2.0 SITE CHARACTERISTICS

2.5.2 Vibratory Ground Motion

2.5.2.1 Introduction

Vibratory ground motion for a site is evaluated based on seismological, geological, geophysical, and geotechnical investigations carried out to determine the site-specific ground motion response spectrum (GMRS), which must meet the regulations for safe shutdown earthquake (SSE) provided in Title 10 of the *Code of Federal Regulations* (10 CFR) 100.23, "Geologic and seismic siting criteria." The GMRS is defined as the free-field horizontal and vertical ground motion response spectra at the plant site. The development of the GMRS is based upon a detailed evaluation of earthquake potential, taking into account the regional and local geology, Quaternary tectonics, seismicity, and site-specific geotechnical engineering characteristics of the site subsurface material. The specific investigations necessary to determine the GMRS include the seismicity of the site region and the correlation of earthquake activity with seismic sources. Seismic sources are identified and characterized, including the rates of occurrence of earthquakes associated with each seismic source. Seismic sources that are located within 320 km (200 mi) of the site must be identified. Seismic sources can be capable tectonic sources or seismogenic source zones. The staff's review covers the following specific areas: (1) seismicity; (2) geologic and tectonic characteristics of the site and region; (3) correlation of earthquake activity with seismic sources; (4) probabilistic seismic hazard analysis (PSHA) and controlling earthquakes; (5) seismic wave transmission characteristics of the site; and (6) site-specific GMRS.

2.5.2.2 Summary of Application

In Site Safety Analysis Report (SSAR) (TVA, 2017 – ADAMS Accession No. ML18003A374), Section 2.5.2, "Vibratory Ground Motion," the applicant describes the potential vibratory ground motion at the Clinch River Nuclear (CRN) Site. To estimate the vibratory ground motion at the site, the applicant used the NUREG–2115, "Central and Eastern United States Seismic Source Characterization for Nuclear Facilities," seismic source model and the Electric Power Research Institute (EPRI) 2013 Ground Motion Model (GMM) in its PSHA. The applicant stated that it developed the GMRS based on the performance-based approach recommended by Regulatory Guide (RG) 1.208, "A Performance-Based Approach to Define the Site-Specific Earthquake Ground Motion." In the SSAR, the applicant presented the following information related to the vibratory ground motion at the CRN Site.

2.5.2.2.1 Seismicity

In SSAR Section 2.5.2.1 the applicant states that it used the most recent earthquake catalog published as part of NUREG–2115 (NRC, 2012 – ADAMS Accession no. ML12048A776) for its seismic hazard assessment of the CRN Site. The NUREG–2115 earthquake catalog covers earthquakes in the Central and Eastern United States (CEUS) region from 1568 through 2008. Because the NUREG–2115 earthquake catalog covers only through 2008, the applicant developed a separate earthquake catalog covering from 2009 through the mid-September 2013. After declustering the new catalog, the applicant merged the two catalogs and used the updated catalog in its seismic hazard evaluation at the CRN Site. The updated catalog identified nine additional mainshock earthquakes of magnitude **M**2.9 and greater in the 320 km (200 mi) site region. The applicant indicated that among the earthquakes listed in the earthquake catalog, six small to moderate size earthquakes ranging in magnitude from **M**4.01 to **M**5.8 are of particular significance to the site. The largest of these is the **M**5.8 Mineral, Virginia earthquake that occurred on August 23, 2011. The Mineral earthquake is located 615 km (382 mi) away from the CRN Site, but is considered here due to its influence on scientific understanding of the seismicity in the CEUS. Nearer the site, two small earthquakes (**M**4.01 and **M**4.57) are highlighted because they represent the largest observed earthquakes in the Eastern Tennessee Seismic Zone (ETSZ), a southwest to northeast trending region of elevated seismicity that extends from northern Alabama through portions of Georgia and North Carolina to Eastern Tennessee (Figure 2.5.2-1).

The applicant noted in SSAR Section 2.5.2.1.3 that recent United States Geological Survey (USGS) studies of induced earthquakes (USGS Open-File Report 2015-1070) identified 17 regions of apparent induced seismicity occurring over the last 50 years. None of these 17 regions are located within 320 km (200 mi) of the site.

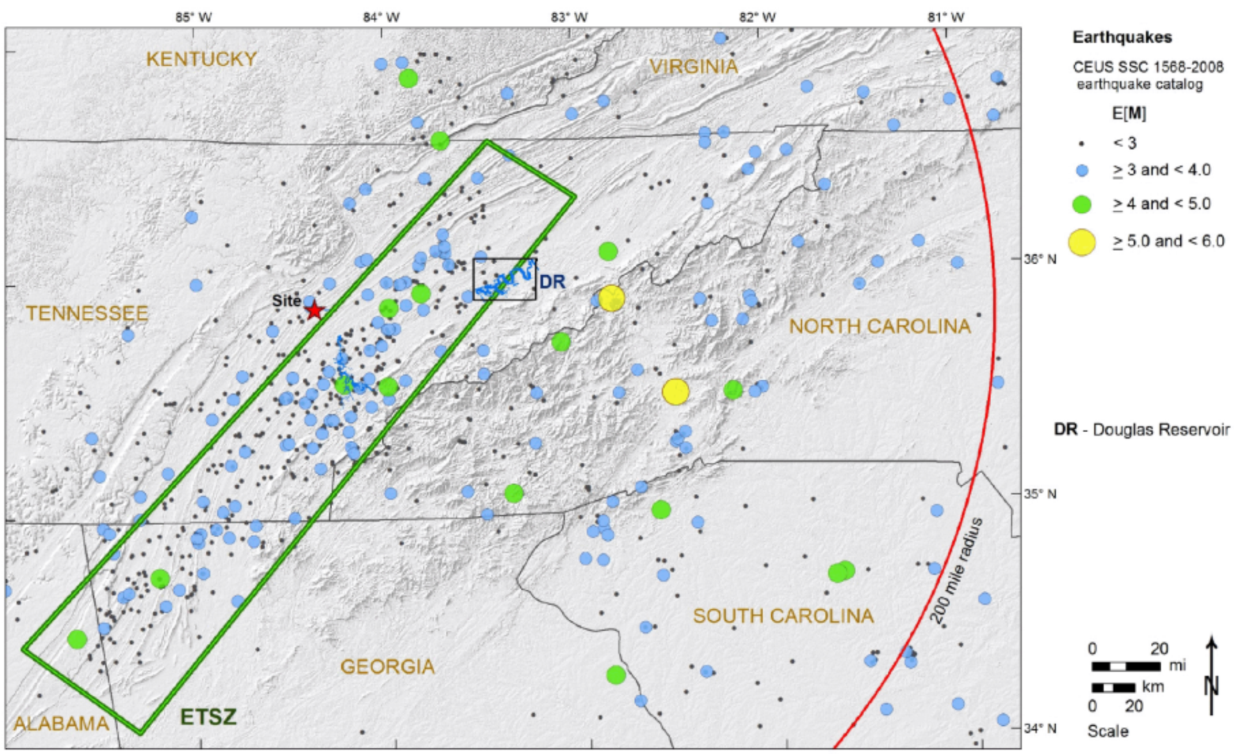

Figure 2.5.2-1: Map of seismicity in the CEUS surrounding the CRN Site. Colored circles are earthquakes in the NUREG–2115 earthquake catalog. Red circle denotes 320 km (200 mi) radius. Green box is outline of ETSZ. Modified from SSAR Figure 2.5.2-26

2.5.2.2.2 Geologic and Tectonic Characteristics of the Site and Region

In SSAR Section 2.5.2.2 the applicant describes the seismic sources and seismic model parameters that the applicant used to calculate the seismic ground motion hazard at the CRN Site. The applicant used the NUREG–2115 regional seismic source characterization model developed for the CEUS region as a starting point for its seismic source characterization (SSC) model. The NUREG–2115 seismic source model is a model published in January 2012. The model development followed the Senior Seismic Hazard Analysis Committee (SSHAC) Level 3 procedures as outlined in NUREG/CR-6372, “Recommendations for Probabilistic Seismic

Hazard Analysis: Guidance on Uncertainty and the Use of Experts." NUREG–2115 states that this is a regional seismic source model to be used as a starting model in seismic hazard calculations for nuclear facilities in the CEUS region. The applicant stated that it conducted a review of the CEUS-SSC model to identify whether there is a need to update any of the seismic sources. Based on its review results, the applicant stated that the regional model, as published is adequate for use in seismic hazard calculations for the CRN Site. The following describes a summary of the CEUS-SSC model.

Summary of the NUREG–2115 Seismic Source Model

In the early site permit (ESP) application, the applicant stated that the CEUS-SSC model described in NUREG–2115 contains two types of seismic sources: (1) distributed seismicity sources; and (2) repeated large magnitude earthquake sources (RLME). While the distributed seismicity sources were developed based on available earthquake locations and regional geologic/tectonic characterizations, the RLME sources are based on geologic and paleo-earthquake records. The RLME sources (e.g., New Madrid Fault System) represent zones of repeated (two or more) large magnitude earthquakes (**M**>6.5) in the CEUS region.

The CEUS-SSC model categorizes the distributed seismicity sources into two subgroups: maximum magnitude (M_{max}) zones and seismotectonic zones. These subgroups capture the uncertainties in source characterizations and differences of opinions in seismic source identification in the region. For the CEUS-SSC model (NUREG–2115), the M_{max} and seismotectonic sources are weighted by 40 percent and 60 percent, respectively, to determine their relative contribution to the total seismic hazard at the site. The M_{max} zones are broad seismic sources identified based on limited tectonic information and represent potential seismic sources of future earthquakes. The seismotectonic zones are those developed by extensive analysis of regional geology, tectonics, and seismicity in the CEUS region. Both the M_{max} and the seismotectonic zones include alternative source geometries, accommodating uncertainty in seismic source characterization. The RLME sources are superimposed on these distributed seismicity sources.

2.5.2.2.3 Correlation of Earthquake Activity with Seismic Sources

SSAR Section 2.5.2.3 describes the applicant's correlation of updated seismicity with the NUREG–2115 seismic source model. The applicant provided the following conclusions regarding the correlation of earthquake activity with the seismic sources.

- The updated seismicity catalog does not contain any earthquakes within the site region that can be positively associated with a known geologic structure.

- The updated seismicity catalog does not show a pattern of seismicity different from that of the CEUS-SSC catalog that would suggest a new seismic source in addition to those included in the CEUS-SSC characterization.

- The updated seismicity catalog shows a similar spatial distribution of earthquakes to that of the CEUS-SSC catalog, suggesting that no significant revisions to the geometry of the seismic sources in the CEUS-SSC are required.

- The updated seismicity catalog does not contain any earthquakes that suggest revisions to the M_{max} distributions for CEUS-SSC zones is required.

- Seismicity rates determined from the updated catalog range from a decrease of 5.5 percent to an increase of 12.5 percent compared to the rates published in the CEUS-SSC.

2.5.2.2.4 Probabilistic Seismic Hazard Analysis and Controlling Earthquakes

SSAR Section 2.5.2.4 presents the results of the applicant's PSHA for the CRN Site. In performing this analysis, the applicant followed the guidance provided in RG 1.208 to determine the seismic hazard curves and controlling earthquakes for the CRN Site. The applicant based its analysis on the CEUS-SSC model (NUREG–2115) and the EPRI (2013) GMM. The PSHA curves generated by the applicant represent reference hard rock conditions characterized by a shear wave velocity (V_S) in excess of 2.8 kilometers per second (km/s) (9,200 feet per second (fps)). The applicant also described the earthquake potential for the site in terms of a Uniform Hazard Response Spectra (UHRS) and the controlling earthquakes, as defined in RG 1.208. The applicant determined the low- and high-frequency (HF) controlling earthquakes by deaggregating the PSHA curves at selected mean annual frequency-of-exceedance levels. The summary of the applicant's PSHA study is described below.

2.5.2.2.4.1 PSHA Inputs

To conduct the PSHA and obtain the UHRS at the site, it is necessary to study the site location and its surrounding regions to determine the geological and seismological properties, as outlined in RG 1.208. This requires determinations of active seismic source zones in the area, the seismic sources' model parameters, and an appropriate ground motion model (GMM) for the region. The following subsections summarize the applicant's efforts in these areas.

2.5.2.2.4.1.1 Seismic Source Models and Parameters

The input source model for the CRN Site PSHA study is primarily the CEUS-SSC (NUREG–2115). The applicant updated the earthquake recurrence rates and b-values for each of the distributed seismicity sources based upon its seismicity catalog updates.

SSAR Section 2.5.2.2.1 describes how the applicant updated its seismicity catalog to create a comprehensive list of earthquakes for the CRN Site to assess the overall seismicity in the region and also assess the validity of the earthquake recurrence rates used for the CEUS-SSC model. The applicant found that minor changes to seismicity rates from those used for the CEUS-SSC model were warranted based upon the updated seismicity catalog.

2.5.2.2.4.1.2 Ground Motion Models

In SSAR Section 2.5.2.4.2, the applicant stated that it used the CEUS GMM developed by EPRI in 2013 for its PSHA calculations (EPRI, 2013). This model, which consists of 12 individual GMPEs, was reviewed by the staff as part of prior COL application reviews (e.g. North Anna COL; William States Lee III COL) and the staff concluded that it adequately represents the expected ground motion in the CEUS region.

2.5.2.2.4.2 PSHA Methodology and Calculation

Using the CEUS-SSC model (NUREG–2115) and the EPRI 2013 GMPEs, the applicant performed PSHA calculations for peak horizontal ground acceleration (PGA) and horizontal spectral acceleration at ground motion frequencies of 0.5, 1.0, 2.5, 5, 10, and 25 Hz. The applicant performed PSHA calculations for the CRN Site assuming generic hard rock conditions at the site with a V_S of 2.8 km/s (9,200 fps). The applicant first calculated mean and fractile rock seismic hazard curves at the spectral frequencies noted above and annual frequencies of exceedance (10^{-4}, 10^{-5}, and 10^{-6}). The applicant then deaggregated the results as described in RG 1.208 to calculate the controlling earthquakes for low-frequency (LF) and HF ground motions. Finally, the applicant used the CRN Site controlling earthquakes, and hard rock spectral shapes for CEUS earthquake ground motions recommended in NUREG/CR-6728 to calculate the hard rock UHRS.

2.5.2.2.4.3 PSHA results

In SSAR Section 2.5.2.4.3, the applicant stated that local earthquakes are the major contributor to seismic hazard at the CRN Site for both high frequencies (5 and 10 Hz) and low frequencies (1 and 2.5 Hz). However, there is some contribution from the large seismic sources outside the site region, such as the New Madrid Fault System RLME. The applicant demonstrated that the other large seismic sources in the CEUS region, such as the Charleston and Wabash Valley seismic sources, make a minimal contribution to the total hazard.

Table 2.5.2-1 of this report shows the controlling earthquake magnitude and distance combinations for low and high spectral frequencies for the CRN Site. Following guidance in RG 1.208, the applicant developed low frequency inputs for the 10^{-4} and 10^{-5} UHRS for distances greater then 100 km. As shown in Table 2.5.2-1, the applicant reported the nearby, smaller magnitude, controlling earthquake because the 10^{-6} UHRS is not used to calculate the GMRS.

Table 2.5.2-1 Controlling earthquakes for the CRN Site (From SSAR, Table 2.5.2-18)

	Mean 10^{-4}	Mean 10^{-5}	Mean 10^{-6}
Low-frequency **M**[1]	7.5[3]	7.6[3]	6.7
Low-frequency R (km)[1]	380[3]	330[3]	13
High-frequency **M**[2]	5.9	6.1	6.3
High-frequency R (km)[2]	16	12	11

[1]Based on 1 and 2.5 Hz results
[2]Based on 5 and 10 Hz
[3]**M** and R are calculated for R>100 km per RG 1.208

Following the calculations of the controlling earthquake distances and magnitudes, the applicant determined the smoothed UHRS at the reference elevation beneath the site in Figure 2.5.2-2 of this report.

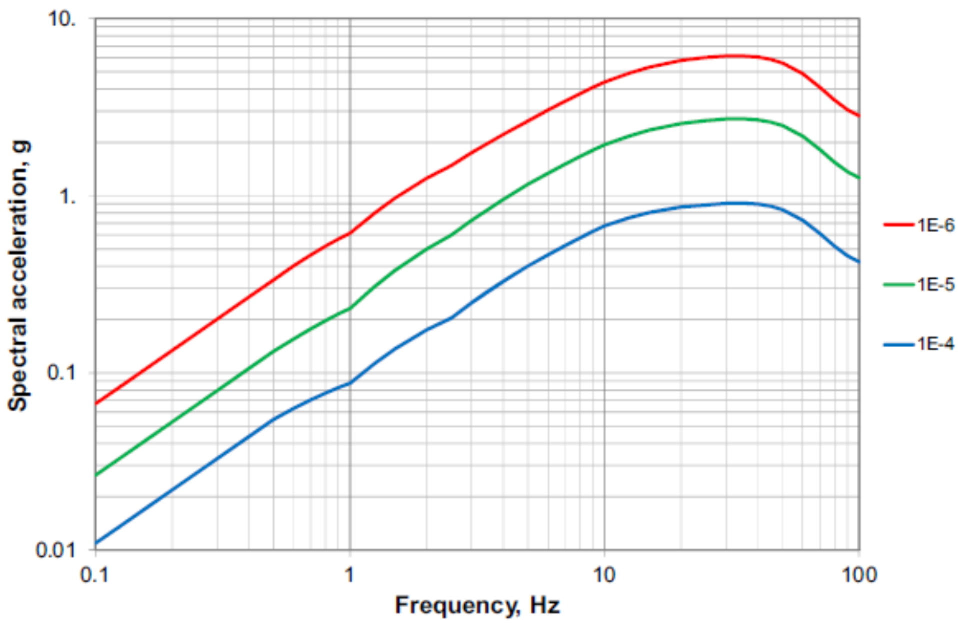

Figure 2.5.2-2: Mean Rock Uniform Hazard Response Spectra (UHRS) for the CRN Site. Modified from SSAR Figure 2.5.2-53

2.5.2.2.5 Seismic Wave Transmission Characteristics of the Site

SSAR Section 2.5.2.5 describes the applicant's development of a site-specific seismic velocity model to characterize seismic wave transmission characteristics of the CRN Site. The EPRI (2013) GMPEs are representative of ground motion at very stiff hard rock sites, which are characterized as sites with Vs of 2.8 km/s (9200 fps). For the CRN Site, the applicant states that these hard rock conditions are encountered at a depth of greater than 3650 m (12,000 ft) beneath the ground surface; while rock of lower Vs exists above in the upper 3650 m (12,000 ft). The applicant conducted a site response analysis to determine the impacts of the lower Vs rocks on the calculated seismic hazard values. The applicant first developed a site response model and then used the random vibration theory (RVT) methodology to calculate the site amplification functions to transfer the generic hard rock hazard curves to the near-surface GMRS elevation. The following sections summarize the applicant's site response calculation procedures.

2.5.2.2.5.1 Site Response Model

The applicant stated that the subsurface of the CRN Site is characterized by rock strata with a dip angle of greater than 30 degrees. As such, the applicant developed a site-specific mean V_S profile for the upper 3650 m (12,000 ft) beneath the ground surface for two locations (termed Location A and Location B) at the CRN Site to account for the dipping subsurface and to accommodate the relatively small footprint of small modular reactors. The applicant stated that the shallow subsurface V_s was determined using downhole suspension logging data collected at the site. In addition, the applicant stated that data collected at nearby TVA dam sites was reviewed and used as appropriate.

The applicant stated that geologic profiles for locations A and B (with similar subsurface geology) were developed using stratigraphic cross-sections (SSAR Figures 2.5.4-12 and

2.5.4-13) and that separate geologic profiles were developed for each location. The applicant developed a best case Vs profile for each location using available geophysical data. These profiles extended to depths of between 91 and 106 m (300 – 350 ft) beneath the GMRS elevation. Below this depth, the applicant stated that there is no data for rock units at the site. Therefore, the applicant used available data from the Watts Bar Two Nuclear Plant which has the same (similar) age rock strata and considered the depth dependent nature of seismic velocities using generic relationships for the CEUS to develop deeper portions of the V_S profiles. The applicant used regional stratigraphic cross-sections to define layer boundaries at depths greater than 100 m (300 ft). Figure 2.5.2-3 of this report shows the applicant's base case V_S profiles for Locations A and B.

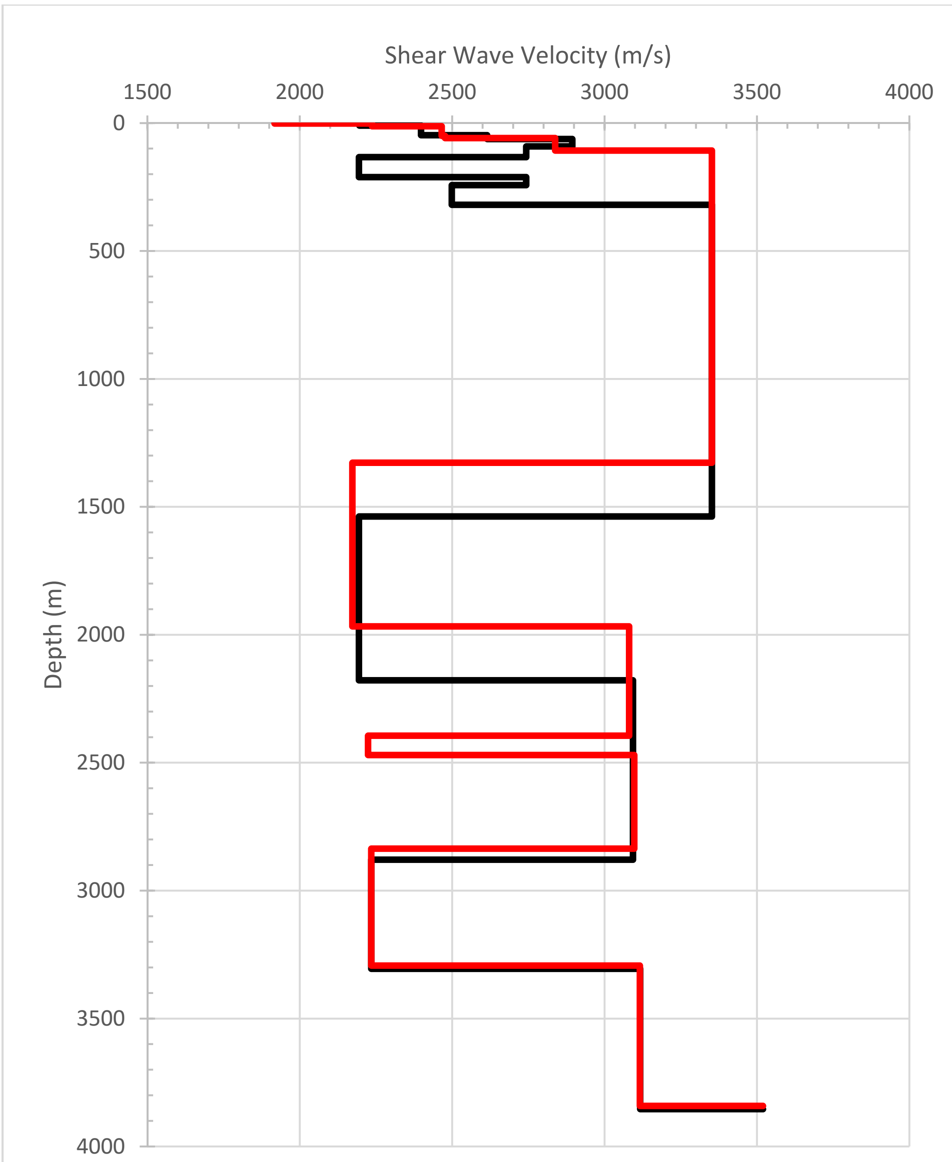

Figure 2.5.2-3: Base case velocity profiles for Area A (Black) and Area B (Red) used by applicant in site response analysis based on SSAR Tables 2.5.4-30 and 2.5.4-31

The applicant developed these profiles considering the variability of all available profiles for the site. The applicant determined that a lognormal standard deviation of 0.15 was appropriate for conditions at the site and determined a 5 and 95 percentile (lower and upper, respectively) case velocity profile based on this standard deviation. SSAR Figures 2.5.4-20 and 2.5.4-21 show all three base cases for Locations A and B, respectively. The applicant gave the lower (0.2), base (0.6), and upper (0.2) V_S profiles different weights in the site response evaluation. The applicant also considered nonlinear and linear responses, which it gave equal weight in the site response evaluation. For the nonlinear case, the applicant used modified EPRI rock (Silva, et al., 1996) damping and shear modulus degradation (G/G_{max}) curves with the low-strain damping adjusted to 2 percent to account for the firm nature of the rocks. For the linear case, the applicant used a constant damping value of 1.25 percent. For rock layers deeper than 150 m (500 ft), the applicant used site kappa (low-strain damping) values determined from earthquake spectra recorded at the nearby Tellico Dam site to constrain the total amount of site damping.

2.5.2.2.5.2 Site Response Methodology and Results

Consistent with RG 1.208, the applicant performed its site response analysis using Approach 3 as described in NUREG CR/6728. Approach 3 is a fully probabilistic approach to incorporating site response into the PSHA. The applicant first generated 60 random profiles for each site profile and associated shear moduli and damping parameters. The applicant computed the site amplification factors as characterized by a mean and distribution for each set of site profiles using the RVT methodology. As input to the RVT methodology, the applicant selected an **M**5.5 and an **M**7.5 earthquake spectra to represent HF and LF inputs. These two spectra were given equal weight in determining the amplification factors. The applicant finally integrated the fractile and mean hazard curves for the reference hard rock conditions with the site amplification factors to arrive at a set of site-specific hazard curves for the CRN Site.

In summary, the applicant's site response calculations resulted in a suite of amplification functions that are combined with the site-specific hard rock seismic hazard curves to generate site-specific hazard curves at the GMRS elevation. As shown in Figure 2.5.2-4, the amplification factors for the CRN Site do not differ significantly from one at frequencies lower that 20 Hz. The dip in amplification factors at high frequencies varies as a function of input ground motion and is an effect of nonlinearity on site response.

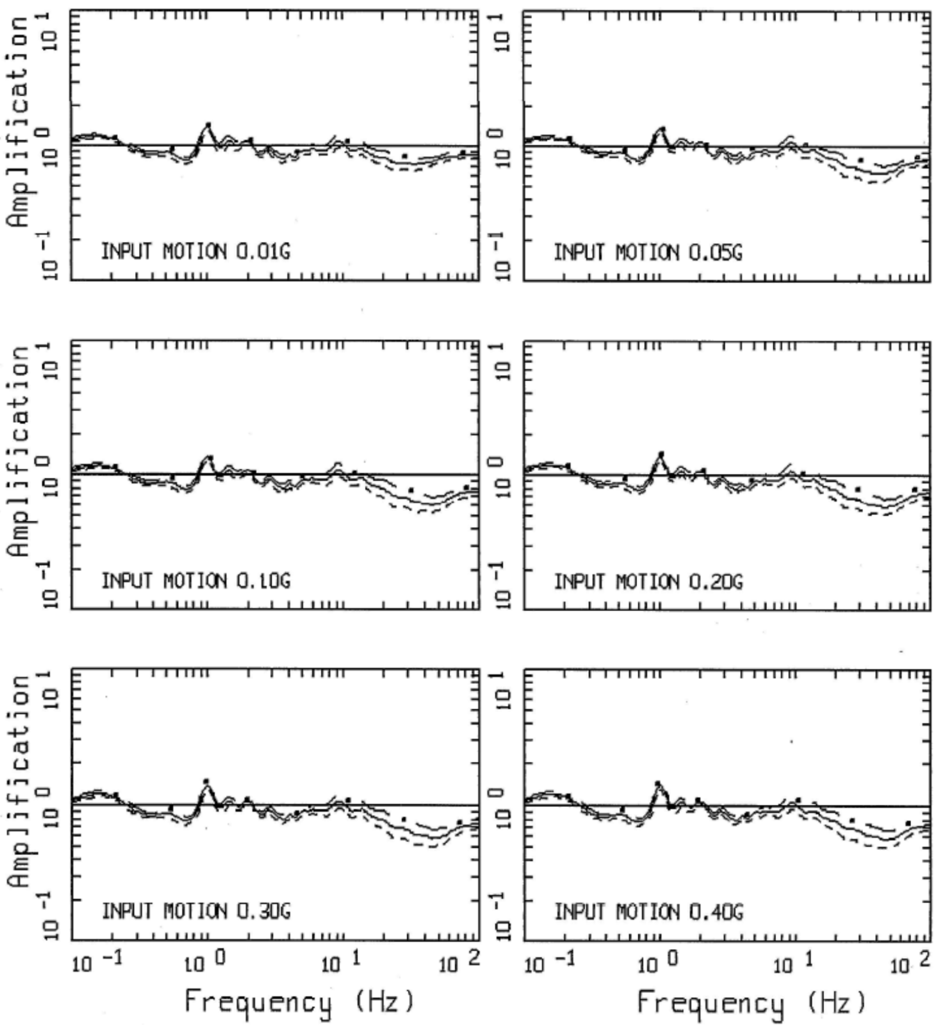

Figure 2.5.2-4: Horizontal amplification factors for base case profile at Area A considering an M5.5 input response spectrum (From SSAR, Figure 2.5.2-62)

2.5.2.2.6 2D Sensitivity Analysis

To investigate the impact of the 30 degree dip of rock layers on site response results, the applicant performed a two dimensional (2D) sensitivity analysis. The applicant stated that the sensitivity analysis was performed to investigate how the simplifying nature of the traditional one dimensional (1D) analysis impacts site response results and ensures that the epistemic uncertainty considered in the 1D analysis adequately accounts for potential 2D effects.

The applicant developed a 2D finite element model using the stratigraphic model considered in developing the 1D site response inputs. The applicant performed the analysis using Structural Dynamics Engineering - System for Analysis of Soil Structure Interaction (SDE-SASSI) Version 2.0 with input basement rock time histories consistent with the seismic hazard at the site. The applicant stated that the 2D sensitivity results for the best-estimate profile indicates no significant differences from the 1D response. Based on this result, the applicant determined that 2D effects at the CRN Site were negligible.

2.5.2.2.7 Ground Motion Response Spectra

SSAR Section 2.5.2.8 describes the method used by the applicant to develop the horizontal and vertical site-specific GMRS. The applicant first developed the horizontal GMRS and then obtained the vertical GMRS using vertical to horizontal (V/H) ratios.

2.5.2.2.7.1 Horizontal GMRS

The applicant calculated a horizontal, site-specific, performance-based GMRS using the method described in RG 1.208. The performance-based method achieves the annual target performance goal (P_F) of 10^{-5} per year for frequency of onset of significant inelastic deformation. This damage state represents a minimum structural damage state, or essentially elastic behavior, and falls well short of the damage state that would interfere with functionality. The GMRS is calculated using the following relationship.

$$GMRS = UHRS * DF$$

where

$$UHRS = UHRS_{10^{-4}}$$

$$DF = max\{1.0, 0.6(A_R)^{0.8}\}$$

$$A_R = \frac{UHRS_{10^{-5}}}{UHRS_{10^{-4}}}$$

RG 1.208 also states, if A_R, as defined above, is greater than 4.2, then this relationship is no longer valid. In this case, RG 1.208 recommends setting the GMRS to 45 percent of the 10^{-5} site-specific surface UHRS curve. Figure 2.5.2-5 of this report shows the horizontal GMRS curve calculated for the CRN Site by the applicant for both Locations A and B, as well as the envelope of these two spectra.

2.5.2.2.7.2 Vertical GMRS

In SSAR Section 2.5.2.7, the applicant used the V/H ratios form NUREG/CR-6728 and incorporated epistemic uncertainty determined from a literature survey. Similar to the approach taken to developing the horizontal amplification factors. The applicant used the site-specific horizontal hazard curves and integrated V/H ratios and their associated uncertainties to develop site-specific vertical seismic hazard curves. Figure 2.5.2-5 of this report shows the vertical GMRS curve calculated for the CRN Site by the applicant.

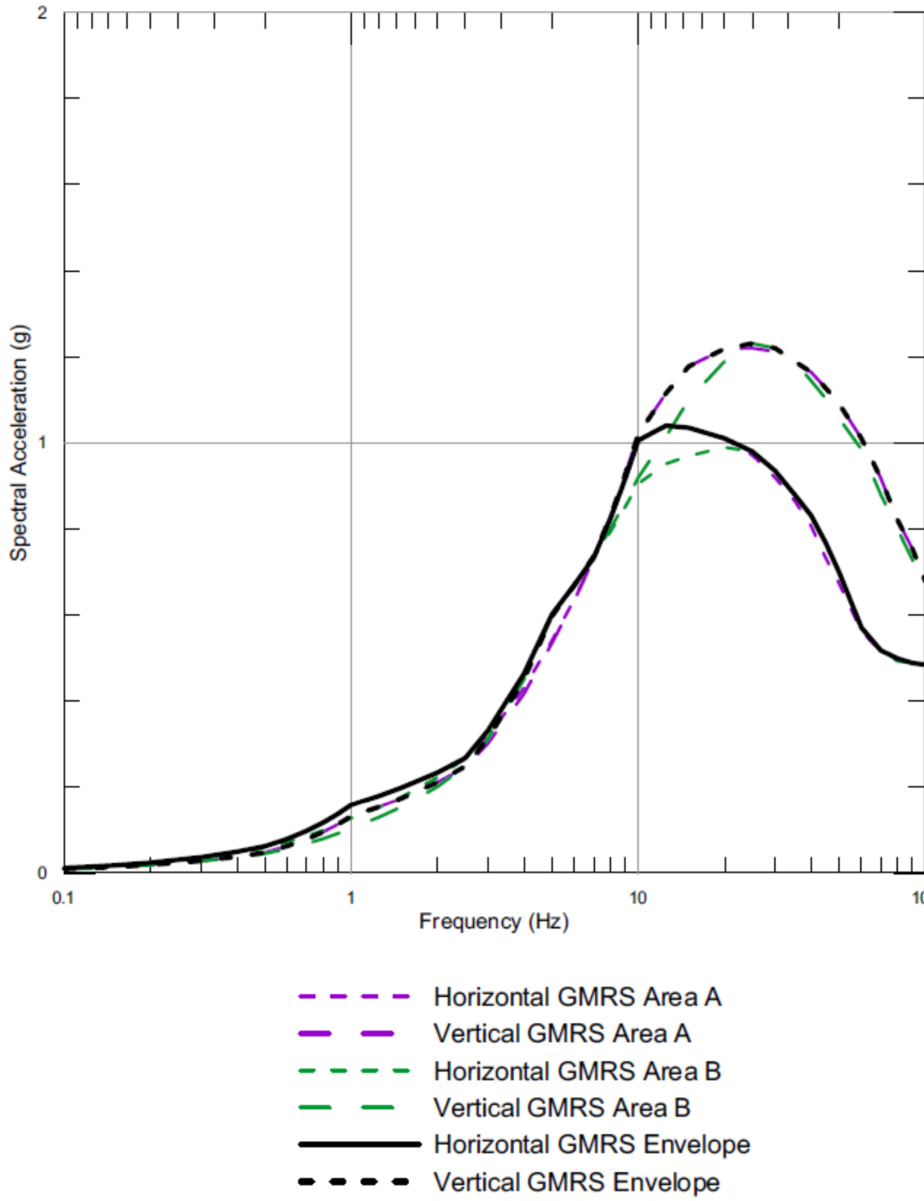

Figure 2.5.2-5: Horizontal (solid black) and Vertical (dashed black) GMRS for the CRN Site (From SSAR Figure 2.5.2-78)

2.5.2.3 Regulatory Basis

The applicable regulatory requirements for reviewing the applicant's discussion of vibratory ground motion are as follows:

- 10 CFR 100.23(c) as it relates to obtaining sufficient geological and seismological information to support the estimates of the SSE ground motion.

- 10 CFR 100.23(d)(1) as it relates to the establishment of the SSE ground motion considering appropriate uncertainties through an appropriate analysis such as a PSHA or suitable sensitivity analyses.

- 10 CFR 52.17(a)(1)(vi), as it relates to consideration of the most severe of the natural phenomena that have been historically reported for the site and surrounding area and with sufficient margin for the limited accuracy, quantity and period of time in which the historical data have been accumulated.

In addition, the related acceptance criteria from NUREG–0800, Section 2.5.2 are summarized as follows:

- Seismicity: To meet the requirements of 10 CFR 100.23, this SSAR section is accepted when the complete historical record of earthquakes in the region is listed and when all available parameters are given for each earthquake in the historical record.

- Geologic and Tectonic Characteristics of the Site and Region: Seismic sources are identified and characterized.

- Correlation of Earthquake Activity with Seismic Sources: To meet the requirements of 10 CFR 100.23, acceptance of this SSAR section is based on the development of the relationship between the history of earthquake activity and seismic sources of a region.

- Probabilistic Seismic Hazard Analysis and Controlling Earthquakes: For CEUS sites relying on NUREG–2115 methods and data bases, the staff will review the applicant's PSHA, including the underlying assumptions and how the results of the site investigations are used to update the existing sources in the PSHA, how they are used to develop additional sources, or how they are used to develop a new data base.

- Seismic Wave Transmission Characteristics of the Site: In the PSHA procedure described in RG 1.208, the controlling earthquakes are determined for generic rock conditions.

- Ground Motion Response Spectra: In this section, the staff reviews the applicant's procedures to determine the GMRS. In addition, the geological and seismic characteristics should be consistent with appropriate sections from: RG 1.60, "Design Response Spectra for Seismic Design of Nuclear Power Plants," RG 1.132; RG 1.206, "Combined License Applications for Nuclear Power Plants (LWR Edition)," and RG 1.208.

2.5.2.4 Technical Evaluation

The staff reviewed Section 2.5.2 of the application to verify that the information represented the complete scope of information relating to the characterization of vibratory ground motion for the CRN Site. The staff's review confirmed that the CRN Site ESP application addresses the required information related to the vibratory ground motion.

Section 2.5.2.4 of this safety evaluation report (SER) provides the staff's evaluation of the seismic, geologic, geophysical, and geotechnical investigations carried out by the applicant to determine the site-specific GMRS leading to the estimation of the SSE ground motion for the

CRN Site. The development of the GMRS is based upon a detailed evaluation of earthquake potential, taking into account the regional and local geology, Quaternary tectonics, seismicity, and site-specific geotechnical engineering characteristics of the CRN Site subsurface material.

On July 17-18, 2013, during the early site investigation stage, the staff visited the site and interacted with the applicant regarding the geologic, seismic, and geotechnical investigations for the ESP application (NRC, 2013 - Agencywide Documents Access and Management System (ADAMS) Accession No. ML13210A307). The staff made an additional visit to the CRN Site in May 2017, to confirm interpretations, assumptions, and conclusions presented by the applicant related to potential geologic and seismic hazards (NRC, 2017 - ADAMS Accession No. ML17223A428). As discussed at the beginning of this report Section 2.5, "Geology, Seismology, and Geotechnical Engineering", the staff issued several RAIs to the applicant and evaluated the responses received during the review process.

2.5.2.4.1 Seismicity

SSAR Section 2.5.2.1 states that the earthquake catalog used for the CRN Site seismic hazard assessment is the CEUS-SSC earthquake catalog, supplemented with earthquakes occurring between 2009 and mid-September of 2013. The earthquake catalog, published as part of the CEUS-SSC model, covers the entire CEUS region from 1568 through 2008 and includes a uniform moment magnitude scale for all earthquakes listed in the catalog. Because the staff reviewed the CEUS-SSC earthquake catalog previously, the staff technical evaluation of SSAR Section 2.5.2.1 focused on the applicant's efforts to update the CEUS-SSC earthquake catalog for use in the CRN Site PSHA. The CEUS-SSC earthquake catalog covers the seismicity of the region through 2008; as such, the applicant provided a quantitative analysis in the SSAR of earthquakes occurring within 320 km (200 mi) of the site from 2009 through mid-September 2013. In addition to documenting the seismic activity in the site region, the applicant also updated the seismicity rates and b-values developed in the CEUS-SSC model to account for potential changes in seismicity patterns since 2008.

As part of its confirmatory analysis, the staff developed a supplementary earthquake catalog covering the CEUS region from 2013 through July 30, 2017. The staff used the USGS National Earthquake Information Center[1] earthquake catalog for this analysis. The staff reviewed its confirmatory catalog to determine whether there are new earthquakes in the CEUS region since the submission of the CRN Site ESP application that might impact either the M_{max} of the seismic sources identified in the CEUS-SSC model or the earthquake recurrence rates calculated for each of the CEUS-SSC seismic sources used for the CRN Site PSHA. The staff searched for earthquakes in its confirmatory catalog with magnitude 2.9 and above within the time window from October 2013 through July 30, 2017, and within 500 km of the CRN Site. Figure 2.5.2-6 of this report shows the results of the staff's earthquake search. As shown in Figure 2.5.2-6, there are no recent significant earthquakes within 500 km of the site nor are there any new clusters of seismic activity not captured by the CEUS-SSC model. In particular, the staff's catalog showed that there were 31 earthquakes that occurred between October 2013 and July 30, 2017. None of these earthquakes have magnitudes greater than **M**5.0 and the majority of the earthquakes identified by the staff in its supplementary catalog are small (**M**<4.0). Therefore, the staff

[1] National Earthquake Information Center (NEIC), NEIC Catalog Search, https://earthquake.usgs.gov/earthquakes/search/

concludes from its confirmatory analysis that the earthquakes in the staff's supplementary catalog support the information used in the applicant's catalog for its PSHA.

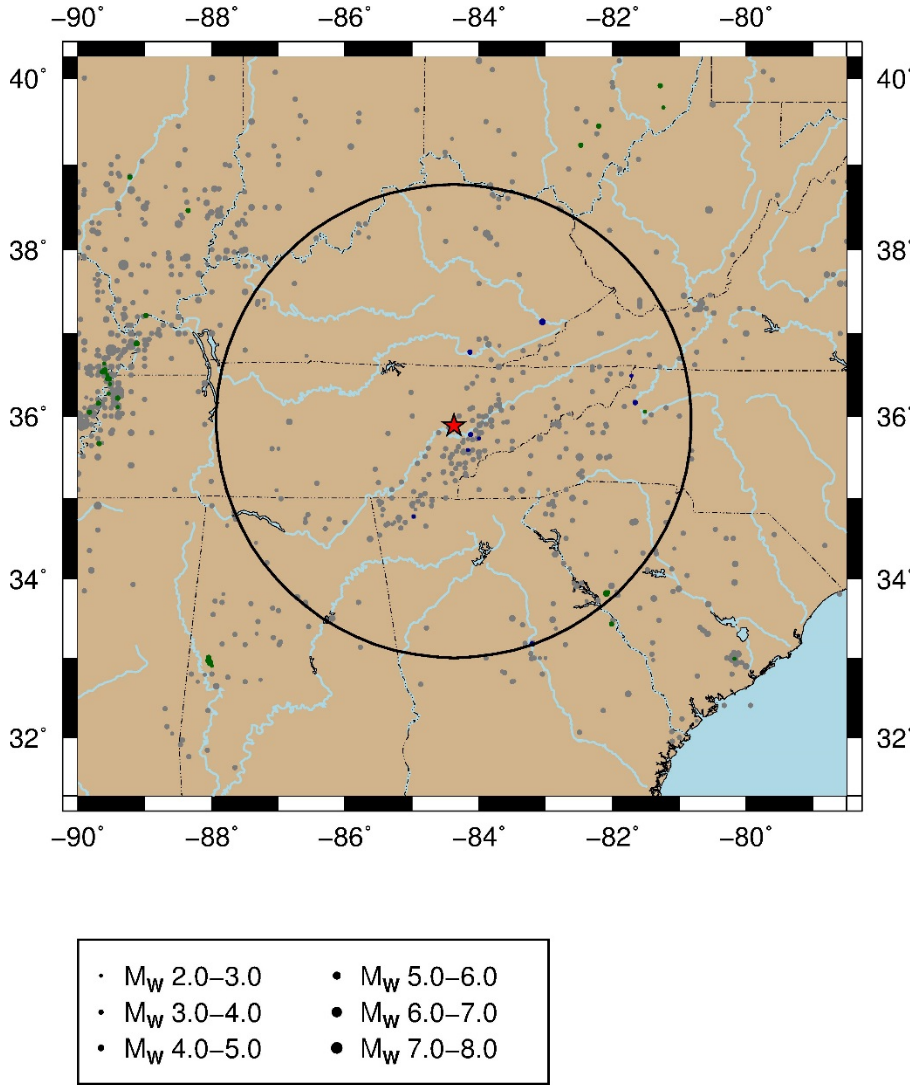

Figure 2.5.2-6: Map of the staff's supplementary earthquake search. Grey dots are earthquakes included in NUREG–2115 catalog (M>2.9). Dark blue dots are M>2.9 earthquakes added by the applicant to the catalog between 2009 and mid-September 2013. Dark green dots are those M>2.9 earthquakes identified by the staff occurring between October 2013 and July 30, 2017. The black circle marks the 320 km (200 mi) radius from the CRN Site.

2.5.2.4.1.1 Staff Conclusions Regarding Seismicity

Based on its review of the applicant's SSAR Section 2.5.2.1 and the staff's confirmatory assessment of the CEUS-SSC seismicity catalog, the staff concludes that the applicant developed a complete and accurate earthquake catalog for the region surrounding the CRN Site. The staff concludes that the seismicity catalog as described by the applicant in SSAR

Section 2.5.2.1 forms an adequate basis for the seismic hazard characterization of the site and meets the requirements of 10 CFR 52.17(a)(1)(vi) and 10 CFR 100.23.

2.5.2.4.2 Geologic and Tectonic Characteristics of the Site and Region

SSAR Section 2.5.2 describes the seismic sources and seismicity parameters used by the applicant to calculate the seismic ground motion hazard for the CRN Site. Specifically, the applicant described the CEUS-SSC model, published as NUREG–2115 in 2012.

The staff previously reviewed the CEUS-SSC seismic source model and approved its use as a starting regional model for nuclear power plant applications. However, the CEUS-SSC model is a regional model and NUREG–2115 specifically states that it should be compared against potential nearby local seismic sources to determine if refinements to the CEUS-SSC model are necessary to account for changes in earthquake magnitude, location, or recurrence rates. As such, the staff primarily focused on the applicant's investigation of potential local seismic sources and source parameter adjustments to the CEUS-SSC model.

2.5.2.4.2.1 Modifications to CEUS-SSC Model Due to Updated Earthquake Catalog

The applicant's updated earthquake catalog (2009-2013) identified six earthquakes with the potential to impact the site hazard. Of these six earthquakes, five are located within 320 km (200 mi) of the site. The largest earthquake is the **M**5.9 in August 23, 2011, Mineral, Virginia earthquake, which is 615 km (380 mi) from the CRN Site. Studies of the Mineral, Virginia earthquake resulted in minor changes to the CEUS-SSC model, particularly an increase in the minimum M_{max} value for one of the CEUS-SSC source zones (Extended Continental Crust – Atlantic Margin).

The applicant evaluated its updated seismicity catalog to determine if changes to the recurrence rates developed for the sources in the CEUS-SSC model are necessary. Based on its evaluation, the applicant determined that minor changes to the seismicity rates and b-values were warranted for 10 of the CEUS-SSC sources. To update the recurrence parameters for the CEUS-SSC sources, the applicant used the same methodology that was originally used for the published model.

To assess the applicant's update of the recurrence parameters for the CEUS-SSC models, the staff reviewed the applicant's methodology, updated parameters, and performed its own independent confirmatory analysis, discussed in Section 2.5.2.4.4.2 of this SER. In considering the applicant's updated recurrence parameters, the staff reviewed the updated catalog and the applicant's maps of updated recurrence parameters (e.g., SSAR Figure 2.5.2-27). The updates to the recurrence parameters as a result of catalog updates are minimal and have a negligible impact on the PSHA results as shown in Figure 2.5.2-7 of this report. Based on the staff's review and confirmatory analysis, the staff has determined that the applicant's updates are acceptable.

2.5.2.4.2.2 Modifications to CEUS-SSC Seismic Source Model

In NUREG–2115, Chapter 9, "Use of the CEUS-SSC Model in PSHA," describes the approximations or simplifications that applicants may implement when using the CEUS-SSC model. The primary simplification used by the applicant was to model the CEUS-SSC background seismic sources as point sources rather than as finite ruptures with multiple fault orientations, dips, and crustal thicknesses. The applicant noted that a sensitivity study performed during the development of the CEUS-SSC model found that these simplifications had a minor impact on the overall hazard results. However, as recommended in NUREG–2115, the applicant did include the finite fault ruptures for the CEUS-SSC New Madrid and Charleston RLME sources. The applicant also included the simplifications needed to combine the CEUS-SSC with the EPRI (2013) GMM, such as exclusion of the sense of fault slip and simplification of the depth distribution to a single value. Based on the fact that the above simplifications are determined to be acceptable in the CEUS-SSC, necessary for use with the EPRI (2013) GMM, and have been demonstrated to have a small impact on the overall hazard (e.g., NUREG–2202), these simplifications are acceptable.

2.5.2.4.2.3 Consideration of the Eastern Tennessee Seismic Zone

SSAR Section 2.5.2.2 discusses analyses performed by the applicant to assess the CEUS-SSC source models developed to characterize the seismicity associated with the ETSZ. The ETSZ is located to the east of the CRN Site and is a defined region approximately 300 km (186 mi) long and less than 100 km (62 mi) wide. It is one of the most active seismic regions in eastern North America in terms of seismic rate. The ETSZ is associated with small (**M**<5.0) earthquakes with the 1973 **M**4.6 Fort Payne, Alabama earthquake being the largest historical earthquake. The CEUS-SSC models do not characterize the ETSZ as an RLME since definitive paleoseismic evidence of previous ruptures has not yet been discovered. Instead, the CEUS-SSC characterizes the ETSZ using background source zones. The Paleozoic Extended Crust source zone, which is the highest weighted CEUS-SSC zone that covers the ETSZ, has a M_{Max} distribution that ranges from M5.9 to M7.9 with M6.8 receiving the most weight. Because the ETSZ is covered by a background source zone, Chapter 5.3 of NUREG–2115 describes the sensitivity studies conducted by the model developers to ensure that the distributed seismicity approach does not artificially dilute the seismic hazard for sites near the ETSZ. The CEUS-SSC model is based on the assumption that the spatial stationarity of seismicity in the CEUS will persist for time periods of interest for well-engineered critical facilities (i.e., approximately the next 50 years). However, because the locations of the generally small- to moderate-magnitude CEUS earthquakes that are covered by the CEUS-SSC background zones are not tightly constrained, a moderate amount of spatial smoothing is used in the CEUS-SSC models to allow for the occurrence of earthquakes over a broader area.

A recent geologic study of potential paleoseismic features with the ETSZ (Hatcher et al., 2012) has hypothesized that the ETSZ has produced at least two **M**≥6.5 earthquakes in the last approximately 73 to 112 thousand years. Due to this recent study, the applicant undertook a SSHAC Level 2 assessment of potential paleoseismic features associated with the ETSZ. The applicant performed two sensitivity studies to determine if the ETSZ needs to be considered as an RLME rather than as a background zone for the CRN Site PSHA.

In its first study, the applicant investigated the implications of the Hatcher et al. (2012) study with respect to the CEUS-SSC M_{max} distributions for the sources that encompass the ETSZ. The applicant compared the M_{max} suggested by Hatcher et al. (2012), which is approximately **M**=7.5, with the M_{max} distributions for the CEUS-SSC source zones that encompass the ETSZ. The M_{max} distributions for the CEUS-SSC source zones that encompass the ETSZ range from M5.9 to M8.1 with the highest weights for M6.8 to M7.3. Based on this comparison of M_{max} values, the applicant concluded that no update to this parameter is required for any of the CEUS-SSC sources.

For the second study, the applicant used the magnitude-frequency distributions assigned to the CEUS-SSC sources to determine if these sources produced large earthquakes frequently enough to account for the recently postulated paleoseismic features. The applicant's analysis showed that the CEUS-SSC Paleozoic Extended Zone seismotectonic source (the highest weighted host zone for the ETSZ) produces **M**6.5 earthquakes approximately every 13,000 years and **M**7.0 earthquakes approximately every 88,000 years. These recurrence intervals are broadly consistent with the proposed rates from the Hatcher et al. (2012) study. Therefore, the applicant determined that no updates to the magnitude recurrence rates of the CEUS-SSC models are required.

The staff reviewed both of the applicant's sensitivity studies and the Hatcher et al. (2012) study (and references therin) regarding the potential for large earthquakes in the ETSZ. Based on the preliminary nature of the geologic studies and the fact that CEUS-SSC model adequately accounts for the potential for large earthquakes at expected recurrence rates, the staff agrees with the applicant's assertion that no modifications to the CEUS-SSC model are required to explicitly model the seismicity associated with the ETSZ.

2.5.2.4.2.4 Staff Conclusions Regarding Geologic and Tectonic Characteristics of the Site and Region

Based on its review of SSAR Sections 2.5.2.2 and 2.5.2.4, the staff concludes that the applicant adequately assessed the CEUS-SSC models as input to its PSHA for the CRN Site. In addition, the staff concludes that the applicant adequately considered modifications to the CEUS-SSC model for the CRN Site. The staff concludes that the applicant's use of the CEUS-SSC models as described by the applicant in SSAR Sections 2.5.2.2 and 2.5.2.4 forms an adequate basis for the seismic hazard characterization of the site and meets the requirements of 10 CFR 52.17(a)(1)(vi) and 10 CFR 100.23.

2.5.2.4.3 Correlation of Earthquake Activity with Seismic Sources

In SSAR Section 2.5.2.3 describes the correlation of seismicity in the region with the seismic source model used in the CRN Site PSHA study. The applicant noted that the CEUS-SSC model uses earthquake locations and characteristics in defining the seismic source geometries. The applicant compared the CEUS-SSC seismicity catalog with its updated catalog to assess any changes in patterns of seismicity. The applicant also examined the catalogs to determine if there exists any correlation between geologic structures and seismicity not identified within the CEUS-SSC study that needs to be accounted for at the CRN Site. Based on the staff's review of the applicant's assessment, its updated seismicity catalog, and the staff's confirmatory analysis described in Section 2.5.2.4.1 of this report, the staff concludes that the applicant's characterization of the correlation of earthquake activity is adequate.

2.5.2.4.4 Probabilistic Seismic Hazard Analysis and Controlling Earthquakes

In SSAR Section 2.5.2.4, the applicant stated that it used the CEUS-SSC model and the EPRI (2013) GMM to develop base hard rock seismic hazard curves for the CRN Site. Subsequently, using the hard rock seismic hazard curves, the applicant obtained UHRS at the annual frequency of exceedances of 10^{-4}, 10^{-5}, and 10^{-6}. In addition, using the procedures outlined in RG 1.208, the applicant also determined the controlling earthquake magnitude and distance combinations for both LF and HF ground motions. The following subsections describe the staff's assessment of the applicant's PSHA and its determination of the controlling earthquakes.

2.5.2.4.4.1 PSHA Inputs

As described in Section 2.5.2.2.4 of this report, the applicant implemented the CEUS-SSC model with updated seismicity parameters, consistent with guidance provided in RG 1.208. The applicant also considered the potential impact of the ETSZ on seismic hazard and determined that the CEUS-SSC model adequately captures the hazard from this region of elevated seismicity. The applicant's PSHA inputs, including its decision to update the seismicity parameters for the CEUS-SSC sources, are consistent with RG 1.208; therefore, the staff concludes that the applicant's PSHA inputs are adequate.

2.5.2.4.4.2 PSHA Calculation and Confirmatory Analysis

Using the CEUS-SSC model and the EPRI (2013) GMM, the applicant performed PSHA calculations for PGA and ground motion frequencies of 25, 10, 5, 2.5, 1, and 0.5 Hz. As described in Section 2.5.2.4.2 of this report, the applicant implemented a simplification in the seismic hazard calculations of the background seismic sources used to determine total seismic hazard at the site. The applicant's simplification was to implement the point source model as described in Section 9.3.1.11 of NUREG–2115 when calculating the hazard of background seismic sources. As described in Section 2.5.2.4.2.2, the staff determined that the applicant's simplification was acceptable and would result in the adequate calculation of seismic hazard at the CRN Site.

As part of its confirmatory analysis, the staff used the CEUS-SSC model background (distributed seismicity) sources and independently calculated the seismic hazard curves at the CRN Site for all seven ground motion frequencies defined in the EPRI (2013) GMPEs. The staff's confirmatory calculations also included RLME sources. From the CEUS-SSC model, the staff first selected all background seismic sources that are within 640 km (400 mi) of the site, which is consistent with the applicant's approach. Also consistent with the approach taken by the applicant, the staff included all RLME sources within 1000 km (620 mi) of the site. For its confirmatory PSHA, the staff used the original seismicity rates specified in the CEUS-SSC model rather than the updated rates used by the applicant. Figure 2.5.2-7 of this report shows the staff's results compared to those of the applicant for PGA and ground motion frequencies of 10 and 1 Hz. The staff confirmatory calculations show that for the annual exceedance frequencies of 10^{-4}, 10^{-5}, and 10^{-6}, the staff's seismic hazard curves are in good agreement with the applicant's seismic hazard curves. As such, the staff concludes that the applicant's update of the seismicity rates for the CEUS-SSC sources does not have a significant impact on the final base rock hazard results. Based on its confirmatory analysis, the staff concludes that the applicant adequately characterized the mean seismic hazard at the CRN Site.

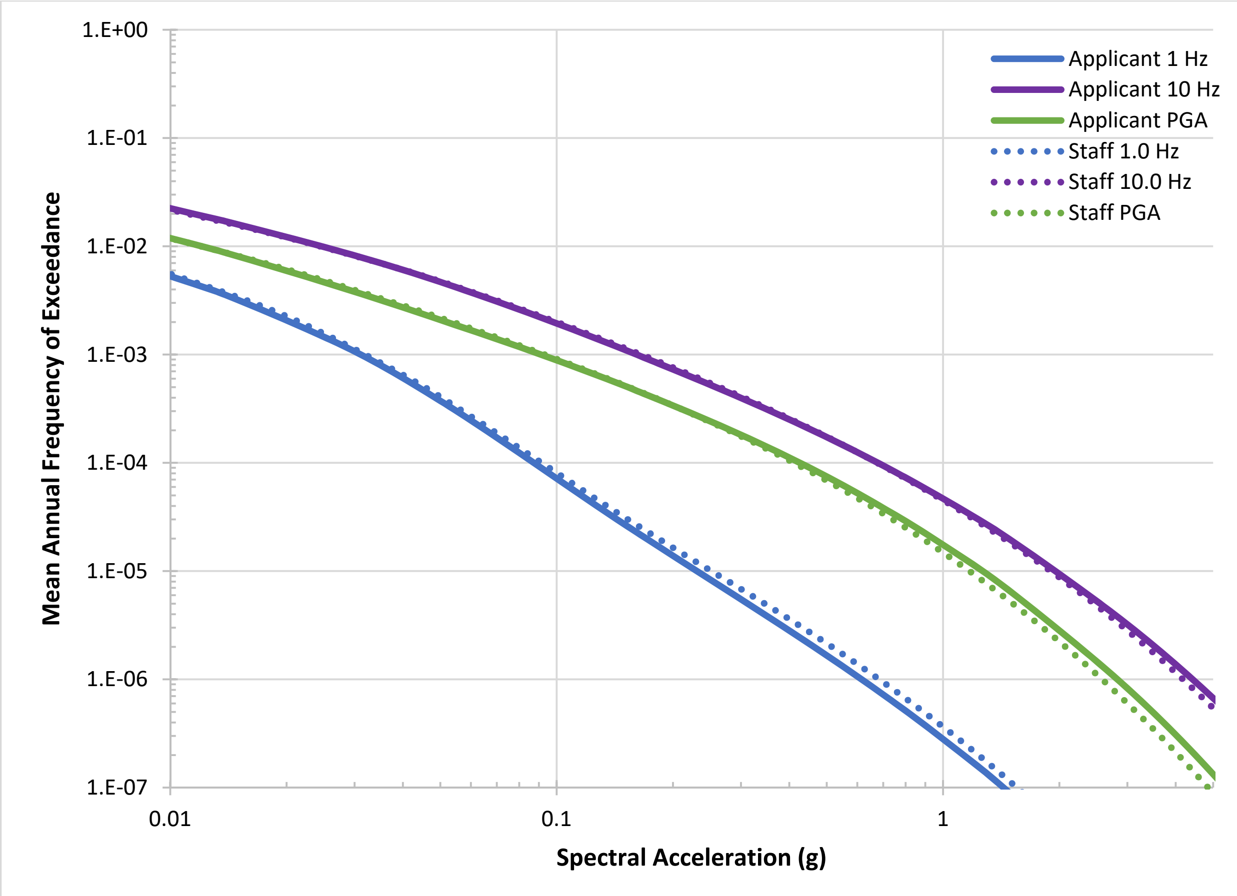

Figure 2.5.2-7: Comparison of applicant's base rock hazard curves with the staff's confirmatory hazard curves for the CRN Site

2.5.2.4.4.3 Controlling Earthquakes

To determine the LF and HF controlling earthquakes' magnitudes and distances, the applicant used a procedure called deaggregation. The applicant followed the deaggregation procedures outlined in RG 1.208, Appendix D. The deaggregation results showed that local seismic sources within 100 km (62 mi) of the CRN Site are the primary contributors to the HF seismic hazard at the site, while the RLME sources as well as regional sources were contributors to the LF seismic hazard at the site. Table 2.5.2-1 of this report shows the applicant's deaggregation results for the mean 10^{-4}, 10^{-5}, and 10^{-6} PSHA results. As shown in Table 2.5.2-1, for the HF hazard, the controlling earthquakes are those with magnitudes of approximately **M**6.0 occurring near the site. For the LF hazard, the controlling earthquakes are several hundred kilometers away with magnitudes of approximately **M**7.5. As such, the applicant selected the magnitudes of **M**5.5 and **M**7.5 to use for the development of input motions for its site response analysis, as described below in Section 2.5.2.4.5.

Because the applicant used the guidance outlined in RG 1.208 to determine the controlling earthquake magnitude and distance, the staff concludes that the procedures used by the applicant are adequate and the resultant controlling earthquake parameters are representative of the controlling earthquakes in the region.

2.5.2.4.4.4 Staff Conclusions Regarding PSHA and Controlling Earthquakes

Based on its review of the applicant's PSHA and independent confirmatory PSHA, the staff concludes that the applicant's PSHA adequately characterizes the seismic hazard for the CRN Site and that the controlling earthquakes determined by the applicant are representative of the earthquakes that would be expected to contribute the most to the hazard.

2.5.2.4.5 Seismic Wave Transmission Characteristics of the Site

In SSAR Section 2.5.2.5 describes the method used by the applicant to develop the CRN Site amplification functions and the control point elevation seismic hazard curves. For its site response analysis the applicant selected the control point elevation to be at depth of 42 m (138 ft) below the surface grade elevation of 250 m (821 ft) mean sea level. As described above in Section 2.5.2.4.4, the base rock seismic hazard curves calculated by the applicant were developed assuming the EPRI (2013) GMM reference rock V_S of 2.8 km/s (9,200 fps). The applicant stated that these hard rock conditions are encountered at a depth of 92 m (302 ft) beneath Location A and at a depth of 50 m (161 ft) beneath Location B at the site. However, because there are minor V_S reversals for some of the deeper rock strata beneath the site, the applicant extended its V_S profiles down to a depth of approximately 3650 m (12,000 ft) below the GMRS elevation at the CRN Site. To determine the amplification of this 3650 m (12,000 ft) profile of rock with respect to the base rock, the applicant performed a site response analysis. The output of the applicant's site response analysis are the site amplification functions, which are then convolved with the base rock seismic hazard curves to determine the control point seismic hazard curves at the GMRS elevation.

2.5.2.4.5.1 Site Response Inputs and Methodology

In SSAR Sections 2.5.4.2, 2.5.4.4, and 2.5.4.7, the applicant described its base case rock profiles in terms of the V_S, layer thicknesses, material damping, and strain-dependent properties, which the applicant used as the input models to its site response calculations. The applicant stated that the upper portions of the profiles for the CRN Site subsurface are based on the numerous site geophysical and geotechnical investigations, which are described in detail in SSAR Section 2.5.4. For the deeper portions of the profiles, the applicant used geophysical measurements of the same rock strata (Conasauga shale, Rome Formation sandstone, and Pumpkin Valley shale) made for the Watts Bar 2 site, located approximately 50 km (31 mi) to the southwest as a guide.

The applicant accounted for dip in the rock strata beneath the site through the development of multiple base case profiles. In Request for Additional Information eRAI-8893 (RAI No. 3), Question 2.5.2-2 (NRC, 2017 – ADAMS Accession No. ML17172A689), the staff requested that the applicant provide a more explicit explanation of the manner in which the use of multiple profiles was expected to account for dipping layers in the subsurface. In the applicant's response to eRAI-8893 (RAI No. 3), Question 2.5.2-2, dated July 17, 2017 (TVA, 2017 - ADAMS Accession No. ML17201F323), the applicant stated that its development of three base cases for each site profile (Location A and Location B) are to account for the fact that each geologic unit is encountered at a different depth across the footprint of the site as well as potential 2D site effects in the upper 91 m (300 ft). The staff reviewed the applicant's response to eRAI-8893 (RAI No. 3), Question 2.5.2-2 and concluded that the applicant's approach effectively smears the geology across the footprint of the site through the use of two base case profiles and then accounts for the dipping layers through the use of the lower and upper profiles about the two base case profiles for Locations A and B. Based on the results of the staff's independent confirmatory analysis (described below in Section 2.5.2.4.5.3) and applicant's 2D sensitivity study (described below in Section 2.5.2.4.5.2), the staff considers the applicant's approach to modeling the effects of the dipping rock layers beneath the site to be acceptable. The staff confirmed that SSAR Revision 1, dated December 15, 2017 (ADAMS Accession No. ML18005A067), was revised as committed in the RAI response. Accordingly, the staff considers eRAI-8893 (RAI No. 3), Question 2.5.2-2, closed.

In Section 2.5.2.5.2, the applicant described its development of site-specific kappa values for the CRN Site. Kappa is a measure of the seismic energy lost to the anelastic behavior of rocks and wave scattering due to small scale heterogeneities in rock structure. In its kappa analysis, the applicant used seismic recordings of small earthquakes at a seismograph located at Tellico Dam, approximately 16.7 km (10 mi) from the site. The applicant applied two methods for determining kappa using the information contained in these ground motion recordings. Based on the similar geology for the Tellico Dam site and the CRN Site, the applicant determined that the site kappa value ranged from 0.006 sec to 0.016 sec. The applicant used these kappa values to constrain the amount of damping in the site profiles used in its site response analysis.

The applicant used the RVT methodology to calculate the site response amplification functions at the CRN Site. The use of RVT in site response calculations is specified in RG 1.208 as an acceptable alternative to the time series approach. For the input to its site response analysis, the applicant used a suite of 11 input response spectra, ranging from a PGA of 0.01 to 1.5 g. The applicant developed a set of input spectra for both **M**5.5 and **M**7.5 based on the controlling earthquakes for the site. For each of the six site profiles; lower, base case, and upper for Location A and Location B, the applicant generated 60 randomized profiles using a natural log standard deviation of 0.25 over the upper 15.2 m (50 ft) and 0.15 below for each of the layers. These profiles are combined with the input response spectra to develop a suite of amplification functions in terms of the median and natural log standard deviation for each of the seven spectral frequencies (0.5, 1, 2.5, 5, 10, 25 Hz and PGA) covered by the EPRI (2013) GMM. The applicant then convolved these amplification functions with the rock hazard curves to determine seismic hazard curves at the control point or GMRS elevation. The staff reviewed the applicant's site response methodology and inputs and performed its own independent confirmatory analysis, as described in Section 2.5.2.4.5.3 in this SER. Based on this, the staff determined that the applicant's site response inputs are adequate for use at the CRN Site.

2.5.2.4.5.2 2D Sensitivity Analysis

RG 1.208 recommends a 2D site response analysis or sensitivity study for sites with a significantly dipping subsurface. In SSAR Section 2.5.2.6, the applicant presents its results for a 2D sensitivity analysis. The applicant developed a 2D model for the site using regional geologic cross-sections and site-specific data. The applicant performed a finite element analysis using the SDE-SASSI Version 2.0 software. The applicant compared its 2D amplification factors beneath the site to an amplification factor developed for the best-estimate profile using a method different from that used for determining the site-specific hazard. In eRAI-8893 (RAI No. 3), Question 2.5.2-1, the staff requested that the applicant provide its comparison of its 2D results to those actually calculated for determining the site-specific GMRS. In the applicant's response to eRAI-8893 (RAI No. 3), Question 2.5.2-1, dated July 27, 2017 (TVA, 2017 - ADAMS Accession No. ML17201F323), the applicant made the relevant comparison and proposed SSAR modifications. The applicant's response showed that the 2D amplification factors are generally lower than those developed using the 1D method. The applicant noted minor exceedances of the 1D results at a few frequencies. The staff notes that these exceedances are low in amplitude, and the overall comparison shows that the 1D approach adequately accounts for potential 2D effects. 2D effects at the CRN Site are likely limited by the relatively high seismic velocities and low impedance contrast at layer boundaries. Therefore, the staff considers the applicant's response to eRAI-8893 (RAI No. 3), Question 2.5.2-1 acceptable. The staff confirmed that SSAR Revision 1, dated December 15, 2017 (ADAMS Accession No. ML18005A067), was revised as committed in the RAI response. Accordingly, the staff considers eRAI-8893 (RAI No. 3), Question 2.5.2-1, closed.

2.5.2.4.5.3 NRC Site Response Confirmatory Analysis

The staff performed a confirmatory site response analysis to determine the adequacy of the applicant's site response calculations. As input, the staff used the available geophysical data to develop three site response input models. In contrast to the approach taken by the applicant, the staff explicitly modeled the dipping layers by incorporating an up-dip, center, and down-dip profile for each location. Because the site-specific kappa values developed by the applicant are consistent with literature values for similar rock types and thickness (e.g. Campbell, 2009), the staff used the applicant's values in its confirmatory analysis. To represent the input rock motions, the staff used a magnitude of **M**6.5 with 11 input PGAs ranging from 0.1 to 1.5 g. The staff convolved the results of its amplification function with its confirmatory PSHA results to develop site-specific hazard curves at the GMRS elevation.

The staff's site-specific GMRS is compared to the applicant's in Figure 2.5.2-8 of this report. Given the high seismic velocities and relatively low impedance contrasts at the site, the staff considered a bounding analysis using a generic hard rock velocity of 2.8 km/s (9,200 fps). As shown in Figure 2.5.2-8, the applicant's and the staff's GMRS are consistent, demonstrating that amplification factors determined by the staff and the applicant are consistent even when considering differences in site response inputs and methodology. In addition, a GMRS calculated using generic hard rock conditions is consistent with both the applicant's and the staff's GMRS developed using site-specific information. This comparison further demonstrates the relative insensitivity of the site to site response inputs due to high seismic velocities and low impedance contrast between layers in the subsurface. Based on the above assessment, the staff concludes that the applicant's site response calculations adequately characterize the site effects at the CRN Site.

2.5.2.4.5.4 Staff Conclusions Regarding Seismic Wave Transmission Characteristics of the Site

The staff concludes that the applicant's site response methodology and results are acceptable since the applicant followed the general guidance provided in RG 1.208 in its site response calculations and used an adequate range of input parameters. The staff's confirmatory analysis also showed that the applicant's calculations are acceptable.

2.5.2.4.6 Ground Motion Response Spectra

In SSAR Section 2.5.2.5.8 describes the method used by the applicant to develop the horizontal and vertical, site-specific, GMRS. To obtain the horizontal GMRS, the applicant used the performance-based approach described in RG 1.208 and American Society of Civil Engineers/Structural Engineering Institute Standard 43-05, "Seismic Design Criteria for Structures, Systems, and Components in Nuclear Facilities." In SSAR Section 2.5.2.5.8 states that the horizontal GMRS (for each spectral frequency) is obtained by scaling the 10^{-4} soil UHRS by the design factor specified in RG 1.208. A comparison of the applicant's and the staff's confirmatory horizontal GMRS is shown in Figure 2.5.2-8 of this report.

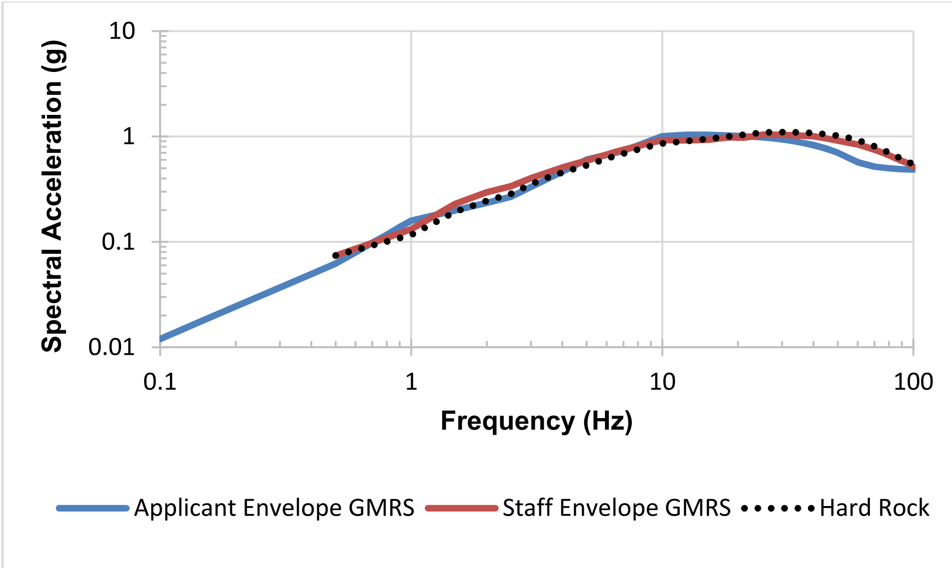

Figure 2.5.2-8: Comparison of applicant's (blue) and the staff's confirmatory GMRS (red) for the CRN Site. The generic hard rock (V_S=2.8 km/s (9,200 fps)) GMRS (black dotted) is shown for comparison

In SSAR Section 2.5.2.5.6, the applicant describes its approach to developing the vertical GMRS. The applicant used an approach similar to that used for developing the site-specific hazard curves to develop the V/H ratios. The applicant used the V/H ratios from NUREG/CR-6728 and incorporated the epistemic uncertainty in the ratios by evaluating the uncertainty in several V/H ratio models taken from the literature. The staff compared the applicant's V/H ratios to those found in NUREG/CR-6728, Appendix J and found that the applicant's approach, which incorporates epistemic uncertainty, generally results in ratios that exceed those suggested by NUREG/CR-6728. Since the applicant used an approach to determining V/H ratios that is conservative relative to the approach suggested by NUREG/CR-6728, the staff finds the applicant's V/H ratios and resulting vertical GMRS adequate.

2.5.2.4.6.1 Staff Conclusions Regarding Ground Motion Response Spectra

Because the applicant used the standard procedures outlined in RG 1.208 to calculate the final horizontal GMRS, and conservatively estimated the vertical GMRS, the staff concludes that the applicant's GMRS adequately represents the site ground motion and that the GMRS calculated meets the requirements of 10 CFR 100.23 for the establishment of the SSE ground motion.

2.5.2.5 Conclusion

The staff reviewed the CRN Site ESP application. The staff confirmed that the applicant addressed the required information relating to vibratory ground motion, and there is no outstanding information expected to be addressed in the SSAR related to this subsection.

As set forth above, the staff reviewed the seismic information submitted by the applicant in SSAR Section 2.5.2. On the basis of its review of SSAR Section 2.5.2, the staff finds that the applicant provided a thorough characterization of the seismic sources surrounding the site, as required by 10 CFR 100.23. In addition, the staff finds that the applicant adequately addressed the uncertainties inherent in the characterization of these seismic sources through a PSHA, and that this PSHA follows the guidance provided in RG 1.208. The staff concludes that the controlling earthquakes and associated ground motion derived from the applicant's PSHA are consistent with the seismogenic region surrounding the CRN Site. In addition, the staff finds that the applicant's GMRS, which was developed using the performance-based approach, adequately represents the regional and local seismic hazards and accurately includes the effects of the local site subsurface properties. The staff concludes that the proposed GMRS for the Clinch River ESP site adequately establishes the site SSE ground motion at the GMRS elevation and meets the requirements of 10 CFR 52.17(a)(1)(vi) and 10 CFR 100.23.