2.5 Geology, Seismology, and Geotechnical Engineering

In SSAR Section 2.5, the applicant described the geological, seismological, and geotechnical engineering properties of the ESP site. SSAR Section 2.5.1 describes the basic geologic and seismologic data for the site and region surrounding the site. SSAR Section 2.5.2 describes the vibratory ground motion at the site in terms of a probabilistic seismic hazard analysis (PSHA) and develops a site SSE ground motion. SSAR Section 2.5.3 describes the potential for surface faulting at or near the surface of the ESP site. SSAR Section 2.5.4 presents information on the stability of the site's subsurface materials. SSAR Section 2.5.5 describes the stability of slopes at the site. Finally, SSAR Section 2.5.6, which covers embankments and dams, states that the applicant did not reanalyze the North Anna Dam as part of the ESP application.

Since the ESP site is located adjacent to NAPS Units 1 and 2, abandoned Units 3 and 4, and the independent spent fuel storage installation (ISFSI), the applicant stated in SSAR Section 2.5 that it used the previous site investigations for these facilities as its starting point for the characterization of the geological, seismological, and geotechnical engineering properties of the ESP site. As such, the material in Section 2.5 of the ESP application focuses on any newly published information since the publication of the NAPS updated safety analysis report in the 1970s as well as recent geological, seismological, geophysical, and geotechnical investigations performed for the ESP site. The applicant stated that it conducted these investigations in progressively greater detail closer to the ESP site. The applicant defined the following zones of investigation around the site:

- region—within 200 miles
- vicinity—within 25 miles
- area—within 5 miles

The ESP site itself is defined as the area within 0.6 mile of the site location.

The applicant also used the seismic source and ground motion models published by the Electric Power Research Institute (EPRI) for the central and eastern United States (CEUS), "Seismic Hazard Methodology for the Central and Eastern United States," as the starting point for its seismic hazard evaluation. The applicant updated the EPRI seismic source and ground motion models in accordance with RG 1.165, "Identification and Characterization of Seismic Sources and Determination of Safe Shutdown Earthquake Ground Motion," issued March 1997. RG 1.165 indicates that applicants may use the seismic source interpretations developed by Lawrence Livermore National Laboratory (LLNL) in the "Eastern Seismic Hazard Characterization Update," published in 1993, or the EPRI models, published in 1986, as inputs for a site-specific analysis.

2.5.1 Basic Geologic and Seismic Information

SSAR Section 2.5.1 describes the geologic and seismologic characteristics of the ESP site region and area. SSAR Section 2.5.1.1 describes the geologic and tectonic setting of the site region, and SSAR Section 2.5.1.2 describes the structural geology of the site area.

2.5.1.1 Technical Information in the Application

2.5.1.1.1 Regional Geology

SSAR Section 2.5.1.1 describes (1) the physiographic provinces that encompass a 200-mile radius of the site, (2) the geologic history in terms of the major tectonic events, (3) regional stratigraphy, (4) the regional tectonic setting, and (5) regional gravity and magnetic data.

<u>Physiographic Provinces</u>

SSAR Section 2.5.1.1.1 describes the regional physiography and geomorphology of the ESP site. The ESP site lies within the Piedmont physiographic province. The Piedmont province lies between the Coastal Plain province to the east and the Blue Ridge province to the west and is characterized by deeply weathered bedrock. Elevations in the Piedmont province range from 800 to 1500 ft in the western portion of the province to about 200 ft in the eastern portion, near the Coastal Plain province. Figure 2.5.1-1, reproduced from SSAR Figure 2.5-1, illustrates each of the physiographic provinces within the site region.

<u>Regional Geologic History</u>

SSAR Section 2.5.1.1.2 describes the geologic history of the ESP site region, which is composed of episodes of continental collisions with intervening episodes of continental rifting. Episodes of continental collisions have produced a series of accreted terranes that are separated by low-angle detachment faults. In contrast, intervening episodes of continental rifting have produced high-angle normal faults that either extend downward into the low-angle detachment faults or penetrate entirely through the accreted terranes. The latest major tectonic events in the region include the Allegheny orogeny (mountain building) and Mesozoic and Cenozoic crustal extension (rifting) episodes. The collision of the North American and African plates caused the Allegheny orogeny, which occurred during the late Carboniferous Period (about 290–330 million years (Ma) ago) and extended into the Permian Period (240–290 Ma). Crustal extension followed the Allegheny orogeny during the early Mesozoic Era (200–240 Ma) that began the opening of the Atlantic Ocean. This early Mesozoic extensional episode continued with the development of the mid-Atlantic spreading center during the Cenozoic Era (63 Ma–present). Currently, the site region is located on the passive, divergent trailing margin of the North American plate following this last episode of continental extension and rifting.

<u>Regional Stratigraphy</u>

Section 2.5.1.1.3 of the SSAR describes the regional stratigraphy of the ESP site. Two distinct rock types mark the regional stratigraphy of the Piedmont province. The first and oldest type is the crystalline rock of the late Precambrian (570–1500 Ma) and Paleozoic age (240–570 Ma). Overlying these rocks are Mesozoic-age (63–240 Ma) sedimentary rocks deposited locally in down-faulted basins within the crystalline rocks. Residual soils derived from weathering of the crystalline rocks, as well as Quaternary-age (2 Ma–present) alluvium and colluvium, overlay both the sedimentary and crystalline rocks.

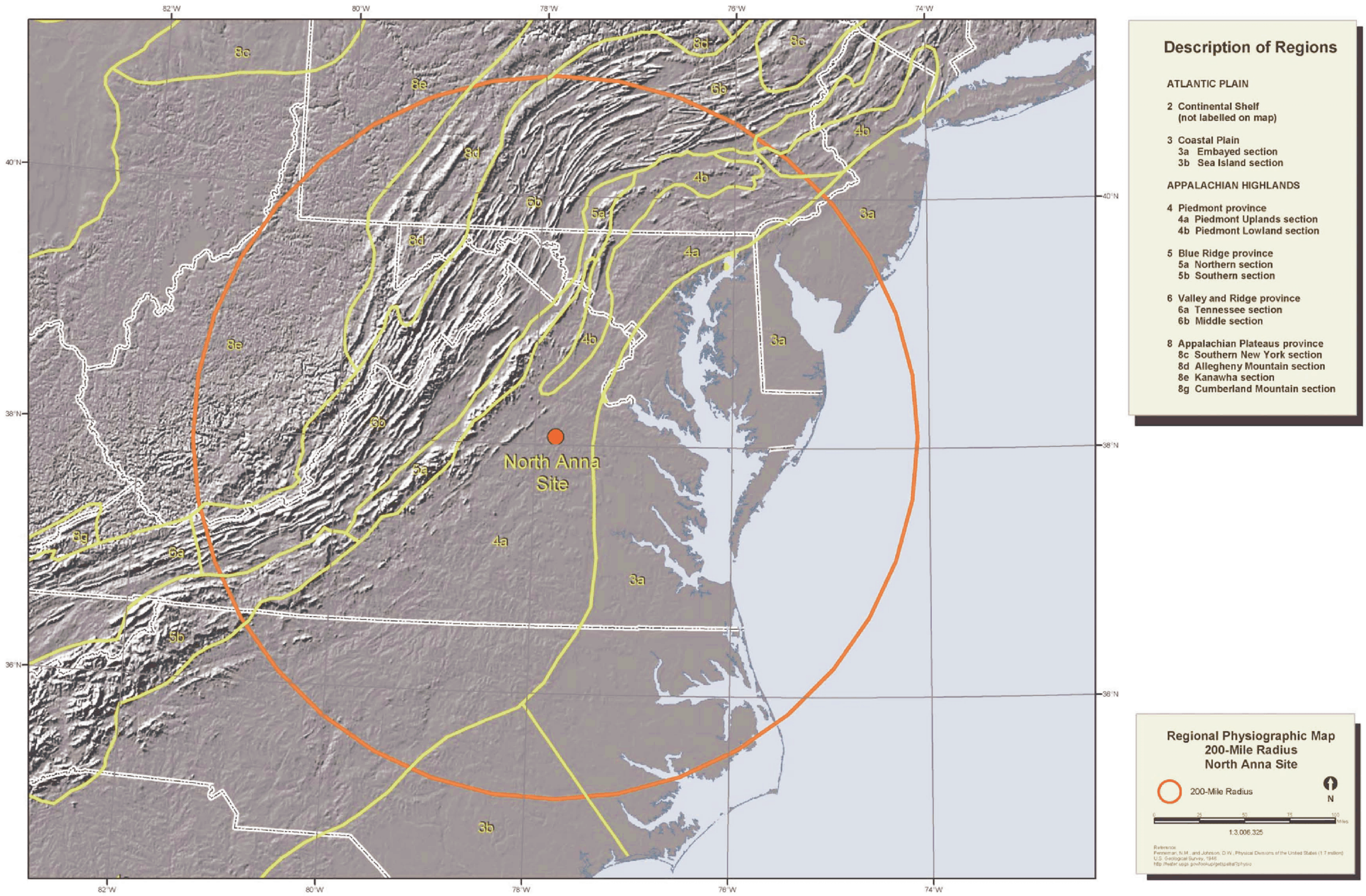
82°W
80°W
78°W
76°W
74°W
40°N
38°N
36°N
8c
8e
8d
6b
5a
4b
4a
3a
6a
8g
5b
3b
North Anna
Site
Description of Regions
ATLANTIC PLAIN
2 Continental Shelf
(not labelled on map)
3 Coastal Plain
3a Embayed section
3b Sea Island section
APPALACHIAN HIGHLANDS
4 Piedmont province
4a Piedmont Uplands section
4b Piedmont Lowland section
5 Blue Ridge province
5a Northern section
5b Southern section
6 Valley and Ridge province
6a Tennessee section
6b Middle section
8 Appalachian Plateaus province
8c Southern New York section
8d Allegheny Mountain section
8e Kanawha section
8g Cumberland Mountain section
Regional Physiographic Map
200-Mile Radius
North Anna Site
200-Mile Radius
N
0
25
50
75
100
Miles
1:3,006,325
Reference
Fenneman, N.M., and Johnson, D.W., Physical Divisions of the United States (1:7 million)
U.S. Geological Survey, 1946
http://water.usgs.gov/lookup/getspatial?physio

Figure 2.5.1-1 Regional physiographic map (200-mile radius)

Regional Tectonic Setting

Section 2.5.1.1.4 of the SSAR describes the regional tectonic setting for the ESP site. Figure 2.5.1-2, reproduced from SSAR Figure 2.5-5, presents a simplified tectonic and stratigraphic map of the site region, including many of the local faults.

The ESP site lies within the central Appalachian region of Virginia, which is part of the northeast-trending Appalachian orogenic belt that extends nearly the entire length of the eastern United States. The tectonic stress in the CEUS, including the Appalachian region, is primarily characterized by northeast-southwest-directed horizontal compression. The expert teams that participated in the 1986 EPRI hazard evaluation concluded that the most likely source of the tectonic stress in the CEUS region is a ridge-push body force associated with the mid-Atlantic ridge, which is transmitted to the interior of the North American tectonic plate. Studies cited in SSAR Section 2.5.1.1.4 found the magnitude of the northeast-southwest-directed stress to be about 2 to 3×10^{12} N/m, which corresponds to average equivalent stresses of about 40 to 60 MPa, distributed across a 30-mile-thick elastic plate.

SSAR Section 2.5.1.1.4 categorizes four principal tectonic structures within the 200-mile ESP site region based on the age of formation or reactivation of the structures, including those active during (1) the Paleozoic Era (240–570 Ma), (2) the Mesozoic Era (63–240 Ma), (3) the Tertiary Period (2–63 Ma), and (4) the Quaternary Period (2 Ma–present).

Paleozoic Tectonic Structures

The rocks and structures within the physiographic provinces that encompass the ESP site region are associated with thrust sheets that formed during the convergent Appalachian orogenic events of the Paleozoic Era (240–570 Ma). The majority of these thrust sheets are shallow and dip eastward into a low-angle, basal Appalachian decollement. Below the decollement are rocks that form the North American basement complex. The basement rocks contain normal faults that formed during the late Precambrian to Cambrian Period (570–1500 Ma). Literature cited in the SSAR states that much of the sparse seismicity in the

Appalachian region occurs within this North American basement complex and not within the more abundant, shallow thrust sheets mapped at the surface.

Major Paleozoic tectonic structures near the ESP site include the Hylas shear zone, Spotsylvania thrust fault, Long Branch thrust fault, Chopawamsic thrust fault, Lake of the Woods thrust fault, and Mountain Run fault zone. No seismic activity has been attributed to any of the Paleozoic faults within 200 miles of the site, and, as such, the applicant considers none to be capable tectonic sources, as defined in Appendix A to RG 1.165. Of these tectonic structures, the Hylas shear zone, the Lake of the Woods thrust fault, and the Mountain Run fault zone are the most prominent. In response to RAI 2.5.1-4, the applicant revised SSAR Section 2.5.1.1.4 to state that there is no reported geomorphic expression, historical seismicity, or Quaternary deformation along either the Hylas shear zone or the Lake of the Woods thrust fault. Diffuse, scattered seismicity occurs throughout the Central Virginia seismic zone (CVSZ), but it is not spatially concentrated or aligned with either of these two structures. SER Section 2.5.1.3.1 provides a complete description of the applicant's response to RAI 2.5.1-4 and the staff's evaluation of the applicant's response.

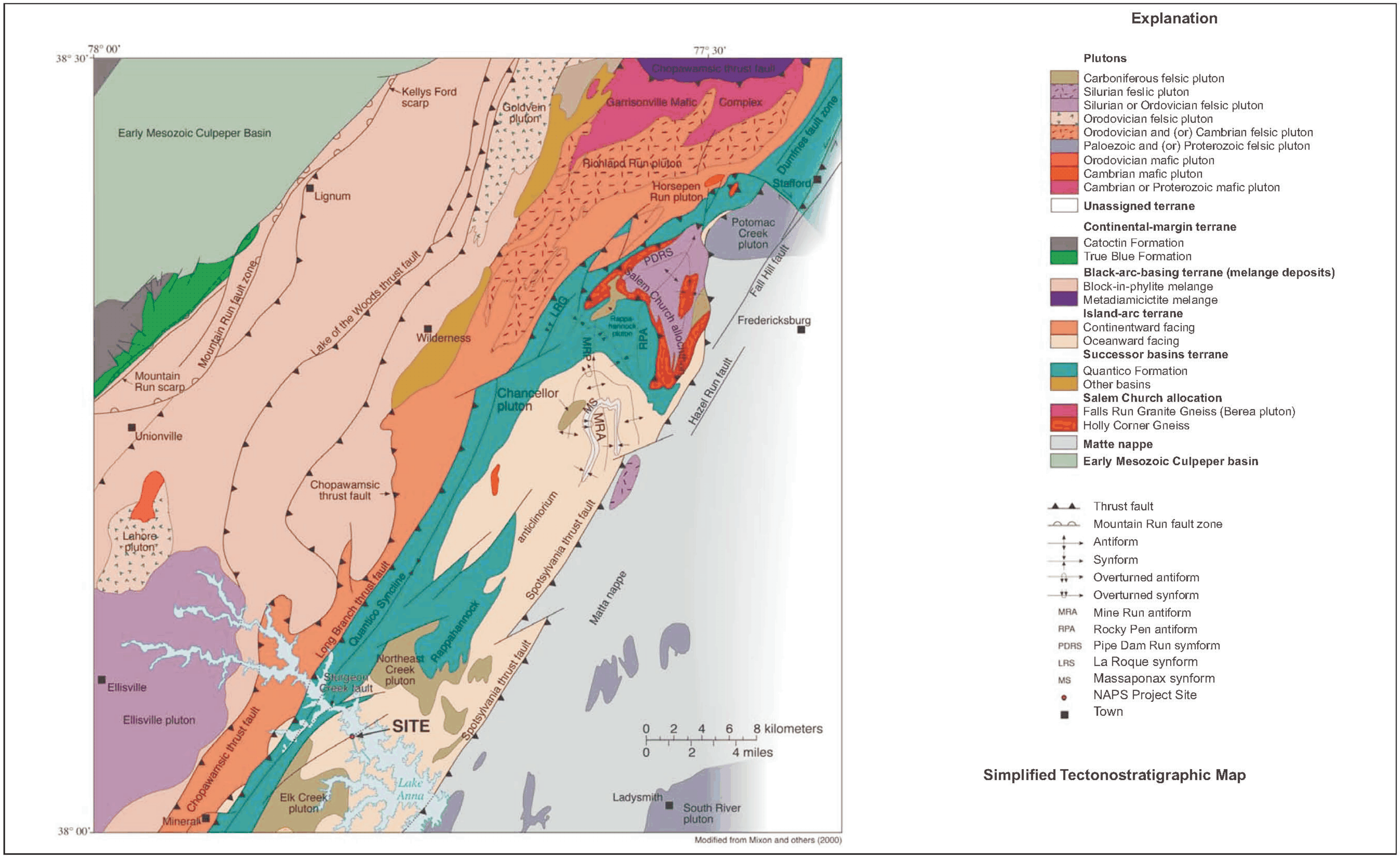

Figure 2.5.1-2 Simplified tectonostratigraphic map

Since the Mountain Run fault zone is one of the most clearly recognizable faults in the region with two pronounced scarps occurring along the fault zone, the applicant identified it as a potential Quaternary tectonic feature. SSAR Section 2.5.1.1.4 states that these two pronounced scarps along the Mountain Run fault zone have led some experts to suggest that the fault has experienced a late Cenezoic (63 Ma–present) phase of movement. The Mountain Run fault zone is a 75-mile-long fault zone that lies approximately 18 miles northwest of the site. The following excerpt from SSAR Section 2.5.1.1.4 describes the applicant's investigation of the Mountain Run fault zone:

> Field and aerial reconnaissance performed for this ESP application did not reveal any geologic or geomorphic features indicative of potential Quaternary activity along the Mountain Run fault zone. A review of 1:24,000 scale topographic maps revealed that the steeper portions of the Mountain Run scarp correlate with the areas where the Mountain Run (stream) is impinging on the scarp. In addition, the northwest side of the narrow Mountain Run valley is steepest where the stream is impinging on that side of the valley. These observations suggest that the scarp most likely formed due to erosion, as southeastward-migrating streams impinge against the more resistant rocks in the Mountain Run fault zone.

Based on the reconnaissance described above, the applicant concluded that the Mountain Run fault zone is not a capable tectonic source. In response to RAI 2.5.1-5, the applicant stated that its reconnaissance field and aerial evaluations demonstrated that the Mountain Run and Kelly's Ford scarps along the Mountain Run fault zone are associated with incised drainages that are preferentially eroding the southeast valley walls, creating asymmetric valley profiles. As such, the applicant determined that the scarps are most likely products of fluvial erosion. SER Section 2.5.1.3.1 provides a complete description of the applicant's response to RAI 2.5.1-5 and the staff's evaluation of the applicant's response.

<u>Mesozoic Tectonic Structures</u>

A series of elongated Mesozoic Era (63–240 Ma) rift basins are exposed in a belt extending from Nova Scotia to South Carolina. These rift basins exhibit a high degree of parallelism with the surrounding structural grain of the Appalachian orogenic belt. They were formed during the extension and thinning of the Earth's crust as Africa and North America rifted apart to form the Atlantic Ocean. Section 2.5.1.1.4 of the SSAR states that, although the Mesozoic basins have long been considered potential sources for earthquakes along the eastern seaboard, none of the basins in the site region is associated with a known capable tectonic source.

<u>Tertiary Tectonic Structures</u>

Tertiary Period (2–63 Ma) tectonic structures within 200 miles of the ESP site include the Brandywine fault system in Maryland, the National Zoo faults in Washington, DC, the Dutch Gap fault in Virginia, and the Stafford fault system. The Stafford fault is a 42-mile-long fault system that comes within 16.5 miles of the site. Section 2.5.1.1.4 states that the NAPS licensee's (Virginia Power's) detailed drilling, trenching, and mapping of the Stafford fault system in the Fredericksburg region in the early 1970s showed that the youngest identifiable fault movement occurred before the middle Miocene Epoch (i.e., more that 10 Ma ago). Subsequent investigations have shown some minor, later activity along the Stafford fault system. However, none of this activity has occurred during the Quaternary Period (i.e., the past 2 Ma). Thus, the applicant concluded that the Stafford fault system is not a capable tectonic source. The applicant stated that the EPRI 1986 seismic source models incorporated all of the available information on the Stafford fault system. In addition, the applicant stated that no new significant information has been developed since 1986 regarding the potential activity of the Stafford fault system. In response to RAI 2.5.1-6, the applicant stated that it based its conclusion that the Stafford fault system is not a capable tectonic source on a review of existing literature, discussions with researchers familiar with the area, areal and field reconnaissance, and geomorphic analyses. SER Section 2.5.1.3.1 provides a complete description of the applicant's response to RAI 2.5.1-6 and the staff's evaluation of the applicant's response.

Quaternary Tectonic Features

To define Quaternary tectonic (2 Ma–present) features, the applicant used the study of Crone and Wheeler (Ref. 59, SSAR Section 2.5) as one of its criteria. Crone and Wheeler compiled geologic information on Quaternary faults, liquefaction features, and possible tectonic features in the CEUS. They evaluated and classified these features into one of four categories (Classes A, B, C, and D) based on geologic evidence of Quaternary faulting or deformation. Within a 200-mile radius of the ESP site, Crone and Wheeler identified 11 potential Quaternary features. Of these 11 features, only the CVSZ showed geologic evidence that demonstrates the existence of a Quaternary fault of tectonic origin (Class A). SSAR Section 2.5.1.1.4 states that none of the other features compiled by Crone and Wheeler have "demonstrated evidence of Quaternary activity that would imply recurrent activity in the past 500,000 years." The applicant investigated many of these features, such as the Mountain Run fault zone described above, in great detail to determine their potential for Quaternary activity. Figure 2.5.1-3, reproduced from SSAR Figure 2.5-12, shows the Quaternary features identified by Crone and Wheeler.

The ESP site is located near the northern boundary of the CVSZ. Because the causative faults have not been identified, the applicant characterized the CVSZ as a seismogenic source rather than a capable tectonic source. The largest earthquake known to have occurred in the CVSZ is the body-wave magnitude (m_b) 5.0 Goochland County event in 1875. The CVSZ is an area defined by moderate to low historical seismic activity, as well as paleoseismicity, since Obermeier and McNulty recently identified two paleoliquefaction features within the CVSZ (Ref. 71, SSAR Section 2.5). However, SSAR Section 2.5.1.1.4 states that the absence of widespread paleoliquefaction led Obermeier and McNulty to conclude that an earthquake of magnitude 7 or larger has not occurred within the CVSZ in the last 2000–3000 years, or in the eastern portion of the seismic zone for the last 5000 years. In addition, the applicant stated that "these isolated locations of paleoliquefaction may have been produced by local shallow moderate magnitude earthquakes of [moment magnitude (M_w)] 5 to 6." In RAI 2.5.1-1, the staff asked the applicant to describe these two paleoliquefaction features and their impact on the seismic characterization of the CVSZ. In its response, the applicant modified SSAR Section 2.5.1.1.4 to reaffirm its conclusion that the original 1986 EPRI study adequately characterizes the magnitude level of the CVSZ. SER Section 2.5.1.3.1 provides a complete description of the applicant's response to RAI 2.5.1-1 and the staff's evaluation of the applicant's response.

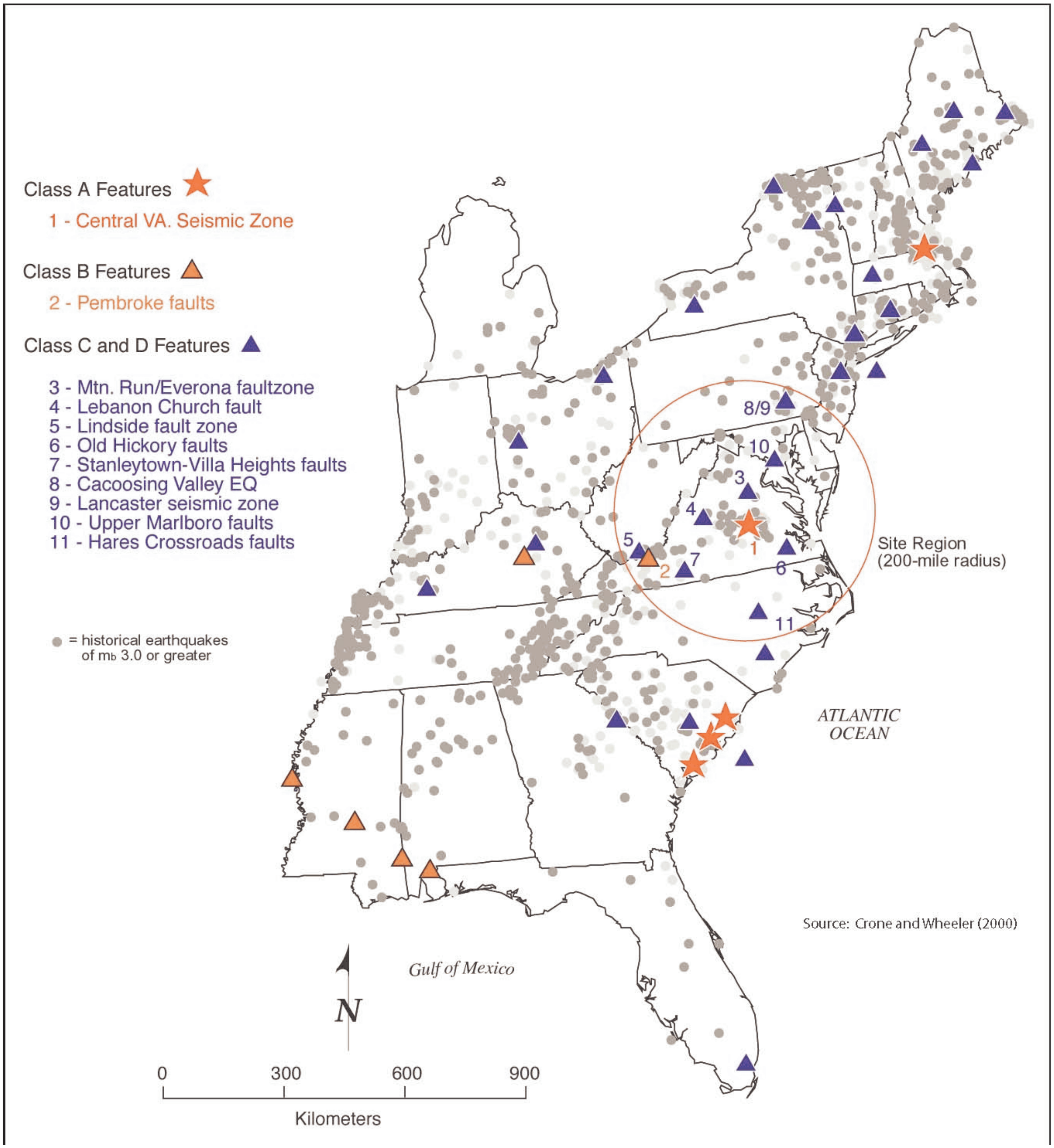

Figure 2.5.1-3 Quaternary features map

The applicant also identified the seven fall lines across the Piedmont and Blue Ridge provinces of North Carolina as another potential Quaternary tectonic feature. Weems identified these seven fall lines (Ref. 70, SSAR Section 2.5), which are based on the alignment of short stream segments with anomalously steep gradients. Because other studies of potential tectonic features in the CEUS do not include the seven fall lines identified by Weems, the applicant concluded that they do not represent a capable tectonic source. In RAI 2.5.1-3, the staff asked the applicant to more strongly justify its conclusion that the seven fall lines do not represent a capable tectonic source. In its response, the applicant revised SSAR Section 2.5.1.1.4 to strengthen its conclusion by stating that Weems does not present direct credible evidence for a tectonic origin of the fall lines. The applicant also stated that, based on its evaluation of the stratigraphic, structural, and geomorphic relations across and adjacent to the fall zones, differential erosion resulting from variable bedrock hardness is a more plausible explanation than Quaternary tectonism. SER Section 2.5.1.3.1 provides a complete description of the applicant's response to RAI 2.5.1-3 and the staff's evaluation of the applicant's response.

The applicant cited another potential Quaternary tectonic feature known as the East Coast fault system (ECFS). The ECFS is a 370-mile-long fault system that consists of three 125-mile-long segments extending from the Charleston area in South Carolina northeastward to near the James River in Virginia. The southern segment of the ECFS (ECFS-S) is associated with the Charleston earthquake of 1868 (with an estimated magnitude of about 7) and continues to show microseismic activity. Only Marple and Talwani postulated the central and northern segments of the ECFS (ECFS-C and ECFS-N) as tectonic features (Ref. 75, SSAR Section 2.5). The closest approach of the northern segment to the site is approximately 70 miles to the southeast. Because the ECFS-N and ECFS-C have not been associated with any seismicity and gravity or magnetic anomalies, the applicant concluded that they are not likely to exist or, if they do exist, they have a very low probability of activity. In RAI 2.5.1-2, the staff asked the applicant to describe the aerial reconnaissance and other sources it used to support its conclusions regarding the ECFS-N, which is the closest segment to the ESP site. Consistent with its response, the applicant revised SSAR Section 2.5.1.1.4 to reaffirm this conclusion by demonstrating that other researchers and studies have determined that the ECFS-N is not a potential source of seismic activity. SER Section 2.5.1.3.1 provides a complete description of the applicant's response to RAI 2.5.1-2 and the staff's evaluation of the applicant's response.

SSAR Section 2.5.1.1.4 also describes the Giles County, Virginia, seismic zone, which is located near the border with West Virginia. The Giles County seismic zone is defined by a concentration of small to moderate earthquakes and produced the largest historical earthquake in Virginia. This earthquake, referred to as the Giles County earthquake, had an estimated m_b of 5.8 and occurred in 1897. The applicant stated that the shaking at the ESP site from this earthquake would have been about an intensity level of 5, which signifies ground motion that is felt by nearly everyone in the vicinity of the ESP site and might crack plaster or overturn unstable objects. The applicant stated that geologists have not identified any capable tectonic sources in the area that can be associated with the concentration of seismic activity within the Giles County seismic zone. Geologists have identified a zone of small Quaternary-age surface faults within the Giles County seismic zone, near Pembroke, Virginia. However, the applicant stated that these faults do not appear to be related to the seismicity within the Giles County seismic zone, which occurs at depths between 3 and 16 miles beneath the Appalachian basal decollement in the North American basement. The EPRI seismic source model maximum magnitudes (M_{max}) for the Giles County seismic source zone vary from m_b 6.6 to 7.2.

Subsequent hazard studies have used similar values for the M_{max} of the Giles County seismic zone. Therefore, the applicant decided not to revise the EPRI seismic source model for the Giles County seismic zone.

In addition to the principal tectonic features and seismic zones within the ESP site region, the applicant, in SSAR Section 2.5.1.1.4, also described the major active seisomogenic source zones located outside the site region. These sources include the Eastern Tennessee seismic zone (ETSZ), the Charleston seismic source, and the New Madrid seismic zone (NMSZ). These three seismic source zones are more than 300 miles from the ESP site. However, large earthquakes from sources at this distance could contribute to the long-period ground motion hazard at the ESP site. Figure 2.5.1-4, reproduced from SSAR Figure 2.5-14, illustrates these three seismic source zones, as well as other regional seismic source zones.

<u>Eastern Tennessee Seismic Zone</u>

The ESP site is located over 300 miles east of the ETSZ. The ETSZ is about 185 miles long and 30 miles wide and is located in the Valley and Ridge Province of eastern Tennessee. Although the ETSZ has not produced a damaging earthquake in historical time, this zone did produce the second highest release of seismic strain energy in the CEUS during the 1980s. Earthquakes in the ETSZ occur at depths between 3 and 16 miles, and none have exceeded an M_w of 4.6 (Ref. 88, SSAR Section 2.5). In addition, earthquakes within the ETSZ have not been attributed to known faults, and no capable tectonic faults have been identified within the seismic zone. The EPRI seismic source model includes various source geometries and parameters to represent the seismicity of the ETSZ. The M_{max} values used by EPRI for the ETSZ range from m_b 6.6 to 7.4. Subsequent hazard studies have used M_{max} values of m_b 6.45 and 7.25 (Refs. 57 and 79, SSAR Section 2.5). The applicant concluded that both of these more recent estimates of M_{max} are similar to those used by EPRI for the ETSZ. Therefore, the applicant decided not to revise the EPRI seismic source model for the ETSZ.

<u>Charleston Seismic Source</u>

The Charleston seismic source is located about 375 miles south of the ESP site. The earthquake which occurred in Charleston, South Carolina, on August 31, 1886, is the largest historical earthquake event to occur in the eastern United States. The earthquake produced intense shaking in the epicentral area (Modified Mercalli Intensity (MMI) X) and was felt as far away as Chicago (MMI V) (Ref. 90, SSAR Section 2.5). Estimates of the magnitude for the 1886 Charleston earthquake are 7.3 (Ref. 90, SSAR Section 2.5) and 6.8 (Ref. 93, SSAR Section 2.5). The applicant stated that both of these more recent estimates of the magnitude of the Charleston earthquake are similar to the upper bound range of M_{max} values used in the 1986 EPRI study (m_b 6.8 to 7.5). Therefore, the applicant concluded that no new information has been developed since 1986 that would warrant a significant revision to the EPRI seismic source model in terms of earthquake magnitude. However, estimates of earthquake recurrence for the Charleston source, based on dates of paleoliquefaction events, have been updated since 1986. The most recent summary of paleoliquefaction data (Ref. 91, SSAR Section 2.5) for the Charleston source indicates a mean recurrence time of 550 years. This mean recurrence time is roughly an order of magnitude less than the seismicity-based

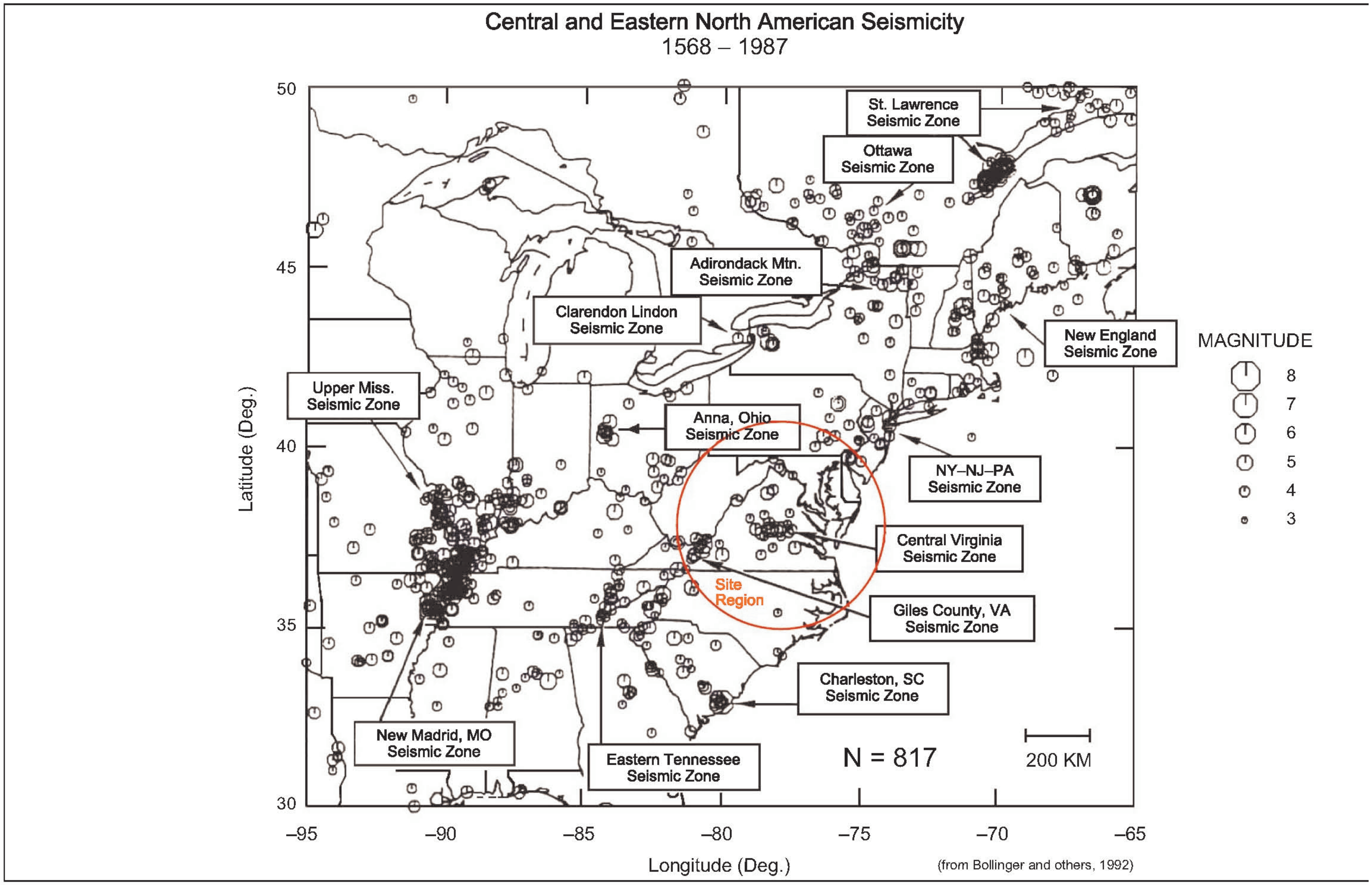

Figure 2.5.1-4 **Seismic source zones and seismicity in central and eastern North America**

recurrence estimates used in the 1986 EPRI study. Therefore, the applicant modified the Charleston recurrence interval from several thousand years to 550 years, based on the paleoseismic observations. The applicant included this reduction in recurrence interval in its sensitivity analysis, which is described in SSAR Section 2.5.2.

New Madrid Seismic Zone

The NMSZ extends from northeastern Arkansas to southwestern Tennessee and is over 620 miles west of the ESP site. The NMSZ produced three large-magnitude earthquakes between December 1811 and February 1812. Estimates of the magnitudes of these events range between 7 and 8. However, because of the considerable distance between the NMSZ and the ESP site, the NMSZ only contributed 1 percent of the hazard at the NAPS site in the 1986 EPRI study. Since 1986, estimates of the M_{max} for the NMSZ have generally been within the range of M_{max} values used by the EPRI study (m_b 7.2 to 7.9). However, the recurrence interval for the NMSZ, based on paleoseismic observations, is now only 500 years, which is considerably less than the recurrence estimates used in the 1986 EPRI study. The applicant included this reduction in recurrence interval in its sensitivity analysis, which is described in SSAR Section 2.5.2.

Regional Gravity and Magnetic Data

The applicant reviewed regional maps of gravity and magnetic data in SSAR Section 2.5.1.1.5. The Geological Society of America (GSA) published regional maps of gravity and magnetic fields in North America in 1987. The maps present gravity and magnetic field data at a 1:5,000,000 scale. The applicant stated that these maps are useful for identifying and assessing gravity and magnetic anomalies with wavelengths on the order of tens of kilometers or greater.

The gravity map of the eastern United States shows that, at the latitude of Virginia, there is a long-wavelength, east-to-west gravity gradient, referred to as the Piedmont gravity gradient. The Piedmont gravity gradient stretches across the Blue Ridge and Piedmont provinces of Virginia. The applicant stated the following about the Piedmont gravity gradient:

> The presence of the Piedmont Gravity Anomaly was known at the time of the 1986 EPRI study. This anomaly is a first-order feature of the gravity field and is interpreted to reflect eastward thinning of the North American crust and lithosphere.

Magnetic data published by GSA reveal numerous northeast-southwest-trending magnetic anomalies, generally parallel to the structural features of the Appalachian orogenic belt. However, in contrast to the gravity data, the magnetic anomalies do not provide information on crustal-scale features in the lithosphere. Rather, the applicant stated that anomalies in the magnetic field are associated primarily with upper crustal variations in magnetic susceptibility, such as mafic and ultramafic rocks. The magnetic data provide additional characterization of the geophysical properties of the upper crust and supporting evidence for the interpretation of the seismic reflection data. The applicant stated that the magnetic data published since 1986 do not reveal any new anomalies related to geologic structures that had not been identified before the 1986 EPRI study.

2.5.1.1.2 Site Geology

SSAR Section 2.5.1.2 describes the site area in terms of (1) physiography, (2) geologic history, (3) stratigraphy, (4) geologic structure, (5) geologic hazard evaluation, (6) engineering geology, and (7) ground water conditions.

Site Area Physiography

The ESP site is located within the Piedmont province and is bordered by Lake Anna to the north and east. The ESP site is in an area with a topography that is gently undulating, varying in elevation from about 200 to 500 ft. The applicant stated that the slopes in the region typically range from 2 to 5 percent, with steeper slopes along the lower tributaries of some of the larger streams ranging from 7 to 10 percent. Site grade for the existing units is at an approximate elevation of 271 ft. The ground surface gently rises to the west and south to elevations of over 300 ft. Figure 2.5.1-5, reproduced from SSAR Figure 2.5-16, presents the site topographic map.

Site Area Geologic History

The applicant stated that, since early Paleozoic time (about 500 Ma), rocks of the Piedmont province have undergone three compressional orogenies during the Paleozoic Era and one extensional episode during the Mesozoic Era (63–240 Ma). These orogenies produced a complex pattern of folding and faulting in the region surrounding the site. The rocks of the Piedmont province exhibit varying degrees of metamorphism, depending on their location in relation to the axis of major stress, which generally trends northeast-southwest. During the more recent Cenozoic time (63 Ma–present), the area surrounding the ESP site was subject to erosion along the passive continental margin. Erosion continued during the Pleistocene (0.01–2 Ma) glacial and interglacial periods. Weathering processes during the glacial and interglacial periods include frost shattering, freeze-thaw cycles, accelerated wind erosion, and accelerated solifluction (flowage of saturated soil). The applicant concluded that these weathering processes, together with downcutting streams and rivers during the present, produced the residual soils that cover the ESP site.

Site Area Stratigraphy

The applicant stated that the ESP site is underlain by rocks of the Ta River Metamorphic Suite, which are in turn underlain by rocks of the Chopawamsic Formation and the Mine Run Complex. Surficial sediments at the site consist of mainly residual soil and saprolite, with some alluvium found along stream channels. The Ta River Metamorphic Suite underlying the site is thousands of feet thick, and the rocks within the suite are dark gray to black gneisses of Cambrian and/or Ordovician age. The applicant stated that borings completed at the ESP site encountered rocks of the Ta River Metamorphic Suite that are gray to dark gray quartz gneiss and hornblende gneiss. Residual soil and saprolite overlie the rocks of the Ta River Metamorphic Suite. The residual soil is derived from the weathering of the underlying metamorphic rocks and generally consists of clay, silt, and sand-sized particles with minor rock fragments. The saprolite is also derived from weathering of the underlying metamorphic rock but, unlike the residual soil, retains many of the structural and mineralogical features of the rock. The saprolite extends down to the top of the rock from which it was derived.

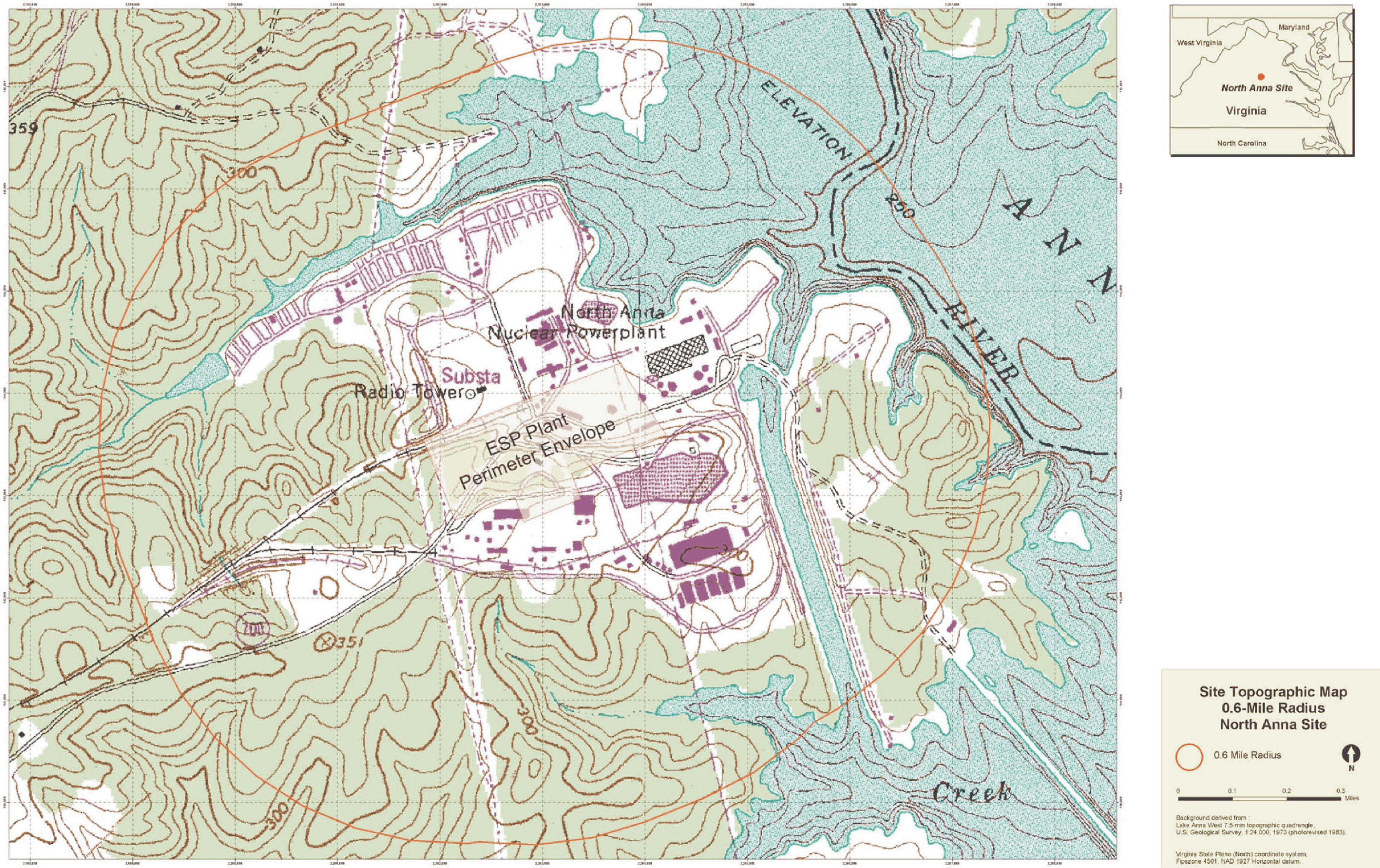

Figure 2.5.1-5 Site topographic map (0.6-mile radius)

Site Area Structural Geology

Structural features at and within a 5-mile radius of the ESP site consist of a series of northeast-striking faults and folds within the metamorphic bedrock. The applicant identified the following bedrock faults within a 5-mile radius of the ESP site:

(4) Spotsylvania thrust
(5) Chopawamsic thrust
(6) Long Branch thrust
(7) Sturgeon Creek fault
(8) unnamed faults “a,” “b,” and “c”

The applicant stated that none of the above faults are considered to be capable tectonic sources, as defined by RG 1.165. The Spotsylvania, Chopawamsic, and Long Branch thrust faults are northeast-striking, east-dipping Paleozoic structures that can be mapped for miles within the Piedmont province and represent the largest surficial tectonic structures within the site area. The Sturgeon Creek fault and the three unnamed faults (“a,” “b,” and “c”) also strike northeast; however, they are smaller structures than the other three thrust faults. Unnamed fault “a,” which traverses NAPS and the ESP site, was the subject of intensive study following its exposure during the excavations for abandoned Units 3 and 4. This fault has a length of about 3000 ft based on geologic mapping of excavations and trenches. The applicant cited the conclusions of a Dames and Moore study (Ref. 9, SSAR Section 2.5), stating that unnamed fault “a” is not a capable tectonic source, as well as the NRC staff’s acceptance of this conclusion found in the SER for abandoned NAPS Units 3 and 4.

The applicant stated that the most prominent folds at the site are the northerly plunging syncline/anticline pair located in the western portion of the site. The axis of the site passes near an area of exposed bedrock, and foliations near the axis of the fold dip steeply (65–90 degrees).

Site Area Geologic Hazard Evaluation

SSAR Section 2.5.1.2.5 states that the only geologic hazards associated with the ESP site are (1) vibratory ground motion from regional earthquake activity and (2) potential surface faulting from site area earthquakes. The applicant discussed these two potential geologic hazards in SSAR Sections 2.5.2 and 2.5.3, respectively. The corresponding sections of this SER provide the staff’s review of these two potential geologic hazards.

Site Engineering Geology

SSAR Section 2.5.1.2.6 briefly describes the engineering behavior of the soil and rock at the ESP site, prior earthquake effects, effects of human activities, construction ground water control, and unforseen geologic features. Section 2.5.4 of the SSAR discusses the results of the applicant’s geotechnical investigation in greater detail.

The applicant described the composition of the saprolite at the ESP site as micaceous silty, clayey sand and sandy silt/clay with occasional to many relict rock fragments. The saprolite more or less retains the fabric or structure of the parent bedrock, depending on the degree of weathering. However, although the saprolite has the relict structure of the parent bedrock, its engineering properties typically resemble those of a soil. The applicant classified the saprolite at the site into Zone IIA and IIB saprolite, based on its general composition and grain size. Zone IIA saprolite is classified as silty sand, clayey sand, and high- and low-plasticity silt and clay. Zone IIB saprolite is classified as silty sand. Zone IIA saprolite is the more weathered of the two saprolites and contains less than 10 percent relict rock fragments. In contrast, Zone IIB saprolite contains between 10 and 50 percent relict rock fragments and is more dense than Zone IIA saprolite. The presence of mica in the saprolite is likely to reduce its maximum compacted density and increase its compressibility. The applicant provided the following example of this phenomenon:

> The SWR [service water reservoir] pump house for the existing units was constructed on about 65 feet of Zone IIA saprolite, consisting mainly of sandy silt, with frequent layers of micaceous sandy silt. For about two years after its construction, the pumphouse structure underwent relatively high settlement that declined significantly thereafter. The settlement was caused by the weight of the SWR dike fill built up around the pumphouse. The micaceous nature of the material is considered to have played a major role in the settlement. High compressibilities and low maximum densities of the saprolite, therefore, preclude using it as engineered fill at the ESP site.

The applicant stated that bedrock at the ESP site is composed of predominantly quartz gneiss with biotite of the Ta River Metamorphic Suite. The gneiss is a hard, foliated rock, which exhibits various degrees of weathering. The degree of weathering of the gneiss affects its engineering behavior and properties. The applicant classified the gneiss at the site into three categories (Zones III, III-IV, and IV) based on its degree of weathering. Zone III is the uppermost weathered part of the bedrock, is highly weathered and fractured, and contains traces of clay and iron oxide. Regarding Zone III, the applicant stated the following:

> Because of the tendency for zones of severely weathered and fractured rock to weather further upon exposure, they would be removed and replaced with cement grout where encountered in excavations for the new units. This would ensure the bearing capacity of the foundation rock mass.

Zones III-IV and IV are considerably less weathered, with the degree of weathering decreasing with increasing depth. Zone III-IV is moderately weathered, and Zone IV is slightly weathered to fresh. Based on the testing of rock borings, the applicant concluded that Zones III-IV and IV are suitable bearing surfaces for Category I plant structures. The applicant did not consider the joints and fractures present in both zones to be of sufficient density or extent to affect the engineering behavior of the rock with respect to its bearing capacity or integrity.

The applicant stated that no physical evidence of any fissuring, liquefaction, landsliding, lurching, or caving of banks exists to indicate that past earthquake ground shaking has disturbed either the surficial sediments or the bedrock beneath the ESP site. This result follows from the relatively low intensity of historic ground shaking at the site.

The major potential effect of human activity on the ESP site is the mining in the vicinity of the site which occurred from the 1700s to 1974. Sulfide and gold deposits have been mined predominantly in and around the town of Mineral, Virginia, approximately 7 miles west of the site. The closest mining deposit, the Allah Cooper deposit, is about 3 miles northwest of the site. The applicant stated that, based on published documentation of these mining activities and their distance from the site, the activities have not affected, nor would they affect, the ESP site.

The applicant stated that ground water withdrawal from the surficial sediments and bedrock around the ESP site is not an issue because of the low withdrawal quantities and the limited areal extent of the withdrawals. Current site ground water withdrawal is generally limited to water supply wells for plant drinking and process water purposes.

Concerning construction ground water control issues, the applicant stated that ground water at the ESP site generally occurs at depths ranging from about 6 to 58 ft below the present day ground surface. The exception to this is the excavation area of the abandoned Units 3 and 4, which was partially backfilled and where ground water is within about 2 ft of the ground surface. The applicant further stated that ground water levels at the site would likely result in the need for temporary dewatering of foundation excavations extending below the water table.

Concerning the potential for unforseen geologic features, the applicant stated that it would (1) geologically map future excavations for safety-related structures and (2) evaluate any unforseen geologic features that are encountered. In addition, the applicant stated that it would notify the NRC “when any excavations for safety-related structures are open for their examination and evaluation.”

<u>Site Ground Water Conditions</u>

The applicant stated that ground water at the ESP site is present in unconfined conditions in both the surficial sediments and underlying bedrock. Ground water movement at the site is generally to the north and east, toward Lake Anna. Hydraulic conductivity values for the saprolite range from about 0.2 to 3.4 ft/d. SSAR Section 2.4.12 provides a detailed description of the site ground water conditions.

2.5.1.2 Regulatory Evaluation

SSAR Section 2.5.1 presents information on the geologic and seismologic characteristics of the ESP site region and area. In SSAR Section 1.8, the applicant stated that the information presented in SSAR Section 2.5.1 conforms to the requirements of GDC 2 in Appendix A to 10 CFR Part 50, Subpart A of 10 CFR Part 52, and 10 CFR Part 100. The applicant also stated in this section that it developed the geologic and seismologic information in accordance with the guidance presented in RGs 1.70, 1.165, 4.7 (Revision 2 dated 1998), 1.132, “Site Investigations for Foundations of Nuclear Power Plants,” Revision 2, dated October 2003, and RS-002. The staff reviewed this portion of the application for conformance with the applicable regulations, and considered the corresponding regulatory guidance, as identified above with the exception that an ESP applicant need not demonstrate compliance with the GDC.

In reviewing the SSAR, the staff considered the regulations at 10 CFR 52.17(a)(1)(vi) and 10 CFR 100.23(c), which require that the applicant for an ESP describe the seismic and geologic characteristics of the proposed site. In particular, 10 CFR 100.23(c) requires that an ESP applicant investigate the geologic, seismologic, and engineering characteristics of the proposed site and its environs with sufficient scope and detail to support evaluations to estimate the SSE ground motion and to permit adequate engineering solutions to actual or potential geologic and seismic effects at the site. Section 2.5.1 of NUREG-0800, RG 1.165, and Section 2.5 of RG 1.70 provide specific guidance concerning the evaluation of information characterizing the geology and seismology of a proposed site.

2.5.1.3 Technical Evaluation

This section of the SER provides the staff's evaluation of the geologic and seismologic information submitted by the applicant in SSAR Section 2.5.1. The technical information presented in SSAR Section 2.5.1 resulted from the applicant's surface and subsurface geological, seismological, and geotechnical investigations performed in progressively greater detail as they moved closer to the site. Through its review, the staff determined whether the applicant complied with the applicable regulations and conducted its investigations with an appropriate level of thoroughness within the four areas designated in RG 1.165, which are based on various distances from the site (i.e., 200 miles, 25 miles, 5 miles, and 0.6 mile).

SSAR Section 2.5.1 contains the geologic and seismic information gathered by the applicant in support of the vibratory ground motion analysis and site SSE spectrum provided in SSAR Section 2.5.2. According to RG 1.165, applicants may develop the vibratory design ground motion for a new nuclear power plant using either the EPRI or LLNL seismic source models for the CEUS. However, RG 1.165 recommends that applicants update the geological, seismological, and geophysical database and evaluate any new data to determine whether revisions to the EPRI or LLNL seismic source models are necessary. As a result, the staff focused its review on geologic and seismic data published since the late 1980s that could indicate a need for changes to the EPRI or LLNL seismic source models.

To thoroughly evaluate the geologic and seismologic information presented by the applicant, the staff obtained the assistance of USGS. The staff and its USGS advisors visited the ESP site and surrounding area to confirm the interpretations, assumptions, and conclusions presented by the applicant concerning potential geologic and seismic hazards. The staff's review of SSAR Section 2.5.1 focused on (1) tectonic or seismic information, (2) nontectonic deformation information, and (3) conditions caused by human activities, with respect to both the regional and site geology.

2.5.1.3.1 Regional Geology

The staff focused its review of SSAR Section 2.5.1.1 on the applicant's description of the regional tectonics, with emphasis on the Quaternary Period, structural geology, seismology, paleoseismology, physiography, geomorphology, stratigraphy, and geologic history within a distance of 200 miles from the site. Based on its review of SSAR Sections 2.5.1.1.1, 2.5.1.1.2, and 2.5.1.1.3, as described below, the staff concludes that the applicant provided a thorough and accurate description of these geologic features and characteristics in support of the ESP application. In SSAR Section 2.5.1.1.1, the applicant described each of the physiographic provinces within the site region, with an emphasis on the Piedmont province, where the ESP site is located. In SSAR Section 2.5.1.1.2, the applicant described the geologic history of the ESP site region, including each of the episodes of continental collisions and rifting. In SSAR Section 2.5.1.1.3, the applicant described the regional stratigraphy of the Piedmont province, including the major rock units underlying the site. These three SSAR sections describe well-documented geologic information, and the staff concludes that they contain an accurate and thorough description of the regional geology as required by 10 CFR 52.17 and 10 CFR 100.23.

In SSAR Section 2.5.1.1.4, the applicant described the principal tectonic structures within the 200-mile ESP site region based on the age of formation or reactivation of the structures. To define the Quaternary tectonic (2 Ma–present) features, the applicant used the study of Crone and Wheeler (Ref. 59, SSAR Section 2.5) as one of its criteria. This study is a compilation of geologic information on Quaternary faults, liquefaction features, and possible tectonic features in the CEUS. Crone and Wheeler evaluated and classified these features into one of four categories (Classes A, B, C, and D) based on geologic evidence of Quaternary faulting or deformation. The Crone and Wheeler classifications are based on an evaluation of the information that is available in the published geoscience literature and not on a direct examination of the actual geologic features. The applicant used the Crone and Wheeler classifications as one of its criteria (SER Section 2.5.1.1.1 describes other criteria used by the applicant) for assessing the potential Quaternary activity of the following faults:

- Hylas shear zone
- Lake of the Woods thrust fault
- Mesozoic rift basins
- Stafford fault system
- Central Virginia seismic zone
- Mountain Run fault zone
- seven fall lines
- East Coast fault system

For some of the above faults, the applicant used the Crone and Wheeler classifications as its primary basis for assessing the potential Quaternary activity.

The staff determined that the applicant's use of the Crone and Wheeler classifications as a sole or primary basis for assessing the potential Quaternary activity of the above features was insufficient. Therefore, the staff asked the applicant in RAIs 2.5.1-1 through 2.5.1-6 to provide additional information to substantiate its claims for categorizing these features as noncapable. The following sections describe the applicant's responses to RAIs 2.5.1-1 through 2.5.1-6 and the staff's evaluation of these responses.

<u>Central Virginia Seismic Zone</u>

Concerning the Quaternary tectonic features within the ESP site region, the applicant concluded that only the CVSZ shows geologic evidence that demonstrates the existence of a Quaternary fault of tectonic origin. The ESP site is located near the northern boundary of the CVSZ (see SER Figures 2.5.1-3 and 2.5.1-4). The CVSZ is an area defined by moderate to low historical seismic activity, as well as paleoseismicity, since Obermeier and McNulty recently identified two paleoliquefaction features within the CVSZ (Ref. 71, SSAR Section 2.5). In its response to RAI 2.5.1-1, the applicant stated that it interpreted the liquefaction features identified by Obermeier and McNulty to represent at least one, and possibly two, moderate magnitude earthquakes in the CVSZ in the middle to late Holocene epoch. However, because of the absence of liquefaction features in otherwise susceptible middle to late Holocene deposits elsewhere in the study area, Obermeier interprets these liquefaction features as the result of localized, moderately sized (magnitude approximately 5.5 to 6.5) earthquakes. The applicant stated that larger earthquakes with a magnitude of approximately 7 would have produced a more widespread liquefaction field with more numerous, larger liquefaction features. As a basis for its conclusion, the applicant stated that Dr. Obermeier canvassed thousands of meters of exposure of liquefiable deposits in his search area, and the absence of liquefaction in these deposits and the restricted nature of the observed liquefaction features indicate that a magnitude 7 earthquake has not occurred in the Holocene and that abundant magnitude 6 to 7 earthquakes have not occurred in the Holocene within the CVSZ.

Concerning the implications of possibly two moderate-sized (magnitude 5.5 to 6.5) earthquakes occurring in the CVSZ during the middle to late Holocene epoch (past 5,000 to 10,000 years), the applicant stated that the occurrence of these earthquakes is consistent with the EPRI seismic source recurrence estimates for the CVSZ. The average recurrence interval for earthquakes with a magnitude greater than 6 within the CVSZ in the EPRI source model is 7055 years. For somewhat smaller events (magnitude greater than 5.5), the EPRI source model estimates about six events over a period of 10,000 years.

Because of the absence of widespread liquefaction features in susceptible Holocene soil deposits surveyed by geologists, the staff concurs with the applicant’s conclusion that the few liquefaction features within the CVSZ are most likely caused by a few local moderate-magnitude earthquakes. The staff concludes that the applicant accurately characterized the impact of the paleoliquefaction features on the overall seismic characterization of the CVSZ. In addition, the staff concurs with the applicant’s conclusion that the occurrence of these earthquakes is consistent with the EPRI seismic source recurrence estimates for the CVSZ. Section 2.5.1.1.1 of this SER summarizes the applicant’s revisions to SSAR Section 2.5.1 as a result of RAI 2.5.1-1.

<u>East Coast Fault System</u>

The applicant cited another potential Quaternary tectonic feature known as the ECFS. The ECFS-N is located approximately 70 miles southeast of the ESP site. Figure 2.5.1-6, reproduced from the applicant’s response to RAI 2.5.1-2, shows the postulated ECFS-S, ECFS-C, and ECFS-N. The applicant concluded, in SSAR Section 2.5.1.1.4, that the ECFS-N “probably does not exist or has a very low probability of activity if it does exist.” The applicant based its conclusion, in part, on an aerial reconnaissance of the ECFS-N. In its response to RAI 2.5.1-2, the applicant stated that it primarily relied on a review of the evidence presented by Marple and Talwani (Ref. 74, SSAR Section 2.5) to conclude that the ECFS-N probably does not exist or, if it does exist, it has a very low probability of being active during the late Cenozoic Era. Specifically, the applicant stated that, “In our view, Marple and Talwani did not perform a very detailed or rigorous geomorphic analysis to conclude that an active fault is present beneath the coastal plain of North Carolina and Virginia.” The applicant stated that its aerial reconnaissance of the ECFS-N played an important, but less significant, role in developing this conclusion.

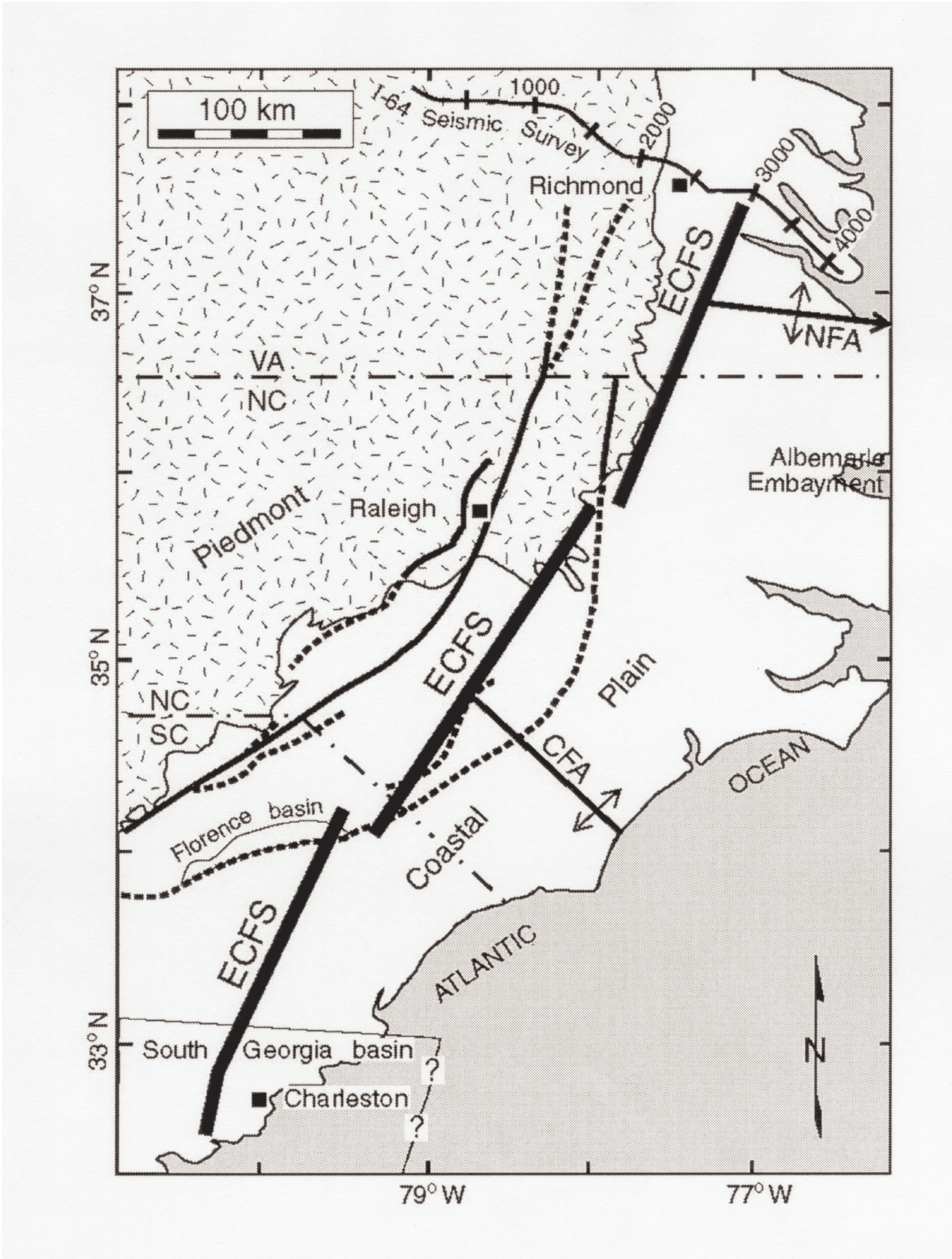

Figure 2.5.1-6 Map showing general area of coverage of Obermeier and McNulty (1998) liquefaction study relative to interpretations of the Central Virginia Seismic Zone.

To support its conclusion regarding the ECFS-N, the applicant evaluated the (1) geological data, (2) geophysical and seismological data, and (3) geomorphic data used by Marple and Talwani to infer the presence of the ECFS-N. The applicant stated that the only geologic data that Marple and Talwani cite in support of the ECFS-N is the coincidence of the ECFS-N with the westward termination of the Norfolk arch axis, which is shown above in Figure 2.5.1-6. In their paper, Marple and Talwani note that their depiction of the Norfolk arch axis is modified from a small-scale map in Pazzaglia (Ref. 6, RAI 2.5.1-2 in RAI Letter No. 3), which shows the Norfolk arch axis terminating westward against the Fall Line. The Fall Line is the boundary between the Coastal Plain and Piedmont physiographic provinces and is a narrow zone of small waterfalls and rapids that occurs at the point where the major rivers pass from the resistant granites and other ancient rocks of the Piedmont to the more easily eroded sands, clays, and shales of the Coastal Plain. Low hills rise to elevations of about 300 ft along the Fall Line. Regarding this modification by Marple and Talwani, the applicant stated the following:

> Specifically, Marple and Talwani (2000) have modified Pazzaglia's map by showing the Norfolk arch axis as terminating about 25 km east of the Fall Zone, on trend with their inferred location of the ZRA-N [ECFS-N]. Marple and Talwani (2000) provide no additional references, interpretations or original data to justify their changes to Pazzaglia's map of the Norfolk arch axis. Thus, it is not possible to determine if their modification of the Norfolk arch axis is based on independent data, or simply a re-interpretation of the Norfolk arch location that is compatible with their model of the ZRA-N [ECFS-N]. We conclude that the location of the Norfolk arch axis, as presented in Marple and Talwani (2000), does not provide independent geologic evidence in support of the ZRA-N [ECFS-N]. Therefore, there is no known geologic evidence to support the existence of the ZRA-N [ECFS-N].

The geophysical or seismological data presented by Marple and Talwani in support of the ECFS-N is an east-west trending seismic reflection profile along Interstate 64 (I-64) through Central Virginia. This geophysical inference of the ECFS-N is based on the Marple and Talwani characterization of the seismic reflection data presented in a publication by Pratt et al. (Ref. 7, RAI 2.5.1-2 in RAI Letter No. 3). However, the applicant pointed out that Pratt and others do not interpret a steeply dipping crustal shear zone in the vicinity of the ECFS-N. The only crustal-scale structure in this region interpreted by Pratt and others is an east-dipping shear zone that underlies the Goochland terrain about 30 km beneath the inferred location of the ECFS-N. As such, the applicant concluded that the I-64 seismic reflection profile does not support the interpretation by Marple and Talwani.

The geomorphic data that Marple and Talwani use to postulate the existence of the ECFS-N are inferred river anomalies. Specifically, Marple and Talwani use their interpretation of geomorphic anomalies along streams that cross the inferred location of the ECFS-N to postulate its existence. These anomalies include channel incision, upward-displaced fluvial surfaces, cross-valley change, sinuosity change, anastomosing stream pattern, and stream deflections. The applicant stated that of these six categories of river anomalies, only "upward-displaced fluvial surfaces" require a tectonic interpretation. The other five anomalies are examples of channel pattern change that can be and typically are produced by non-tectonic processes. The applicant examined each of these river anomaly categories with reference to the ECFS-N to weigh the evidence for its existence and concluded the following:

> Based on our independent assessment of “river anomalies” on the ZRA-N [ECFS-N], we find (1) no evidence for the existence of a fault and (2) direct stratigraphic evidence against the types of deformation postulated by Marple and Talwani (2000). In some cases, we could not verify or duplicate geomorphic observations, such as channel incision, cited by Marple and Talwani (2000). The “upward displaced fluvial surfaces” cited in their paper are inferred only from qualitative analysis of convexities of river profiles and, therefore, this type of “anomaly” does not provide evidence for tectonic uplift and is inconsistent with other geomorphic observations. And finally, we documented direct stratigraphic evidence for no Quaternary deformation in the vicinity of a large meander of the Nottoway River that Marple and Talwani (2000) interpreted to have formed in response to systematic folding and northeastward tilting. We conclude that the fluvial geomorphic features cited by Marple and Talwani (2000) are likely produced by non-tectonic fluvial processes, are not anomalous, and, thus do not support their interpretation of the presence and activity of the ZRA-N (northern segment of the ECFS).

To evaluate the applicant’s response to RAI 2.5.1-2, the staff reviewed the evidence presented by Marple and Talwani as well as the applicant’s analyses of the evidence to support the existence of the ECFS-N. The staff finds that the geologic, seismologic, and geomorphic evidence presented by Marple and Talwani to support the existence of the ECFS-N is questionable. The staff concurs with the applicant’s conclusion that the majority of the geologic data cited by Marple and Talwani in support of their postulated ECFS apply only to the central and southern segments. There are no Cenozoic faults or structure contour maps indicating uplift along the ECFS-N. Accordingly, the staff finds that evidence for the existence and recent activity of the northern segment of the ECFS is low; however, the staff believes that the ECFS-N should be included as a possible contributor to the seismic hazard for the ESP site. The applicant gave the ECFS-N a 10 percent probability of existence as part of its modeling of the seismic sources to determine the SSE. The staff believes, based on its review of the evidence, that a 10 percent probability of existence is an acceptable value. In summary, the staff concludes that the applicant has adequately investigated the possibility of the existence of an ECFS-N. Section 2.5.1.1.1 of this SER summarizes the applicant’s revisions to SSAR Section 2.5.1 resulting from RAI 2.5.1-2.

<u>Local Faults</u>

Other potential Quaternary tectonic features characterized by the applicant include the Hylas shear zone, Mountain Run fault zone, and Lake of the Woods thrust fault. The Hylas shear zone, Mountain Run fault zone, and Lake of the Woods thrust fault are prominent structural features between 5 and 25 miles from the ESP site (see SER Figure 2.5.1-2). The applicant concluded that these Paleozoic faults have not been reactivated and are therefore not capable tectonic sources. In RAI 2.5.1-4, the staff asked the applicant to explain its conclusions regarding the Hylas shear zone and Lake of the Woods thrust fault. In its response to RAI 2.5.1-4, the applicant stated that these faults show no concentration or alignment of historic seismicity, geomorphic expression, or Quaternary deformation. The applicant further stated that, based on its review of the literature, these faults are Paleozoic structures with mylonitic shear textures. This implies that the faults formed at deep crustal levels and that their current surface exposure is the result of exhumation. Based on geologic evidence of Quaternary faulting or deformation, Crone and Wheeler (Ref. 59, SSAR Section 2.5) categorize the

Mountain Run fault zone as only Class C. Crone and Wheeler's comprehensive database of Quaternary features does not mention the Hylas shear zone and Lake of the Woods thrust fault. Based on the lack of historical seismicity, geomorphic evidence, and Quaternary deformation along the Lake of the Woods thrust fault and Hylas shear zone, the staff concurs with the applicant's conclusion that these two faults are Paleozoic faults that have not been reactivated during the Quaternary Period. Section 2.5.1.1.1 of this SER summarizes the applicant's revisions to SSAR Section 2.5.1 resulting from RAI 2.5.1-4.

In RAI 2.5.1-5, the staff asked the applicant to describe the physiographic features associated with the Mountain Run and Kelly's Ford scarps along the Mountain Run fault zone which led the applicant to conclude that the scarps resulted from fluvial erosion and not tectonic deformation. In its response, the applicant stated that it performed reconnaissance-level field and aerial evaluations of the Mountain Run fault zone. To evaluate the potential for Quaternary activity of the Mountain Run fault zone, the applicant examined several geologic profiles across the Mountain Run fault zone, including both the Mountain Run and Kelly's Ford scarps. Based on its examination across these geologic profiles, the applicant concluded the following:

- No consistent expression of a scarp is present along the Mountain Run fault in the vicinity of the Rappahannock River. The northwest-facing Kelly's Ford scarp is similar to a northwest-facing scarp along the southeastern valley margin of Mountain Run; both scarps were formed by streams that preferentially undercut the southeastern valley walls, creating asymmetric valley profiles.

- No northwest-facing scarp is associated with the Mountain Run fault zone between the Rappahannock and Rapidan rivers. Undeformed late Neogene (2–5 Ma) colluvial deposits bury the Mountain Run fault zone in this region, demonstrating the absence of Quaternary (2 Ma–present] fault activity.

- The northwest-facing Mountain Run scarp southwest of the Rapidan River alternates with a southeast-facing scarp on the opposite side of the Mountain Run valley; both sets of scarps have formed by the stream impinging on the edge of the valley.

Based on the evidence cited in the applicant's response, the staff concludes that the scarps along the Mountain Run fault zone are most likely products of fluvial erosion and not Cenozoic fault activity. In particular, the Mountain Run fault zone is overlain by undeformed late Neogene colluvial deposits and thus has not experienced Quaternary surface fault rupture.
Section 2.5.1.1.1 of this SER summarizes the applicant's revisions to SSAR Section 2.5.1 resulting from RAI 2.5.1-5.

The applicant also identified the seven fall lines across the Piedmont and Blue Ridge provinces of North Carolina as another potential Quaternary tectonic feature. Weems identified these seven fall lines (Ref. 70, SSAR Section 2.5), which are based on the alignment of short stream segments with anomalously steep gradients. Because other studies of potential tectonic features in the CEUS do not include the seven fall lines identified by Weems, the applicant concluded that they do not represent a capable tectonic source. In its response to RAI 2.5.1-3, the applicant stated that Weems does not present direct credible evidence for a tectonic origin of the fall lines. The applicant stated that the fall lines described by Weems are not defined by formal, consistently applied criteria, and thus are not as well defined and laterally continuous as depicted. In particular, Weems selectively correlated different features to form a laterally continuous fall line, while in other cases similar features are not correlated. The applicant also stated that, based on its evaluation of the stratigraphic, structural, and geomorphic relations across and adjacent to the fall zones, differential erosion resulting from variable bedrock hardness is a more plausible explanation than Quaternary tectonism. As part of its response to RAI 2.5.1-3, the applicant presented a detailed analysis of geologic and geomorphic data to support its conclusion that the fall lines are not tectonic features. This analysis shows that Weems postulated three hypotheses for the origins of the fall lines in the Blue Ridge and Piedmont provinces:

(1) variable erosion across linear belts of rocks of varying hardness

(2) late Cenozoic climatic and sea level fluctuations, producing “waves” of headwater-retreating nick points that are expressed as fall zones and fall lines

(3) localized neotectonic uplift along fall lines

Weems rejected the first two hypotheses, stating that control of fall lines by rock hardness “is true only locally and occurs as a consequence of uplift.” He also stated that climatic control does not adequately explain the observed patterns of fall lines. Weems concluded that tectonic uplift “is the dominant cause of the existing Piedmont fall lines” because neither differential rock erosion, nor regional creation of nick points by climate-driven changes in fluvial patterns, could “adequately explain the observed patterns.” The applicant concluded that Weems adopted a tectonic interpretation primarily because the alternative interpretations were less compelling, and not because of direct evidence supporting a tectonic origin. The applicant also found that it was unable to reproduce Weems’ delineation of individual fall zones or his correlations of fall zones as laterally continuous fall lines. In summary, the applicant found that Weems’ model for the lateral continuity of fall lines for hundreds of miles along trend in the Blue Ridge and Piedmont provinces is based on subjective assessments of some steep stream reaches as anomalous fall zones.

To further assess the claims made by Weems, the applicant conducted geomorphic analyses of the Tidewater and Central Piedmont fall lines because these two features lie within the North Anna site vicinity. Concerning the Tidewater fall line, the applicant found that a profile of Pliocene marine sand shows no deformation across the Tidewater fall line at the Rappahannock River. The applicant also found that a very strong correlation exists between variations in rock type and gradient changes in the South Anna River profile that strongly suggests that the Tidewater fall line formed as a result of variable erosion across rocks of varying hardness. Concerning the Central Piedmont fall line, the applicant found that the increased gradients along the Rapidan and Rappahannock Rivers as they exit the Culpeper Basin are associated with Jurassic igneous rocks and Paleozoic metamorphic rocks, not Triassic basin sediments as stated by Weems. The applicant stated that the observed gradient as the streams leave the basin is explained by differential erosion of bedrock without invoking tectonic deformation along the Central Piedmont fall line.

Based on the evidence cited by the applicant in response to this RAI, in particular the applicant’s evaluation of the stratigraphy and structural relations associated with the fall zones, the staff concludes that the applicant has accurately characterized the seven fall lines as nontectonic features. The staff concurs with the applicant’s interpretation that differential erosion resulting from variable bedrock hardness is a more plausible explanation than

Quaternary tectonism for the fall lines. The staff notes that evidence for the existence of the seven fall lines as a Quaternary tectonic feature is based solely on the work of Weems and that other geologists have not made this inference. Section 2.5.1.1.1 of this SER summarizes the applicant's revisions to SSAR Section 2.5.1 resulting from RAI 2.5.1-3.

The Stafford fault system approaches to within 16.5 miles of the ESP site to the northeast. In SSAR Section 2.5.1.1.4, the applicant concluded that there is no Quaternary activity along the fault system. In RAI 2.5.1-6, the staff asked the applicant to elaborate on the field observations and aerial reconnaissance that support this conclusion. In its response, the applicant stated that it based its conclusion that the Stafford fault system is not a capable tectonic source on a review of existing literature, discussions with researchers familiar with the area, aerial and field reconnaissance, and geomorphic analyses. The applicant examined the topographic profiles of several terraces that cross the Stafford fault system and found only minor, nontectonic relief on some of the terrace surfaces. In addition, the applicant did not find any scarps or anomalous breaks in the topography on the terrace surfaces associated with the mapped fault traces. Based on the evidence cited by the applicant, in particular the applicant's examination of the topography of the profiles that cross the fault system, the staff concludes that the applicant accurately characterized the Stafford fault system as being inactive during the Quaternary Period.

Based on its review of SSAR Section 2.5.1.1.4 and the applicant's responses to the RAIs, cited above, the staff concludes that the applicant identified and properly characterized all regional tectonic features. The staff concludes that SSAR Section 2.5.1.1.4 provides an accurate and thorough description of the regional tectonics, with an emphasis on potential Quaternary activity, as required by 10 CFR 52.17 and 10 CFR 100.23.

To support its geologic interpretations of the region surrounding the ESP site, the applicant in SSAR Section 2.5.1.1.5 reviewed the regional maps of gravity and magnetic anomalies published by GSA in 1987. The applicant used the regional gravity map to identify the Piedmont gravity gradient and interpreted this feature as an eastward thinning of the North American crust and lithosphere. The applicant interpreted the regional magnetic anomalies as upper crustal variations in magnetic susceptibility, such as mafic and ultramafic rocks, and used the magnetic data as supporting evidence for its interpretation of its seismic reflection data. The staff concludes that the regional gravity and magnetic data support the applicant's overall conclusions concerning the regional geologic and tectonic features.

2.5.1.3.2 Site Geology

The staff focused its review of SSAR Section 2.5.1.2 on the applicant's description of the site-related geologic features, seismic conditions, and conditions caused by human activities. Based on its review of SSAR Sections 2.5.1.2.1 and 2.5.1.2.2, described below, the staff concludes that the applicant has provided a thorough and accurate description of these geologic features and characteristics in support of the ESP application. In SSAR Section 2.5.1.2.1, the applicant described the local topography as gently undulating, varying in elevation from about 200 to 500 ft with the site grade for the existing units at about 271 ft. In SSAR Section 2.5.1.2.2, the applicant described the compressional orogenies and extensional episode that produced the folding and faulting in the region surrounding the site. The applicant also described the local erosion and weathering that produced the residual soils that cover the ESP site. The staff concludes that these two SSAR sections, which describe readily observable local geologic features, contain an accurate and thorough description of the local site geology as required by 10 CFR 52.17 and 10 CFR 100.23.

In SSAR Section 2.5.1.2.3 the applicant described the soil and rock layering beneath the ESP site. The applicant based its description of the site stratigraphy on several borings performed for the existing NAPS Units 1 and 2 and the abandoned NAPS Units 3 and 4, and as part of the ESP application subsurface program. The applicant stated in SSAR Section 2.5.1.2.3 that the borings drilled as part of the ESP application subsurface program reveal "severely weathered, fractured and jointed intervals in Zone III-IV and Zone IV rock," and that these fracture zones range in thickness from about 0.5 to 1 foot thick. The applicant encountered these fracture zones in four of the seven new borings performed as part of the ESP subsurface program. In RAI 2.5.4-2, the staff asked the applicant to describe the impact of the fracture zones on the suitability of the site to host safety-related structures. In response to RAI 2.5.4-2, the applicant stated that it would excavate and replace with lean concrete any weathered or fractured zones encountered at the foundation level. In addition, the applicant stated that it would perform multiple borings once the building locations are chosen. These borings will identify whether there are any fracture zones beneath the foundation thicker than those encountered in the ESP borings. The staff concludes that the applicant's proposal to excavate and replace weathered or fractured zones with lean concrete is an adequate method to ensure the stability of the foundation. The replacement of fractured rock with lean concrete is well understood and commonly done to enhance the strength and stability of the rock to support building loads. Accordingly, the NRC staff proposes to include a condition in any ESP that might be issued requiring that the ESP holder and/or an applicant referencing such an ESP replace weathered or fractured rock at the foundation level with lean concrete before initiation of foundation construction. This is **Permit Condition 5.** In addition, the applicant's proposal to perform additional borings, once it has selected building locations, is necessary to ensure that any significant weathered or fractured zones are identified. The need for additional borings to identify any weathered or fractured rock beneath the new foundations is **COL Action Item 2.5-1.** Section 2.5.4 of this SER provides further discussion of the above permit condition and action item as well as the engineering properties of the soil and rock beneath the ESP site.

Based on its review of SSAR Section 2.5.1.2.3 and the applicant's response to the staff's RAIs, cited above, the staff concludes that the applicant adequately described the site area stratigraphy. The staff concludes that SSAR Section 2.5.1.2.3 provides an accurate and thorough description of the site area stratigraphy, with an emphasis on the uppermost layers of rock and residual soil, as required by 10 CFR 52.17 and 10 CFR 100.23. Section 2.5.4 of this SER provides the staff's complete evaluation of the applicant's description of the ESP site subsurface materials and engineering properties.

SSAR Section 2.5.1.2.4 describes the local faults and folds within the metamorphic bedrock underlying and surrounding the site. The applicant identified seven bedrock faults within a 5-mile radius of the ESP site and concluded, based on site area investigations and a review of the published literature, that none of the faults are capable tectonic sources, as defined in RG 1.165. The NAPS licensee thoroughly investigated one of the faults, unnamed fault "a," which traverses the ESP site, following its exposure within the excavations for the abandoned Units 3 and 4. The staff concluded in its 1974 SER for the abandoned Units 3 and 4 that the "North Anna fault zone is neither genetically nor structurally related to any known capable fault," and concurred with Virginia Power's conclusion that fault "a" is not a capable tectonic source.

Subsequent to Virginia Power's investigation, a local geologist mapped fault "a" over a total distance of about 7 miles, which is considerably longer than the original length of about 3000 ft mapped by Virginia Power. In RAI 2.5.3-2, the staff asked the applicant to evaluate the evidence for the continuation of fault "a" beyond the ESP site. In its response, the applicant stated that the local geologist, L. Pavlides, is deceased and did not document an explanation or basis for his mapping of fault "a" beyond the ESP site. The applicant performed aerial reconnaissance, field reconnaissance, and an air photo interpretation of fault "a" and, based on these studies, concluded that no stratigraphic, structural, or geomorphic evidence would support the existence of fault "a" beyond the EPS site. Based on the evidence presented by the applicant, in particular the evidence cited as a result of the field reconnaissance described below, the staff concludes that the applicant has adequately investigated the possible extension of fault "a" beyond the ESP site. During its field reconnaissance, the applicant found no scarps or lineaments along the trace of fault "a" as mapped by Pavlides. The staff notes that the NAPS licensee's trenching of the fault shows that fault "a" is most likely a minor fault or bedrock shear within the Ta River metamorphic suite and that it is very unlikely that such a minor fault could be recognized or mapped over a significant distance without a significant number of exposures. Section 2.5.3 of this SER provides further discussion of fault "a" and RAI 2.5.3-2.

Based on its review of SSAR Section 2.5.1.2.4 and the applicant's response to RAI 2.5.3-2, cited above, the staff concludes that the applicant adequately described the site area structural geology. The staff concludes that SSAR Section 2.5.1.2.4 provides an accurate and thorough description of the site area structural geology, with an emphasis on the structural features within a 5-mile radius of the ESP site, as required by 10 CFR 52.17 and 10 CFR 100.23. Section 2.5.3 of this SER provides the staff's complete evaluation of the applicant's description of the local bedrock faults near the ESP site and their potential for tectonic deformation and producing vibratory ground motion.

SSAR Section 2.5.1.2.5 states that the only geologic hazards associated with the ESP site are (1) vibratory ground motion from regional earthquake activity and (2) potential surface faulting from site area earthquakes. SSAR Sections 2.5.2 and 2.5.3, respectively, discuss these two potential geologic hazards. The corresponding sections of this SER provide the staff's review of these potential hazards. In SSAR Table 1.9-1, the applicant identified the item, "Capable Tectonic Structures or Sources," as an ESP site characteristic and design parameter. This item specifies that there is no fault displacement potential within the investigative area. The staff reviewed the applicant's description of the site area geologic hazards provided in SSAR Section 2.5.1.2.5 and concludes that the ESP site has no fault displacement potential. Section 2.5.3 of this SER provides the staff's evaluation of the fault displacement potential for the ESP site. The staff concludes that SSAR Section 2.5.1.2.5 does not address two other potential site area geologic hazards, namely slope instability and liquefaction, also arising from local or regional earthquakes. However, the applicant addressed these two topics in detail in SSAR Sections 2.5.4 and 2.5.5.

SSAR Section 2.5.1.2.6 describes the engineering behavior of soil and rock at the ESP site. In addition, SSAR Section 2.5.1.2.6 addresses prior earthquake effects, effects of human activities (mineral extraction and ground water withdrawal), construction ground water control, and unforseen geologic features. In its description of the soil engineering behavior, the applicant stated that the high compressibilities and low maximum densities of the saprolite preclude its use as engineered fill at the ESP site. Because of the relatively high initial settlement of the NAPS pumphouse structure, constructed on about 65 ft of saprolite fill, the staff agrees with this conclusion. Accordingly, the staff is proposing **Permit Condition 6**, which would prohibit the ESP holder and/or an applicant referencing such an ESP from using an engineered fill with high compressibility and low maximum density, such as saprolite.

Based on its review of SSAR Section 2.5.1.2.6, the staff concludes that the applicant has adequately described the site soil and rock characteristics. In particular, the applicant thoroughly described zones of weathering and structural weakness within the soils and bedrock, soil and rock types that could be unstable because of their physical properties, and the effects of human activities (e.g., mining extraction and ground water withdrawal) at the site. The staff concludes that SSAR Section 2.5.1.2.6 provides an accurate and thorough description of the local site conditions, as required by 10 CFR 100.23. In addition, because of limited ground water withdrawal and the distance of any mining activity from the site, the staff concludes there is no potential for the effects, such as subsidence or collapse, of human activity that could compromise the safety of the site.

SSAR Section 2.5.1.2.7 describes the ground water at the ESP site in terms of flow direction and hydraulic conductivity. SSAR Section 2.4.12 provides a detailed discussion of the site ground water conditions; Section 2.4.12 of this SER discusses the staff's evaluation of SSAR Section 2.4.12.

2.5.1.4 Conclusions

As set forth above, the staff reviewed the geologic and seismologic information submitted by the applicant in SSAR Section 2.5.1. On the basis of its review, as described above, the staff finds that the applicant provided a thorough characterization of the geologic and seismologic characteristics of the site, as required by 10 CFR 100.23. These results provide an adequate basis to conclude that no capable tectonic faults exist in the plant site area (5 mi) that have the potential to cause near-surface displacement. The staff concurs with the applicant's classification of the CVSZ as a capable seismogenic source zone rather than a tectonic source zone, since no capable tectonic sources have been identified within the CVSZ. In addition, the staff concludes, as described above, that the applicant has identified and appropriately characterized all the seismic sources significant to determining the SSE for the ESP site, in accordance with RG 1.165 and NUREG-0800, Section 2.5.1. Based on the applicant's geological, geophysical, and geotechnical investigations of the site vicinity and site area, the staff concludes that the applicant has properly characterized the site lithology, stratigraphy, geological history, structural geology, and the characteristics of subsurface soils and rocks. The staff also concludes that there is no potential for the effects of human activity (i.e., ground water withdrawal or mining activity) to compromise the safety of the site.

2.5.2 Vibratory Ground Motion

SSAR Section 2.5.2 describes the applicant's determination of the ground motions at the ESP site from possible earthquakes in the site area and region. SSAR Sections 2.5.2.1 through 2.5.2.4 describe the seismic source and ground motion models used by the applicant. SSAR Section 2.5.2.5 summarizes the seismic wave transmission characteristics of the ESP site. Finally, SSAR Section 2.5.2.6 describes the development of the SSE ground motion for the ESP site.

The applicant stated that the information provided in SSAR Section 2.5.2 complies with NUREG-0800 and uses the procedures recommended in RG 1.165. In addition, the applicant based its seismic ground motion calculations on the EPRI seismic source model for the CEUS. According to RG 1.165, applicants may use the seismic source interpretations developed by LLNL in 1993 or those developed by EPRI as inputs for a site-specific analysis. RG 1.165 also recommends a review and update, if necessary, of both the seismic source and ground motion models used to develop the SSE ground motion for a given site.

2.5.2.1 Technical Information in the Application

2.5.2.1.1 Seismicity

SSAR Section 2.5.2.1 describes both the review and update of the earthquake catalog used to define the seismic sources for the ESP site. The applicant used the original EPRI seismicity catalog, which is complete only through 1984. Therefore, in addition to reevaluating the EPRI catalog, the applicant added seismicity data for the time period from 1985 through 2001 (see SER Figure 2.5.1-4).

The seismicity catalog used for the original EPRI study compiled the data from the seismic networks in the CEUS. Therefore, to develop the EPRI catalog, it was necessary to remove duplicate earthquakes, ensure a consistent magnitude scale (m_b), remove data from events other than earthquakes (e.g., mine blasts and sonic booms), and perform a final check to ensure that the catalog includes significant historic events. To update the 1984 EPRI seismicity catalog, the applicant focused on sources of seismic data in the region surrounding the ESP site. The applicant stated that the most complete regional catalog for recent earthquakes is published by the Virginia Polytechnic Institute and State University (VT) and maintained by Martin Chapman of VT. The VT seismic catalog is complete through 2001 for Virginia, Maryland, Delaware (south of latitude 40E N), West Virginia (south of latitude 40E N), North Carolina, South Carolina, Georgia, Florida, Alabama, Tennessee (east of longitude 88E W), and Kentucky (east of longitude 88E W). However, the VT seismic network and database do not completely cover the region surrounding the ESP site. To supplement the VT catalog, the applicant used the seismic catalog from the Advanced National Seismic System (ANSS) for latitudes of 39.7E N and higher. The updating of seismicity in the ESP site region bounded by latitude 35E to 41E N and longitude 74E to 82E W resulted in the identification of 30 additional earthquakes (24 from the VT catalog and 6 from the ANSS catalog).

2.5.2.1.2 Geologic Structures and EPRI Seismic Source Model for the Site Region

SSAR Section 2.5.2.2 describes the seismic source interpretations from the 1989 EPRI study and the evaluation of new information on seismic sources since the EPRI study. In general, the applicant found that the 1989 EPRI seismic source models did not need to be updated for the ESP site seismic source characterization.

Six independent earth science teams (ESTs) developed the characterization of CEUS seismic sources in the EPRI project. These ESTs evaluated geological, geophysical, and seismological data to model the occurrence of future earthquakes and analyze earthquake hazards at nuclear power plant sites in the CEUS. The six ESTs involved in the EPRI project included (1) the Bechtel Group, (2) Dames and Moore, (3) Law Engineering, (4) Roundout Associates, (5) Weston Geophysical Corporation, and (6) Woodward-Clyde Consultants. EPRI implemented the results of the seismic source characterizations from each of the ESTs in a PSHA for nuclear power plant sites in the CEUS. SSAR Tables 2.5-5 through 2.5-10 summarize the seismic source information developed by each of the ESTs for sources in the region surrounding the ESP site. This information includes the M_{max}, closest distance to the ESP site, probability of activity, and an indication as to whether new information regarding the seismic source has been identified since the original EPRI seismic hazard analyses. The application does not present earthquake recurrence values for each of the seismic sources because the recurrence values were computed for each 1-degree latitude and longitude cell that intersects any portion of a seismic source and, as such, many larger source zones have multiple recurrence values.

In RAI 2.5.2-4(a), the staff asked the applicant to provide additional seismicity parameters, beyond those shown in SSAR Tables 2.5-5 through 2.5-11, for the seismic source zones surrounding the ESP site. In response to RAI 2.5.2-4(a), the applicant provided the seismic source recurrence values used for the EPRI study for the 1-degree latitude and longitude cell encompassing the ESP site region. SER Section 2.5.2.3.2 provides a complete description of the applicant's response to RAI 2.5.2-4(a) and the staff's review of the applicant's response.

The applicant stated the following concerning the seismic source characterizations of the original EPRI study:

> Except for the three specific cases described earlier [below], no new seismological, geological, or geophysical information in the literature published since the publication of the 1986 EPRI source model (Reference 120) suggests that these sources should be modified. The three cases where new information requires modification of the EPRI source characterizations is the addition of the northern segment of the [East Coast Fault System] ECFS (ECFS-N) as a new potential seismic source, the new recurrence and geometry parameters for the existing Charleston source (modeled after the southern segment of the [East Coast Fault System] ECFS (ECFS-S), and the new recurrence parameters for the New Madrid source.

SSAR Sections 2.5.2.2.2 through 2.5.2.2.7 briefly describe the seismic source characterizations made by the six ESTs for each of the sources surrounding the ESP site. Since the largest contributor to the seismic hazard at the ESP site is the CVSZ, the applicant described its source characterization by the six ESTs in SSAR Section 2.5.2.2.8. The six ESTs characterize the largest M_{max} earthquake for the CVSZ as m_b 6.6 to 7.2, with each magnitude value accompanied by a weight. For example, the Dames and Moore EST assigned the M_{max} values for the CVSZ as m_b 6.6 and 7.2, with a corresponding weight for these two magnitudes of 0.8 and 0.2, respectively. The applicant stated that, since the EPRI study, two paleoliquefaction features have been found within the CVSZ, and that these new observations are "consistent with the M_{max} values and recurrence parameters assigned by the EPRI teams." Furthermore, in SSAR Section 2.5.2.2.8, the applicant concluded the following:

> The lack of widespread liquefaction features in the 300 km of stream exposures searched within the CVSZ, despite the presence of mid-to-late-Holocene potentially liquefiable deposits, has led some researchers (Reference 71) to conclude that it is unlikely that any earthquakes have occurred in the area investigated in excess of M-7 during the Holocene.

In RAI 2.5.2-7, the staff asked the applicant to describe how the modern and historical seismicity of the CVSZ is distributed within either a specific source zone or a background source zone. In its response, the applicant described the source model used by each of the six EPRI teams to characterize the CVSZ. SER Section 2.5.2.3.2 provides a complete description of the applicant's response to RAI 2.5.2-7 and the staff's review of the applicant's response.

In RAI 2.5.2-4(b), the staff asked the applicant to justify its decision not to update the M_{max} assigned to the CVSZ for the 1989 EPRI seismic source models, considering the 1994 EPRI study, "Seismotectonic Interpretation and Conclusion from the Stable Continental Region Database." In its response, the applicant stated that EPRI initiated the 1994 study in the mid-1980s specifically for use by the EPRI teams in their development of the 1989 EPRI seismic source models. EPRI provided the preliminary results of the 1994 study to each of the EPRI teams for their use in assigning M_{max} values in stable continental regions (SCRs), such as the ESP site region. As such, the EPRI teams used the estimates of M_{max} and source zone geometry drawn from the preliminary results of the 1994 EPRI study for their 1989 seismic source models. SER Section 2.5.2.3.2 provides a complete description of the applicant's response to RAI 2.5.2-4(b) and the staff's review of the applicant's response.

SSAR Section 2.5.2.2.9 describes the post-EPRI PSHA studies within the North Anna site region for comparison with the PSHA completed as part of the ESP application. Since the EPRI seismic hazard project, researchers have completed three PSHA studies that overlap or include the seismic sources within the North Anna site region. These three studies include the following:

- Savannah River nuclear site (Ref. 125, SSAR Section 2.5)
- seismic hazard of Virginia (Ref. 126, SSAR Section 2.5)
- USGS National Seismic Hazard Mapping Project (Ref. 127, SSAR Section 2.5)

The PSHA performed for the Savannah River nuclear site in South Carolina specifies sources, recurrence rates, focal depths, and M_{max} values for earthquake sources in the southeastern United States. As part of the Savannah River PSHA, Bollinger (Ref. 125, SSAR Section 2.5) identified three seismic sources that fall within the North Anna site region. These sources include the CVSZ, the Giles County seismic zone, and a complementary background zone. For the CVSZ, the Savannah River PSHA assigns an M_{max} of m_b 6.4, which is comparable to the range of M_{max} values given for the CVSZ by the EPRI teams. For the Giles County seismic zone and complementary background zone, the Savannah River PSHA assigns maximum values of 6.3 and 5.7, respectively. These M_{max} values are also similar to those used by the EPRI teams for these two source zones.

The applicant stated that researchers at VT (Ref. 126, SSAR Section 2.5) performed a seismic hazard assessment of Virginia in 1994 on a county-by-county basis. The study defined a total of 10 seismic sources based primarily on patterns of seismicity, with 7 of the 10 sources located within the region surrounding the North Anna site. For each source zone, the authors of the study assumed an M_{max} of m_b 7.25. This M_{max} is based on the assumption that an earthquake similar to the one that occurred in 1868 in Charleston, South Carolina (m_b 6.8 to 7.5), could occur in any of the sources within the North Anna site region. The applicant stated that this M_{max} is consistent with the range of M_{max} values that the EPRI teams assigned to the CVSZ and Giles County seismic zones.

The third PSHA performed after the EPRI 1989 study was the 2002 USGS National Seismic Hazard Mapping Project. The 2002 USGS national seismic hazard maps are the updated 1996 USGS seismic hazard maps that incorporate changes in the recurrence and geometry of the Charleston, South Carolina, seismic source, as well as the recurrence and M_{max} assigned to the New Madrid seismic source zone. Rather than defining many local seismic source zones, the USGS hazard study includes only a small number of sources surrounded by larger background zones. Within the ESP site region, the USGS model defines a single source zone, the Extended Margin Background Zone, which covers nearly the entire eastern and southeastern United States. The M_{max} value assigned to the Extended Margin Background Zone by USGS is 7.5, which corresponds to m_b 7.2. The applicant stated that this M_{max} value is consistent with the range of maximum values assigned to the CVSZ by the EPRI teams.

2.5.2.1.3 Correlation of Seismicity with Geologic Structures and EPRI Sources

As part of the review and update of the 1989 EPRI seismic source model, the applicant compared the updated seismicity (1985 through 2001) with the earlier EPRI seismicity catalog (1627 through 1984). As a result of this comparison, the applicant concluded that the updated catalog does not show (1) any earthquakes within the site region that can be associated with a known geologic structure, (2) a unique cluster of seismicity that would suggest a new seismic source outside of the EPRI source model, (3) a new pattern of seismicity that would warrant significant revision to the EPRI seismic source geometry, (4) an increase in the M_{max} for any of the EPRI seismic sources, and (5) any changes to the recurrence values for the EPRI seismic sources.

2.5.2.1.4 1989 EPRI Probabilistic Seismic Hazard Analysis, Deaggregation, and 1-Hz, 2.5-Hz, 5-Hz, and 10-Hz Spectral Velocities

SSAR Section 2.5.2.4 describes the confirmation of the 1989 EPRI PSHA results for North Anna. For its confirmation, the applicant used the peak ground acceleration (PGA) hazard curves for comparison with the 1989 EPRI PSHA results for North Anna. The applicant found that the average difference in annual probability of ground motion exceedance is +1.1 percent, which corresponds to a 0.3 to 0.7 percent increase of the ground motion amplitude. This difference is much less than the total uncertainty in seismic hazard calculations, and, as such, the applicant concluded that the current PSHA for the ESP site correctly models the seismic sources and ground motion equations. To further confirm the accuracy of the current PSHA, the applicant also replicated the 1-, 2.5-, 5-, and 10-Hertz (Hz) spectral velocity hazard curves using the 1989 EPRI seismic sources and ground motion models. In addition, using the procedure described in RG 1.165, the applicant calculated the controlling earthquakes for the ESP site using the 1989 EPRI results. The low-frequency controlling earthquake magnitude and distance are M_w 5.9 and 25 km, respectively, and the high-frequency controlling earthquake magnitude and distance are M_w 5.5 and 18 km, respectively. The applicant used these controlling earthquakes for comparison with the updated PSHA results for the ESP site presented in SSAR Section 2.5.2.6.1.

2.5.2.1.5 Seismic Wave Transmission Characteristics of the Site

SSAR Section 2.5.2.5 briefly summarizes the subsurface model used for the ESP site. The foundation materials are divided into the following five zones from surface to bedrock:

- residual clays and clay silts (Zone I)
- weathered saprolite (Zone IIA)
- saprolite (Zone IIB)
- weathered rock (Zone III)
- parent rock (Zone IV)

The applicant stated that the containment (reactor building) and primary safety-related structures would be founded on sound bedrock, either Zone IV or Zone III-IV (slightly to moderately weathered rock). The applicant also stated that other safety-related structures (possibly the diesel generator building and certain tanks) may be founded on Zone III weathered rock or Zone II saprolitic soils.

Section 2.4.5.7 of the SSAR presents a detailed description of the seismic wave transmission characteristics of each of the above soil and rock layers. The description includes the shear wave velocity, as well as the variation of shear modulus and damping with strain for each of the zones.

In RAIs 2.5.2-1(c) and 2.5.2-8, the staff asked the applicant to explain how it factored the properties of the site-specific subsurface materials into the determination of the SSE. In its responses, the applicant stated the following:

> The SSE spectrum is calculated directly using the EPRI 2003 ground motion models. For the North Anna ESP site, the selected SSE directly incorporates the hard rock foundation assumption of the EPRI 2003 ground motion models (a shear-wave velocity of 2.8 km/s or about 9,200 ft/s). The containment (reactor) building and primary supporting safety-related structures would be founded on sound bedrock, either Zone IV or Zone III-IV materials (see SSAR Section 2.5.2.5) for which this shear wave velocity is a good approximation. Therefore, site-specific materials are factored into the determination of the SSE by recognizing that the hazard analysis performed to develop the SSE uses attenuation relations that are directly applicable to specific subsurface conditions at the North Anna site.

As set forth in the DSER, the staff considered the applicant's response above to be inadequate based on a comparison of the hard rock shear wave velocity (9200 ft/s) assumed by the EPRI 2003 ground motion models and the bedrock Zone III-IV shear wave velocity (3300 ft/s) beneath the ESP site. DSER Open Item 2.5-2 covered the necessity to include the local site conditions in the determination of the SSE. As a result of Open Item 2.5-2, the applicant reran its analysis to determine the seismic wave transmission characteristics of the site. The applicant's new analysis used a rock subsurface profile that extends from the top of Zone III-IV bedrock to a depth of 160 ft under the site where the shear wave velocity reaches about 9200 ft/s. The applicant used the ESP rock subsurface profile to estimate the amplification of the SSE ground motion at a control point located at the top of competent Zone III-IV rock. The following SER Section (2.5.2.1.6) provides a complete description of the applicant's response to Open Item 2.5-2, and SER Section 2.5.2.3.5 provides the staff's evaluation of the applicant's response.

2.5.2.1.6 Safe-Shutdown Earthquake Ground Motion

SSAR Section 2.5.2.6 describes the development of the SSE ground motion for the ESP site. The first four subsections of SSAR Section 2.5.2.6 describe the updating of the 1989 EPRI PSHA in terms of (1) a new regional earthquake catalog, (2) new M_{max} information, (3) new seismic source characterizations, and (4) new ground motion models. The subsequent subsections of Section 2.5.2.6 describe (1) the controlling earthquakes, (2) the selected SSE ground motion, (3) sensitivity studies, and (4) the future modification of the selected SSE spectrum.

SSAR Section 2.5.2.6 addresses the new geoscience information (new seismic sources, new magnitudes, new recurrence intervals, new ground motion models) by examining the effect of this new information on the median seismic hazard at levels of 10^{-5} per year. The applicant used the 1989 EPRI seismic sources and ground motion models to compare the effect of this new information on the seismic hazard at the ESP site with the seismic hazard developed for North Anna.

New Regional Earthquake Catalog

This section compiles the seismic sources surrounding the ESP site that contribute 99 percent of the seismic hazard, using both the PGA hazard results and the 1-Hz spectral velocity hazard results. The applicant used this compilation of seismic sources from the 1989 EPRI PSHA to determine whether the seismic activity rates used in the 1989 EPRI study are still adequate. The applicant examined recent seismic activity rates using earthquakes recorded in the region since 1984 and compared these rates to those used in the 1989 EPRI PSHA. The results of this comparison show that recent seismicity, recorded from 1985 to 2001, indicates that seismic activity rates have decreased for the sources contributing most to the ESP site. Therefore, the applicant used the seismic activity rates derived from the 1989 EPRI study to calculate the seismic hazard at the ESP site.

New Maximum Magnitude Information

This section describes the applicant's review of the geologic and seismologic data published since the 1986 EPRI seismic source model to determine if changes to the M_{max} values for any of the seismic source zones are needed. The applicant stated that the M_{max} used for the EPRI source models relied on an EPRI study (Ref. 195, SSAR Section 2.5) of large earthquakes occurring worldwide within SCRs. Based on its review, the applicant concluded that the range of M_{max} values assigned by the EPRI teams for the Charleston, South Carolina, seismic source is too low. For the Charleston seismic source, the applicant identified a new geologic structure as the possible source of the 1886 Charleston earthquake, referred to as the ECFS-S. For the ECFS-S M_{max} values, the applicant decided to use the 2002 USGS values and weights. These M_{max} values range from M_w 6.8 to 7.5. The Charleston source M_{max} values used by the six EPRI teams for the 1989 PSHA range from M_w 6.5 to 8.0.

New Seismic Source Characterizations

This section describes the applicant's review of the geologic and seismologic data published since the 1989 EPRI seismic source model to determine whether any new seismic sources have been postulated or whether significant changes to the characterizations of previously identified sources are needed. The applicant concluded that three changes to the 1989 EPRI seismic source characterizations were necessary, namely (1) identification of a postulated ECFS-N, (2) revision to the recurrence interval and source geometry of the Charleston seismic source, and (3) revision to the recurrence interval of the New Madrid seismic source.

As modeled, the ECFS runs along the Atlantic seaboard and consists of the ECFS-N, ECFS-C, and ECFS-S (see SER Figure 2.5.1-6). The ECFS-N is located approximately 70 miles southeast of the ESP site and was not previously included in the 1989 EPRI PSHA. For the ECFS-N, the applicant assumed a probability of existence of 0.1 and a probability of activity (given existence) of 0.1. For the ECFS-N, the applicant adopted the M_{max} parameters and weights used in the 2002 USGS national seismic hazard map for the Charleston source. The applicant selected the recurrence values and weights of 550 years (0.1), 25,000 years (0.5), and 50,000 years (0.4), respectively. The applicant stated that it assigned low weights to the probability of existence and probability of activity because the existence of the fault is not well documented and is highly uncertain. In addition, no geologic, geomorphic, or seismologic evidence indicates that the fault exists as a tectonic feature or, if it does exist, that it is active.

New data published since the original EPRI study have resulted in revisions to the recurrence interval and source geometry for the Charleston seismic source. As stated earlier, the applicant adopted the M_{max} values used by the 2002 USGS national hazard maps for the Charleston seismic source. In addition to the M_{max} values, the applicant also reduced the recurrence interval for the Charleston source from several thousand years, used by the 1989 EPRI PSHA, to 550 years. The applicant stated that it based the reduction in the recurrence interval for the Charleston seismic source on recent paleoliquefaction studies, which provide evidence of previous earthquakes in the Charleston source area. In addition to M_{max} values and recurrence intervals, the applicant used the ECFS-S as an alternative source geometry for the Charleston source. The applicant also assumed that the mean recurrence interval of 550 years applies to the M_{max} values. The applicant stated that this approach is conservative because the mean recurrence interval may not be directly associated with earthquakes as large as the assumed M_{max} values.

In RAI 2.5.2-5, the staff asked the applicant to explain how it incorporated the alternative characterization of the ECFS-S into the final PSHA. In its response, the applicant stated that it evaluated the alternative characterization of the ECFS-S, both independently and additively, to conservatively assess the maximum possible change to hazard at the North Anna ESP site from this newly postulated source. The revisions to the ECFS-S include a shorter recurrence interval (550 years) and different weights for the M_{max} (M_w 6.8 to 7.5). The applicant added the ECFS-S to the source models of each of the six EPRI teams for the final PSHA. SER Section 2.5.2.3.4 provides a complete description of the applicant's response to RAI 2.5.2-5 and the staff's evaluation of the applicant's response.

SSAR Section 2.5.2.6.5 states that the applicant examined the effects of the new characterization of the ECFS-N and ECFS-S fault segments by calculating the seismic hazard from these two fault segments and comparing this seismic hazard to that predicted from the 1989 EPRI seismic sources. The applicant calculated the seismic hazard from these two fault segments using the 2003 EPRI ground motion models rather than the earlier 1989 ground motion models. As shown in SSAR Figures 2.5-40 and 2.5-41, the ECFS-S fault increases the total median and mean hazard for 1-Hz spectral acceleration by several percent at the 10^{-5} hazard level. The ECFS-N fault segment, for which the applicant assigned a 10 percent probability of existence and activity, does not contribute to the overall hazard. For higher frequency ground motion (i.e., 10-Hz spectral acceleration), neither the ECFS-S nor the ECFS-N fault segments contribute significantly to the overall seismic hazard. SSAR Section 2.5.2.6.5 states that this results from the domination of the higher frequency ground motion by seismic sources closer than the distant ECFS. The ECFS-N fault segment is 70 miles southeast of the ESP site, and the ECFS-S is 300 miles south of the ESP site.

New Ground Motion Models

To estimate the ground motion at the ESP site from each of the seismic sources, the applicant used the new 2003 EPRI-sponsored study that compiles and evaluates 13 new ground motion attenuation models for the CEUS (Ref. 116, SSAR Section 2.5). The previous EPRI PSHA used only three ground motion attenuation models.

For lower frequency ground motion (i.e., 1-Hz spectral acceleration), the new ground motion models result in median hazard results that are about the same as the hazard results derived using the 1989 ground motion models. In contrast, the 2003 mean hazard is significantly lower than the 1989 mean hazard. In addition, for higher frequency ground motion (i.e., 10-Hz spectral acceleration), SSAR Section 2.5.2.6.5 states that both the median and mean hazards increase significantly at annual frequencies of 10^{-5}. Figure 2.5-44 in the SSAR compares a 10-Hz seismic hazard for both the 1989 ground motion models and the 2003 ground motion models. SSAR Section 2.5.2.6.5 provides the following rationale for the higher hazard for higher frequency ground motion determined by the newer model:

> A major difference between the 1989 and 2003 ground motion models is that the estimates of aleatory [random] uncertainty are larger in the 2003 study. In 1989, a standard deviation of natural log (ground motion) of 0.5 was used for all frequencies, whereas in 2003, values of 0.6 and 0.7 are common (they vary depending on magnitude, distance, and frequency). At annual frequencies of 10^{-5}, which are sensitive to the tails of the ground motion aleatory distribution, this difference in standard deviation increases seismic hazard. This would likely be true for any CEUS location. A compensating factor at low frequencies (1 and 2.5 Hz) [1 Hz] is the use of ground motion models that reflect a two-corner source, which acts to reduce low frequency [1 Hz] ground motion estimates from those used in 1989. Thus the median 1 Hz seismic hazard is about the same for both models. The mean amplitudes using the 2003 ground motion models are closer to the median amplitudes than is the case for the 1989 models, reflecting convergence on what are reasonable models to use for ground motion estimation in the eastern US. In 1989, the ground motion models were quite diverse, with one model developed by estimating peak ground acceleration and velocity, then using spectral amplification factors to estimate spectral amplitudes. In 2003, the available models estimate spectral amplitudes directly.

PSHA and Controlling Earthquakes

Using the 2003 EPRI ground motion models and adding the ECFS-S fault segment, the applicant calculated the PSHA results for the ESP site. Table 2.5-22 of the SSAR, reproduced below, compares the 1989 EPRI PSHA and the 2003 PSHA results.

Table 2.5.2-1 Updated Seismic Hazard Results at ESP Site

Frequency	Median/Mean	Updated PSHA	1989 PSHA	Difference
1 Hz	10^{-5} median	0.096 g	0.091 g	6%
	10^{-5} mean	0.134 g	0.219 g	-39%
2.5 Hz	10^{-5} median	0.316 g	0.232 g	36%
	10^{-5} mean	0.364 g	0.519 g	-30%
5 Hz	10^{-5} median	0.639 g	0.439 g	46%
	10^{-5} mean	0.735 g	0.753 g	-2%
10 Hz	10^{-5} median	1.020 g	0.660 g	55%
	10^{-5} mean	1.216 g	0.827 g	47%

As shown in Table 2.5.2-1 above, the largest difference is at 10 Hz, where the updated PSHA indicates higher ground motion amplitudes for the 10^{-5} median and mean by 55 percent and 47 percent, respectively. At 1 Hz, 2.5 Hz, and 5 Hz, the updated PSHA shows a higher median 10^{-5} hazard, but a lower mean 10^{-5} hazard.

Selected SSE Ground Motion

The method for determining the SSE for a site, as described in RG 1.165, is based on the use of a reference probability. The basis for the procedure in RG 1.165, as well as the determination of the reference probability, is that existing nuclear power plants do not represent an undue risk to the health and safety of the public. As such, using the existing plants as a reference, RG 1.165 recommends a procedure to determine the seismic design basis for future plants. The reference probability is the average probability of exceeding the SSE ground motion at 5 Hz and 10 Hz, using either the 1993 LLNL PSHA or the 1989 EPRI PSHA. The NRC staff calculated a reference probability level for 29 nuclear power plant sites in the CEUS; the median reference probability for these 29 sites, using median hazard results, is 10^{-5} per year. A similar value was obtained using both the 1993 LLNL and the 1989 EPRI PSHA level; therefore, RG 1.165 endorses both the LLNL and the EPRI PSHA results as suitable for seismic hazard estimation for future siting.

To determine the site SSE, the applicant used the method described in RG 1.165, but with a higher reference probability. In RAI 2.5.2-1(d), the staff asked the applicant to justify this higher reference probability. The applicant cited Section B.3 in Appendix B to RG 1.165 and the following three factors to justify changing the reference probability:

(1) The revised EPRI ground motion models (Ref. 116, SSAR Section 2.5) indicate generally higher ground motions and aleatory uncertainties at higher frequency amplitudes of interest than previous models.

(2) The mean recurrence time for large earthquakes in the New Madrid, Missouri, region and in the Charleston, South Carolina, region has decreased since the EPRI and LLNL studies in the 1980s.

(3) Use of the mean hazard instead of the median hazard results in a higher reference probability because mean hazard curves lie above median hazard curves.

The applicant stated that the combined effect of these three factors would increase the reference probability by a factor of at least 5. Therefore, the applicant selected a mean hazard value of $5x10^{-5}$ as its reference probability. The applicant then deaggregated the PSHA results using the new reference probability to determine the controlling earthquakes for the ESP site. The controlling earthquakes for the ESP site have a magnitude of 5.4 at 12 miles (19.31 km) and a magnitude of 7.2 at 191 miles (307.4 km). The first magnitude-distance pair is the high-frequency (i.e., 5 and 10 Hz) controlling earthquake and is consistent with an earthquake from the CVSZ. The second magnitude-distance pair is the low-frequency (i.e., 1 and 2.5 Hz) controlling earthquake and is consistent with an earthquake from the ECFS-S fault. Figures 2.5.2-1 and 2.5.2-2, reproduced from SSAR Figures 2.5-49 and 2.5-50, respectively, depict the results of the deaggregation of the PSHA results.

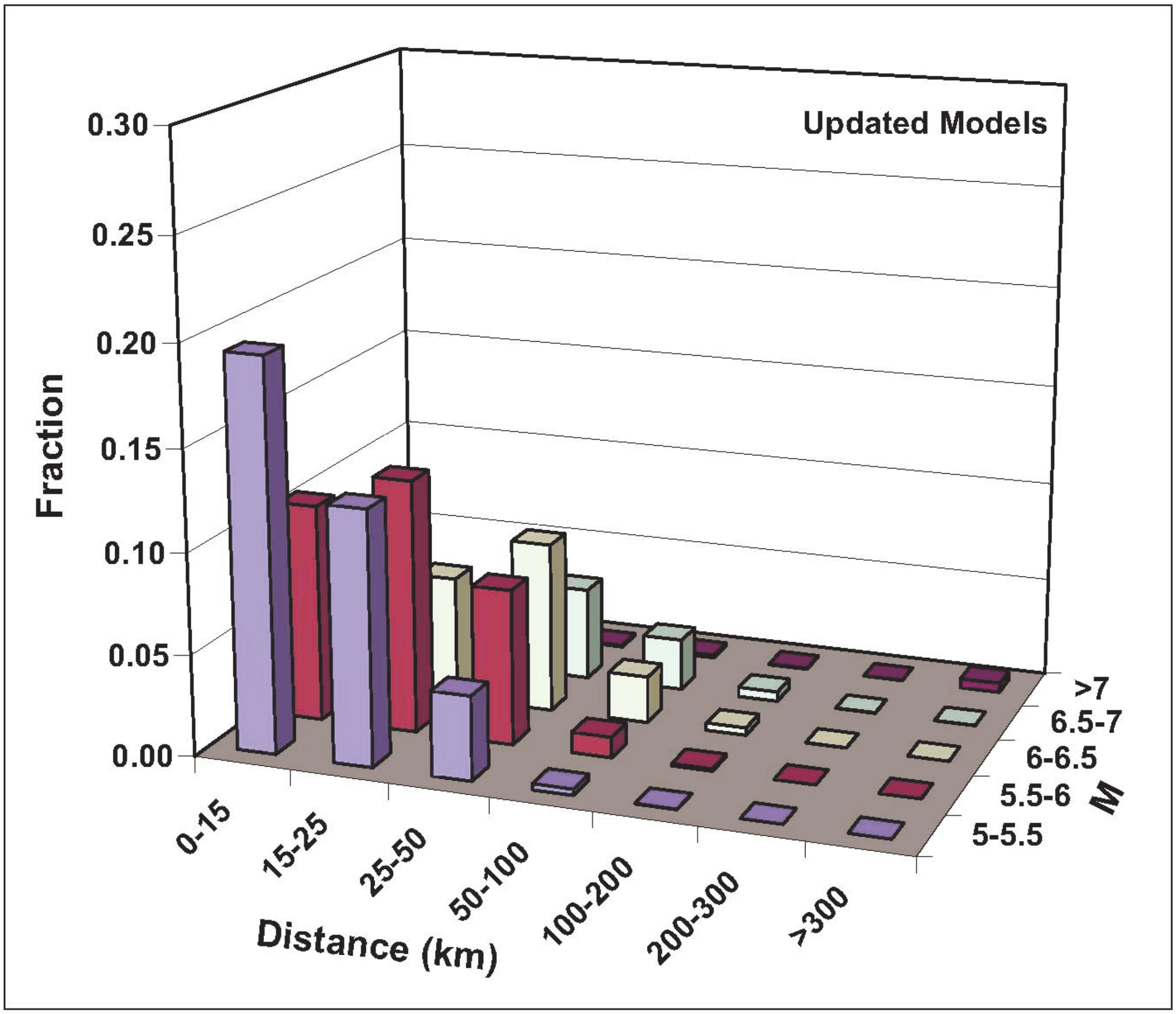

Figure 2.5.2-1 Magnitude-distance deaggregation for low frequencies (1 and 2.5 Hz) at a mean annual frequency of $5{\times}10^{-5}$ using updated source and ground motion models

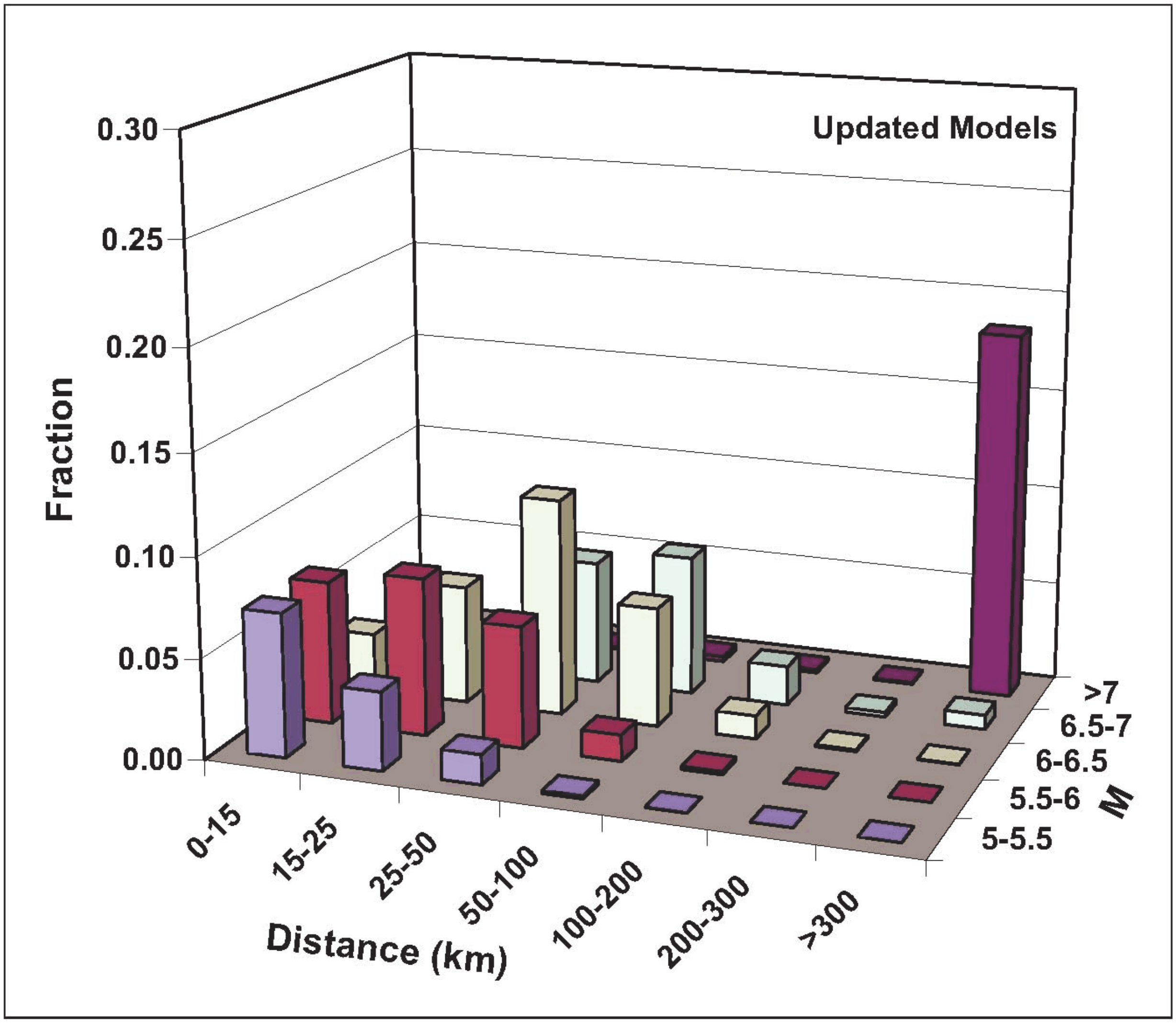

Figure 2.5.2-2 Magnitude-distance deaggregation for high frequencies (5 and 10 Hz) at a mean annual frequency of $5x10^{-5}$ using updated source and ground motion models

To determine these two controlling earthquakes, the applicant followed the procedure in Appendix C to RG 1.165, using the higher reference probability and the mean PSHA hazard results rather than the median results. Using the two controlling earthquakes, the applicant then determined two ground motion response spectra using the EPRI 2003 ground motion relationships and scaling the two spectra to the appropriate ground motion amplitudes. Figure 2.5.2-3, reproduced from SSAR Figure 2.5-48, shows the hard rock (9200 ft/s) ground motion response spectra for the two controlling earthquakes.

In addition to using the methodology described in RG 1.165 to determine the SSE ground motion, the applicant chose to use an alternative approach, described as a performance-based approach. In RAI 2.5.2-1, the staff asked the applicant to explain how the performance-based approach meets the requirements of 10 CFR 100.23, which provides the geologic and seismic siting criteria, as well as a definition of the SSE. In its response, the applicant explained how the performance-based approach conforms to the requirements of 10 CFR 100.23. In RAI 2.5.2-9, the staff asked the applicant for further details on the performance-based approach to supplement the information provided in SSAR Section 2.5.2.6. In its response, the applicant provided further justification for the performance-based approach, including the derivation of some key relationships. Section 2.5.2.3.6 of this SER discusses this further.

Selection of Enveloping Horizontal SSE Spectrum

Initially, to determine the final SSE for the ESP site, the applicant enveloped the two controlling earthquake ground motion response spectra and the performance-based spectrum. Figure 2.5.2-3, reproduced from SSAR Figure 2.5-54A, shows these spectra. However, as a result of Open Item 2.5-2, described above in the previous SER subsection, the applicant incorporated the local site geologic properties into its determination of the final SSE. The applicant's new analysis used a rock subsurface profile that extends from the top of Zone III-IV bedrock (21 ft depth) to depths at which the shearwave velocity in the bedrock under the site reaches about 9200 ft/s (160 ft depth). The applicant used this best-estimate profile to estimate the amplification of the SSE ground motion at a control point located at the top of competent Zone III-IV rock. The applicant selected this control point at the top of Zone III-IV rock to be consistent with Section 3.7.1 of NUREG-0800, which states that the control point for sites with a thin soil layer is specified on "an outcrop or a hypothetical outcrop at a location on the top of the competent material."

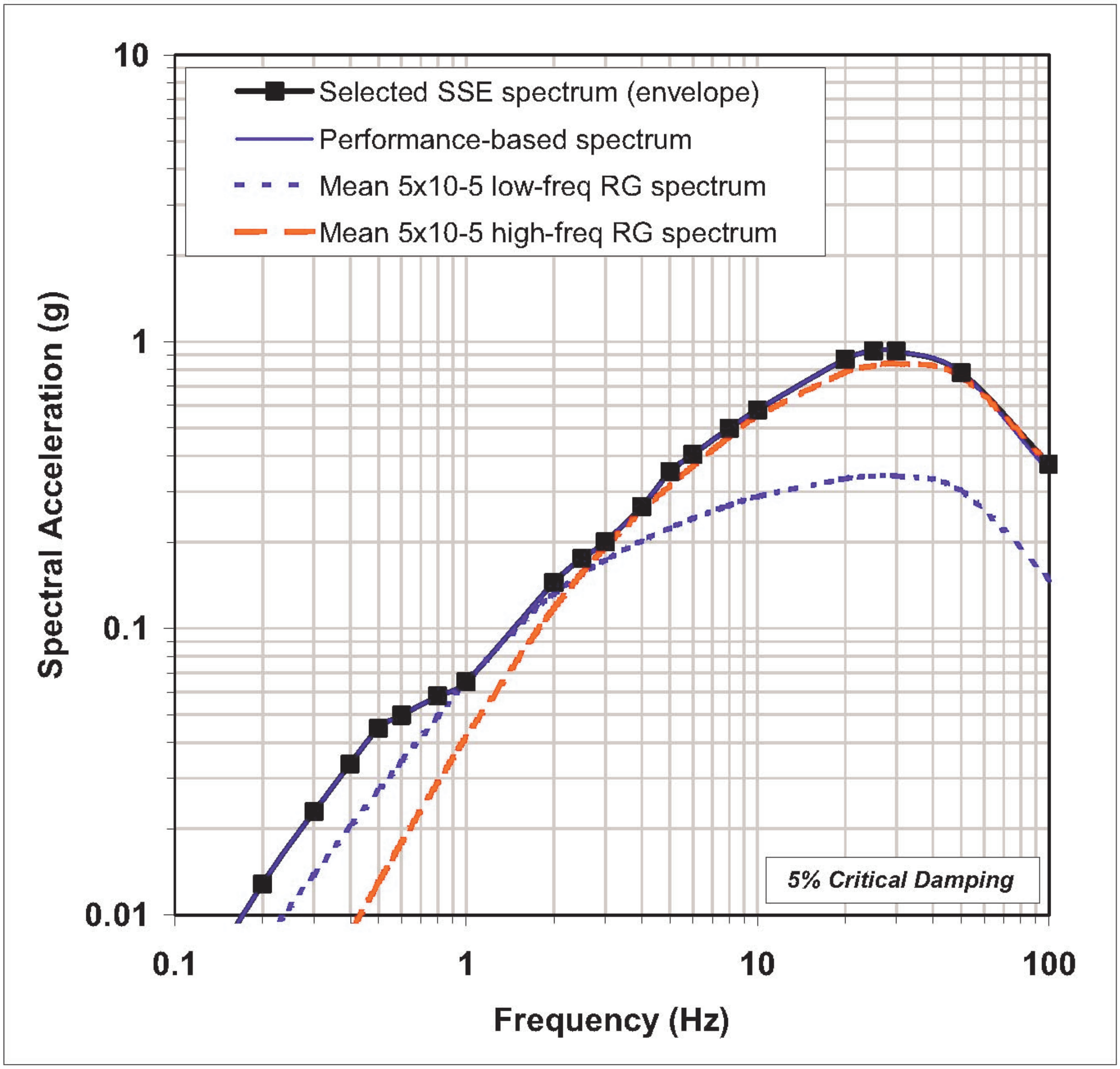

Figure 2.5.2-3 Comparison of performance-based spectrum, mean 5x10^{-5} scaled spectra, and selected SSE spectrum (which overlaps the performance-based spectrum and envelops the other two)

To determine the control point SSE at the top of Zone III-IV rock, the applicant (1) developed a shear wave velocity profile for the ESP site, (2) generated alternative randomized rock columns to incorporate the variability in the rock properties, (3) selected seed earthquake time histories, and (4) performed the final ground response analysis.

The applicant's shear wave velocity profile is based on its subsurface exploration for the ESP site and Virginia Power's subsurface explorations for the existing units. For these explorations, the applicant made shear wave velocity measurements mainly at 5-ft depth intervals, but sometimes at 10-ft depth intervals. The applicant also defined the material properties of density, Poisson's ratio, and the behavior of shear wave velocity and material damping as a function of strain. SSAR Section 2.5.4.7 describes the subsurface shear wave velocity and related material property information for the ESP site.

The applicant developed 50 alternative randomized rock columns by varying the material properties described above. The applicant generated 50 randomizations of the generic ESP site rock column velocity profile between elevations with shear wave velocities of 9200 ft/s and 3300 ft/s. The applicant kept the same damping value for all sublayers within any given profile but varied the damping value between one artificial rock column and the next.

Next, the applicant selected two seed time histories to match the low- and high-frequency controlling earthquake response spectra shapes (see Figure 2.5.2-3). The applicant selected these two time histories using the controlling earthquake magnitude and distance values from the database of CEUS time histories given in NUREG/CR-6728 (Ref. 9, SSAR Section 2.5).

To perform the final ground response analysis, the applicant used the two low-frequency and high-frequency input hard rock motions for each of the 50 artificial rock profiles. The applicant modeled the site using horizontal layers, each 7.5 ft thick, overlying a uniform half-space of hard bedrock (V_s at 9200 ft/s). Figure 2.5.2-4, reproduced from Figure 8 in the March 30, 2005, response to Open Item 2.5-2, shows the 50 response spectra for the high- and low-frequency time histories at the control point at the top of Zone III-IV rock (model layer 1).

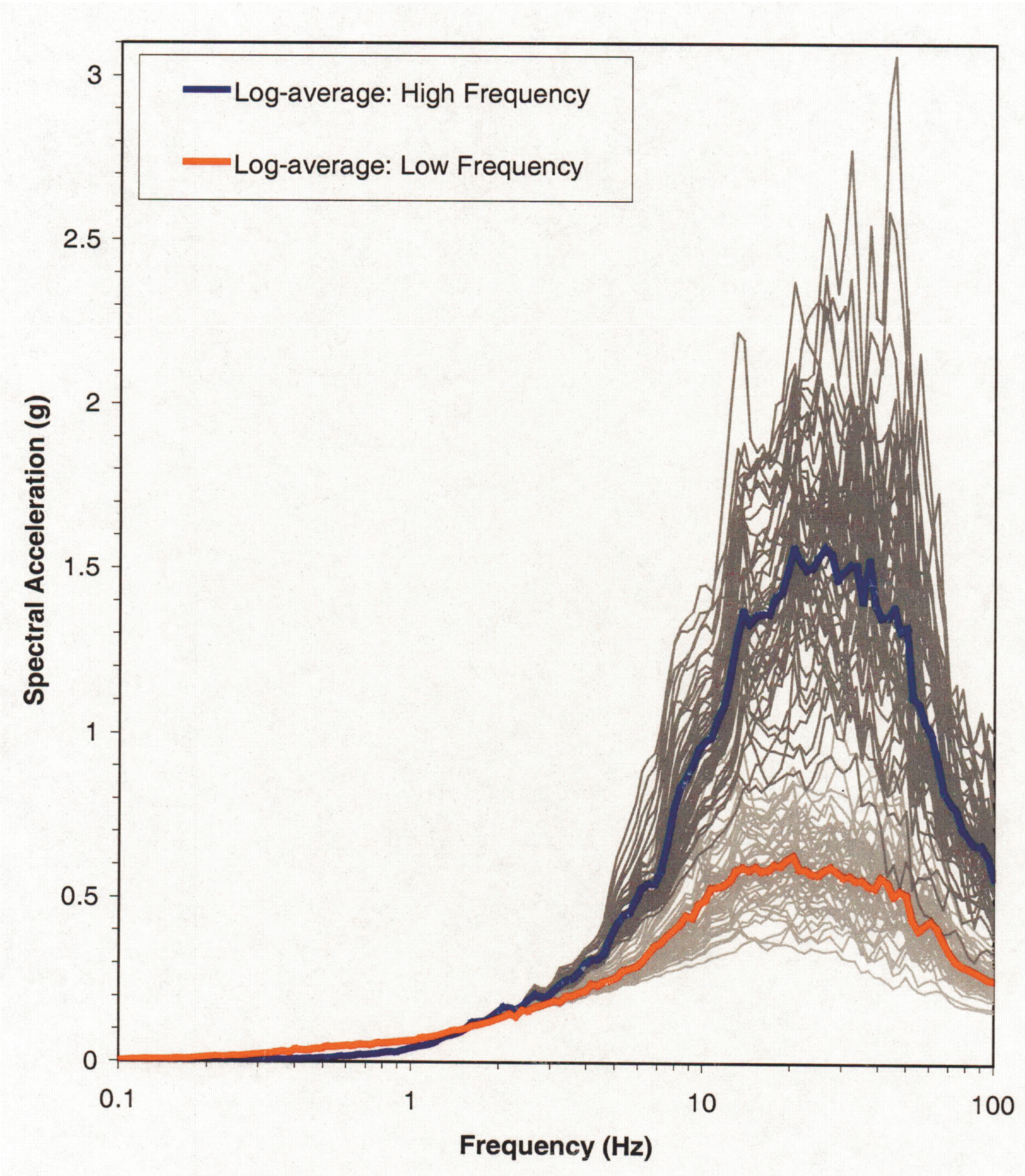

Figure 2.5.2-4 Response Zone III-IV control point (Elevation 250 ft., Layer 1) – 5% Critical Damping ARS – High Frequency (upper dark gray group) and Low Frequency (lower light gray group) time histories. Log-average of each set of 50 response spectra for the high and low frequency time histories indicated by the heavy blue and red lines, respectively.

Next, the applicant fit a smooth function through the enveloped log-average spectrum, which is shown in Figure 2.5.2-4. This smooth function is the final ESP site horizontal SSE ground motion spectrum, which the applicant has defined at the control point at the top of Zone III-IV rock. The spectral acceleration at 25 Hz for the ESP site horizontal SSE is 1.476g and the PGA at 100 Hz is 0.555g.

In order to develop the transfer function between the hard rock (V_s 9200 ft/s) at a depth of 161 ft and the control point at the top of Zone III-IV (V_s 3300 ft/s), the applicant computed the ratio of the hard rock response spectrum and the SSE spectrum at 21 frequency points. The transfer function provides the ground response of the ESP site to the hard rock input SSE motion. Figure 2.5.2-5 shows the transfer function for the ESP site. For some of the lower frequencies (0.1 to 2 Hz), the ESP site slightly de-amplifies the hard rock input ground motion, but for intermediate and high frequencies (2 to 100 Hz), the ESP site amplifies the input ground motion by as much as 1.664 at 20 Hz.

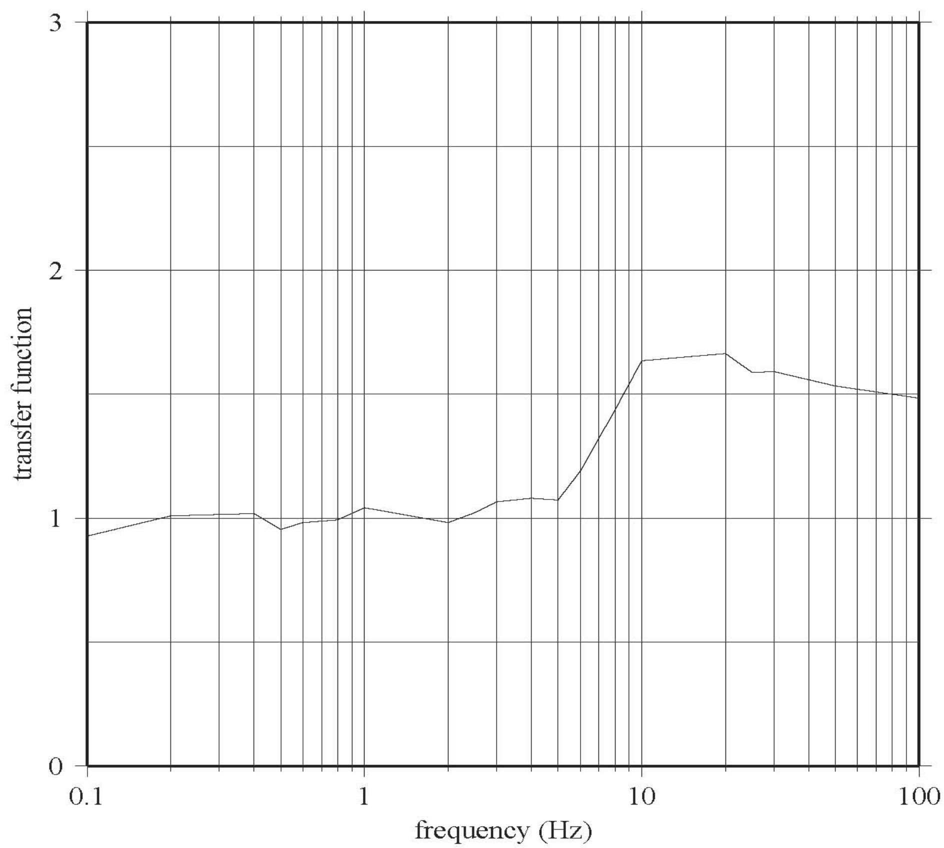

Figure 2.5.2-5 Transfer Function for ESP Site

Development of Vertical SSE Spectrum

To determine the vertical SSE spectrum, the applicant used the vertical-to-horizontal (V/H) response spectral ratios provided in NUREG/CR-6728. The V/H response spectral ratios given in NUREG/CR-6728 are for CEUS hard rock site conditions and depend on the PGA value of the horizontal SSE spectrum. For the ESP site, the V/H ratios used by the applicant are based on having a PGA greater than 0.5g. The vertical SSE spectrum is given by multiplying the horizontal SSE spectrum by the V/H ratios. Figure 2.5.2-6, reproduced from SSAR Figure 2.5-48A, shows the final horizontal and vertical SSE ground response spectrum at the control point at the top of Zone III-IV rock.

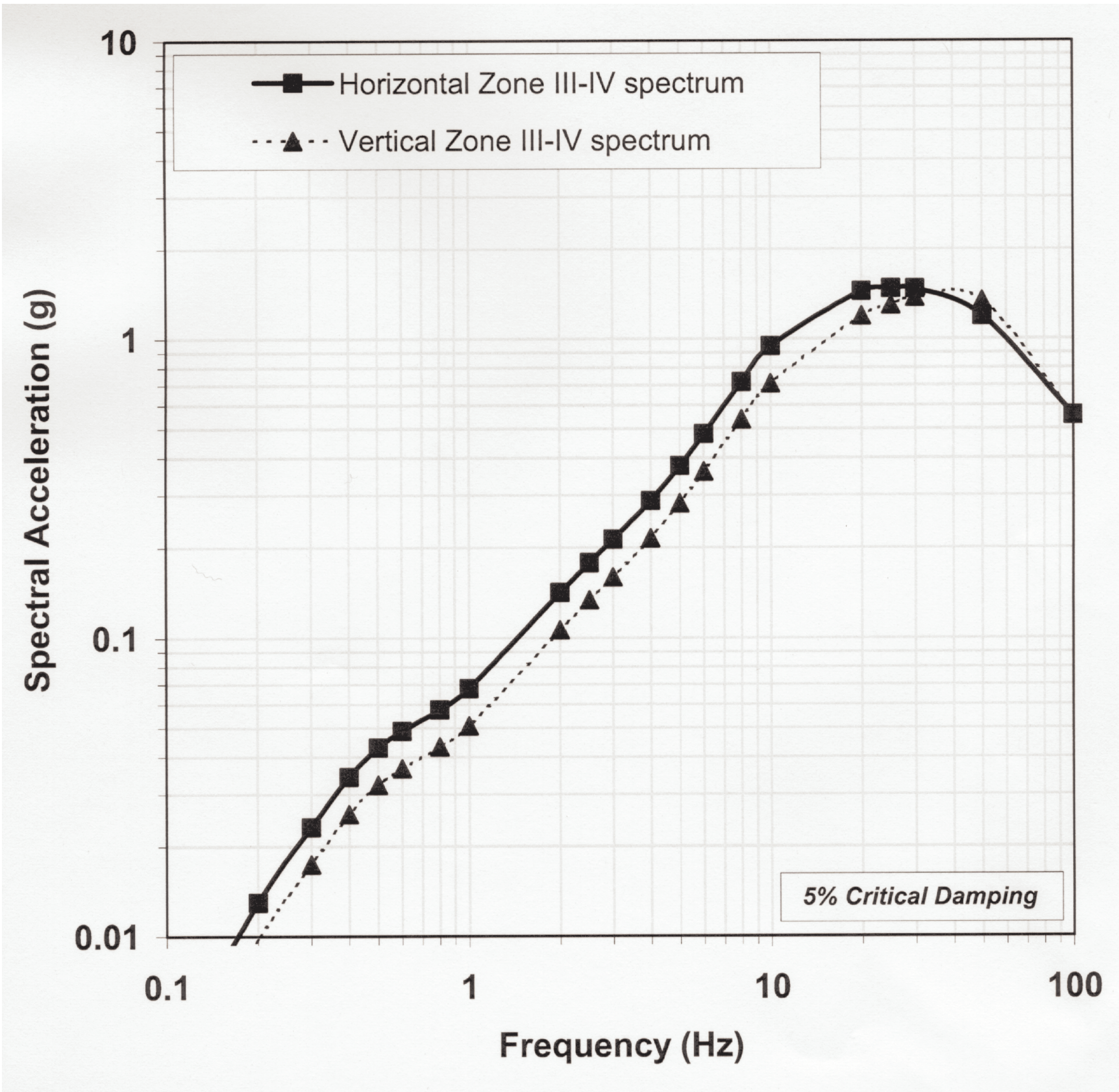

Figure 2.5.2-6 (SSAR Figure 2.5-48A) Selected Horizontal and Vertical Response Spectra for the Hypothetical Rock Outcrop Control Point SSE at the Top of Zone III-IV Material