix C of SRP 3.7.1 Rev. 3 are presented for the frequency range from 0.5 Hz to 80 Hz. Therefore, for the development of the HRHF DRS for all damping ratio values, the upper bound frequency limit of 80 Hz is adopted.

For development of the target PSDs compatible with the HRHF DRS, the 2%-damped HRHF DRS are required. Since the 2%-damped HRHF DRS can only be defined from the 5%-damped HRHF DRS for frequencies up to the high-frequency limit of 80Hz, this high-frequency limit becomes the upper bound frequency limit for development of target PSDs compatible with the horizontal and vertical HRHF DRS.

Even though the target PSDs compatible with the HRHF DRS are developed with the high-frequency limit of 80 Hz, for comparison with the time-history PSDs of the generated HRHF DRS compatible design time histories, the target PSDs are extended by extrapolation and the calculation and comparison of the time-history PSDs with the extended target PSDs are made up to the upper-bound high-frequency limit of 100 Hz, as shown in Figures 3.7-20 through 3.7-22 of APR1400 DCD 3.7.1 Tier 2.

The comparison between the HRHF horizontal time history PSD for the H1H component and PSD given in Appendix B of SRP 3.7.1 Rev. 4 is shown in Figure 5, which shows that the APR1400 HRHF time history PSD envelope the PSD given in Appendix B of SRP 3.7.1 Rev. 4.

DCD Section 3.7.1.1.3, Table 3.7-5, Table 3.7-6, and Figure 3-24 of Technical Report APR1400-E-S-NR-14004-P/NP, Rev. 1 will be revised to reflect the response.

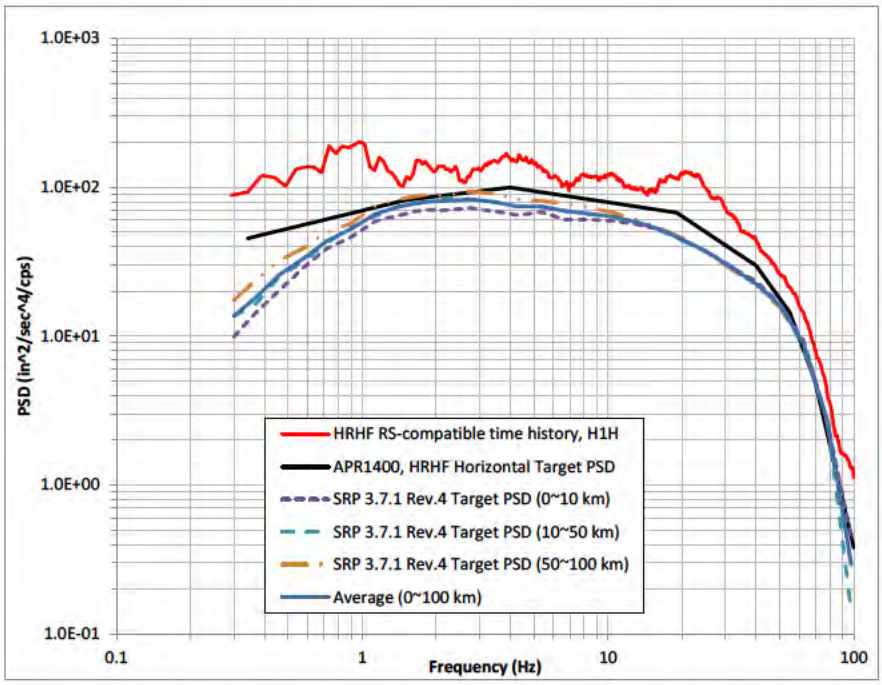

Figure 5. Comparison between APR1400 HRHF PSD, Target PSD and SRP 3.7.1 Rev. 4 CEUS rock target PSDs for H1H component

Impact on DCD

DCD Section 3.7.1.1.2, 3.7.1.1.3, Table 3.7-5 and Table 3.7-6 will be revised as indicated on the attachment associated with this response.

Impact on PRA

There is no impact on the PRA.

Impact on Technical Specifications

There is no impact on the Technical Specifications.

Impact on Technical/Topical/Environmental Reports

Technical Reports APR1400-E-S-NR-14001-P/NP, Rev. 0 Section 3.2.4 and Figure 3-11 and APR1400-E-S-NR-14004-P/NP, Rev. 1 Section 1.8.1 and Figure 3-24 will be revised as indicated on the attachment associated with this response.

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In SRP 3.7.1, the requirement of minimum power spectral density (PSD) to prevent the design ground acceleration time histories from having a deficiency of power over any frequency range is described. SRP 3.7.1 specifies that the use of a single time history is justified by satisfying a target PSD requirement in addition to the design response spectra enveloping requirements.

Since the original NRC RG 1.60 horizontal spectrum and the horizontal CSDRS are identical for frequencies less than 9 Hz, no modification to the target horizontal PSD is done in this frequency range.

This approach is closely matched as compared to the target PSD function developed by using the method described in NUREG/CR-5347 for the frequency range below 9 Hz.

The time-history simulation method described in NUREG/CR-5347 (Reference 8) is used to develop the CSDRS-compatible horizontal target PSD in the higher frequency range above 9 Hz. The resulting piecewise log-log linear horizontal target PSD developed is given in Table 3.7-3. The minimum required horizontal PSD is then 0.8 times the horizontal target PSD.

The vertical target PSD, compatible with the vertical CSDRS, is obtained from the horizontal target PSD, compatible with the horizontal CSDRS using the following equation:

$$S_V(f) = [\, R_V(f\ ,\ 2\ \%)\ /\ R_H(f\ ,\ 2\ \%)]^2 \times S_H(f)$$

where $R_H(f, 2\ \%)$ and $R_V(f, 2\ \%)$ are, respectively, the 2 percent damped horizontal and vertical CSDRS values at the frequency (f). The detailed procedure for generating target PSD is described in Technical Report, APR1400-E-S-NR-14001-P (Reference 9). The minimum required vertical PSD is then 0.8 times the vertical target PSD.

The PSDs of the design acceleration time histories are presented in Figures 3.7-9 through 3.7-11. The PSDs of the design acceleration time histories exceed the minimum required PSD throughout the entire frequency range. The PSDs presented are the averaged PSDs obtained over a moving frequent band of ± 20 percent centered at each frequency. The PSD amplitude at frequency (f) has the averaged PSD amplitude between the frequency range of $0.8f$ and $1.2f$ as stated in Appendix A of SRP 3.7.1.

The time-history PSDs for the 30 time histories of the CSDRS compatible time-history ensembles are calculated and their ensemble-averaged PSDs are computed. After smoothing of the the ensemble-averaged PSDs calculated in accordance with NUREG/CR-5347, the target PSDs compatible with the CSDRS are obtained. The smoothed ensemble-mean PSDs obtained from the PSDs of the 30 time history ensembles are segmentally smoothed using piecewise log-log linear. The detailed procedure for generating target PSD is described in Technical Report, APR1400-E-S-NR-14001-P.

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time histories. Thus, the development of the target values and associated target ranges of values for the maximum velocity (V) and maximum displacement (D) of the CSDRS-compatible time histories to be generated is based on the ground motion study results published in NUREG-0003, which is the basis of the NRC RG 1.60 DRS, and the results in NUREG/CR-6728, which is the basis of NRC RG 1.208.

(4) From the study results published in NUREG-0003, the target median (m) values of maximum velocity (V), maximum displacement (D), V/A ratio, and AD/V² ratio of the time histories to be generated, scaled to the PGA value of 0.3g, are given in Table 3-1.

The target ranges of V, D, V/A, and AD/V² values are developed to be the median ± one standard deviation (σ) (i.e., "$m \pm \sigma$" ranges). The standard deviation for each parameter is derived from the database of values published in NUREG/CR-6728. For conservatism, the smallest of eight σ values each parameter is used, because the smallest σ value will lead to the smallest range of variation for the parameter. The eight σ values are obtained from the ground-motion databases for the Western United States (WUS) and CEUS rock and soil sites, for distance bins 50-100 km, and for earthquake magnitudes 6.3 to 7.5, as given in Table 3-5 (on page 3-12) and Table 3-6 (on pages 3-14 and 3-15) of NUREG/CR-6728.

Based on the σ-value derived for each parameter as described above, the target $m \pm \sigma$ ranges of the parameter values so derived for the CSDRS-compatible time histories to be generated are shown in Table 3-2.

3.2.4 Method for Developing Spectrum-Compatible Target PSD Function

In order to check the adequacy of the PSD of each of the spectrum-compatible time histories generated, horizontal and vertical target PSDs compatible with the horizontal and vertical DRS, respectively, are required.

(1) Horizontal Target PSD for $f \leq 9$ Hz

The horizontal CSDRS are the same as the horizontal NRC RG 1.60 DRS for the frequency range below 9 Hz. The method for developing the horizontal CSDRS-compatible target PSDs below 9 Hz follows the procedure and uses the standard horizontal PSD functions presented in the SRP section 3.7.1, appendix A, which is applicable for the NRC RG 1.60 horizontal DRS anchored to the PGA of 1.0g.

To obtain the horizontal target PSD compatible with the horizontal CSDRS, the one-sided horizontal target PSD, SH(f), where f is cycles per second (cps), expressed in the units of $(m^2/sec^4)/cps$, is obtained from the one-sided PSD, SH(ω), where ω is in the units of radians per second (rps), presented in appendix A of SRP, section 3.7.1, which are in the units of m^2/sec^3, or $(m^2/sec^4)/rps$, scaled by the square of the ratio of the horizontal PGA of 0.3g for the APR1400 to the PGA of 1.0g for the NRC RG 1.60 DRS as follows:

$$S_H(f) = 2\pi S_H(\omega) \times (0.30)^2, \qquad f \leq 9 \text{ Hz}$$

Insert page 3

where the values of $S_H(\omega)$ are obtained from Eq. (2) of SRP section 3.7.1, appendix A.

(2) Horizontal Target PSD for $f > 9$ Hz

For the frequency range between 9 and 50 Hz, for which the CSDRS differ from the NRC RG 1.60 DRS, the method presented in the SRP section 3.7.1, appendix A can no longer be used. Thus, for developing the CSDRS-compatible target PSD in the higher frequency range above 9

A PSD is related to the response spectrum (RS), frequency-by-frequency, approximately by a "PSD-to-RS peak factor". Since the APR1400 CSDRS below 9 Hz is the same as the RG 1.60 spectra anchored to the peak acceleration of 0.3g, the target PSD function for the RG 1.60 horizontal spectra anchored to the peak acceleration of 0.3g is adopted directly as the target PSD for the APR1400 horizontal CSDRS. Below 9 Hz, the target PSD function based on the 30 simulated horizontal CSDRS compatible time histories, as shown in Figure 3-11 is closely matched the target PSD function for the NRC RG 1.60 horizontal response spectra, as shown in Figure 3-12. Therefore, the target PSD function for the RG 1.60 horizontal response spectra below 9 Hz is adopted as the target PSD function for the CSDRS, which is then combined with the target PSD function developed from the 30 simulated time histories for frequencies higher than 9 Hz, to form the target PSD function for the APR1400 horizontal CSDRS. The adopted target PSD function is closely matched as compared to the target PSD function developed from the 30 simulated time histories for the frequency range below 9 Hz.

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Hz, ~~the time history simulation method described in NUREG/CR 5347 (Reference 12) is used. Applying this method for developing the target PSD compatible with the CSDRS involves the following analysis steps:~~

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- The resulting piecewise log-log linear ensemble-mean PSDs generated for the four higher frequency bands, namely, 9 < f ≤ 16 Hz, 16 < f ≤ 25 Hz, 25 < f ≤ 35 Hz, and 35 < f ≤ 50 Hz, are the target PSDs compatible with the horizontal CSDRS for the higher frequency range f > 9 Hz. The smoothed ensemble-mean PSDs and the piecewise log-log linear smoothed PSDs obtained for the generated 30 time-history ensemble are shown in Figure 3-11.

- The target PSD obtained in above steps for the higher frequency range f > 9 Hz is combined with the target PSD compatible with the NRC RG 1.60 horizontal DRS for the lower frequency bands, namely, 0.2 < f ≤ 2.5 Hz and 2.5 < f ≤ 9.0 Hz, to form the complete target PSD compatible with the horizontal CSDRS for the entire frequency range from 0.2 to 50 Hz. This target PSD so obtained is given in Table 3-3.

The target PSD compatible with the horizontal CSDRS, designated as $S_H(f)$, developed as described above and defined in Table 3-3, is the target PSD to be used for checking the adequacy of the power density distribution as function of frequency of the CSDRS-compatible horizontal design time histories.

The minimum required horizontal target PSD, designated as $\bar{S}_H(f)$, for checking power adequacy of the

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~~Equations (7), (8), and (9) of Appendix B of NUREG/CR-5347(Reference 12) for generation of an acceleration time history with its time history PSD function compatible with the 2% damped RG 1.60 response spectrum for the horizontal component of motion is used.~~ Equations (7), (8), and (9) of Appendix B of NUREG/CR-5347 are for generation of an acceleration time history with its time-history PSD function compatible with the 2%-damped RG 1.60 response spectrum for the horizontal component of motion. The target PSD function compatible with the 2%-damped RG 1.60 response spectrum for the horizontal motion is given in ~~Equation (1) of~~ Appendix B of NUREG/CR-5347.

Appendix B of NUREG/CR-5347

It is noted that, in using Equation (7), (8), and (9) to generate an acceleration time history compatible with the RG 1.60 compatible target PSD given in ~~Equation (1)~~, the generation of such a time history involves a random phase angle, Φk, in Equation (8). The random phase angle is uniformly distributed between 0 and 2π. Thus, in principle, an ensemble of such time histories can be generated, each of which has the same target PSD but a different phase angle that is randomly sampled between 0 and 2π. Calculations of the time-history PSDs for the ensemble of time histories so generated can be made and the average of the time-history PSDs so calculated for the time-history ensemble will return back to the target PSD ~~in Equation (1)~~.

given in Appendix B of NUREG/CR-5347

For the APR1400 standard plant DC project, since target PSD functions compatible with the APR1400 CSDRS are not available, they need be developed. The development of such target PSD functions follows the steps as described below.

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compatible time history, horizontal and vertical target PSDs that are compatible with the horizontal and vertical HRHF target response spectra for the APR1400 are needed. The development of the horizontal and vertical target PSDs compatible with the APR1400 horizontal and vertical HRHF response spectra is described below.

1.8.1 HRHF Response Spectrum-compatible Target PSDs

The development of the APR1400-HRHF response spectrum-compatible target PSDs in the frequency range of 0.3 to 80 Hz, the time history simulation method described in NUREG/CR-5347 (Reference 24) is used. Applying this method for developing the target PSD involves the following steps:

(1) ~~An ensemble of 30 artificial time histories is generated using a frequency domain response spectrum-compatible time history generation method developed by Gasparini and Vanmarcke and implemented in SIMQKE (Reference 25). Each time history 30 time history ensemble has a total duration of 20.475 seconds and is modulated by the intensity envelope function shown in Figure 3-16. Each time history generated has a 2%-damped time history response spectrum compatible with the 2% damped horizontal APR1400 HRHF response spectra.~~

~~The SIMQKE frequency domain response spectrum compatible time history generation method starts with synthesizing pure harmonic waves with white noise random phases and with amplitudes generated from an initial response spectrum compatible target PSD within the frequency range of interest, which for the APR1400 HRHF response spectra is 0.3 to 80 Hz. The initial target PSD at each frequency is derived from the 2%-damped target response spectral value divided by a frequency dependent "peak factor" derived from the random vibration theory (Reference 25). The peak factor, which relates the target PSD value to the 2% damped target response spectral value, is a function of frequency and non-exceedance probability of the target response spectra. The initial time history is then modified iteratively by adjusting the initial time history PSD at each frequency using the square of the ratio of the 2% damped time history response spectral value to the 2% damped target response spectral value.~~ Replace with page 7

The 2%-damped time history response spectra for the ensemble of 30 artificial time histories are computed based on which 2%-damped "ensemble-median" time history response spectrum is derived. This spectrum for the ensemble of 30 artificial time histories is shown in Figure 22 for the horizontal motion and in Figure 3-17 for the vertical motion. The 2%-damped horizontal and vertical "ensemble-median" time history response spectra are then compared with the 2%-damped horizontal and vertical target HRHF response spectra. These comparisons are shown in Figures 3-18 and 3-19.

As indicated in Figures 3-18 and 3-19, the ensemble-median time history response spectra derived from the generated horizontal and vertical 30 time history ensembles compared closely with the horizontal and vertical target horizontal and vertical APR1400 HRHF response spectra. The good comparisons indicate that the ensembles of the 30 generated time histories are compatible with the horizontal and vertical target HRHF response spectra and are therefore representative time history ensembles from which the target PSDs compatible with the horizontal and vertical target APR1400 HRHF response spectra can be developed.

(2) The PSD of each individual time history in each 30 time history ensemble is computed. Because each time history in the ensemble is intensity modulated and is therefore a non-stationary motion, an equivalent stationary duration for the motion must be determined for use in computing the PSD of the individual time history. The PSDs computed for the 30 time history ensemble are shown in Figure 3-20 for the horizontal motion and in Figure 3-21 for the vertical motion.

(3) The "ensemble-average" or "ensemble-mean" PSDs obtained from the horizontal and vertical 30 time history PSDs computed in Step (2) and shown in Figures 3-20 and 3-21 are smoothed in

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(1) Initial target PSDs compatible with the APR1400 HRHF response spectra are developed from the 2%-damped APR1400 HRHF response spectra using a "PSD-to-response-spectrum peak factor", as a function of frequency developed from the random vibration theory. The peak factor, which relates the target PSD value to the 2%-damped target response spectral value, is a function of frequency and non-exceedance probability of the target response spectra. The initial time history is then modified iteratively by adjusting the initial time history PSD at each frequency using the square of the ratio of the 2%-damped time history response spectral value to the 2%-damped target response spectral value. In this step, the computer program SIMQKE (Reference 25) developed by Gasparini, D. A. and Vanmarcke, E. H., at Department of Civil Engineering, Massachusetts Institute of Technology Publication No. R76-4, November 1976 is utilized to obtain the initial target PSDs compatible with APR1400 HRHF response spectra.

(2) Using the initial target PSDs developed in Step (1), the computer program SIMQKE, which implements the procedure in Equations (7), (8), and (9) of Appendix B of NUREG/CR-5347, is utilized to generate an ensemble of 30 time histories, each of which has the same initial target PSDs developed in Step (1) and a randomly phase angle sampled between 0 and 2π, for each of APR1400 HRHF response spectra. An ensemble of 30 artificial time histories is generated using a frequency domain response spectrum-compatible time history generation method developed by Gasparini and Vanmarcke and implemented in SIMQKE (Reference 25). Each time history 30 time history ensemble has a total duration of 20.475 seconds and is modulated by the intensity envelope function shown in Figure 3-15. Each time history generated has a 2%-damped time history response spectrum compatible with the 2%-damped horizontal APR1400 HRHF response spectra.

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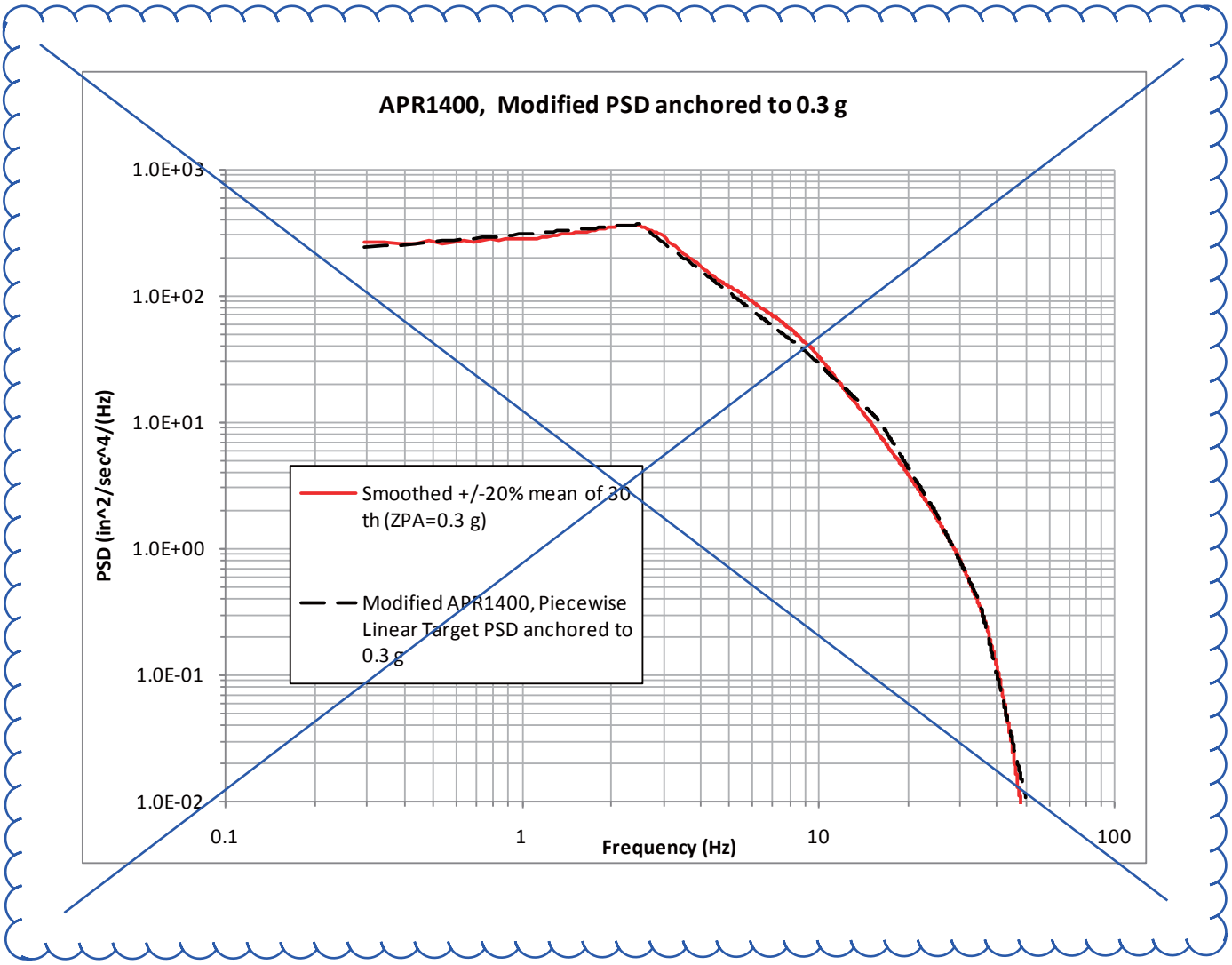

Figure 3-11 Smoothed Ensemble-Mean PSD and Piecewise Log-Log Linear PSD Obtained from Generated 30 Time History Ensemble

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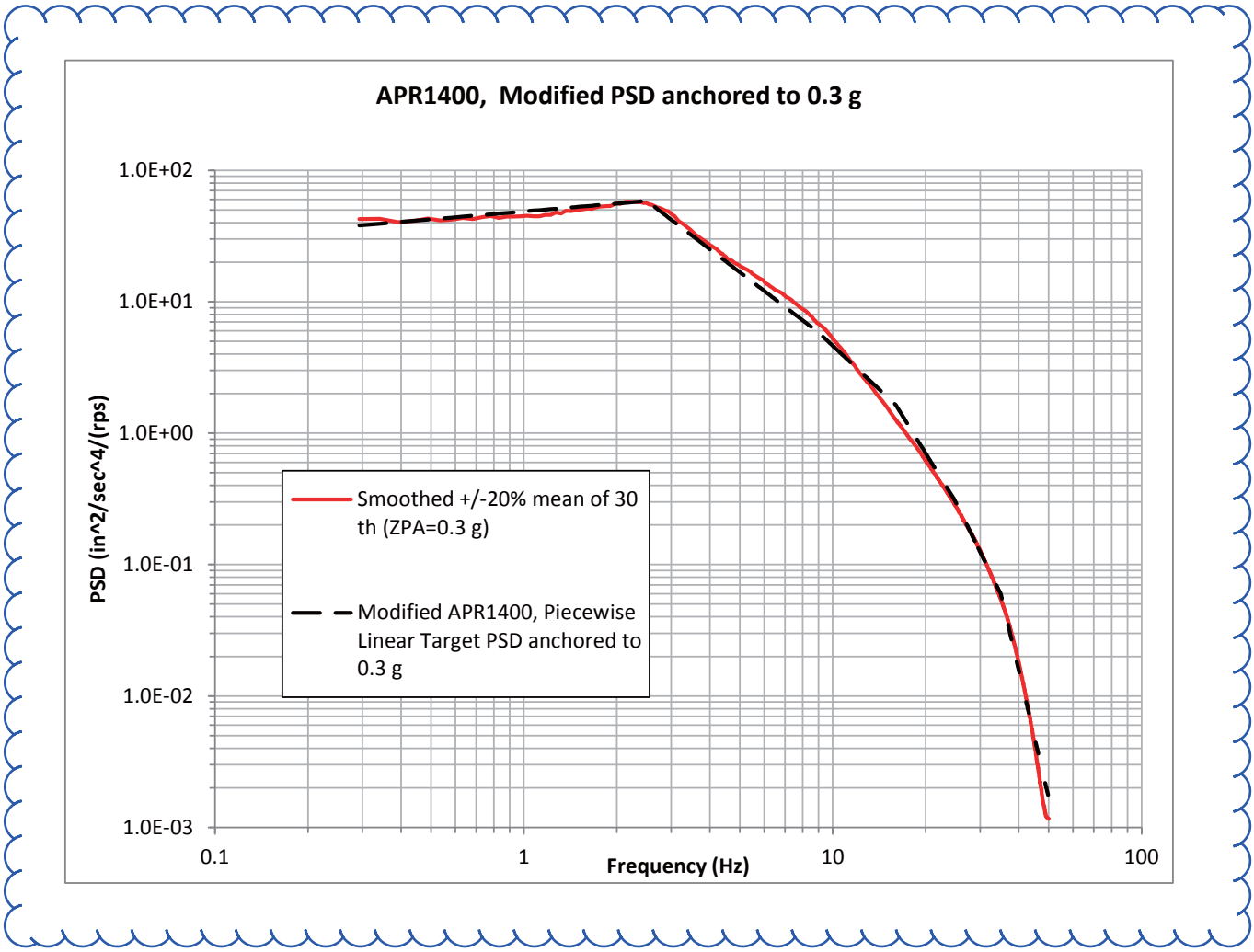

Figure 3-11 Smoothed Ensemble-Mean PSD and Piecewise Log-Log Linear PSD Obtained from Generated 30 Time History Ensemble

The time histories are developed following the spectrum matching acceptance criteria of Option 1, Approach 1, in Section II of SRP 3.7.1. The comparison plots of the response spectra of the time histories versus the HRHF response spectra for 2, 3, 4, 5, 7, and 10 percent critical dampings are shown in Figures 3.7-17, 3.7-18, and 3.7-19. The figures demonstrate that the time histories envelop the HRHF response spectra for those damping values, satisfying the requirement of SRP 3.7.1 that no more than 5 points fall below and by no more than 10 percent below the HRHF response spectra.

According to SRP 3.7.1, the ratio V/A and AD/V^2 should be consistent with characteristic values for the magnitude and distance of the appropriate controlling events defining the uniform hazard response spectra. The target and target ranges of values for the other design ground-motion time-history parameters are the median (m) values and the median (m) ± one standard deviation (σ) (i.e., m ± σ) ranges. The determination of these target and target ranges of values is based on the methodologies and ground motion databases as described in NUREG/CR-6728. Table 3.7-4 shows a comparison of the ratios V/A and AD/V^2 for the time histories and the guidance in NUREG/CR-6728 and that the ratios are between the target values, target median ± σ.

For the development of the HRHF-response spectra-compatible target PSDs in the frequency range from 0.3 to ~~80~~ 100 Hz, the time-history simulation method described in NUREG/CR-5347 is used. The resulting piecewise log-log linear horizontal and vertical target PSD developed is given in Tables 3.7-5 and 3.7-6. The minimum required horizontal and vertical PSD is then 0.8 times the horizontal and vertical target PSD.

The PSDs of the acceleration time histories compatible with the HRHF response spectra are presented in Figures 3.7-20 through 3.7-22. The PSDs of the acceleration time histories exceed the minimum required PSD throughout the entire frequency range.

The evaluation methodology and results of the APR1400 for the HRHF seismic input motions are provided in Appendix 3.7B.

3.7.1.2 Percentage of Critical Damping Values

Damping values used for various nuclear safety-related SSCs are based on NRC RG 1.61 (Reference 10). These values are expressed in percentages of critical damping and are given in Table 3.7-7. Damping values of soil to be used in soil-structure interaction

Table 3.7-5

Target PSD Compatible with Horizontal HRHF Seismic Input Motions

Frequency (f) Range f (Hz or cps)	Piecewise Linear Target PSD $S_H(f)$ (in^2/sec^4/cps)
$0.3 < f \leq 1.5$ Hz	$S_0(f) = 2\pi \times 6.85\,(0.3/f)^{-0.4}$
$1.5 < f \leq 4.0$ Hz	$S_0(f) = 2\pi \times 13.04\,(1.5/f)^{-0.2}$
$4.0 < f \leq 19$ Hz	$S_0(f) = 2\pi \times 15.86\,(4.0/f)^{0.25}$
$19 < f \leq 40$ Hz	$S_0(f) = 2\pi \times 10.75\,(19.0/f)^{1.1}$
$40 < f \leq 55$ Hz	$S_0(f) = 2\pi \times 4.75\,(40.0/f)^{2.3}$
$55 < f \leq 70$ Hz	$S_0(f) = 2\pi \times 2.28\,(55.0/f)^{4.5}$
$70 < f \leq$ ~~80~~ 100 Hz	$S_0(f) = 2\pi \times 0.76\,(70.0/f)^{7.1}$

Table 3.7-6

Target PSD Compatible with Vertical HRHF Seismic Input Motions

Frequency (f) Range f (Hz or cps)	Piecewise Linear Target PSD $S_H(f)$ (in^2/sec^4/cps)
$0.3 < f \leq 1.5$ Hz	$S_0(f) = 2\pi \times 3.44\,(0.3/f)^{-0.5}$
$1.5 < f \leq 4.0$ Hz	$S_0(f) = 2\pi \times 7.69\,(1.5/f)^{-0.1}$
$4.0 < f \leq 19$ Hz	$S_0(f) = 2\pi \times 8.49\,(4.0/f)^{0.15}$
$19 < f \leq 40$ Hz	$S_0(f) = 2\pi \times 6.72\,(19.0/f)^{0.3}$
$40 < f \leq 55$ Hz	$S_0(f) = 2\pi \times 5.38\,(40.0/f)^{1.5}$
$55 < f \leq 70$ Hz	$S_0(f) = 2\pi \times 3.34\,(55.0/f)^{3.9}$
$70 < f \leq$ ~~80~~ Hz	$S_0(f) = 2\pi \times 1.31\,(70.0/f)^{6.2}$

100

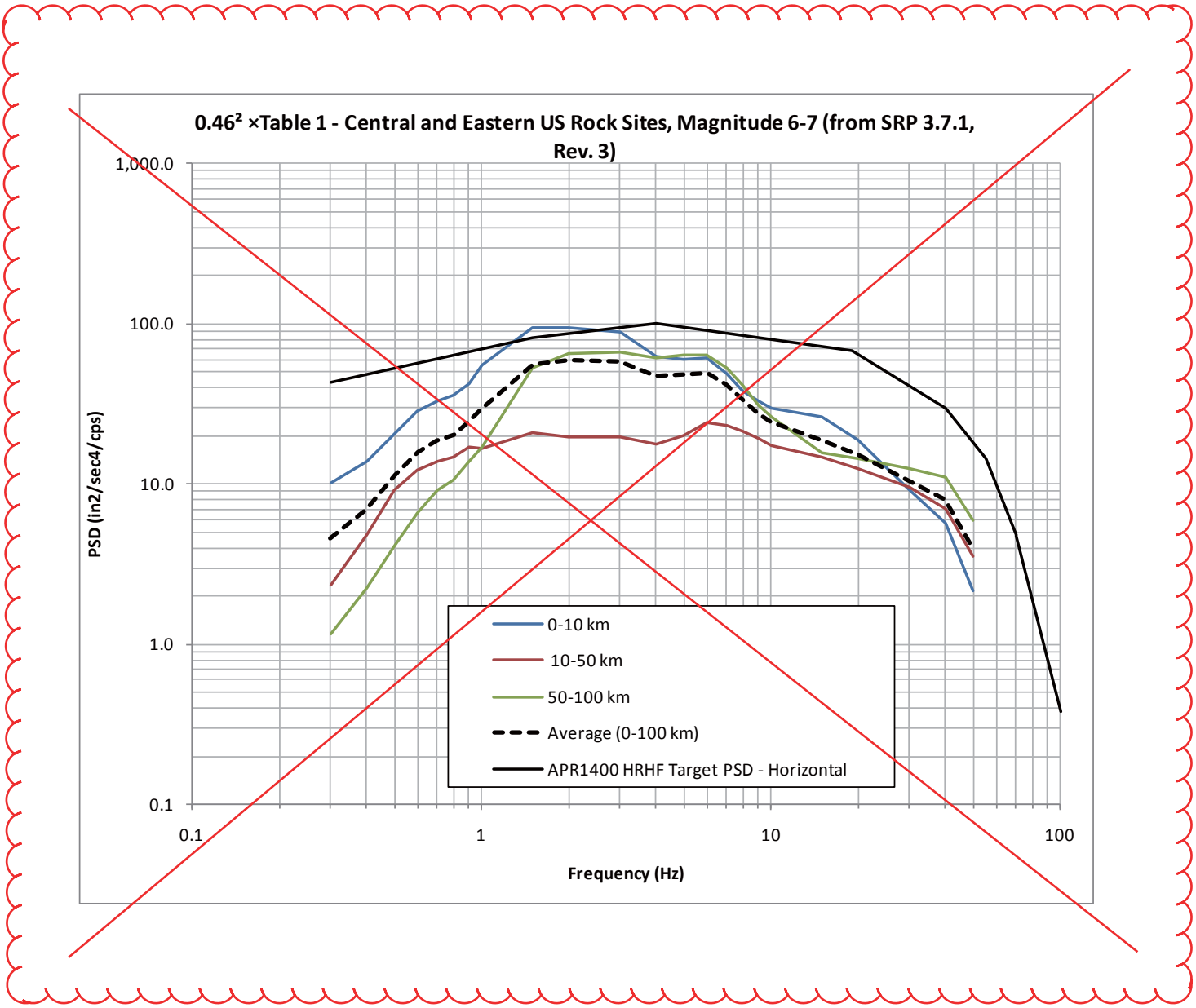

Figure 3-24 Comparison of the Horizontal Target PSD Compatible with APR1400 HRHF Horizontal Response Spectra with the SRP 3.7.1 PSDs for CEUS Rock Sites

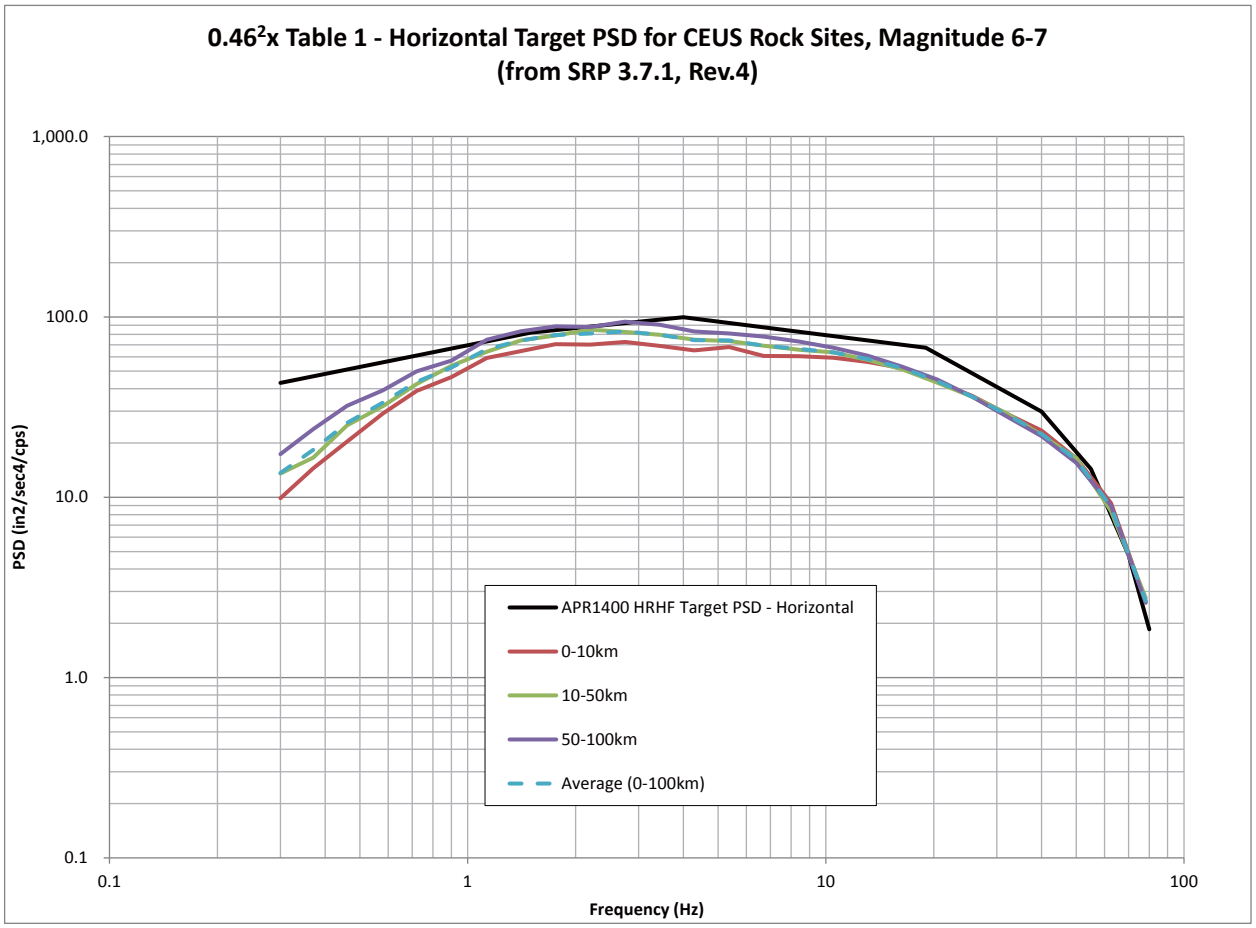

Figure 3-24 Comparison of the Horizontal Target PSD Compatible with APR1400 HRHF Horizontal Response Spectra with the SRP 3.7.1 PSDs for CEUS Rock Sites