2.5 Geology, Seismology, and Geotechnical Engineering

In Section 2.5, “Geology, Seismology, and Geotechnical Engineering,” of the VEGP SSAR, the applicant described geologic, seismic, and geotechnical engineering properties of the VEGP ESP site. SSAR Section 2.5.1, “Basic Geologic and Seismic Information,” presents information on geologic and seismic characteristics of the VEGP site and region surrounding the site. SSAR Section 2.5.2, “Vibratory Ground Motion,” describes the vibratory ground motion assessment for the ESP site through a PSHA and develops the SSE ground motion. SSAR Section 2.5.3, “Surface Faulting,” evaluates the potential for surface tectonic and non-tectonic deformation at the ESP site. SSAR Sections 2.5.4, “Stability of Subsurface Materials and Foundations,” 2.5.5, “Stability of Slopes,” and 2.5.6, “Embankments and Dams,” describe foundation and subsurface material stability at the ESP site.

The applicant reviewed reports from previous investigations for the existing VEGP Units 1 and 2 as a starting point for the characterization of the geologic, seismic, and geotechnical engineering properties of the site. The applicant also referred to published geologic literature and seismicity data, new borehole data for the proposed VEGP Units 3 and 4, seismic reflection and refraction surveys, and detailed investigations of the nearby SRS. Results of the investigations and analyses performed by the applicant for each of the SSAR Sections (2.5.1 to 2.5.6) provide information used to determine the SSE, as described in NRC RG 1.165 titled, “Identification and Characterization of Seismic Sources and Determination of Safe Shutdown Earthquake Ground Motion.”

The applicant defined the following four terms for areas in which investigations for the VEGP ESP site occurred, as designated by RG 1.165.

Site region: an area within 320 km (200 mi) of the site location.
Site vicinity: an area within 40 km (25 mi) of the site location.
Site area: an area within 8 km (5 mi) of the site location.
Site: an area within 1 km (0.6 mi) of the proposed VEGP Units 3 and 4 locations.

This RG also provides guidance on recommended levels of investigation for each of these areas.

The applicant also used the seismic source and ground motion models published in the EPRI’s (1986) “Seismic Hazard Methodology for the Central and Eastern United States [CEUS]” as the starting point for its seismic hazard evaluation. The applicant used the procedures recommended in RG 1.165 for performing the probabilistic seismic hazard analysis (PSHA) for the ESP site, and employed the performance-based approach described in RG 1.208, “A Performance-Based Approach to Define the Site-Specific Earthquake Ground Motion” for determining the SSE.

The applicant conducted field investigations, examined relevant geologic literature, and concluded that no geologic or seismic hazards have the potential to affect the VEGP ESP site, except for the Charleston seismic zone and a small magnitude local earthquake occurring in the site region. The applicant also concluded that there is only limited potential for non-tectonic surface deformation within the 8 km (5 mi) site area radius, and that this potential could be mitigated by excavation of shallow deposits overlying the foundation bearing unit.

This SER, compiled by the NRC staff, is divided into six main sections, 2.5.1 to 2.5.6, which parallel the six main sections included in the applicant's SSAR. Each of the six SER sections is then divided into four sub-sections: (1) "Technical Information in the Application" that describes the contents of the SSAR, the investigations performed by the applicant, and the results; (2) "Regulatory Basis" that provides a summary of the regulations and NRC regulatory guides used by the applicant to formulate the SSAR; (3) "Technical Evaluation" that describes the staff's evaluation of what the applicant did, including any requests for additional information (RAI's), open items, and any confirmatory analyses performed by the NRC staff; and (4) the final "Conclusions" sub-section for each main section that documents whether or not the applicant provided a thorough characterization for the site and if their results provide an adequate basis for the conclusions made by the applicant.

2.5.1 Basic Geologic and Seismic Information

Section 2.5.1.1 of this SER provides a summary of relevant geologic and seismic information contained in SSAR Section 2.5.1 of the VEGP application. SER Section 2.5.1.2 provides a summary of the regulations and guidance used by the applicant to perform their investigation. SER Section 2.5.1.3 provides a review of the staff's evaluation of SSAR 2.5.1, including any requests for additional information, any open items, and any confirmatory analyses performed by the staff. Finally, SER Section 2.5.1.4 provides an overall summary of the applicant's conclusions, as well as the staff's conclusions, restates any bases covered in the application, and confirms that regulations were met or fulfilled by the applicant.

In SSAR Section 2.5.1, the applicant described geologic and seismic characteristics of the VEGP site region and site area. SSAR Section 2.5.1.1, "Regional Geology," describes the geologic and tectonic setting of the site region (within a 320 km (200 mi) radius), and SSAR Section 2.5.1.2, "Site Geology," describes the structural geology of the site area (within a 8 km (5 mi) radius). In SSAR Section 2.5.1, the applicant also provided an update of geologic, seismic and geophysical data for the VEGP site and then reviewed the updated information, pursuant to RG 1.165, to determine whether any of the data published since the mid-1980's requires an update to the 1986 EPRI seismic source model.

The applicant developed SSAR Section 2.5.1 based on information derived from the review of previously prepared reports for existing VEGP Units 1 and 2, and published geologic literature, new boreholes drilled for potential VEGP Units 3 and 4, and seismic reflection and refraction surveys conducted for the ESP application. The applicant also used recently published literature to supplement and update existing geologic and seismic information.

2.5.1.1 Technical Information in the Application

2.5.1.1.1 Regional Geologic Description

SSAR Section 2.5.1.1, "Regional Geology," discusses the physiography, geomorphology, geologic history, stratigraphy, and geologic setting within a 320 km (200 mi) radius of the VEGP site. The applicant reviewed previous reports prepared for VEGP Units 1 and 2, as well as geophysical data and published geologic literature, in order to compile the regional geologic description. The applicant collected new data in order to assess whether or not the Pen Branch fault is a capable tectonic structure of Quaternary age (1.8 million years ago (mya) to present).

The applicant concluded that regional geologic characteristics pose no safety issues that would impact the VEGP site. The applicant applied the information in this section towards developing a basis for evaluation of the geologic and seismic hazards covered in succeeding sections of the SSAR. Based on its review, the applicant presented the following information related to the regional geology for the ESP site.

Physiography, Geomorphology and Geologic History

SSAR Section 2.5.1.1.1 describes the regional physiography and geomorphology of the ESP site. From northwest to southeast, the site region includes parts of the Valley and Ridge, Blue Ridge, Piedmont, and Coastal Plain physiographic provinces. Figure 2.5.1-1, reproduced from SSAR Figure 2.5.1-1, illustrates these four provinces. The VEGP ESP site lies within the Coastal Plain province approximately 48 km (30 mi) southeast of the line ("fall line") separating crystalline rocks of the Piedmont province from sediments of the Coastal Plain province. The Coastal Plain province is one of low topographic relief. Depositional landforms and topography strongly modified by fluvial erosion characterize the VEGP ESP site within the Coastal Plain province. Based on published information (Soller and Mills, 1991), the applicant described Carolina Bays (shallow, elliptical landforms which commonly occur in the Coastal Plain province) as surficial, non-tectonic features resulting from erosion by southwesterly-oriented winds (eolian erosion) that have no effect on subsurface sediments. Several investigators have documented that strata are continuous and undeformed beneath both bay and interbay areas.

The applicant described the geologic history of the ESP site in SSAR Section 2.5.1.1.2. Although the ESP site is located in the Coastal Plain, all major lithotectonic (characteristically unified rock assemblage) divisions of the Appalachian mountain belt occur within the site region. The applicant stated that geologic structures and stratigraphic sequences within these lithotectonic divisions represent a complex geologic evolution ending in the modern-day, passive Atlantic continental margin. This complex evolution resulted in the deposition of Cretaceous (144 to 65 mya) and Tertiary (65 to 1.8 mya) age sediments of the Coastal Plain; Quaternary (1.8 mya to present) materials in fluvial terraces along the Savannah River and its tributaries; and colluvial (loose, heterogeneous soil material and rock fragments), alluvial (unconsolidated material deposited during relatively recent geologic time by running water) and eolian sediments, all within the site area.

Stratigraphy and Geologic Setting

In SSAR Section 2.5.1.1.3, the applicant described regional stratigraphy and geologic setting (including stratigraphy, rock type, and geologic history) for the (1) Valley and Ridge; (2) Blue Ridge; (3) Piedmont; (4) Mesozoic rift basins; and (5) Coastal Plain provinces.

1. Folded and thrust-faulted Paleozoic (543 to 248 mya) sedimentary cover rocks overlying crystalline basement represent the Valley and Ridge lithotectonic terrane, located about 290 km (180 mi) west-northwest of the VEGP ESP site. A series of northeast-southwest trending, parallel valleys, and ridges are responsible for the physiographic expression within the Valley and Ridge terrane. Most of the folding and faulting deformation is likely late Paleozoic in age (at least 248 mya).

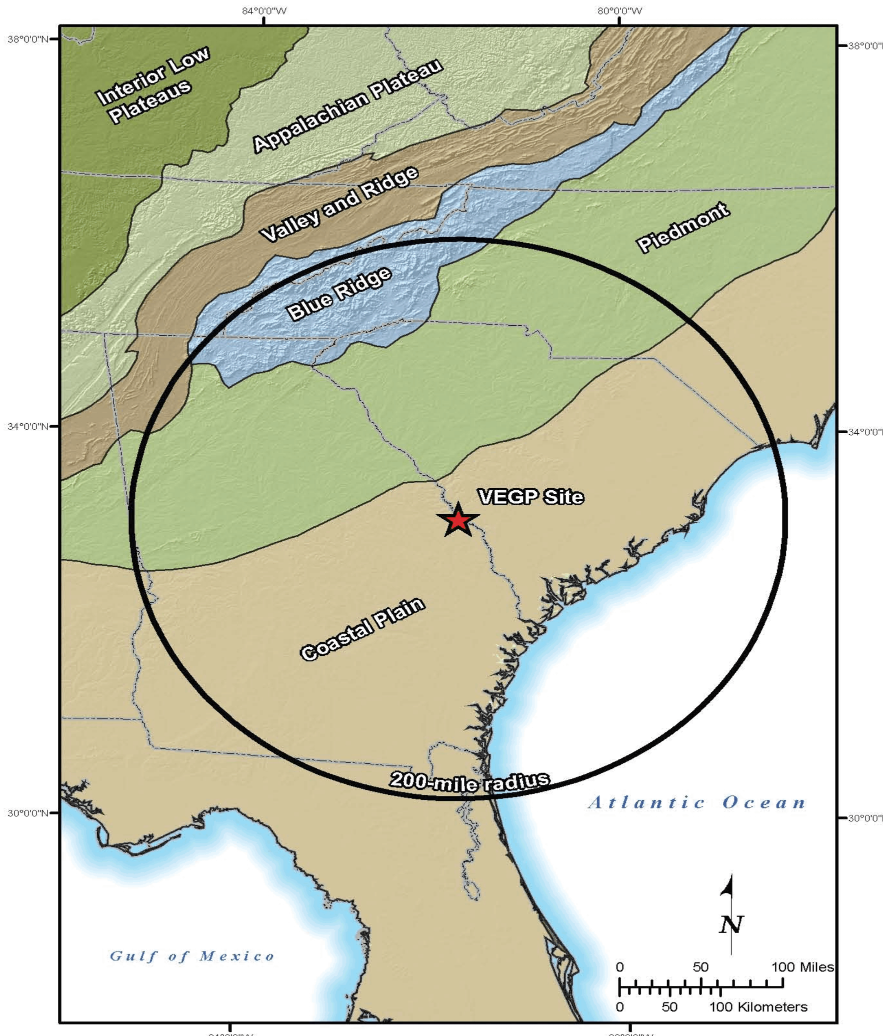

Figure 2.5.1-1 - Physiographic Provinces of the Southeastern United States (Reproduced from SSAR Figure 2.5.1-1)

2. A complexly folded, faulted, penetratively deformed, metamorphosed crystalline basement and cover rock sequence containing intrusive igneous rocks represents the Blue Ridge lithotectonic province, located about 225 km (140 mi) northwest of the ESP site. Multiple deformation events indicated by deformation features in the rocks relate to late Proterozoic to late Paleozoic (248 mya and older) extension and compression.

3. Variably deformed and metamorphosed igneous and sedimentary rocks ranging in age from Proterozoic to Permian (248 mya and older) represent the Piedmont Province, located about 48 km (30 mi) northwest of the ESP site. The applicant stated that Piedmont province rocks generally underlie Coastal Plain province sediments, but that the southeastern extent of the Piedmont province beneath the Coastal Plain is unknown.

4. Mesozoic Rift Basins typically consist of non-marine sandstone, conglomerate, siltstone, shale, carbonates, coal, and basaltic igneous rocks. One of these basins, the Dunbarton Triassic basin, is beneath the Coastal Plain sediments at the VEGP ESP site. Geophysical investigations, including seismic reflection, suggest that the Triassic (206 to 24 mya) section of the Dunbarton basin is at least 2 km (1.2 mi) thick. The primary fault bounding this basin on the northwest side is the Pen Branch fault, which dips to the southeast. The applicant described the Pen Branch fault to be a Paleozoic reverse fault, reactivated as an extensional normal fault during the Mesozoic (248 to 65 mya) and subsequently reactivated as a reverse fault during the Cenozoic (65 mya to present).

5. Erosion-beveled rocks of Paleozoic and Triassic age (543 to 206 mya) and unconsolidated to poorly consolidated Coastal Plain sediments deposited unconformably above the erosional surface represent the Coastal Plain province where the ESP site is located. This seaward-dipping wedge extends from the contact with crystalline rocks of the Piedmont physiographic province (the fall line) to the edge of the continental shelf. Sediment thickness increases from zero at the fall line to about 1200 m (4000 feet) at the Georgia coastline. The sediment thickness is about 335 m (1000 feet) in the center of the VEGP site area and is composed of Upper Cretaceous, Tertiary, and unconsolidated Quaternary deposits.

Quaternary Period (1.8 mya-present) surfaces and deposits are preserved primarily in the fluvial terraces along the Savannah River and its major tributaries, as well as in colluvium, alluvium, and eolian sediments in upland settings. Nested fluvial terraces, preserved along the east side of the Savannah River, can be used to evaluate Quaternary deformation within the Savannah River area. Major stream terraces develop as a result of sequential erosional and depositional events which may be due to tectonism, isostacy, or climatic variations. In SSAR Section 2.5.1.1.3.5, the applicant described two prominent terraces above the modern flood plain and along the east side of the Savannah River in the ESP site vicinity. The Bush Field terrace (mapped as Quaternary terrace surface "Qtb") is preserved primarily on the northeast side of the Savannah River and its surface ranges from 8 to 13 m (26 to 43 ft) above the river. Ellenton terrace surfaces (mapped as "Qte") range from 17 to 25 m (56 to 82 ft) above the river. The applicant estimated the age of the older Ellenton terrace to be 350 thousand to 1 million years old. The younger Qtb terrace is estimated to be about 90 thousand years old.

2.5.1.1.2 Regional Tectonic Description

The applicant described the tectonic setting, tectonic structures, and seismic source zones in sub-sections 2.5.1.1.4.1 through 2.5.1.1.4.6 of SSAR Section 2.5.1.1.4. The applicant discussed plate tectonic evolution of the Appalachian orogenic belt at the latitude of the ESP site, tectonic stress in the mid-continent region, principal regional tectonic structures, Charleston tectonic features, SRS tectonic features, and seismic sources defined by regional seismicity. SSAR Section 2.5.1.1.5 outlines the applicant's review of regional gravity and magnetic data, and the models used to supplement their interpretations of regional geologic and tectonic features discussed in SSAR Sections 2.5.1.1.3 and 2.5.1.1.4. The applicant concluded that (1) tectonic features in the site region are Paleozoic (> 248 mya), Mesozoic (248 to 65 mya), and Cenozoic (< 65.5 mya) in age but only the Quaternary (< than 1.8 mya) features require additional consideration for this ESP; (2) there is no significant change to the understanding of stress in the CEUS that would require updates to the currently accepted data; (3) of 11 potential Quaternary features evaluated by the applicant, only paleoliquefaction features associated with the Charleston source earthquakes clearly demonstrate the existence of a Quaternary tectonic feature; (4) based on new source geometry and earthquake recurrence information, the Charleston seismic source requires updated parameters; and (5) that there are no unexplained anomalies expressed in the gravity or magnetic data for the VEGP site region and no evidence present in the data for Cenozoic age structures or deformation. Based on published information, the applicant presented the following information related to the regional tectonic setting:

<u>Plate Tectonic Evolution and Stress Field</u>

The applicant discussed plate tectonic evolution of the Appalachian orogenic belt at the latitude of the site region in SSAR Section 2.5.1.1.4.1 and acknowledged the four principal tectonic elements of the Appalachian orogen: the Valley and Ridge province, Blue Ridge province, Piedmont province, and Coastal Plain province. These four tectonic elements correspond to the four physiographic provinces described in SSAR Section 2.5.1.1.1 and shown in Figure 2.5.1-1. The Appalachian orogenic belt, trending northeast-southwest and extending from southern New York State into Alabama, records the opening (between 900 to 543 mya) and closing (543 to 248 mya) of the proto-Atlantic Ocean along the eastern margin of ancestral North America. Compressional deformation due to continental collisions occurred during the Ordovician (490-443 mya), Devonian (417 to 354 mya), and Late Paleozoic (320 to 250 mya). Triassic (248 to 206 mya) basins, including the Dunbarton Basin, which occur in the Appalachian orogenic belt, represent Mesozoic rifting. Stratigraphic units of the coastal plain, the province within which the ESP site lies, record development of a passive continental margin along the east coast of the United States that followed the Mesozoic rifting and the opening of the present-day Atlantic ocean basin. The applicant concluded that, despite uncertainties in regard to origin, mode of emplacement, and boundaries of the different structural and lithologic terranes that exist in the principal tectonic provinces, there is reasonable agreement among existing tectonic models on regional structural features of the southern Appalachian orogenic belt.

In SSAR Section 2.5.1.1.4.2, the applicant discussed the regional tectonic stress acting on the mid-continent region, specifically the CEUS. The 1986 EPRI evaluation of intra-plate stresses determined that the CEUS is characterized by northeast-southwest directed horizontal compressive stress attributed mostly to ridge-push forces associated with the Mid-Atlantic ridge. The applicant concluded that based on investigations conducted since the EPRI study, which support the initial EPRI findings, there is no significant change to the understanding of stress in the CEUS and therefore it is not necessary to reevaluate the seismic potential of tectonic sources in the region based on the regional tectonic stress.

Principal Regional Tectonic Structures

In SSAR Section 2.5.1.1.4.3, the applicant defined and discussed four categories of principal regional tectonic structures occurring within a 320 km (200 mi) radius of the VEGP site based on age of formation or reactivation of the structures. These four categories included tectonic structures of (1) Paleozoic (543 to 248 mya); (2) Mesozoic (248 to 65 mya); (3) Tertiary (65 to 1.8 mya); and (4) Quaternary (1.8 mya to present) age. The applicant also discussed regional geophysical anomalies and lineaments potentially equated with tectonic features.

1. Paleozoic Tectonic Structures. The applicant indicated that rocks and structures within the physiographic provinces included in the site region are associated with thrust sheets that formed by convergent Appalachian orogenic events during the Paleozoic. In the case of the Coastal Plain province where the ESP site is located, these rocks and structures are buried beneath sedimentary cover. The majority of these structural features dip eastward into a basal, shallow dipping fault (decollement) structure. The applicant discussed two primary Paleozoic fault zones, the Augusta and the Modoc, as well as a number of other paleozoic faults within the ESP site region, including the Hayesville Fault, the Brevard Fault, the Towaliga Fault, the Central Piedmont Suture, and the Eastern Piedmont Fault System. The applicant concluded that none of these structures are capable tectonic sources of concern for the VEGP site and that no new information has been published since 1986 on these Paleozoic faults in the site region that would result in a significant change to the EPRI seismic source model.

2. Mesozoic Tectonic Structures. The applicant recognized the broad zone of fault-bounded depositional basins associated with crustal extension and rifting in early Mesozoic time (Triassic period, 248 to 206 mya). These are relatively common features along the east coast of North America. Figure 2.5.1-2, taken from SSAR Figure 2.5.1-16, shows one of these east-northeast-trending Triassic basins, the Dunbarton Basin, which lies beneath the VEGP site and the SRS. This basin, approximately 50 km (31 mi) long and 10-15km (6-9 mi) wide, is bounded on its northwest side by the Pen Branch Fault, which experienced normal fault displacement during the Triassic. The Pen Branch fault is interpreted to have been reactivated in the Cenozoic (65 mya to present) as a reverse fault. The applicant stated that no definitive correlation of seismicity with any Mesozoic normal fault has been conclusively demonstrated.

3. Tertiary Tectonic Structures. The applicant stated that only a few tectonic features were active in the Tertiary Period (65-1.8 mya) within the ESP site area. The applicant referred to a series of arches and embayments (topographic highs and lows) that exerted control on Coastal Plain sedimentation from late Cretaceous through Pleistocene time (144 mya to 10,000 ya) as indicative of episodic differential tectonic movement. The applicant concluded that the most prominent arches in the VEGP site

region, the Cape Fear Arch on the South Carolina-North Carolina border, and the Yamacraw Arch on the Georgia-South Carolina border show no evidence of being active.

4. Quaternary Tectonic Structures. The applicant discussed 11 potential Quaternary features within a 320 km (200 mi) radius of the VEGP ESP site as shown in Figure 2.5.1-3, reproduced from SSAR Figure 2.5.1-17. Table 2.5.1-1, reproduced from SSAR Table 2.5.1-1, provides definitions and classes used to categorize these same potential features. The 11 potential Quaternary features discussed by the applicant include the Charleston, Georgetown, and Bluffton paleo-liquefaction features, the East Coast Fault System (ECFS), the Cooke fault, the Helena Banks fault zone, the Pen Branch fault, the Belair fault, the fall lines of Weems (1998), the Cape Fear arch, and the Eastern Tennessee Seismic Zone (ETSZ). The three paleo-liquefaction features are classified by Wheeler (2005) as “Class A”, indicating there is geologic evidence to demonstrate the existence of Quaternary tectonic deformation related to these features. The other eight features are classified as “Class C”, indicating there is insufficient geologic evidence to demonstrate the existence of Quaternary deformation associated with these features. The applicant discussed only the Belair Fault Zone and the fall lines of Weems (1998) in SSAR Section 2.5.1.1.4.3 since the other potential Quaternary features are discussed in detail in other sections of the SSAR.

The applicant documented that the Belair Fault Zone, located about 48 km (30 mi) northwest of the ESP site, occurs as a series of northeast-striking, southeast-dipping oblique-slip faults with no evidence of historic or recent associated seismicity. The applicant concluded that Quaternary slip is allowed, but not clearly demonstrated, by available data.

Weems (1998) identified numerous anomalously steep stream segments in the Blue Ridge and Piedmont physiographic provinces of North Carolina, Virginia, and Tennessee and recognized that these steep “fall zones”, located north and northeast of the ESP site, are aligned from stream to stream along paths that are subparallel to the regional structural grain of the Appalachian orogenic belt. Although Weems (1998) favored a neotectonic (less than 23.8 mya) origin for these fall lines, Wheeler (2005) classified them as Class C features because he did not consider Quaternary tectonic faulting to be demonstrated by the available data.

In addition to the 11 potential Quaternary features listed above, the applicant recognized that a number of regional geophysical anomalies and lineaments occur within 320km (200 mi) of the VEGP site, including the East Coast Magnetic Anomaly (ECMA), the Blake Spur Magnetic Anomaly, the Grenville Front, the New York-Alabama Lineament (NYAL), and the Clingman and Ocoee Lineaments.

The applicant described the ECMA and the Blake Spur Magnetic Anomaly, both of which are located off the east coast of North America and interpreted to be Mesozoic in age. The applicant concluded that neither of these anomalies are associated with a regional fault or other tectonic structure and do not represent a potential seismic source for the VEGP site.

The applicant classified the NYAL as a linear feature 1600 km (1000 mi) in length defined by a series of northeast-southwest-trending magnetic gradients in the Valley and Ridge physiographic province that intersects and truncates other magnetic anomalies. King and Zietz (1978) interpreted this lineament to be a major strike-slip fault in PreCambrian basement, while Shumaker (2000) equated it to a right-lateral wrench fault that formed during an initial phase of PreCambrian continental rifting.

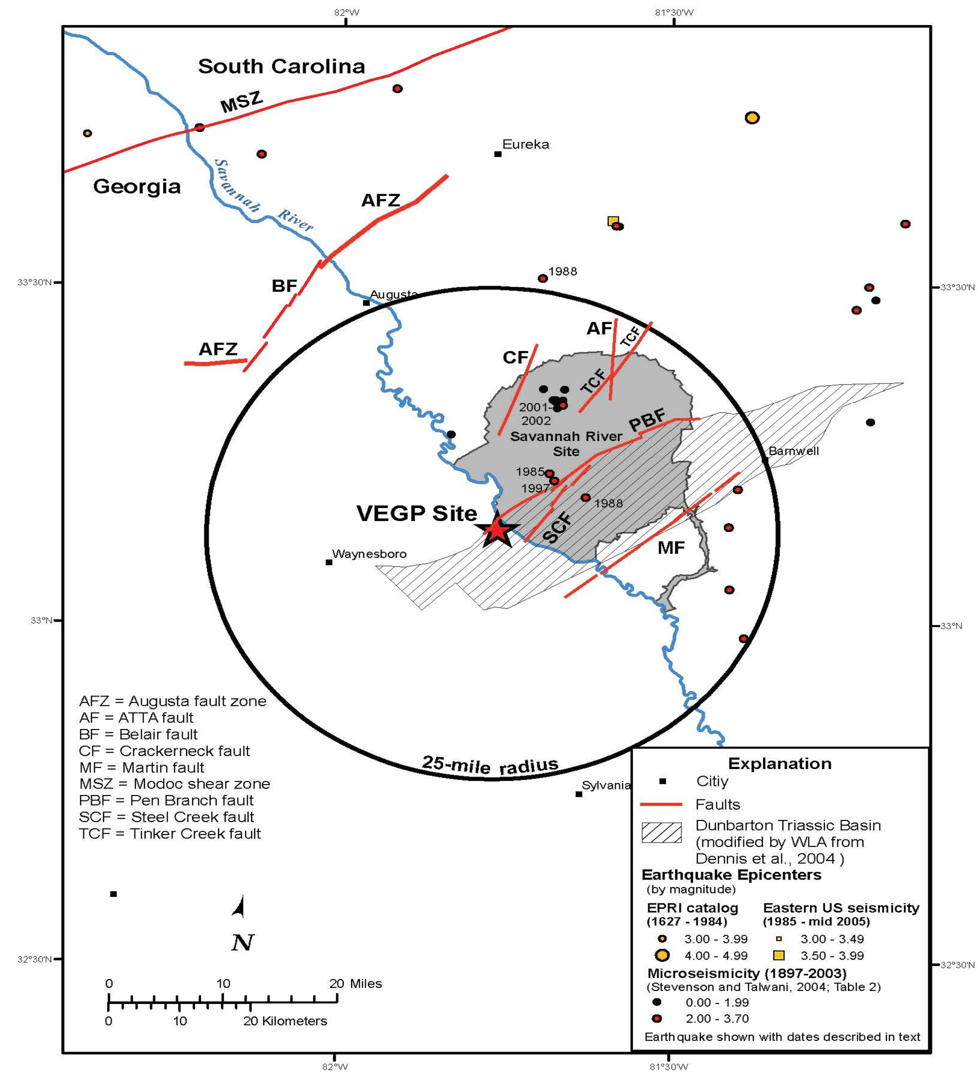

Figure 2.5.1-2 - Site Vicinity Tectonic Features and Seismicity (Reproduced from SSAR Figure 2.5.1-16)

Table 2.5.1-1 - Definitions of Classes Used in the Compilation of Quaternary Faults, Liquefaction Features, and Deformation in the Central and Eastern United States (Reproduced from SSAR Table 2.5.1-1 after Crone and Wheeler, 2000)

Class Category	Definition
Class A	Geologic evidence demonstrates the existence of a Quaternary fault of tectonic origin, whether the fault is exposed for mapping or inferred from liquefaction to other deformational features.
Class B	Class B Geologic evidence demonstrates the existence of a fault or suggests Quaternary deformation, but either (1) the fault might not extend deeply enough to be a potential source of significant earthquakes, or (2) the currently available geologic evidence is too strong to confidently assign the feature to Class C but not strong enough to assign it to Class A.
Class C	Class C Geologic evidence is insufficient to demonstrate (1) the existence of tectonic fault, or (2) Quaternary slip or deformation associated with the feature.
Class D	Class D Geologic evidence demonstrates that the feature is not a tectonic fault or feature. This category includes features such as demonstrated joints or joint zones, landslides, erosional or fluvial scarps, or landforms resembling fault scarps, but of demonstrable non-tectonic origin.

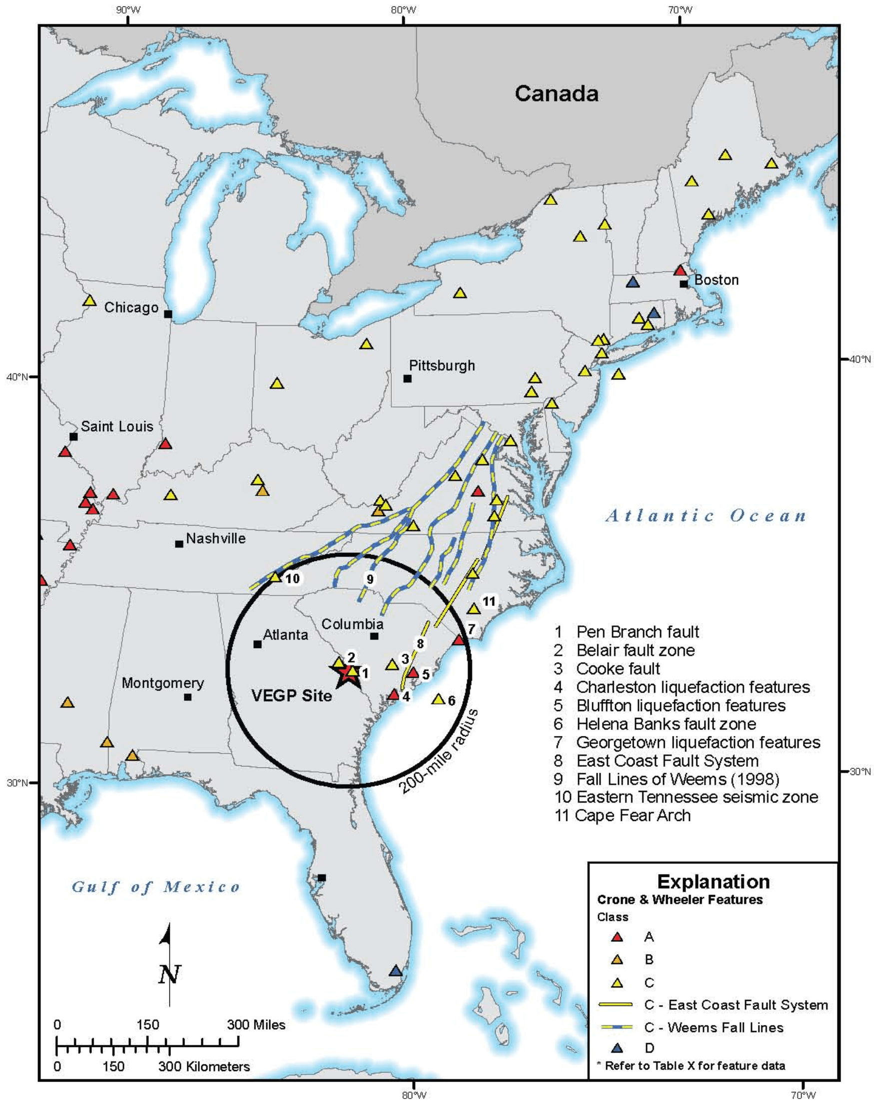

Figure 2.5.1-3 - Potential Quaternary Features Map (Reproduced from SSAR Figure 2.5.1-17)

The Clingman Lineament is 1200 km (750 mi) in length and also trends northeast, showing up as an aeromagnetic linear feature passing through parts of the Blue Ridge and the eastern Valley and Ridge provinces from Alabama to Pennsylvania. The Ocoee Lineament is described as a splay that branches southwest from the Clingman Lineament approximately at latitude 36N. The Clingman-Ocoee Lineaments are subparallel to and located 50-100 km (30-60 mi) east of the NYAL.

The applicant described the "Ocoee block" as a PreCambrian basement block located northwest of the ESP site and just outside of the 320-km (200-mi) site radius. The majority of southern Appalachian seismicity is interpreted to occur within the Ocoee block that coincides with the western margin of the ETSZ, as discussed in SSAR Section 2.5.1.1.4.6 "Seismic Sources Defined by Regional Seismicity". Johnston et al. (1985) interpreted seismicity within the Ocoee block as related to strike-slip displacement on faults striking north-south and east-west. More recently, Wheeler (1996) proposed that earthquakes within the Ocoee block may be related to reactivation of Precambrian normal faults as reverse or strike-slip faults in the "modern" tectonic setting.

The applicant described regional gravity and magnetic data in relation to the VEGP site region in Section 2.5.1.1.5 of the SSAR. Regional maps of North American gravity and magnetic fields were published by the Geological Society of America in 1987 as part of the Decade of North American Geology project. These maps are at a scale that allows identification and assessment of gravity and magnetic anomalies with wavelengths of about 10 km (6 mi) or greater. The applicant concluded there are no unexplained anomalies in the gravity data for the VEGP site region, and no data or gravity modeling results show evidence of Cenozoic tectonic activity or specific structures of Cenozoic age in the site region.

The applicant discussed regional magnetic signatures for the VEGP site region in Section 2.5.1.1.5.2 of the SSAR. The applicant concluded that (1) magnetic data do not have sufficient resolution to identify discrete faults such as the Pen Branch Fault; (2) there are no unexplained anomalies in the magnetic data for the VEGP site region; and (3) no data show evidence for Cenozoic structures in the VEGP site region.

Savannah River Site Tectonic Features

In SSAR Section 2.5.1.1.4.5, the applicant discussed faults that are interpreted to occur at the SRS on the eastern side of the Savannah River directly across from the VEGP ESP site. Locations of most of these faults are indicated on Figure 2.5.1-2. Most SRS faults are defined in the subsurface by interpretation of seismic reflection profiles, although information from seismic refraction studies and borehole studies is also used. The applicant stated that considerable uncertainty exists in regard to orientation and continuity of some of these faults. The applicant made no conclusion as to the capability of any of the SRS faults except for the Millet fault, which the applicant concluded showed no evidence of being a capable tectonic structure younger than the middle Eocene (40 mya). Four of the SRS faults occur within the VEGP site area: (1) Pen Branch, (2) Steel Creek, (3) Ellenton, and (4) Upper Three Runs faults.

1. The applicant described the northeast-trending Pen Branch fault as extending southwest off the SRS and across the Savannah River to the VEGP site location (Figure 2.5.1-2

from SSAR Figure 2.5.1–16). Since the Pen Branch is interpreted to extend beneath the VEGP site, the applicant discussed this feature in detail in SSAR Section 2.5.1.2.4.

2. The applicant described the northeast-trending Steel Creek fault, shown in Figure 2.5.1-2, as extending southwest into the VEGP site area to a point off the SRS on the west side of the Savannah River. This fault is located about 4 km (2.5 mi) east-southeast of the VEGP site location. Stieve and Stephenson (1995) considered the age of latest movement on this fault to be unresolved, but indicated that Cretaceous (144 to 65 mya) units are cut by the fault.

3. The applicant stated that the Ellenton fault strikes north-northwest, is near vertical, and extends into the VEGP site area with a location about 8 km (5 mi) northwest of the site location. However, data quality for definition of this structure is defined as poor and some researchers do not show this fault trace on their map of SRS faults.

4. The applicant stated that research indicates the Upper Three Runs fault is restricted to crystalline basement rocks, and that seismic reflection revealed no evidence for this fault offsetting Coastal Plain sediments. There is some indication that this fault extends southwest from the SRS, across the Savannah River, into the VEGP site area, and is located about 5 mi north of the site location. However, other investigators do not show this fault trace on their map of SRS faults.

Additional faults have been proposed outside the VEGP site area: (1) ATTA, (2) Crackerneck, (3) Martin, (4) Tinker Creek, (5) Lost Lake, and (6) Millet faults.

1. As described by the applicant, the ATTA fault is near vertical, strikes north-northeast, and is located about 25 km (16 mi) northeast of the VEGP site location, as shown in Figure 2.5.1-2. Research indicated a vertical separation of basement rocks by this fault of 25 m (82 ft) based on seismic reflection data, and also that penetration of the ATTA fault above basement is uncertain due to a lack of good seismic reflectors.

2. The applicant described the Crackerneck fault, which is located about 16 km (10 mi) north of the VEGP site location. Shown in Figure 2.5.1-2, this fault strikes northeast and dips steeply southeast. Research indicates that the fault exhibits a maximum vertical separation of basement rocks of about 30 m (98 ft) based on seismic reflection data, with offset decreasing upward to about 7 m (23 ft) at the top of the Upper Eocene Dry Branch formation (approximately 38.8 mya). The Middle Eocene Blue Bluff Marl (about 40 mya in age), the proposed foundation bearing unit for VEGP Units 2 and 3, underlies the Dry Branch.

3. The applicant described the Martin fault, which is located about 14.5 km (9 mi) south-southeast of the VEGP site location (based on aeromagnetic data). Shown in Figure 2.5.1-2, this fault strikes northeast with an undefined dip. Researchers estimated a vertical separation of the basement surface of about 18.5-31 m (60-100 ft) based on data from two boreholes.

4. The applicant described the Tinker Creek fault, which is located about 19 km (12 mi) north-northeast of the VEGP site location. Shown in Figure 2.5.1-2, this is interpreted to strike northeast and dips southeast. Seismic reflection data suggest a vertical separation of basement rocks by the Tinker Creek fault of 24 m (79 ft) at its northeastern extent, but the southeastern extent of the fault remains unresolved.

5. Cumbest et al (1998) defined the trace of the Lost Lake Fault based on its apparent control of groundwater flow pathways, locating it about 12 mi north of the VEGP site location. The applicant reported that seismic and borehole data to constrain location, geometry, sense of slip, and age of latest movement are lacking.

6. The Millet fault is located about 9 mi south-southeast of the VEGP site location. A study of this proposed fault by Bechtel (1982) was reviewed by the NRC staff, who concluded that there is no evidence for a capable tectonic structure as young as the Middle Eocene (40 mya) Blue Bluff Marl, which was characterized as tectonically undeformed.

Charleston Tectonic Features

In SSAR Section 2.5.1.1.4.4, the applicant discussed Charleston tectonic features, including potential source faults, area seismic zones, and area seismically-induced liquefaction features. These features, some defined since the EPRI (1986) seismic source models were developed, have been identified in or near the meizoseismal area (area of maximum damage) of the August 1886 Charleston earthquake and occur about 136 km (85 mi) east-southeast of the VEGP site.

The 1886 Charleston earthquake is recognized as one of the largest historical earthquakes to occur in the eastern United States. It produced a Modified Mercalli Intensity (MMI) X in the epicentral area near Charleston, and was felt as far away as Chicago, IL. Bakun and Hopper (2004) estimated a maximum magnitude for the 1886 Charleston earthquake ranging between M 6.4 to 7.1, a value similar to the upper-bound maximum magnitude used by EPRI (1986) for its source model. Due to a lack of observable surface deformation, the source of this earthquake has been inferred based on geology, paleoseismic features, and instrumented seismicity. The applicant recognized that, although the 1886 event was almost certainly related to a capable tectonic source, the earthquake has not been tied to any specific tectonic structure. The applicant concluded, in light of new information about source geometry and earthquake recurrence rate, that the EPRI (1986) source models for the 1886 Charleston earthquake warranted an update. The applicant presented the updated seismic source parameters in SSAR Section 2.5.2.2.2.4.

The applicant discussed the following potential causative faults for the 1886 Charleston earthquake event: (1) ECFS, (2) Adams Run fault, (3) Ashley River fault, (4) Charleston fault, (5) Cooke fault, (6) Helena Banks fault zone, (7) Sawmill Branch fault, (8) Summerville fault, and (9) Woodstock fault. Figure 2.5.1-4, taken from SSAR Figure 2.5.1-19, shows these faults.

1. The applicant described the inferred ECFS, the southern section of which is marked by an alignment of river bends and consequently referred to as the “zone of river anomalies” (ZRA), as a northeast-trending fault system extending a total distance of about 600 km (373 mi) from Charleston, SC to southeastern Virginia. Researchers

identified geomorphic anomalies (the ZRA) located along (and northwest of) the Woodstock fault and consequently defined the southern segment of the ECFS to extend the strike trend of the Woodstock fault. Data suggests that the fault system may have been active in the past 130,000 to 10,000 years and may remain active at the present time. It is further suggested that the ECFS may have been the source for the 1886 Charleston earthquake. Wheeler (2005) classified the ECFS as a Class C structure based on lack of demonstrable evidence for tectonic faulting or Quaternary slip or deformation associated with the feature.

2. The applicant described the Adams Run fault as being inferred from microseismicity and borehole data, but stated that the data were not consistent with the occurrence of fault displacement. The applicant further indicated no geomorphic evidence for the Adams Run fault and local microseismicity, as shown in Figure 2.5.1-5 from SSAR Figure 2.5.1-20, does not define a discrete structure.

3. The applicant described the Ashley River fault as being defined by a northwest-trending zone of seismicity in the meizoseismal area of the 1886 Charleston earthquake. This fault is interpreted to be a southwest-side-up reverse fault that offsets the northeast-trending Woodstock fault.

4. The applicant described the Charleston fault, also shown in Figure 2.5.1-5, as being defined by data from geologic maps and boreholes. This fault is interpreted as a major highangle reverse fault which has been active in the Holocene (past 10,000 years). The applicant indicated that this fault has no clear geomorphic expression, nor is it clearly defined by the pattern of microseismicity in the vicinity of the fault.

5. The applicant described the Cooke fault, shown in Figure 2.5.1-5, as being defined by seismic reflection profiles in the meizoseismal area of the 1886 Charleston earthquake and interpreted as either an east-northeast-striking, northwest-dipping structure, or part of the ECFS. Crone and Wheeler (2000) classified the Cooke fault as a Class C feature based on lack of evidence for faulting younger than Eocene (54.8 to 33.7 mya).

6. The Helena Banks fault zone, located about 10-20 mi (15-30 km) off the coast of South Carolina, is clearly shown in seismic reflection lines. The applicant documented that Crone and Wheeler (2000) described this fault zone as a potential Quaternary tectonic feature, but classified it as a Class C feature since there is insufficient evidence to demonstrate Quaternary activity in the zone. The applicant stated that data suggest that the fault zone could, at a "low probability", be considered a potentially active fault. The applicant also stated that, if the Helena Banks fault zone is active, it could possibly explain distribution of paleoliquefaction features along the South Carolina coast.

7. The applicant described the Sawmill Branch fault, shown in Figure 2.5.1-5, as a northwest-trending structure defined by microseismicity and interpreted to be an extension of the Ashley River fault that offsets the Woodstock fault in a left-lateral sense. The applicant stated that microseismicity in the vicinity of the proposed Sawmill Branch fault does not clearly define a structure distinct from the Ashley River fault. (The Ashley River Fault was also defined based on seismicity.)

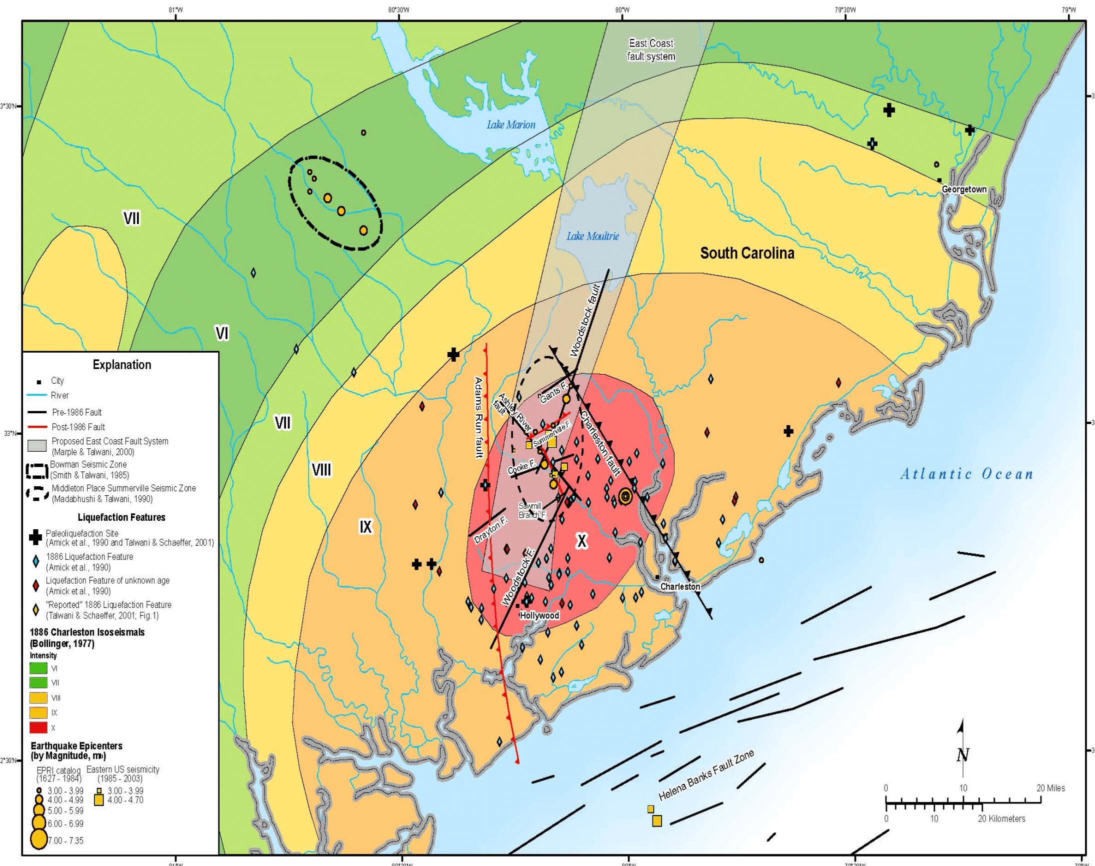

Figure 2.5.1-4 - Local Charleston Tectonic Features (Reproduced from SSAR Figure 2.5.1-19)

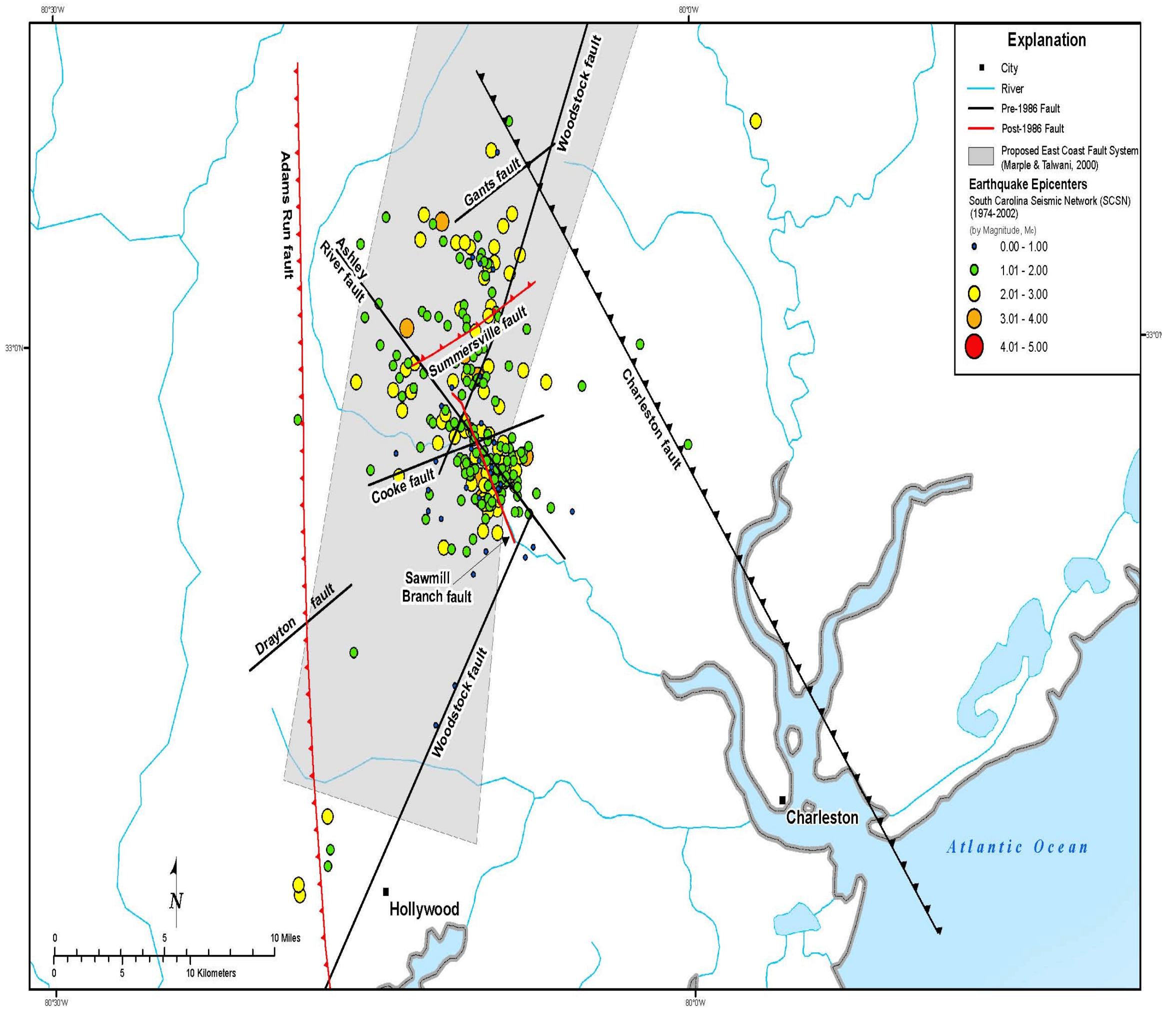

Figure 2.5.1-5 - Local Charleston Seismicity
(Reproduced from SSAR Figure 2.5.1-20)

8. The applicant described the Summerville fault, shown in Figure 2.5.1-5, which was initially defined by Weems et al. (1997) based on microseismicity. However, the applicant concluded that there is no geomorphic expression, borehole evidence, or microseismicity related to a discrete structure to indicate the existence of the Summerville fault.

9. The applicant described the Woodstock fault, shown in Figure 2.5.1-5, as a postulated north-northeast-trending, dextral strike-slip fault in the meizoseismal area of the 1886 Charleston earthquake defined by a linear zone of seismicity. Researchers subdivided this fault into two segments offset in a left-lateral sense across the Ashley River Fault, and later included it as a part of the proposed ZRA in the southern portion of the ECFS.

Charleston Area Seismic Zones

The applicant discussed three zones of increased seismicity identified in the greater Charleston area, including the (1) Middleton Place-Summerville, (2) Bowman, and (3) Adams Run seismic zones. These three zones are shown in Figure 2.5.1-4. Details of the seismicity data catalog are discussed in SSAR Section 2.5.2.1.

1. The applicant described the Middleton Place-Summerville Seismic Zone as an area of elevated microseismicity located about 19 km (12 mi) northwest of Charleston. Between 1980 and 1991, 58 events with magnitudes ranging from body wave magnitude ($m_{b)}$ 0.8 to 3.3 and hypocentral depths ranging from 2-11 km (1-7 mi) were recorded in this zone, which lies inside the meizoseismal area of the 1886 Charleston earthquake. The elevated microseismicity in the Middleton Place-Summerville seismic zone has been attributed to stress concentrations associated with intersection of the Ashley River and Woodstock faults, and there is speculation that the 1886 Charleston earthquake had its source in this zone. Persistent foreshock activity was reported prior to the 1886 Charleston earthquake in the Middleton-Summerville seismic zone.

2. The applicant documented that the Bowman seismic zone lies outside the meizoseismal area of the 1886 Charleston earthquake. It is located about 80 km (50 mi) northwest of Charleston and 96 km (60 mi) east-northeast of the VEGP site as shown in Figure 2.5.1-4. The zone was identified based on a series of earthquakes with magnitudes of M3-4 which occurred in that zone between 1971-1974.

3. The applicant described the Adams Run seismic zone, located within the meizoseismal area of the 1886 Charleston earthquake as being defined by four earthquakes with magnitudes less than M2.5. Three of these four earthquakes occurred over a 2-day period in December 1977. This seismic zone occurs about 120 km (75 mi) east-southeast of the VEGP site and is not shown in Figure 2.5.1-4 as the text indicates.

Charleston Area Seismically-Induced Liquefaction Features

The applicant discussed Charleston area soil liquefaction in SSAR Section 2.5.1.1.4.4, which has proven to be the most broadly observable earthquake-induced phenomenon in the Charleston area. Liquefaction occurs when a mass of saturated, granular material temporarily loses its shear strength and its ability to act as a solid due to an increase in pore water pressures that exceeds overburden pressures. During an earthquake, waves are propagated upward through rock and soil, creating shear stresses that cause sediments with a high volume change capacity (saturated sediments) to compact. As pore water pressures increase, saturated materials are forced to flow in the direction of maximum principal compressive stress, typically upward through zones of weakness in dense overlying sediments. The presence of liquefaction features in the geologic record, and radiometric age dating of these features, aids in formulating an earthquake chronology with estimated magnitudes based on characteristics of the features and their geographic distribution. This extends the earthquake record back in time for defining longer-term earthquake occurrence rates.

The applicant presented data on liquefaction features observed in the South Carolina Coastal Plain and these features are shown in Figure 2.5.1-4. These liquefaction features were produced by the 1886 Charleston earthquake and earlier moderate to large earthquakes in the region. The presence of liquefaction features attributed to the 1886 Charleston earthquake and paleoliquefaction features related to earlier Quaternary earthquake events demonstrates repeated seismicity within the region and, hence, the presence of a capable tectonic source in the vicinity of Charleston. The applicant recognized that liquefaction features interpreted to have been produced by the 1886 Charleston earthquake are most heavily concentrated in the meizoseismal area for that earthquake as well as in some outlying areas. The applicant provided a description of potential Charleston earthquake sources in SSAR Section 2.5.1.1.4.4, but no definitive link has yet been made between a particular fault and the 1886 Charleston event, or any previous earthquake event. The applicant presented refinements of earthquake recurrence estimates for the Charleston area in detail in SSAR Section 2.5.2.2.2.4.

Paleoliquefaction features attributed to pre-1886 earthquakes are abundant along the South Carolina coast. These features were evaluated to estimate earthquake recurrence rates in the Charleston area. Talwani and Schaeffer (2001) proposed two earthquake scenarios: Scenario 1 assumes that some events in the paleoearthquake record were smaller in magnitude (estimated M6+) than events to the northeast of Charleston, while Scenario 2 allows all earthquakes in the record to be large events (estimated M7+) located near Charleston. Based on these two scenarios, Talwani and Schaeffer (2001) estimated recurrence intervals of about 550 years (Scenario 1) and 900-1000 years (Scenario 2).

<u>Seismic Sources Defined by Regional Seismicity</u>

In SSAR Section 2.5.1.1.4.6, the applicant discussed the ETSZ and three other seismogenic and capable tectonic source zones located outside the 320-km (200-mi) radius of the site region (Central Virginia, New Madrid, and Giles County seismic zones (GCSZ)). These seismic zones are shown in SER Figure 2.5.1-6 taken from SSAR Figure 2.5.1-15.

The ETSZ is a northeast-trending area of concentrated seismicity, characteristically generated by small-to-moderate earthquakes, which is located in the Valley and Ridge Physiographic province of eastern Tennessee. The applicant recognized that, although most seismic events in ETSZ have occurred more than 320 km (200 mi) from the VEGP site location and consequently outside the site region, diffuse seismicity on the southeastern margin of the zone is located just within the boundary of the site region. This zone, approximately 300 km (185 mi) long and 50 km (30 mi) wide, has produced no damaging earthquake in historical time. The zone exhibits no geologic evidence of prehistoric earthquakes larger than any historical event that has occurred within the zone. However, the ETSZ has been classified by some as the second most active seismic area in the United States east of the Rocky Mountains (after the New Madrid Seismic Zone (NMSZ)). Others have determined that this zone produced the second highest release of seismic strain energy in the CEUS during the 1980s.

Earthquakes in the ETSZ occur at depths of 5-26 km (3-16 mi) in Precambrian crystalline basement rocks that underlie exposed thrust sheets made up of Paleozoic rock units, suggesting that seismogenic structures in the zone are not related to surface geologic features of the Appalachian orogen. None of the earthquakes exceeded a moment magnitude of M4.6. Earthquakes within the ETSZ cannot be attributed to known faults and the applicant reported that no capable tectonic sources have been identified within the zone, although seismicity appears to be spatially associated with the prominent magnetic field gradient defined by the NYAL. Most seismicity in the ETSZ lies between the NYAL on the west and the Clingman and Ocoee lineaments on the east, in a "block" labeled as the Ocoee block. The applicant concluded that no new information has been developed since 1986 for the ETSZ to require a significant revision to the EPRI (1986) source model, but provided additional discussion of the ETSZ in relation to potential seismic hazard for the VEGP site location in SSAR Section 2.5.2.2.2.5.

The applicant recognized the potential for distant large earthquakes in the CEUS to contribute to the long-period ground motion hazard at the VEGP site, and consequently discussed the following three additional seismic source zones–(1) Central Virginia, (2) New Madrid, and (3) Giles County–located more than 320 km (200 mi) from the site location.

1. The Central Virginia Seismic Zone (CVSZ), shown in Figure 2.5.1-6, is an area of low-level seismicity located more than 560 km (350 mi) north-northeast of the VEGP site location, extending about 120 km (75 mi) north-south and 144 km (90 mi) east-west between Richmond and Lynchburg, VA. The largest historical earthquake to occur in the CVSZ (December 1875) had a body-wave magnitude of 5.0 and a maximum intensity of VII in its epicentral region. Wheeler and Johnston (1992) indicated that seismicity in the CVSZ ranges in depth from about 4-13 km (2-8 mi), suggesting that the events extend both above and below the Appalachian detachment zone (discussed in SSAR Section 2.5.1.1.4.1). Two paleoliquefaction sites reflecting prehistoric seismicity have been found within the CVSZ, but no capable tectonic sources have been identified. The applicant concluded that no new information has been developed since 1986 for the CVSZ to require a significant revision to the EPRI (1986) source model.

2. The NMSZ is an area defined by post-Eocene (younger than 33.7 mya) to Quaternary (1.8 mya to the present) faulting located more than 640 km (400 mi) west of the VEGP site location, extending from eastern Missouri to southwestern Tennessee (Figure 2.5.1-6 from SSAR Figure 2.5.1-15). The zone, approximately 220 km (125 mi) long and 40 km (25 mi) wide, is interpreted to be made up of three fault segments: a southern northeast-trending strike-slip fault, a middle northwest-trending reverse fault, and a northern northeast-trending strike-slip fault. Three large-magnitude historical earthquakes occurred in this zone between December 1811 and February 1812 with magnitudes ranging from M7.1 to M7.5. Since the EPRI (1986) study, estimates of maximum magnitude have generally been in the range of those used in the 1986 EPRI models. However, recent summaries of paleoseismic data suggest a mean recurrence

time of 500 years, an order of magnitude less than seismicity-based recurrence estimates used in EPRI (1986).

The applicant concluded that this estimate of recurrence time represents a significant update of source parameters for the NMSZ used by EPRI (1986).

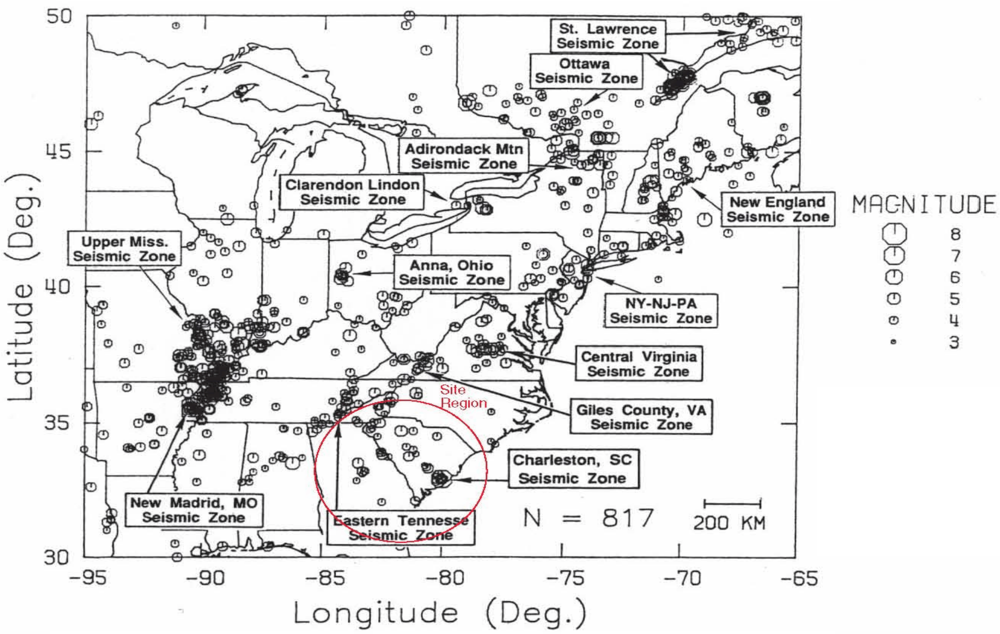

Figure 2.5.1-6 - Seismic Source Zones and Seismicity in the Central and Eastern U.S. (Reproduced from SSAR Figure 2.5.1-15)

3. The GCSZ is located in Giles County, VA, more than 250 mi from the VEGP site location, as shown in Figure 2.5.1-6. Bollinger and Wheeler (1988) reported that earthquakes in this zone occur in Precambrian crystalline basement beneath the overlying Appalachian thrust sheets at depths from 5-25 km (3-16 mi). The data on depth of earthquakes in the GCSZ imply that seismogenic structures in the zone are unrelated to surface geology of the Appalachian orogen. Shallow Late Pliocene to Early Quaternary faults near Pembroke, VA, which lie within the area defined as the GCSZ, are classified as Class B features because it is not determined if they are of tectonic origin or related to solution collapse. The applicant concluded that no new information has been developed since 1986 for the GCSZ to require a significant revision to the EPRI (1986) source model.

2.5.1.1.3 Site Area Geologic Description

Sub-sections 2.5.1.2.1 to 2.5.1.2.3 of SSAR Section 2.5.1.2 describe the geology of the site area, including physiography and geomorphology, geologic history, and stratigraphy). The applicant concluded that the physiography, geomorphology, geologic history, and stratigraphy of the site area pose no safety concerns for the ESP site. The applicant presented the following information related to site area geology.

Physiography, Geomorphology and Geologic History

In SSAR Section 2.5.1.2.1, the applicant described physiography and geomorphology of the ESP site area. The site area lies within the Upper Coastal Plain, about 48 km (30 mi) southeast of the fall line that separates the Piedmont and Coastal Plain physiographic provinces, as shown in Figure 2.5.1-1. The Savannah River, located on the east side of the ESP site, is the primary drainage system in the site area and acts as the state line boundary between Georgia and South Carolina. The Savannah River is incised into surrounding topography to form steep bluffs and a topographic relief of nearly 45 m (150 ft) from river level to the VEGP site. The surface topography, characterized by gently rolling hills, ranges from about 60-90 m (200-300 ft) above mean sea level (msl) across the site area.

The applicant reported that two types of surface depressions occur in the Coastal Plain that are both non-tectonic in origin. The first type of surface depression is referred to as “Carolina Bays”, and result from eolian, surficial processes. The second type of non-tectonic surface depression most likely results from the dissolution of calcareous stratigraphic units at depth. The applicant stated that these surface depressions in the site area were noted and extensively studied during the initial site investigations for VEGP Units 1 and 2.

The applicant described the geologic history of the ESP site area in SSAR Section 2.5.1.2.2. The Upper Coastal Plain is a relatively flat-lying section of unconsolidated marine and fluvial sediments overlying a basement complex of Paleozoic (>248 mya) metamorphic and igneous rocks, and Triassic (248-206 mya) basin sedimentary rocks. Paleozoic and Triassic rocks were beveled by erosion prior to deposition of Coastal Plain sediments. The applicant reported that this erosional surface dips southeast beneath the sediments at approximately 9.5 m/km (50 ft/mi). The Coastal Plain section consists of stratified sands, clays, limestone, and gravel deposits that dip gently seaward, with the oldest sediments in the site area being Upper

Cretaceous (>65 mya) units and the youngest sediments being Quaternary (1.8 mya to Present) alluvium in stream and river valleys.

Stratigraphy

The applicant described the stratigraphy of the ESP site area in SSAR Section 2.5.1.2.3, including basement rock and coastal plain stratigraphy within the site area. The applicant based the stratigraphic descriptions on information from regional geologic maps, site area studies performed for VEGP, borehole data, and surface geophysical surveys. Figure 2.5.1-7, reproduced from SSAR Figure 2.5.1-38, shows a detailed, site-specific stratigraphic column, including sedimentary and depth-to-basement data, based on borehole B-1003, drilled within the VEGP site area.

The applicant described basement rock in the site area in SSAR Section 2.5.1.2.3.1. Basement lithologies consist of Paleozoic (543-248 mya) crystalline rock underlying Coastal Plain sediments in the northwestern portion of the site area, and sedimentary rock of the Dunbarton Triassic Basin beneath Coastal Plain sediments in the southeastern part. Based on logs from borehole B-1003 and inferences from seismic reflection and refraction surveys performed as part of the ESP investigation program, the applicant indicated that Triassic basement at the site occurs at a depth of 318 m (1,049 feet), or 250 m (826 ft) below mean sea level. The applicant stated that rocks of the Dunbarton Basin consist of mudstones, sandstones, and conglomerates with varying degrees of lithification based on borehole B-1003.

The applicant described site area Coastal Plain stratigraphy in SSAR Section 2.5.1.2.3.2, including the Cretaceous (144-65 mya), Tertiary (65-2 mya), and Quaternary (1.8 mya - present) stratigraphy. Weakly consolidated to unconsolidated Coastal Plain sediments that dip and thicken to the southeast unconformably (i.e., not succeeding the underlying rocks in immediate order of age and not fitting together with them as part of a continuous sequence) overlie Paleozoic (543-248 mya) and Triassic (248-206 mya) basement rocks in the site area. These units range in age from Upper Cretaceous (100-65 mya) to Miocene (23.8-5.3 mya) and are about 318 m (1,049 ft) thick in the site area.

The upper Cretaceous (100-65 mya) stratigraphic units logged in borehole B-1003, which unconformably overlie basement rocks, include the Cape Fear, Pio Nono, Upper Gaillard/Black Creek, and Steel Creek Formations. The applicant stated that these Upper Cretaceous units are primarily a mix of stratified sands, silts, clays, and gravels deposited in a fluvial deltaic environment.

Tertiary (65-2 mya) sediments ranging in age from Paleocene (65-54.8 mya) to Miocene (23.8-5.3 mya), unconformably overlie the Upper Cretaceous (100-65 mya) section in the site area and include the following formations: Black Mingo, Snapp, Congaree, Still Branch Sand, Lisbon, Clinchfield, Dry Branch, Tobacco Road, and Hawthorne of the Barnwell Group, and the Pinehurst. The applicant stated that the Tobacco Road and Hawthorne Formations of the Barnwell Group and the Pinehurst Formation were not identified in any site borings but do occur in the site area. The applicant indicated that fluvial deposits at the base of the Tertiary give way to marginal marine, shallow shelf, mixed inner-tidal deposits, and to high-energy fluvial deposits.

AGE				UNIT	DEPTH (FT)	ELEVATION (FT MSL)
Cenozoic	TerTiary	Eocene	Upper	Barnwell Group	Ground surface	+223
				• Tobacco Road Sand		
				• Dry Branch Formation		
				• Clinchfield Formation		
				o Utley Limestone Member	48	+175
			Middle	Claiborne Group		
				• Lisbon Formation	86	+137
				o Blue Bluff Member / McBean Member		
				• Still Branch Sand	149	+74
				• Congaree Formation	216	+7
			Lower			
		Paleocene	Upper	• Snapp Formation	331	-108
				• Black Mingo Formation	438	-215
			Lower			
Mesozoic	Cretaceous	Upper		• Steel Creek Formation	477	-254
				• Gaillard Formation/ Black Creek Formation	587	-364
				• Pio Nono Formation / Unnamed Sand	798	-575
				• Cape Fear Formation	858	-635
	Triassic			Triassic (Dunbarton) basin	1049	-826
					Boring terminated at 1338	

Figure 2.5.1-7 - Site Stratigraphic Column Based on Boring B-1003 (Reproduced from SSAR Figure 2.5.1-38)

The applicant reported that the Tertiary age (65-2 mya) Lisbon Formation includes the extensively mapped, shallow-shelf Blue Bluff Marl, which is the foundation-bearing stratigraphic unit for VEGP Units 1 and 2. This unit is the dominant facies in the VEGP site area and contains shell fragments suspended in a fine-grained micrite (carbonate-rich mud) matrix with occasional shell-rich zones and a carbonate unit referred to as the McBean Limestone.

The applicant reported that Quaternary age (1.8 mya - present) sediments occur as alluvium in stream and river valleys, forming terraces above the modern (Holocene age) flood plain of the Savannah River in the ESP site area. The applicant stated that these terraces are Pleistocene in age.

2.5.1.1.4 Site Area Structural Geology

In SSAR Section 2.5.1.2.4, the applicant reviewed published information to identify four faults and one monoclinal fold within a 5-mile radius of the VEGP ESP site. The four identified faults, each of which originates in basement rock underlying the Coastal Plain sediments, include the Pen Branch, Ellenton, Steel Creek and Upper Three Runs faults. The applicant interpreted the Upper Three Runs and Steel Creek faults as being incapable structures based on the fact that they are restricted to basement rock units and show no evidence that they have offset overlying Coastal Plain sediments. The Ellenton fault is no longer projected on updated fault maps and is considered by the applicant to be an incapable tectonic structure, if it does exist. The Pen Branch fault was examined in detail by the applicant and is discussed in detail below. The northeast-southwest trending monoclinal fold, located in the Blue Bluff Marl, was interpreted by the applicant to be spatially associated with the Pen Branch fault and potentially indicative of reverse fault movement on the Pen Branch.

In addition to reviewing published data, the applicant presented new information from seismic reflection and refraction surveys as well as from an evaluation of Quaternary age fluvial terraces overlying the Pen Branch Fault. The applicant collected this information for the ESP application specifically to determine whether the Pen Branch Fault is a capable tectonic feature. The applicant concluded that the structural geology of the site area poses no safety issues for the ESP site and that the Pen Branch Fault exhibits no Quaternary displacement and does not require further analysis for seismic hazard or surface faulting at the site.

<u>Faults, Folds, Lineaments, Deformation Zones</u>

The Pen Branch fault was first discovered in the subsurface of the SRS. Based on borehole and seismic reflection data, it is interpreted to exceed 40 km (25 mi) in length; to comprise several subparallel, northeast striking, southeast dipping segments; and to project southwestward beneath the VEGP ESP site. Although the Pen Branch fault is interpreted to be a non-capable structure from previous investigations by Bechtel (1989), Snipes et al. (1989), Geomatrix (1993), and Cumbest et al. (1998), the applicant conducted a detailed investigation of the fault based on its proximity to the VEGP site, and presented the findings from that investigation in SSAR Section 2.5.1.2.4.1.

The applicant conducted a review of previous investigations of the Pen Branch fault as a basis for conducting its own investigation. The applicant collected and processed seismic reflection and refraction data at the VEGP site to better characterize the fault parameters. Finally, the applicant undertook a focused geomorphic study to survey and interpret remnants of a Quaternary (1.8 mya - present) river terrace (the Ellenton Terrace), including mapping, collection of elevation data, and construction of a longitudinal profile of the terrace.

The applicant reviewed 17 years of previous investigations of the Pen Branch fault and provided a brief historical interpretation in SSAR Section 2.5.1.2.4.1. The Pen Branch fault is interpreted to be the western boundary fault of the Dunbarton Triassic Basin that juxtaposes Paleozoic (543-248 mya) crystalline rock against Triassic (248-206 mya) sedimentary rock. Seismic reflection data identifies a maximum vertical separation of the contact between basement rocks and Coastal plain sediments of about 28 m (92 ft), with offset decreasing upward into the Coastal Plain stratigraphic section. There is no evidence for post-Eocene (54.8-33.7 mya) displacement in previous subsurface investigations of the Pen Branch fault, which prompted Crone and Wheeler (2000) to assign the Pen Branch fault as a Class C feature.

In January and February 2006, the applicant collected seismic reflection and refraction data along four lines designed to image the Pen Branch fault and assess depth and character of basement rocks beneath the Coastal Plain sediments in the VEGP site area. Based on results of this survey, included in SSAR Section 2.5.1.2.4.2, the applicant concluded that the Pen Branch fault does indeed strike northeast, dips southeast, and lies beneath the site. Just as reported for the Pen Branch fault at the SRS, the strike of the fault beneath the VEGP is somewhat variable. Seismic sections indicate that the fault strikes about N34°E beneath the VEGP (southwest of the Savannah River), changing to about N45°E, then continuing southwest along the strike, and dipping 45°SE. Figure 2.5.1-8, reproduced from SSAR Figure 2.5.1-34, illustrates this interpreted change in strike from the SRS and across the VEGP site. The applicant also interpreted that, based on the new data, there is evidence that the Pen Branch fault intersects a monoclinal fold occurring in the Middle Eocene (54.8-33.7) Blue Bluff Marl. The Blue Bluff unit shows reverse fault displacement due to movement on the Pen Branch fault. Therefore the applicant concluded that Eocene age slip occurred on the Pen Branch fault.

In SSAR Section 2.5.1.2.4.3, the applicant described an evaluation of the Ellenton Terrace (Qte), a Quaternary age Savannah River terrace, located about 6 km (4 mi) east-northeast of the VEGP site, which overlies the Pen Branch Fault on the SRS and is estimated to be between 350 ka and 1 my old. Savannah River fluvial terraces represent the only significant Quaternary deposits and surfaces that straddle the trace of the Pen Branch fault. The applicant conducted this evaluation of the Qte to improve the resolution of the terrace surface elevation and to independently assess the presence or absence of any Quaternary tectonic deformation associated with the Pen Branch fault. This investigation included a review of previously published literature, aerial photographic analysis and geomorphic mapping, and field reconnaissance. The applicant surveyed about 2600 new elevation data points on the terrace surface and constructed a longitudinal profile approximately normal to the local strike of the Pen Branch Fault and parallel to the long axis of the terrace.

The applicant stated that results of a longitudinal profile of the Ellenton terrace surface in the study area provides evidence of no discernable tectonic deformation that can be attributed to the underlying Pen Branch fault within the resolution of the terrace elevation data, estimated to be about 1 m (3 ft). Based on this lack of evidentiary deformation in the Ellenton Qte, the absence of any post-Eocene (older than 33.7 mya) fault displacements interpreted in the seismic reflection and refraction study, and results of previous studies related to the Pen Branch fault, the applicant concluded that the Pen Branch fault is not a capable tectonic structure and that this conclusion is further supported by the previous results in Bechtel (1989), Snipes et al. (1989), Geomatrix (1993), and Cumbest et al. (1998 and 2000).

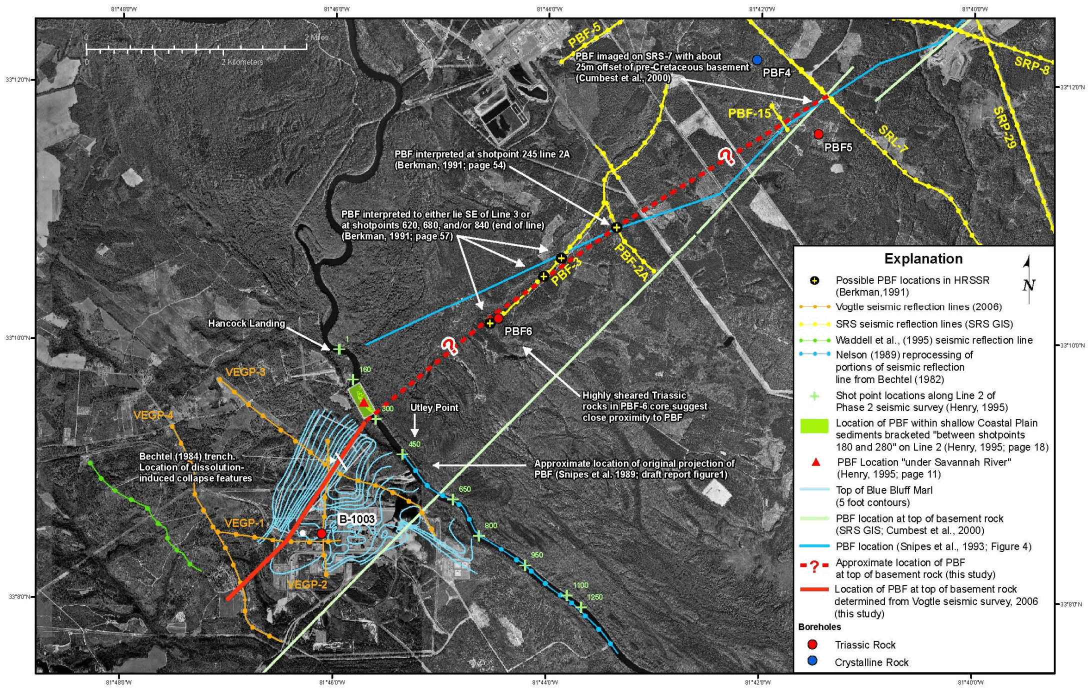

Figure 2.5.1-8 - Location of the Pen Branch Fault (Reproduced from SSAR Figure 2.5.1-34)

2.5.1.1.5 Site Area Earthquakes and Seismicity

Historical and Instrumentally Recorded Seismicity

The applicant summarized seismicity data in the VEGP ESP site vicinity (within a 40-km (25-mi) radius of the site) in SSAR Sections 2.5.3.1.4 and 2.5.3.3. The EPRI catalog of historical seismicity demonstrates that no known earthquake greater than m_b 3 occurred within the site vicinity prior to 1984, while the SRS seismic recording network documents no recent microseismic activity ($m_b < 3$) within an 8-km (5-mi) radius of the VEGP site since 1976. The applicant stated that the nearest microseismic event to the VEGP ESP site was located on the SRS, about 7 mi (11 km) northeast of the VEGP site. Figure 2.5.1-2, taken from SSAR Figure 2.5.1-16, shows diffuse microseismic activity recorded by the SRS seismic recording network since 1976, within a 40-km (25-mi) radius of the VEGP site.

Correlation of Earthquakes with Tectonic Features

The applicant described three small earthquakes that occurred between 1985 and 1997 with magnitudes ranging between 2.0 and 2.6 and depths ranging from 2.5-6 km (1.5-3.5 mi). In addition to these events, the applicant described a magnitude 3.2 event located north of the SRS in Aiken, SC, and a series of several small events (magnitudes $\leq$ 2.6) that occurred in 2001-2002 within the SRS boundaries. The applicant reviewed the locations of these events with respect to mapped faults in the ESP site vicinity–as well as previous studies of these events by Stevenson and Talwani (2004), Talwani et al. (1985), and Crone and Wheeler (2000)–and concluded that there is no spatial correlation of seismicity with known or postulated faults or geomorphic features.

2.5.1.1.6 Site Area Non-Tectonic Deformation Features

In SSAR Section 2.5.3.8, the applicant addressed the potential for the following non-tectonic deformation features at the VEGP ESP site: (1) dissolution collapse features and (2) clastic dikes.

In SSAR Section 2.5.3.8.2, the applicant discussed the potential for non-tectonic surface deformation at the ESP site, including interpretation of dissolution collapse features and "clastic dikes". Regarding dissolution collapse features discussed in SSAR Section 2.5.3.8.2.1, the applicant indicated that small-scale structures (including warped bedding, fractures, joints, minor fault offsets, and injected sand dikes) identified in the walls of a trench at the VEGP site were local features related to dissolution of the Utley Limestone (Clinchfield Formation) and subsequent collapse of overlying Tertiary sediments. The age of these features was interpreted to be younger than Eocene-Miocene host sediments and older than the overlying late-Pleistocene Pinehurst Formation. The applicant stated that no late Pleistocene or Holocene dissolution features were identified at the site. The applicant indicated that mitigation of collapse due to dissolution of the Utley Limestone, which overlies the Blue Bluff Marl at the site, could be accomplished by planned excavation and removal of the Utley to establish the foundation grade of the plant atop the Blue Bluff Marl.

In SSAR Section 2.5.3.8.2.2, the applicant addressed clastic dikes, described as relatively planar, narrow (centimeters to decimeters in width), clay-filled features that flare upwards and are decimeters to meters in length. Bechtel (1984) distinguished two types of clastic dikes in the walls of the trench on the VEGP site where dissolution collapse features were found. The first type of clastic dikes was interpreted to be “sand dikes” that resulted from injection of poorly consolidated fine sand into overlying sediments. The second type was “clastic dikes” produced by weathering and soil-formation processes that were enhanced along fractures that formed during dissolution collapse. Bechtel (1984) concluded the dikes were primarily a weathering phenomena controlled by depth of weathering and paleosol development in Coastal Plain sediments and subsequent erosion of the land surface. Clastic dike features identified by Bartholomew et al. (2002) within the site area were observed during the ESP field reconnaissance. The applicant interpreted these features to be non-tectonic in origin, although Bartholomew et al. (2002) suggested they may be evidence for paleoearthquakes associated with late Eocene to late Miocene faulting, possibly along the Pen Branch Fault.

2.5.1.1.7 Human-Induced Effects on Site Area Geologic Conditions

SSAR Section 2.5.1.2.6.5 states that no mining operation, other than borrow of surficial soils, and no excessive extraction or injection of groundwater, or impoundment of water has taken place within the site area that would impact the geologic conditions at the VEGP site.

2.5.1.1.8 Site Area Engineering Geology Evaluation

The applicant described the engineering geology evaluation of the ESP site in SSAR Section 2.5.1.2.6, including engineering soil properties and behavior of foundation materials; zones of alteration, weathering, and structural weakness; deformational zones; prior earthquake effects; and effects of human activities. In SSAR Section 2.5.1.2.6.1 for engineering soil properties and behavior of foundation materials, the applicant indicated that engineering soil properties were discussed in SSAR Section 2.5.4 and acknowledged that variability of properties in the foundation-bearing layer will be evaluated and mapped as the excavation is completed. The applicant discussed zones of alteration, weathering, and structural weakness in SSAR Section 2.5.1.2.6.2 and indicated that any desiccation, weathered zones, joints, or fractures will be mapped and evaluated as the excavation proceeds. In SSAR Section 2.5.1.2.6.4 on prior earthquake effects, the applicant stated that extensive studies of outcrops, alluvial terraces, and flood plain deposits have not shown evidence for post-Miocene (older than 5.3 mya) earthquake activity. In SSAR Section 2.5.1.2.6.5 on effects of human activities, the applicant stated that no effects resulting from human activity (e.g., mining operations, extraction or injection of groundwater, or impoundment of surface water) have occurred in the site area that affected geologic conditions at the site.

2.5.1.2 Regulatory Evaluation

The acceptance criteria for identifying basic geologic and seismic information are based on meeting the relevant requirements of 10 CFR Part 52.17 and 10 CFR Part 100.23. The staff considered the following regulatory requirements in reviewing the applicant’s discussion of basic geologic and seismic information:

1. 10 CFR 52.17(a)(1)(vi), which requires that an ESP application contain a description of the geologic and seismic characteristics of the proposed site.

- 10 CFR 100.23(c), which requires an ESP applicant to investigate geologic, seismic, and engineering characteristics of a site and its environs in sufficient scope and detail to permit an adequate evaluation of the proposed site; to provide sufficient information to support evaluations performed to determine the SSE Ground Motion; and to permit adequate engineering solutions to actual or potential geologic and seismic effects at the proposed site.

- 10 CFR 100.23(d), which requires that geologic and seismic siting factors considered for design include a determination of the SSE Ground Motion for the site; the potential for surface tectonic and non-tectonic deformation; the design bases for seismically-induced floods and water waves; and other design conditions including soil and rock stability, liquefaction potential, and natural and artificial slope stability. Siting factors and potential causes of failure to be evaluated include physical properties of materials underlying the site, ground disruption, and effects of vibratory ground motion that may affect design and operation of the proposed power plant.

The basic geologic and seismic information assembled by the applicant in compliance with the above regulatory requirements should also be sufficient to allow a determination at the COL stage of whether the proposed facility complies with the following requirements in Appendix A to 10 CFR Part 50:

- GDC 2, which requires that SSCs important to safety be designed to withstand the effects of natural phenomena such as earthquakes, hurricanes, floods, tsunami, and seiches without loss of capability to perform their safety functions.

To the extent applicable in the regulatory requirements cited above, and in accordance with RS-002, the staff applied NRC-endorsed methodologies and approaches (specified in Section 2.5.1 of NUREG-0800) for evaluation of information characterizing the geology and seismology of the proposed site as recommended in RG 1.70, Revision 3 and RG 1.165.

2.5.1.3 Technical Evaluation

This SER section presents the staff's evaluation of the geologic and seismic 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 geologic, seismic, and geotechnical investigations, which were undertaken at increasing levels of detail moving closer to the site. Through its review, the staff determined whether the applicant had complied with the applicable regulations and conducted these investigations at the appropriate levels of detail within the four circumscribed areas designated in RG 1.165 which are defined based on various distances from the site (i.e., circular areas drawn with radii of 320 km (200 mi), 40 km (25 mi), 8 km (5 m), and 1 km (0.6 mi) from the site).

SSAR Section 2.5.1 contains geologic and seismic information collected by the applicant in support of the vibratory ground motion analysis and site SSE spectrum provided in SSAR Section 2.5.2. RG 1.165 indicates that applicants may develop the SSE ground motion for a new nuclear power plant using either the EPRI or Lawrence Livermore National Laboratory (LLNL) seismic source models for the CEUS. However, RG 1.165 recommends that applicants update the geologic, seismic, and geophysical database and evaluate any new data to determine whether revisions to the EPRI or LLNL seismic source models are necessary. Consequently, the staff focused its review on geologic and seismic data published since the late 1980s to assess whether these data indicate a need for changes to the EPRI or LLNL seismic source models.

To thoroughly evaluate the geologic and seismic information presented by the applicant, the staff obtained the assistance of the USGS. The staff and its USGS advisors visited the ESP site to confirm interpretations, assumptions, and conclusions presented by the applicant related to potential geologic and seismic hazards.

2.5.1.3.1 Regional Geologic Description

In SSAR Sections 2.5.1.1.1, 2.5.1.1.2, and 2.5.1.1.3, the applicant reviewed and summarized published information related to the physiography and geomorphology (Section 2.5.1.1.1), geologic history (Section 2.5.1.1.2), and stratigraphy and geologic setting (Section 2.5.1.1.3) of the site region. Based on information presented in SSAR Sections 2.5.1.1.1, 2.5.1.1.2, and 2.5.1.1.3, the applicant concluded that the physiography, geomorphology, geologic history, stratigraphy, and geologic setting of the site region posed no safety issues for the ESP site. Consequently, the applicant considered the site suitable in regard to these specific regional features and their characteristics. The staff's evaluation of SSAR Sections 2.5.1.1.1, 2.5.1.1.2, and 2.5.1.1.3 is presented below.

Physiography, Geomorphology, and Geologic History

The staff focused its review of SSAR Sections 2.5.1.1.1 and 2.5.1.1.2 on the applicant's descriptions of the physiography, geomorphology, and geologic history within the site region, with an emphasis on the Quaternary Period (1.8 mya to the present). In SSAR Section 2.5.1.1.1, the applicant described each physiographic province within the site region, with emphasis on the Coastal Plain physiographic province since the ESP site is located in that province. In SSAR Section 2.5.1.1.2, the applicant described geologic history of the site region, including each episode of continental rifting and collision as well as the deposition of Coastal Plain sedimentary units found at the ESP site.

Based on its review of SSAR Sections 2.5.1.1.1 and 2.5.1.1.2, the staff concludes that the applicant presented a thorough and accurate description of the physiography, geomorphology, and geologic history of the site region in support of the ESP application as required by 10 CFR 52.17(a)(1)(vi), and 10 CFR 100.23(c), and 10 CFR 100.23(d). These two SSAR sections present well-documented geologic information which the applicant derived from published sources. The applicant provided an extensive list of references for these sources which the staff examined in order to ensure the accuracy of the information presented by the applicant in the SSAR.

Stratigraphy and Geologic Setting

The staff focused its review of SSAR Section 2.5.1.1.3 on the applicant's descriptions of the stratigraphy and geologic setting within the site region. The staff's review concentrated on surfaces and deposits of Quaternary age that are preserved primarily in subhorizontal fluvial terraces occurring along the Savannah River and its major tributaries. Development of fluvial terraces can be related to sequential erosion and deposition in response to faulting, climatic, isostatic (i.e., regional changes in crustal loading leading to upwarping or downwarping of portions of the earth's crust), or eustatic (i.e., global sea level changes) effects or a combination of these mechanisms. Because fluvial terrace deposits initially form as relatively level to gently inclined surfaces, the possibility exists for analyzing variations in elevations of the terrace surfaces to evaluate the potential for Quaternary deformation (i.e., tilting, warping, or offset due to fault displacement) in the site area as long as nontectonic processes, such as surficial erosion or dissolution at depth, have not strongly modified its morphology. In particular, the applicant identified a series of four abandoned fluvial terraces (Qty, Qtb, Qte, and Qto from youngest to oldest) that occur in the site area at elevations above the present-day flood plain of the Savannah River and overlie the Pen Branch fault, a structure that the applicant determined does underlie the ESP site. The applicant used these terraces to assess the presence or absence of Quaternary tectonic deformation on the Pen Branch fault.

Regarding the Pen Branch fault, the applicant analyzed seismic reflection data collected for the ESP application to determine that the fault underlies the ESP site. The fault has also been imaged beneath the SRS on the eastern side of the Savannah River, although it shows no surface expression either at the SRS or the ESP site. Although evidence from stratigraphic data discussed by the applicant in the SSAR suggests that the last motion on the Pen Branch fault was pre-Eocene (greater than 33.7 mya) in age, the applicant understood the need to analyze this fault in more detail because of its location relative to the ESP site.

In RAI 2.5.1-1, the staff asked the applicant to indicate whether the fluvial terraces (Qty, Qtb, Qte, and Qto) are regional in extent or are local features uplifted by slip along the Pen Branch fault. In response, the applicant stated that the four abandoned terraces of the Savannah River extend well beyond the vicinity of the Pen Branch fault and are regional in extent. The four terraces extend for at least 33 km (20 mi) upstream and 29 km (18 mi) downstream (i.e., straight-line distances) from the VEGP ESP site. In addition, the applicant stated that the development of a sequence of laterally extensive fluvial terraces is characteristic of other major Piedmont-draining river systems as well as the Savannah River. In conclusion, the applicant stated, "The fact that the major fluvial terrace surfaces are correlative between major Piedmont-draining river systems suggests that these terraces form in parallel response to regional climatic and/or eustatic conditions, and are not the result of local tectonic perturbations."

Based on an evaluation of the applicant's response, the staff concludes that, since the terraces are regional in extent, it is highly unlikely that they developed due to tectonic displacement along the Pen Branch fault. The trace of the fault is nearly perpendicular to the long axis of the terrace surfaces (see SSAR Figure 2.5.1-43), so the terraces are favorably oriented to register Quaternary deformation along the Pen Branch fault. Alternatively, the staff believes a more likely origin for the terraces involves regional changes in sea level relative to the continental land mass. These regional changes resulted from either climatic, isostatic, or eustatic effects or some combination of these nontectonic mechanisms. Climatic, isostatic, and eustatic perturbations alter sea level relative to the land mass on a regional scale, either by raising the sea level itself (climatic and eustatic changes) or isostatically uplifting blocks of continental crust due to regional crustal unloading (isostatic changes). The mechanism of tectonic perturbations is separate and distinct from these regional changes in sea level and would involve tectonic uplift (e.g., fault displacement) to raise a fault block and produce abandoned fluvial terraces atop that block. The staff's conclusion that the fluvial terraces developed as a result of nontectonic processes rather than by tectonic uplift is based on the staff's evaluation of the applicant's response to RAI 2.5.1-1, and subsequent RAI responses pertaining to the same subject (i.e., RAI 2.5.1-2 and RAI 2.5.1-3).

To evaluate the potential for Quaternary displacement on the Pen Branch fault, the applicant implemented a detailed investigation of fluvial terrace Qte (the Ellenton terrace) at a location approximately 6 km (4 mi) east-northeast of the ESP site. The purpose of the applicant's study was to "improve the resolution of the terrace surface elevation and independently assess the presence or absence of Quaternary tectonic deformation on the Pen Branch fault." A previous study of the fluvial terraces by Geomatrix (1993) concluded that the Pen Branch fault is not a capable tectonic source and that there is no observable deformation, within a resolution of 2-3 km (7-10 ft), of the overlying Ellenton terrace (Qte). The applicant's investigation improved on the previous investigation by surveying approximately 2600 elevation data points along the Qte terrace surface in the vicinity of the Pen Branch fault. The applicant estimated its uncertainty to be about 1 m (3 ft) and concluded that its profile of the Qte fluvial terrace surface demonstrates the absence of discernible tectonic deformation on the underlying Pen Branch fault within a 1-m (3-ft) limit of resolution for the elevation data.

In RAI 2.5.1-2, the staff asked the applicant to address whether the range in elevation of the Qtb (8-13 m (26–43 ft)) and Qte (18-25 m (56–82 ft)) terrace surfaces above the Savannah River surface can be attributed to tilting of these terrace surfaces due to Quaternary slip on the Pen Branch fault. The staff also asked the applicant to discuss the implications of the deformation detection limit of about 1 m (3 ft) for the terrace surfaces. This limit resulted from the applicant's field study. This clarification is particularly important for terrace Qte (the Ellenton terrace), which the applicant analyzed in detail to conclude that the terraces do not exhibit deformation due to Quaternary displacement along the Pen Branch fault. The applicant selected terrace surface Qte for the analysis because of its lateral extent and because it could potentially record tectonic deformation along the Pen Branch fault for up to 1 mya based on its interpreted age of 350,000 to 1 million years. The younger terraces, Qty and Qtb, covered shorter time periods, and the older terrace, Qto, exhibited too much dissection for this type of analysis. To define the best-preserved remnants of terrace surface Qte for analysis, the applicant performed geomorphic mapping and field reconnaissance studies and then surveyed approximately 2600 elevation data points on these terrace surface remnants. The applicant estimated that the overall uncertainty in elevation values of the best-preserved remnants of terrace Qte was about 1 m (3 ft) due to the presence of depressions related to dissolution collapse at depth and local deposition of alluvium and colluvium.

In response to RAI 2.5.1-2, the applicant addressed whether the terrace elevation ranges suggested tilting or warping of terrace Qte by tectonic deformation along the Pen Branch fault and the implications of the 1-m (3-ft) limit of detection for deformation. The applicant concluded that variations in elevation of the Qte terrace surface are due largely to the eroded and dissected character of terrace Qte and not from warping or tilting of the terrace by Quaternary displacement on the Pen Branch fault. The applicant cited supporting evidence that these terrace surfaces clearly exhibit a range of surface elevations resulting directly from erosion and dissection which cannot be obviously equated with displacement along the Pen Branch fault. The applicant also concluded that the deformation detection limit of 1 m (3 ft) is an improvement over that attained in previous studies and consequently acceptable for assessing the possibility of Quaternary deformation of the terrace surface due to displacement along the Pen Branch fault. The applicant stated the following:

> Work performed for the VEGP application uses the 350 ka to 1 Ma Ellenton (Qte) terrace surface as a Quaternary strain marker to assess the presence or absence of evidence for tectonic deformation across the underlying Pen Branch fault. A longitudinal profile of the Qte terrace surface in the study area provides evidence demonstrating the absence of tectonic deformation within a resolution of about 1 m (3 ft). This provides a much smaller deformation detection limit than previous studies, thereby providing greater confidence in the evidence demonstrating the lack of Quaternary deformation on the Pen Branch fault.

To completely evaluate the applicant's field study of the Qte fluvial terrace, as well as the applicant's response to RAI 2.5.1-2, the staff and its consultants visited the ESP site and examined the terrace surface. In particular, the staff focused on the adequacy of the applicant's investigations of the Qte terrace and its suitability as a strain marker to assess the presence or absence of tectonic deformation across the underlying Pen Branch fault. Based on the site visit and an examination of aerial photographs and geologic maps, the staff concludes the following:

1. The Qte fluvial terrace shows no obvious surface warping, tilting, or offset.

2. The 1-m (3-ft) detection limit is equivalent to or less than the topographic variations observed for the terrace surface.

3. The variations in elevation of the Qte terrace surface are likely the result of the eroded and dissected character of the Qte surface rather than tectonic tilting and warping due to Quaternary displacement along the Pen Branch fault.

4. The deformation detection limit of 1 m (3 ft), which the applicant achieved during the ESP-related terrace investigations, is a great improvement over previous studies and is a reasonable limit based on measured variability detected in elevation of this terrace surface due to erosion and dissection of the terrace.

SER Figure 2.5.1-9 is a photograph of the Qte fluvial terrace taken during the site visit by the NRC staff and its USGS consultants. This photograph illustrates the relatively flat terrace surface extending a considerable distance toward the horizon, and reinforces the interpretation of the applicant that this terrace surface is not offset by displacement along the Pen Branch fault.

In RAI 2.5.1-3, the staff asked the applicant to discuss the use of the youngest terrace, Qty (4,000 to 90,000 years in age), as an indicator for more recent (i.e., Holocene (10,000 years to the present in age)) potential displacement or uplift along the underlying Pen Branch fault. In response to RAI 2.5.1-3, the applicant stated the following:

> The discontinuous Qty terrace surface of late Pleistocene to possibly Holocene age does not provide constraints for evaluating the potential for Quaternary displacement on the Pen Branch fault. The significantly older and more laterally continuous remnants of the 350 ka to 1 Ma (Geomatrix, 1993) Ellenton terrace

(Qte) provide a more robust datum to evaluate potential tectonic deformation on the Pen Branch fault.

The applicant concluded that the discontinuous nature of terrace Qty does not provide adequate constraint for evaluating the potential for Quaternary displacement on the Pen Branch fault. The applicant cited supporting technical evidence derived from field observations and mapping that the terrace is too discontinuous to permit construction of a longitudinal profile for properly assessing tilting and warping of the terrace surface. The applicant also concluded that terrace Qty is not developed only near the Pen Branch fault and cited evidence derived from its field observations and mapping that the Qty terrace extends outside the site area.

After review of the applicant's response to RAI 2.5.1-3, as well as geologic field maps of the area, the staff concurs with the applicant's conclusions that terrace Qty is too discontinuous to be a suitable strain marker for deformation of the terrace surface or the underlying strata. Furthermore, the terrace extends beyond the location of the Pen Branch fault. The staff also agrees with the applicant that terrace Qte provides a much more robust indicator for potential Quaternary displacement of the underlying Pen Branch fault than terrace Qty.

Based on review of SSAR Section 2.5.1.1.3, the staff concludes that the applicant presented a thorough and accurate description of the regional stratigraphy and geologic setting in support of the ESP application, as required by 10 CFR 52.17(a)(1)(vi), 10 CFR 100.23(c) and 10 CFR 100.23(d). In addition, based on observations made during the site visit and review of the applicant's responses to RAI 2.5.1-1 through RAI 2.5.1-3, the staff concludes that the applicant's detailed examination of fluvial terrace surface Qte demonstrates the absence of significant Quaternary displacement on the underlying Pen Branch fault. As a result, the staff concurs with the applicant's conclusion that the Pen Branch Fault is not a capable tectonic structure (as defined by RG 1.165).

2.5.1.3.2 Regional Tectonic Description

In SSAR Sections 2.5.1.1.4 and 2.5.1.1.5, the applicant reviewed and summarized published information related to the tectonic setting (Section 2.5.1.1.4) and gravity and magnetic data (Section 2.5.1.1.5) of the site region. Based on information presented in SSAR Sections 2.5.1.1.4 and 2.5.1.1.5, the applicant concluded the following:

1. Tectonic features in the site region include structures that are Paleozoic (greater than 248 mya), Mesozoic (248–65 mya), Tertiary (65–1.8 mya), and Quaternary (1.8 mya to present) in age. Only structures of Quaternary age warrant further consideration for the ESP site with regard to the potential for surface fault displacement and seismic hazards.

2. Of the 11 regional geologic features assessed with regard to their potential for Quaternary activity, only the paleoliquefaction features associated with the 1886 Charleston earthquake clearly demonstrate the existence of a Quaternary tectonic feature.

3. Based on more recent information derived from other investigators on source geometry and earthquake recurrence rates for the Charleston seismic source, the 1986 EPRI Charleston seismic source models need to be updated.

4. All regional seismic source zones, other than the Charleston seismic source zone, have less influence on the ESP site due to their distance from the site. The Charleston seismic source model dominates the ground motion hazard for the ESP site.

5. Within the site region, there is no spatial correlation of earthquake epicenters with known or postulated faults. In general, earthquakes occurring in the South Carolina and Georgia portions of the Coastal Plain and Piedmont provinces are not concentrated or aligned with any mapped faults.

Figure 2.5.1-9 - Photograph of the relatively horizontal remnant of fluvial terrace Qte (the Ellenton terrace, dated at 1 Ma to 350 ka years old) which occurs on the eastern side of the Savannah River on SRS property and crosses the trace of the Pen Branch fault. This terrace surface exhibits no tilting, warping, or offset due to Quaternary (1.8 mya to the present) displacement along the Pen Branch fault.

The staff's evaluation of SSAR Sections 2.5.1.1.4 (including SSAR Sections 2.5.1.1.4.1 through 2.5.1.1.4.6) and 2.5.1.1.5 (including SSAR Sections 2.5.1.1.5.1 and 2.5.1.1.5.2) is presented below.

Plate Tectonic Evolution and Stress Field

The staff focused its review of SSAR Sections 2.5.1.1.4.1 and 2.5.1.1.4.2 on the applicant's descriptions of plate tectonic evolution and tectonic stresses within the site region, with an emphasis on the Quaternary Period (1.8 mya to present). In SSAR Section 2.5.1.1.4.1, the applicant described plate tectonic evolution of the Appalachian orogenic belt at the latitude of the site region. The applicant stated that stratigraphic units of the Coastal Plain, the province within which the ESP site lies, record development of a passive continental margin along the east coast of the United States that followed Mesozoic extensional rifting and the opening of the present-day Atlantic Ocean basin. In SSAR Section 2.5.1.1.4.2, the applicant described a detailed study of the orientations and magnitudes of the principal tectonic stresses performed by Moos and Zobach (1992) for the SRS. The applicant stated that the regional stress analyses performed for the CEUS, including the study performed by Moos and Zobach (1992), which characterized a northeast-southwest orientation for the maximum principal compressive stress, did not suggest a need to alter the seismic source models developed by EPRI (1986).

Based on its review of SSAR Sections 2.5.1.1.4.1 and 2.5.1.1.4.2, the staff concludes that the applicant presented a thorough and accurate description of plate tectonic evolutionary history and tectonic stress for the site region in support of the ESP application, as required by 10 CFR 52.17(a)(1)(vi) and 10 CFR 100.23(c), and 10 CFR 100.23(d). These two SSAR sections present well-documented geologic information which the applicant derived from published sources. The applicant provided an extensive list of references for these sources which the staff used to confirm the accuracy of the information in the SSAR.

Principal Regional Tectonic Structures

The staff focused its review of SSAR Section 2.5.1.1.4.3 on the applicant's descriptions of tectonic structures (principally faults), with emphasis on the Quaternary Period. In SSAR Section 2.5.1.1.4.3, the applicant described the principal regional tectonic structures based on the age of formation or reactivation of the structures, including those of Paleozoic (greater than 248 mya), Mesozoic (248–65 mya), Tertiary (65–1.8 mya), and Quaternary (1.8 mya to the present) age. The staff's evaluation of SSAR Section 2.5.1.1.4.3 is presented below.

Paleozoic Tectonic Structures. The applicant described the Paleozoic tectonic structures that are located in the site region—the Augusta fault zone, Modoc fault zone, Central Piedmont Suture, Eastern Piedmont Fault System, and the Brevard, Hayesville, and Towaliga faults. The applicant concluded that (1) there is no seismicity that can be associated with any of these Paleozoic features; (2) none of the structures are capable tectonic sources; and (3) there is no new information associated with these Paleozoic structures that would necessitate an update of the EPRI (1986) seismic source models.

In SSAR Section 2.5.1.1.4.3, the applicant described two distinct deformation fabrics that are contained in both the Augusta and Modoc fault zones. These deformation fabrics suggest that more than one phase of tectonic deformation may have occurred in these zones. Specifically, the applicant stated that a brittle deformation fabric overprinted (i.e., postdated) formation of a ductile deformation fabric in the Augusta and Modoc fault zones. In RAI 2.5.1-5, the staff asked the applicant to clarify whether the brittle fabric may have formed during a post-Alleghanian deformation event (e.g., during the Quaternary). This clarification is important to document that these two structures are old tectonic features exhibiting no evidence for reactivation during Quaternary time.

In response to RAI 2.5.1-5, the applicant addressed the timing of the development of these two deformation fabrics. The applicant concluded that the brittle deformation fabrics associated with the Augusta and Modoc fault zones, which postdate the ductile mylonitic deformation fabrics in the zones, are either late Alleghanian (greater than 248 mya at the end of the Paleozoic) or early Mesozoic in age and do not represent Quaternary reactivation in the modern-day stress regime. The applicant cited several supporting lines of evidence for this conclusion:

1. Both the brittle and ductile fabrics exhibit similar movement directions (i.e., similar kinematic histories) during deformation.

2. The observed normal components of brittle movement are not compatible with the modern-day stress field.

3. The observed mineralization of some brittle fabrics exposed at the surface (e.g., silicification of breccias and growth of zeolite minerals and epidote) cannot form under modern-day geologic and hydrothermal conditions.

Based on its review of the applicant’s response to RAI 2.5.1-5, the staff concludes that the brittle deformation fabrics do not represent Quaternary deformation, or deformation in the modern-day stress field, along the Augusta or Modoc fault zones. In particular, the staff concurs with the applicant’s assertion that the normal components of the brittle movement are incompatible with the modern-day stress regime (i.e., currently a northeast to east-northeast-trending orientation of maximum principal compressive stress) indicating that these fabrics could have developed only as the result of an earlier stress field. The movement history for the brittle deformation fabrics is compatible with the stress field associated with Alleghanian orogeny at the end of the Paleozoic (greater than 248 mya), such that the brittle fabrics of both the Augusta and Modoc fault zones are considerably older than Quaternary. As the applicant stated, Maher et al. (1994) suggest Alleghanian extensional movement along the Augusta fault zone about 274 mya, and Dallmeyer et al (1986) suggest extensional movement of the Modoc fault zone from 310–290 mya. Based on this information, the staff also concludes that it is not necessary for the applicant to reassess the seismic hazard potential of these regional structures for the ESP site.

In RAI 2.5.1-6, the staff asked the applicant to include the Central Piedmont Suture and the Eastern Piedmont Fault System on a corrected SSAR Figure 2.5.1-14. In response to this RAI, the applicant confirmed that this correction would be made in the next revision of the ESP application. The staff confirmed that this change was made in revision 2 to the SSAR.

Mesozoic Tectonic Structures. The applicant discussed Mesozoic tectonic structures in SSAR Section 2.5.1.1.4.3, noting that the Dunbarton Triassic basin, an east-northeast-trending Mesozoic (i.e., Triassic (248–206 mya)) extensional rift basin, is located beneath both the ESP site and the SRS. The extensional Dunbarton Triassic basin is bounded on its northwest side by the Pen Branch fault, a structure determined by the applicant to underlie the ESP site and to exhibit rejuvenation as an oblique-slip reverse fault during the Cenozoic (65 mya to present) after earlier normal fault displacement during the Mesozoic (248–65 mya). The applicant presented a detailed assessment of the potential for Quaternary (1.8 mya to present) displacement along the Pen Branch fault in SSAR Section 2.5.1.2.4. The staff's evaluation of SSAR Section 2.5.1.2.4 is presented in SER Section 2.5.1.3.4.

With regard to regional Mesozoic extensional tectonic terranes, the applicant recognized that areas of extended crust (e.g., such as the eastern part of the Piedmont and beneath the Coastal Plain province in the southeastern United States) may host large earthquakes that are associated spatially with buried faults initially developed in response to extensional rifting. The Pen Branch fault, which forms the northwest boundary of the Dunbarton Triassic basin, is such a fault. The applicant indicated that these buried faults which bound the Triassic basins may be either listric (i.e., a fault with a dip angle that decreases with depth) or a high-angle fault. In RAI 2.5.1-9, the staff asked the applicant to discuss whether there is any evidence that these buried normal faults are listric or are high-angle faults that could extend through the crust to depths where larger magnitude earthquakes commonly nucleate. In response, the applicant stated the following:

> Data constraining the down-dip geometry of faults that bound Mesozoic basins are equivocal. Seismic reflection data, borehole studies, gravity and magnetic signatures, and geologic mapping have all been used to characterize these faults, but different studies have depicted these faults as both listric and high-angle features. The effects of these two possible geometries on hazard at the site are highly uncertain, but both geometries can produce moderate-to-large magnitude earthquakes on seismogenic structures. Because of the uncertainty regarding their geometry, the EPRI ESTs used area sources instead of individual fault sources to represent these basin-bounding faults in the PSHA.

Due to the uncertainty in the location and subsurface geometry of these faults that bound Mesozoic basins, the staff concurs with the applicant's use of area source zones. Rather than characterizing the seismic potential of each identified or postulated fault, seismic hazard studies for the CEUS generally define broad area seismic source zones. Both the EPRI and LLNL seismic source models use this approach, which is endorsed by RG 1.165. Therefore, the staff concludes that the applicant's response to RAI 2.5.1-9 is adequate and that the applicant has conservatively modeled the seismic sources in the region surrounding the ESP site by using area sources rather than individual fault sources.

Tertiary Tectonic Structures. The applicant described Tertiary tectonic structures in SSAR Section 2.5.1.1.4.3. Within 200 miles of the ESP site only a few tectonic features were active during the Tertiary Period (65–1.8 mya). The two most prominent Tertiary structures are the Cape Fear Arch on the South Carolina-North Carolina border and the Yamacraw Arch on the

Georgia-South Carolina border. Based on Crone and Wheeler (2000), the applicant concluded that these features do not exhibit any evidence for Quaternary faulting.

Quaternary Tectonic Structures. The applicant discussed potential Quaternary tectonic structures in the region surrounding the ESP site in SSAR Section 2.5.1.1.4.3. To evaluate each of these potential Quaternary features, the applicant used the database of Quaternary tectonic features developed by Crone and Wheeler (2000) and Wheeler (2005) for the CEUS. These two studies present a compilation and description of the faults, paleoliquefaction features, seismic zones, and geomorphic features that may have been active or capable during the Quaternary period. Crone and Wheeler categorize each feature as fitting into one of four "fault classes" (Classes A, B, C, D) based on geologic evidence for Quaternary deformation. This categorization is determined from the authors' survey of the published literature rather than from direct field examination of the features. These four fault classes are defined by Crone and Wheeler (2000) and Wheeler (2005) as follows:

- Class A—Geologic evidence demonstrates the existence of a Quaternary fault of tectonic origin, whether mapped or inferred from liquefaction or other features.

- Class B—Geologic evidence demonstrates the existence of Quaternary deformation, but either the fault may not cut deeply enough to be a potential earthquake source or available geologic evidence is too strong to assign the feature to Class C but not strong enough to assign it to Class A.

- Class C—Geologic evidence is insufficient to demonstrate the existence of tectonic faulting or Quaternary deformation associated with the feature.

- Class D—Geologic evidence demonstrates that the feature is not a tectonic fault.

Using Crone and Wheeler (2000) and Wheeler (2005), the applicant identified the following potential Quaternary tectonic features in the region surrounding the ESP site:

- Charleston, Georgetown, and Bluffton paleoliquefaction features (Class A)
- ECFS (Class C)
- Cooke fault (Class C)
- Helena Banks fault zone (Class C)
- Pen Branch fault (Class C)
- Belair fault zone (Class C)
- Fall Lines of Weems (Class C)
- Cape Fear Arch (Class C)
- ETSZ (Class C)

The applicant discussed Charleston features (including the ECFS, the Cooke fault, the Helena Banks fault zone, and the Charleston, Georgetown, and Bluffton paleoliquefaction features) in detail in SSAR Section 2.5.1.1.4.4. The applicant presented its detailed analysis of the Pen Branch fault in SSAR Section 2.5.1.2.4 and discussed the ETSZ in SSAR Section 2.5.1.1.4.6. The applicant evaluated the remaining features (i.e., the Belair fault zone, the Fall Lines of Weems, and the Cape Fear Arch) in SSAR Section 2.5.1.1.4.3. The staff's evaluation of those three remaining features is presented below.

Belair Fault Zone

As mapped, the Belair fault zone is located about 20 km (12 mi) north-northwest of the ESP site and is at least 25 km (15 mi) in length. The applicant indicated that undeformed strata overlying the disrupted stratigraphic units constrain the last episode of displacement along this fault zone between post-Late Eocene and pre-26,000 years ago, allowing for Cenozoic (i.e., 65 mya to present), including Quaternary, displacement along the fault zone. The applicant also stated that the Belair fault zone is probably a tear fault or lateral ramp in the hanging wall of the Augusta fault zone. If this association between the Augusta and Belair fault zones exists, then movement on the Belair zone may be related to displacement on the longer, regional-scale Augusta fault zone. In RAI 2.5.1-10, the staff asked the applicant to explain how the inference of Cenozoic displacement on the Belair fault zone and a possible association with the regional Augusta fault zone might affect seismic hazard for the ESP site. This clarification is important to document whether the Belair fault zone is structurally linked with the Augusta fault zone and whether it has experienced displacement during the Quaternary.

In its response to RAI 2.5.1-10, the applicant addressed the possibility of a connection between the Belair and Augusta fault zones. The applicant stated that timing and sense-of-slip for the most recent movements on the Belair and Augusta faults demonstrate that these two structures did not respond as a single tectonic element in Cenozoic or younger time. Prowell et al. (1975) and Prowell and O'Connor (1978) document brittle failure due to reverse slip on the Belair fault in the Cenozoic (65 mya to present). In contrast, the applicant stated that the latest movement on the Augusta fault, as demonstrated by brittle overprinting of ductile fabrics, exhibits a normal sense-of-slip which is constrained to late Alleghanian time (greater than 248 mya) based on Maher (1987) and Maher et al. (1994). The applicant acknowledged that Crone and Wheeler (2000) classified the Belair fault zone as Class C, suggesting Quaternary slip on the Belair fault is allowed but not demonstrated by geologic data. The applicant concluded, based on the evidence supporting different slip histories and opposite senses of dip-slip for the Belair and Augusta faults, that reactivation of these two faults as a single structure during the Cenozoic is not indicated.

Based on its review of the applicant's response to RAI 2.5.1-10, the staff concludes that the Belair and Augusta fault zones are not currently linked tectonic features. In particular, the staff concurs that there is strong field evidence for different slip histories and opposite senses of dip-slip for the Belair and Augusta faults and no indication that the structures were reactivated as a single structure during the Cenozoic.

Fall Lines of Weems (1998)

The applicant discussed a series of anomalously steep stream segments derived by Weems (1998) from a study of longitudinal profiles of streams flowing across the Blue Ridge and Piedmont physiographic provinces in North Carolina, Virginia, and Tennessee. Weems (1998) noted that these steep stream segments occurred as seven "fall zones" that were generally subparallel to the northeast-southeast regional "grain" of the Blue Ridge and Piedmont provinces as reflected by physiography, lithologic belts, and regional tectonic features. Weems (1998) suggested three hypotheses to explain this phenomena, including climatic factors, rock characteristics, and neotectonic effects (i.e., tectonic deformation that is post-Miocene, or greater than 5.3 mya, in age). The applicant stated that the Fall Lines of Weems are classified as Class C features by Wheeler (2005) since they do not demonstrate Quaternary age deformation. Consequently, the applicant concluded that these features do not represent Quaternary faulting in the site region.

Cape Fear Arch

The Cape Fear Arch is a topographic high located on the South Carolina-North Carolina border which is bounded by the Salisbury embayment topographic low to the northeast and the Georgia embayment low to the southeast. The applicant stated that the Cape Fear Arch, a feature previously discussed under the section on tertiary tectonic structures, was classified as Class C by Crone and Wheeler (2000) based on a lack of evidence for Quaternary faulting. The applicant concluded that this feature does not exhibit evidence of Quaternary faulting in light of the Crone and Wheeler (2000) classification and that there is no existing evidence to indicate this feature is a tectonically active structure.

Based on its review of SSAR Section 2.5.1.1.4.3 related to a discussion of faults, the staff concludes that the applicant presented a thorough and accurate description of regional Paleozoic, Mesozoic, Tertiary, and Quaternary tectonic deformation features in support of the ESP application, as required by 10 CFR 52.17(a)(1)(vi), 10 CFR 100.23(c), and 10 CFR 100.23(d). In addition, based on its review of the applicant's responses to RAI 2.5.1-5, RAI 2.5.1-6 and RAI 2.5.1-9, the staff concludes that regional Paleozoic (greater than 248 mya), Mesozoic (248–65 mya), and Tertiary (65–1.8 mya) features are older structures that do not exhibit Quaternary deformation, and no further assessment of seismic hazard potential in relation to any of these regional structures is necessary for the ESP site.

In regard to Quaternary structures discussed by the applicant in SSAR Section 2.5.1.1.4.3, the staff concurs with the applicant that there is strong field evidence for different slip histories and opposite senses of dip-slip for the Belair and Augusta faults, as the applicant qualified in the response to RAI 2.5.1-10. The staff further concurs with the applicant that these structures did not reactivate as a single, linked structure during Cenozoic time (65 mya to present, which includes the Quaternary). In addition, concerning Quaternary history for the seven Fall Lines of Weems (1998), the citation by the applicant of Wheeler (2005) as the primary basis for assessing the potential for Quaternary activity, in relation to the fall lines, is deemed insufficient by the staff. From previous analysis of these features in connection with the SER for North Anna (see NUREG-1835, "Safety Evaluation Report for an Early Site Permit (ESP) at the North Anna ESP Site," issued September 2005), the staff concludes that differential erosion resulting from variable hardness in rock units is a more plausible origin for the fall lines than Quaternary tectonism. The staff further notes that interpretation of the fall lines as Quaternary tectonic features comes solely from Weems, and no other investigators have suggested this origin. Concerning Quaternary activity for the Cape Fear Arch, the staff concurs with the applicant that there is no existing evidence to indicate that this feature is a tectonic structure exhibiting Quaternary deformation.

Furthermore, the staff concurs with the applicant that potential seismic effects of tectonic structures are fully incorporated into PSHA, because area sources, rather than individual fault sources, are used to capture tectonic features in PSHA. Therefore, the staff believes that specific regional structures need not be defined for PSHA and concludes that the applicant thoroughly evaluated the seismic potential for each of the faults in the site region to determine whether the EPRI PSHA source models require updating.

Principal Regional Tectonic Structures—Charleston

The staff focused its review of SSAR Section 2.5.1.1.4.4 on potential Charleston-area source faults, seismic zones, and liquefaction features, with emphasis on the Quaternary Period. In SSAR Section 2.5.1.1.4.4, the applicant described Charleston tectonic features, including potential source faults, seismic zones, and seismically induced liquefaction features. Analysis of Charleston tectonic features is very important in regard to a potential seismic hazard at the ESP site because the earthquake that occurred in 1886 in the Charleston area is one of the largest historical earthquakes ever to occur within the eastern United States and its source is certain to occur within the ESP site region. After a review of more recent geologic investigations in the Charleston area, (some of which described liquefaction features related to the 1886 Charleston earthquake and earlier events likely generated from the same seismic source) the applicant concluded that significant new information related to source geometry and earthquake recurrence rate for the Charleston seismic source warrants an update of the EPRI (1986) source models used in the PSHA. The applicant presented and discussed these updated seismic source parameters for the 1886 Charleston earthquake in SSAR Section 2.5.2.2.2.4 The staff's evaluation of SSAR Section 2.5.1.1.4.4 is presented below.

<u>Potential Source Faults for Charleston</u>. The applicant recognized that no known tectonic source exists for the 1886 Charleston earthquake. Consequently, location of a "Charleston tectonic source" is based on historical reports of damage and occurrence of seismically induced liquefaction features to define an area rather than a specific source fault. The applicant discussed nine potential tectonic source faults for the 1886 Charleston earthquake—the ECFS, Adams Run fault, Ashley River fault, Charleston fault, Cooke fault, Helena Banks fault zone, Sawmill Branch fault, Summerville fault, and Woodstock fault. The applicant concluded that no specific linkage between any of these features and the 1886 Charleston earthquake could be proposed based on geomorphic, geologic, borehole, or seismic evidence. The applicant's discussion of potential tectonic source features for the 1886 Charleston earthquake did not include two faults shown on SSAR Figures 2.5.1-19 and 2.5.1-20 to occur in the meizoseismal area (i.e., the area of maximum damage to structures resulting from the earthquake) of the Charleston earthquake, namely the Gants and Drayton faults. The staff asked, in RAI 2.5.1-13, the applicant to acquire additional descriptive information on these two faults to enable a thorough review of all faults postulated to occur in the meizoseismal area of the 1886 Charleston earthquake.

In response to RAI 2.5.1-13, the applicant provided descriptive information for the Gants and Drayton faults. For the Drayton fault, the applicant concluded that Cenozoic (65 mya to present), and consequently Quaternary (1.8 mya to present), displacement is precluded based on interpretations of seismic reflection data (Hamilton et al., 1983) which suggest that the fault terminates at a depth of about 750 m (2500 ft) below the ground surface in a Jurassic (206–144 mya) basalt layer. For the Gants fault, the applicant concluded that seismic reflection data suggested that the fault may disrupt Cenozoic strata, but with decreasing displacement during Cenozoic time. The conclusions drawn by the applicant for both the Gants and Drayton faults are, therefore, supported by the evidence derived from seismic reflection data, as neither fault exhibits any surface expression.

Based on its review of the applicant's response to RAI 2.5.1-13, the staff concludes that the response provides an adequate description of the Gants and Drayton faults. The staff also concludes that neither of these two faults exhibit any obvious linkage to the 1886 Charleston earthquake in space or time. Because the applicant could not correlate this earthquake with any of the nine potential source faults discussed in SSAR Section 2.5.1.1.4.4, including the Gants and Drayton faults, and uncertainty remains in selecting a specific tectonic source, the staff considers it important that the applicant incorporate the new information on source geometry and earthquake recurrence rate for the 1886 Charleston earthquake into the seismic source models for Charleston. The applicant incorporated these new data into the analyses discussed in SSAR Section 2.5.2.2.2.4 (seismic potential for a Charleston source fault is captured in PSHA by use of a source area rather than a specific tectonic structure for the Charleston area).

<u>Potential Seismic Source Zones for Charleston</u>. Regarding seismic source zones for the 1886 Charleston earthquake, the applicant discussed three zones of increasing seismicity identified in the Charleston area. The zones include the Middleton Place-Summerville, Bowman, and Adams Run seismic zones. The characteristics of these zones are discussed in SSAR Section 2.5.1.1.4.4 and SER Section 2.5.1.1.2. The applicant reached no specific conclusions regarding these three seismic zones in SSAR Section 2.5.1.1.4.4. Details related to specific data in the seismicity catalog for these three zones are discussed in SSAR Section 2.5.2.1. The staff found the descriptions of the seismic source zones, based on published literature (provided by the applicant in SSAR Section 2.5.1.1.4.4) to be acceptable.

<u>Charleston Area Liquefaction Features</u>. Regarding seismically induced liquefaction features in the Charleston area, the applicant stated that such features produced by the 1886 Charleston earthquake are most heavily concentrated in the meizoseismal area for that earthquake. The applicant also reported the locations of prehistoric liquefaction features related to significant seismic events that pre-dated the 1886 Charleston earthquake, but likewise interpreted to most likely have been generated by the same tectonic source. The applicant indicated that, based on consideration of these prehistoric liquefaction data, Talwani and Schaeffer (2001) suggested a mean recurrence interval of 550 years for a Charleston-type earthquake. This interval is roughly an order of magnitude less than the seismicity-based estimates used by EPRI (1986) to characterize recurrence interval for earthquakes generated by the Charleston seismic source. Based on the identification of earthquakes pre-dating the 1886 Charleston seismic event from the prehistoric liquefaction features, the applicant refined earthquake recurrence rate estimates for a Charleston-area earthquake in SSAR Section 2.5.2.2.2.4. The applicant made no specific conclusions regarding seismically induced liquefaction features in SSAR Section 2.5.1.1.4.4.

With regard to liquefaction features in the Charleston area, the staff found that the descriptions of these features provided by the applicant in SSAR Section 2.5.1.1.4.4 needed clarification. To better correlate liquefaction features with proposed tectonic sources, in RAI 2.5.1-11, the staff asked the applicant to include new figures that clearly distinguished liquefaction features related to the 1886 Charleston earthquake from the prehistoric liquefaction events shown in SSAR Figure 2.5.1-19. In RAI 2.5.1-12, the staff asked the applicant to include an additional pertinent reference by Bollinger (1977). The applicant provided the new figures and the reference in its responses to RAI 2.5.1-11 and RAI 2.5.1-12.

The staff concludes that the applicant presented a thorough and accurate geologic description of Charleston tectonic features (including potential source faults, seismic source zones, and liquefaction features) in support of the ESP application, as required by 10 CFR 52.17(a)(1)(vi), 10 CFR 100.23(c), and 10 CFR 100.23(d). In addition, based on its review of the information presented by the applicant on Charleston tectonic features in SSAR Section 2.5.1.1.4.4, and the applicant's responses to RAI 2.5.1-11, RAI 2.5.1-12, and RAI 2.5.1-13, the staff concurs with the applicant that no specific linkage between any of the nine faults discussed and the 1886 Charleston earthquake can be proposed based on geomorphic, geologic, borehole, or seismic evidence. The staff also concludes that it is important for the applicant to incorporate new information on source geometry and earthquake recurrence rate for the Charleston seismic source into PSHA source models for the ESP site. Furthermore, with regard to seismically induced liquefaction features, the staff concurs with the applicant that liquefaction features produced by the 1886 Charleston earthquake are most heavily concentrated in the meizoseismal area. The applicant refined earthquake recurrence rate estimates for a Charleston-area earthquake in SSAR Section 2.5.2.2.2.4. The staff considers it important for the applicant to define a seismic source zone for a Charleston-area earthquake by considering all faults and liquefaction features that it deemed feasible to include for establishing reasonable geologic boundaries for the seismic source zone.

Principal Regional Tectonic Structures—Savannah River Site

The staff focused its review of SSAR Section 2.5.1.1.4.5 on the applicant's descriptions of SRS faults, with emphasis on the Quaternary Period. In SSAR Section 2.5.1.1.4.5, the applicant discussed SRS tectonic features, including the Pen Branch, Steel Creek, Ellenton, Upper Three Runs, ATTA, Crackerneck, Martin, Tinker Creek, Lost Lake, and Millet faults. The applicant indicated that four of these faults (i.e., the Pen Branch, Steel Creek, Ellenton, and Upper Three Runs faults) are interpreted to occur within the site area. Because the Pen Branch fault underlies the ESP site, the applicant discussed this fault in great detail in SSAR Section 2.5.1.2.4 on site area structural geology. The staff's evaluation of SSAR Section 2.5.1.1.4.5 is presented below.

Descriptions of faulting at the SRS provided in the SSAR are based on published literature from technical specialists who are very knowledgeable about tectonic features at the SRS. These descriptions are as accurate as possible, based on the consideration that most of these faults are defined in the subsurface primarily from interpretation of seismic reflection profiles (i.e., none of the faults exhibit surface expression at the SRS). The staff asked, in RAI 2.5.1-14, the applicant to obtain clarification of why the density of faults at the SRS on the eastern side of the Savannah River is so much greater than for the ESP site on the western side of the river and the implication this has for the seismic hazard at the ESP site. In RAI 2.5.1-15, the staff asked for a summary of pertinent data derived from the SRS leading to the applicant's conclusion that the Pen Branch fault is not a capable tectonic structure. In RAI 2.5.1-15, the staff also asked the applicant to compare data and analyses for the SRS with data and analyses employed by the applicant to conclude that the Pen Branch fault is not a capable structure at the ESP site. Since detailed studies of faulting at the SRS have been conducted for an extended period of time, and the ESP site is adjacent to the SRS although on the opposite side of the Savannah River, information collected from and analyses performed for the SRS are very pertinent for assessing the potential for capable faults at the ESP site.

In response to RAI 2.5.1-14, the applicant stated that the SRS was the focus of several decades of subsurface exploration and research. The applicant emphasized that the availability of high-resolution seismic reflection profiles that completely traverse the ESP site from north to south (normal-to-regional structural grain) and image the complete Coastal Plain stratigraphic section from the top of the basement to shallow levels, collected as part of the VEGP ESP project, makes the existence of any unrecognized faults at the ESP site unlikely. The applicant also stated that, although the faults shown on the SRS are greater in number, considering the difference in the size of the area of investigation between the SRS and the ESP site, fault densities are comparable. The applicant indicated that resolution and signal-to-noise ratio of the seismic profile that traverses the ESP site (i.e., proposed VEGP Unit 4) are significantly better than almost all of the seismic reflection data available for SRS. Based on these lines of evidence, the applicant concluded that the absence of previously unrecognized faults in the ESP seismic reflection data indicate that faulting at the ESP site and in the site area has been adequately characterized. The applicant thus concluded that no unknown faults exist that would affect the seismic hazard at the site.

In response to RAI 2.5.1-15, the applicant summarized the evidence substantiating that the Pen Branch fault is not a capable tectonic feature as follows:

- Faulting deforms sediments no younger than Eocene in age. The data for this conclusion are based on 18 closely-spaced SRS drill holes that allowed construction of a subsurface geologic map of a formation above the fault. Additional support for this conclusion is based on geologic mapping and data from 20 auger holes in the Long Branch, South Carolina 7.5 minute quadrangle (Nystrom et al. 1994). The auger holes are located adjacent to the SRS but along strike of the Pen Branch fault and showed no evidence for faulting.

- Savannah River Quaternary fluvial terraces are not deformed across the fault trace, within a resolution limit of 2-3 m (7-10 ft), based on longitudinal profiles along two Savannah River terraces (Geomatrix 1993).

- Based on data from Moos and Zoback (1992), regional principal stress orientations determined from boreholes show that the maximum horizontal stress is parallel to the regional orientation of the Pen Branch fault, making strike-slip faulting unlikely and reverse faulting essentially impossible.

- The VEGP terrace study documented that no fault-related deformation of the 350 ka to 1 Ma Ellenton (Qte) terrace above the projected surface trace of the Pen Branch Fault occurs within a resolution of 1 m (3 ft). The resolution of this study makes it the most definitive evidence for non-capability of the Pen Branch Fault both at the SRS and the ESP site.

The conclusion stated by the applicant that the absence of previously unrecognized faults in the ESP seismic reflection data indicates that faulting at the ESP site and in the site area has been adequately characterized, as well as its conclusion that there are no unknown faults that would affect the seismic hazard at the site, is supported by the evidence from high-resolution seismic profile data. The conclusion stated by the applicant that faulting does not deform strata younger than Eocene (54.8–33.7 mya) is supported by the evidence from 18 drill holes at the SRS. The conclusion stated by the applicant that the analysis of the Ellenton terrace, which overlies the Pen Branch fault, revealed no fault-related deformation within a resolution limit of 1 meter (3 feet) is supported by data collected for the ESP application.

Based on its review of the applicant's responses to RAI 2.5.1-14 and RAI 2.5.1-15, the staff concludes that the applicant adequately addressed the topics of concern raised in RAI 2.5.1-14 and RAI 2.5.1-15. The staff summarizes and discusses the evidence presented by the applicant indicating that the Pen Branch fault is not a capable tectonic structure in SER Section 2.5.1.3.4.

The staff concludes that the applicant presented a thorough and accurate description of SRS tectonic features in support of the ESP application, as required by 10 CFR 52.17(a)(1)(vi), 10 CFR 100.23(c), and 10 CFR 100.23(d). In addition, based on its review of the information presented by the applicant on SRS tectonic features in SSAR Section 2.5.1.1.4.5 and the applicant's responses to RAI 2.5.1-14 and RAI 2.5.1-15, the staff concurs with the applicant that the absence of previously unrecognized faults in the ESP seismic reflection data indicate that faulting at the ESP site and in the site area has been adequately characterized. The staff also concurs with the applicant that unknown faults that would affect the seismic hazard at the site are not likely to exist, but the staff will examine all excavations for the ESP site applying regulatory guidance in RG 1.132, "Site Investigations for Foundations of Nuclear Power Plants", to ensure that this point is true. The staff further concurs with the applicant's conclusion that faulting does not deform strata younger than Eocene (54.8–33.7 mya) because this conclusion is supported by evidence from 18 drill holes at the SRS. Finally, the staff concurs with the applicant's conclusion that the analysis of the Ellenton terrace, which overlies the Pen Branch fault, revealed no fault-related deformation within a resolution limit of 1 meter (3 ft) because this conclusion is supported by data collected for the ESP application.

<u>Principal Regional Tectonic Structures—Anomalies and Lineaments</u>

The staff focused its review of SSAR Sections 2.5.1.1.4.3 and 2.5.1.1.5 on the applicant's descriptions of regional geophysical anomalies and lineations and regional gravity and magnetic data, with emphasis on the Quaternary Period. The applicant discussed these anomalies and lineaments in SSAR Section 2.5.1.1.4.3 (the East Coast Magnetic and Blake Spur anomalies and the New York-Alabama, Clingman, and Ocoee lineaments). These two SSAR sections present well-documented geologic information which the applicant derived from published sources. The applicant provided an extensive list of references for these sources which the staff examined to ensure the accuracy of the information in the SSAR. The staff's evaluation of SSAR Sections 2.5.1.1.4.3 and 2.5.1.1.5 is presented below.

The applicant concluded that the geophysical anomalies and lineaments discussed in SSAR Section 2.5.1.1.4.3 did not pose concerns for the ESP site in regard to seismic hazard. In SSAR Section 2.5.1.1.5, the applicant summarized regional gravity and magnetic data and concluded that no large, unexplained anomalies exist in either data set, and no evidence exists for Cenozoic (i.e., including Quaternary age) tectonic activity or features based on that data. Information that the applicant presented for these two topics is well documented in published literature.

The staff asked, in RAI 2.5.1-7, the applicant to acquire information on the Grenville Front, listed among the features occurring within the site region but not discussed in SSAR Section 2.5.1.1.4.3, to enable assessment of whether this feature should be considered as a potential seismic source for the ESP site. The staff asked, in RAI 2.5.1-8, the applicant to (1) locate the Clingman and Ocoee lineaments and the Ocoee block on the map shown in SSAR Figure 2.5.1-12; (2) indicate the age of the "modern" tectonic setting referred to by Wheeler (1996) for earthquakes within the region of the Ocoee block to aid assessment of whether faults in this region are potentially capable structures requiring consideration for the ESP site; and (3) indicate whether the New York-Alabama, Clingman, and Ocoee lineaments could be potential seismic sources for the site.

In response to RAI 2.5.1-7, the applicant indicated that the Grenville Front was incorrectly listed as a feature occurring within 320 km (200 mi) of the ESP site (i.e., within the site region) and agreed to include the feature on SSAR Figure 2.5.1-12 to eliminate any confusion about its location. The applicant described the Grenville Front in SSAR Section 2.5.1.1.4.1 as a feature developed in Precambrian time during the Grenville Orogeny (i.e., 1100 mya) and concluded in the response that it does not represent a potential seismic source based on the firm evidence that it developed in Precambrian time.

In the response to RAI 2.5.1-8, the applicant agreed to include the Clingman and Ocoee lineaments and the Ocoee block in SSAR Figure 2.5.1-12. The applicant also indicated that the "modern" tectonic setting refers to the setting for the east coast of the United States as a passive continental margin, with regional tectonic stress for the CEUS characterized by northeast-southwest horizontal compression. The applicant stated that this regional stress orientation is subparallel to the lineaments, suggesting that they are not in the most favorable orientation for failure in this regional stress field. The applicant concluded that, while the New York-Alabama, Clingman, and Ocoee lineaments bound a block (i.e., the Ocoee block) that appears responsible for earthquakes in the ETSZ, most focal mechanism nodal planes derived from fault plane solutions in the ETSZ are not parallel to the northeast-trending lineaments, suggesting that features with this orientation are not favorably oriented for accommodating fault displacement. The applicant cited evidence related to orientation of nodal planes defined in the Ocoee block, derived from Johnston et al. (1985) as stated in SSAR Section 2.5.1.1.4.3, indicating north-south and east-west faults for the Ocoee block rather than structures parallel to the northeast-southwest strike trend of the lineaments. The applicant further stated that the lineaments were known to the technical teams in the 1986

EPRI study, and no new information has been published since 1986 on the lineaments that would require a significant change in the EPRI seismic source model.

Based on its review of the applicant's responses to RAI 2.5.1-7 and RAI 2.5.1-8, the staff concludes that neither the Grenville Front nor the New York-Alabama, Clingman, and Ocoee lineaments are likely to be viable seismic sources.

The staff concludes that the applicant presented a thorough and accurate description of regional geophysical anomalies and lineations and regional gravity and magnetic data in support of the ESP application, as required by 10 CFR 52.17(a)(1)(vi), 10 CFR 100.23(c), and 10 CFR 100.23(d). Furthermore, based on its review of the information presented by the applicant on regional geophysical anomalies and lineations and regional gravity and magnetic data in SSAR Sections 2.5.1.1.4.3 and 2.5.1.1.5 and the applicant's responses to RAI 2.5.1-7 and RAI 2.5.1-8, the staff concurs with the applicant that no regional anomalies or lineaments and no regional gravity or magnetic data indicated features requiring consideration for seismic hazard analysis at the ESP site. The staff further concurs with the applicant that none of the anomalies or lineaments described by the applicant in SSAR Sections 2.5.1.1.4.3 and 2.5.1.1.5 are likely to be seismic sources requiring seismic hazard consideration at the ESP site.

Seismic Source Zones

The staff focused its review of SSAR Section 2.5.1.1.4.6 on the applicant's descriptions of the seismically defined source zones, including selected seismogenic and capable tectonic sources beyond the site region, with emphasis on the Quaternary Period (1.8 mya to present). In SSAR Section 2.5.1.1.4.6, the applicant described seismic sources (defined based on regional seismicity) comprising the ETSZ within the site region and the Central Virginia, New Madrid, and GCSZs outside of the site region. This SSAR section presents well-documented geologic information which the applicant derived from published sources. The applicant provided an extensive list of references for these sources, and the staff directly examined relevant references to ensure the accuracy of the information derived from published sources and presented in the SSAR. The staff's evaluation of SSAR Section 2.5.1.1.4.6 is presented below.

In regard to seismic sources within, and selected sources outside, the site region, the applicant concluded that only the NMSZ required an update of source parameters- particularly the recurrence rate. This conclusion was rendered necessary by new information that the applicant reported in the SSAR, as derived from the published literature. The applicant concluded further that information for none of the other three zones (i.e., the East Tennessee, Central Virginia, and Giles County zones) required a significant revision to the 1986 EPRI source model in light of data that were also derived from the published literature. This information included interpretations from Wheeler (2005) that the East Tennessee and GCSZs are Class C features based on a lack of geologic evidence for large earthquakes associated with the zones.

The staff concludes that the applicant presented a thorough and accurate description of seismic source zones defined by seismicity within the site region, including selected sources outside the site region, in support of the ESP application, as required by 10 CFR

52.17(a)(1)(vi), 10 CFR 100.23(c), and 10 CFR 100.23(d). Based on its review of the information presented by the applicant on seismic source zones in SSAR Section 2.5.1.1.4.6, the staff also concludes that all regional seismic source zones discussed by the applicant have less influence on the ESP site due to their distance from the site than the updated Charleston seismic source model discussed in SSAR Section 2.5.2.2.2.4. The staff concurs with the applicant that the Charleston seismic source model dominates ground motion hazard for the site. The applicant incorporated new information on source geometry and earthquake recurrence rate for this source into an updated seismic source model in SSAR Section 2.5.2.2.2.4.

Based on its review of SSAR Section 2.5.1.1.4 and the applicant's responses to RAIs as set forth above, the staff concludes that the applicant identified and properly characterized all regional tectonic features. The staff also concludes that SSAR Section 2.5.1.1.4 provides an accurate and thorough description of regional tectonic features, with an emphasis on potential Quaternary deformation, as required by 10 CFR 52.17(a)(1)(vi), 10 CFR 100.23(c), and 10 CFR 100.23(d).

2.5.1.3.3 Site Area Geologic Description

In SSAR Sections 2.5.1.2.1, 2.5.1.2.2, and 2.5.1.2.3, the applicant reviewed and summarized published information related to physiography and geomorphology (Section 2.5.1.2.1), geologic history (Section 2.5.1.2.2), and stratigraphy (Section 2.5.1.2.3) of the site area. Based on information presented in SSAR Sections 2.5.1.2.1, 2.5.1.2.2, and 2.5.1.2.3, the applicant concluded that physiography, geomorphology, geologic history, and stratigraphy of the site area pose no safety issues for the ESP site. Consequently, the applicant considered the site suitable in regard to these area-specific features and their characteristics. The staff's evaluation of SSAR Sections 2.5.1.2.1, 2.5.1.2.2, and 2.5.1.2.3 is presented below.

Physiography, Geomorphology, and Geologic History

The staff focused its review of SSAR Sections 2.5.1.2.1 and 2.5.1.2.2 on the applicant's descriptions of physiography, geomorphology, and geologic history of the site area, with emphasis on the Quaternary Period. In SSAR Section 2.5.1.2.1, the applicant described the geomorphology of the Coastal Plain physiographic province within which the ESP site lies. In SSAR Section 2.5.1.2.2, the applicant described geologic history of the site area, emphasizing the Coastal Plain. These two SSAR sections present well-documented geologic information which the applicant derived from published sources. The applicant provided an extensive list of references for these sources which the staff examined to ensure the accuracy of the information presented by the applicant in the SSAR.

In the description of site area physiography and geomorphology presented in SSAR Section 2.5.1.2.1, the applicant indicated that the Savannah River is relatively straight and incised in the site area in the vicinity of the projected surface trace of the Pen Branch fault. Tectonic uplift, among other factors, can lower the base level to which a stream will naturally erode, resulting in active erosion by down-cutting and incision of the stream channel. The staff asked, in RAI 2.5.1-4, the applicant to address why the Savannah River is relatively straight and incised at a position that appears to correspond with the location of the Pen Branch fault. This clarification is important to enable an assessment of whether reverse or reverse-oblique slip along the Pen Branch fault occurred to uplift the hanging wall fault block; lower the base level to which the Savannah River would erode; and thus create an incised river channel.

In response to RAI 2.5.1-4, the applicant concluded that the straight, incised segment of the Savannah River is not the result of Quaternary displacement along the Pen Branch fault. The applicant cited three lines of evidence interpreted to preclude Quaternary displacement along the Pen Branch fault as being the mechanism that produced this straight, incised segment of the Savannah River channel:

- The geomorphic surface of the 350 ka to 1 Ma Ellenton fluvial terrace along the Savannah River is undeformed to within a resolution of 1 m (3 ft). The applicant stated that this observation is the best evidence precluding late Quaternary activity of the Pen Branch fault and establishing that the Pen Branch is not a capable fault. The applicant considered it highly unlikely that changes in the modern river channel morphology at the location of the Pen Branch fault would be the result of Quaternary fault activity if the Ellenton terrace surface is preserved across the fault with no evidence of deformation.

- Several other examples of linear or incised portions of rivers are present in the Coastal Plain within 80 km (50 mi) of the ESP site that are not associated with any mapped fault. The applicant stated that the occurrence of other linear portions of river channels demonstrates that the morphology of the Savannah River adjacent to the VEGP site is not unique, but relatively common in the region. The applicant indicated that these other linear reaches of river channels are not spatially associated with known mapped faults, strongly suggesting a nontectonic origin for this type of feature.

- Localized remnant surfaces on the modern flood plain that formed as the result of paleochannel migration indicate that, although the river at present appears relatively straight, it has meandered across the flood plain in recent time. Therefore, the applicant stated that the apparent “straight” segment of the Savannah River channel near the ESP site appears to be an ephemeral feature that changes or evolves through geologic time in response to changes in sediment load, discharge, and eustatic base-level change.

Based on its review of the applicant’s response to RAI 2.5.1-4, the staff concludes that the straight, incised channel of the Savannah River which occurs in the site area in the vicinity of the Pen Branch fault does not require a mechanism related to Quaternary displacement along the Pen Branch fault to produce this morphology along the river channel.

Based on its review of SSAR Sections 2.5.1.2.1 and 2.5.1.2.2 and the applicant’s response to RAI 2.5.1-4, the staff concludes that the applicant presented a thorough and accurate description of the physiography, geomorphology, and geologic history of the site area in support of the ESP application, as required by 10 CFR 52.17(a)(1)(vi), 10 CFR 100.23(c), and 10 CFR 100.23(d).

Stratigraphy

The staff focused its review of SSAR Section 2.5.1.2.3 on the applicant's description of stratigraphic units in the site area, with emphasis on sedimentary units of the Coastal Plain within which the ESP site lies. In SSAR Section 2.5.1.2.3, the applicant described Coastal Plain stratigraphy in the site area in detail and also discussed basement rocks (i.e., both Paleozoic crystalline rocks and sedimentary rocks of the Dunbarton Triassic basin) which underlie Coastal Plain sedimentary units in the site area. The applicant used information derived from borehole B-1003 drilled at the ESP site to describe stratigraphic units of the Coastal Plain that occur at the site. The staff also examined core from this specific borehole during a visit to the ESP site, and this examination of subsurface stratigraphy by the staff added credence to the accuracy of the applicant's description of site stratigraphy. The applicant's discussion of previous data on the site-specific stratigraphic units cited well-documented geologic information derived from published sources. The applicant provided an extensive list of references for these sources which the staff examined to ensure the accuracy of the information presented in the SSAR.

Based on its review of SSAR Section 2.5.1.2.3, the staff concludes that the applicant presented a thorough and accurate description of stratigraphic relationships for the site area in support of the ESP application, as required by 10 CFR 52.17(a)(1)(vi), 10 CFR 100.23(c), and 10 CFR 100.23(d). SER Section 2.5.4 provides further discussion of the engineering properties of soil and rock materials that underlie the ESP site and the staff's complete evaluation of the applicant's description of these materials.

2.5.1.3.4 Site Area Structural Geology

In SSAR Section 2.5.1.2.4, the applicant reviewed and summarized published information related to the structural geology of the site area, including the Pen Branch, Ellenton, Steel Creek, and Upper Three Runs faults. Of these four faults, the applicant determined that the Pen Branch fault underlies the ESP site and required further investigation to determine whether it is a capable tectonic feature exhibiting Quaternary displacement. Therefore, in addition to summarizing published results from previous studies of the Pen Branch fault, the applicant presented important new information from seismic reflection and refraction surveys and evaluation of Quaternary-age fluvial terraces overlying the Pen Branch fault. The applicant collected this information for the ESP application specifically to determine whether the Pen Branch fault is a capable tectonic feature. The applicant stated that the Upper Three Runs and Steel Creek faults are restricted entirely to basement rocks and do not offset Coastal Plain deposits, and the Ellenton fault no longer appears on recent maps of the SRS where it was first interpreted to occur based on seismic reflection data.

Based on information presented in SSAR Section 2.5.1.2.4, the applicant concluded that the structural geology of the site area poses no safety issues for the ESP site. With due consideration for the results of previous studies of the Pen Branch fault and the new information collected for the ESP application, the applicant concluded that the Pen Branch fault does not exhibit Quaternary displacement and is not a capable tectonic feature requiring analysis for seismic hazard or surface-faulting issues at the site. The applicant also concluded that the Ellenton, Steel Creek, and Upper Three Runs faults are not capable tectonic features. Consequently, the applicant considered the site suitable in regard to area-specific geologic structures (i.e., faults) and their characteristics, including the Pen Branch fault. The staff's evaluation of SSAR Section 2.5.1.2.4 specifically in regard to the Pen Branch fault, including SSAR Sections 2.5.1.2.4.1, 2.5.1.2.4.2, and 2.5.1.2.4.3 is presented below.

Pen Branch Fault

The staff focused its review of SSAR Section 2.5.1.2.4 on the applicant's descriptions of the Pen Branch fault (SSAR Section 2.5.1.2.4.1), including new information collected for the ESP application derived from site subsurface investigation of the Pen Branch fault (SSAR Section 2.5.1.2.4.2) and evaluation of Quaternary river terrace Qte (Ellenton terrace) which overlies the Pen Branch fault (SSAR Section 2.5.1.2.4.3). The staff's review emphasized the Quaternary Period and included careful analysis of all information presented by the applicant related to determining whether the Pen Branch fault exhibited Quaternary displacement. The applicant's discussion of previous data on the Pen Branch fault cited well-documented geologic information derived from published sources. The applicant provided an extensive list of references for these sources which the staff examined to ensure the accuracy of the information in the SSAR. However, in the extensive list of references, the applicant did not cite a publication by Hanson et al. (1993) in which the investigators suggested that possible rejuvenation of drainage along projected surface traces of the Pen Branch and Steel Creek faults on the SRS may indicate either local tectonic uplift along these faults at a very low rate of displacement (i.e., 0.002–0.009 mm/yr) or nontectonic geologic processes. In RAI 2.5.1-17, the staff asked the applicant to determine whether the concept presented by Hanson et al. (1993), related to the suggestion of possible Quaternary displacement along the Pen Branch fault based on their analysis of drainage morphology at the SRS, held any implications of geologic hazard for the ESP site.

In response to RAI 2.5.1-17, the applicant addressed the suggestion of Hanson et al. (1993) that stream drainage patterns along the trace of the Pen Branch fault on the SRS may suggest local Quaternary tectonic uplift. The applicant summarized results of a 1993 study by Geomatrix that concentrated on collecting and analyzing several types of information in regard to Quaternary tectonic deformation at the SRS. The applicant discussed data derived from a regional slope map, slope profiles, longitudinal stream profiles, and residual maps that Geomatrix (1993) constructed for this analysis. Based on this information, the applicant concluded that no obvious topographic or geomorphic characteristics could be equated with geologic structures or required the occurrence of Quaternary deformation along the Pen Branch fault. The applicant also reviewed data developed from evaluation of drainage basin shape, drainage density, and drainage frequency by Geomatrix (1993). The applicant likewise concluded from this information that none of these aspects of the drainage patterns indicated geologic structures or required Quaternary deformation along the Pen Branch fault. The applicant referred to fluvial terrace studies conducted by Geomatrix (1993), as well as the more refined terrace studies conducted for the ESP application discussed in SSAR Section 2.5.1.2.4.3, as the most conclusive evidence for a lack of Quaternary deformation along the Pen Branch fault.

Based on its review of the applicant's response to RAI 2.5.1-17, the staff concludes that there is no definitive evidence described by Hansen et al. (1993) indicating the existence of Quaternary displacement along the Pen Branch fault in the site area. The staff further concludes that the applicant's response to RAI 2.5.1-17 adequately qualified the conclusion presented by the applicant.

In the discussion of geometry of the Pen Branch fault presented in SSAR Section 2.5.1.2.4.2, the applicant stated that the Pen Branch fault at the ESP site is made up of two specific fault segments trending N45°E and N34°E with a dip of 45°SE. Considering the N50° to 70°E modern-day orientation of maximum principal horizontal compressive stress defined by Moos and Zobach (1992) for the site region in relation to orientations of segments of the Pen Branch fault, the staff asked, in RAI 2.5.1-18, the applicant to determine whether either fault segment is favorably oriented to experience displacement in the existing regional stress field.

In response to RAI 2.5.1-18, considering the N50° to 70°E modern-day orientation of maximum principal horizontal compressive stress defined by Moos and Zobach (1992) for the site region, the applicant chose an average orientation of the maximum horizontal stress as N60°E and determined that planes striking N45°E and N34°E and dipping 45°SE form angles to the maximum horizontal stress of approximately 10° and 20°, respectively. The applicant stated that these orientations are not parallel to the maximum horizontal stress and therefore would experience some amount of resolved shearing stress. However, based on Ramsey and Huber (1987), the applicant indicated that planes of such orientations relative to maximum principal horizontal compressive stress would not experience maximum shearing stress. The applicant pointed out that favorably oriented planes for maximum resolved shearing stress occur at 45° to the maximum horizontal compressive stress direction. Moos and Zoback (1992) further stated that stress magnitudes at shallow depths only approach the frictional strength of favorably oriented reverse faults (i.e., 45°). Therefore, the applicant concluded that stress magnitudes resolved along planes of other orientations will be well below those necessary for displacement in the modern-day stress field. The applicant also concluded that the orientation of the Pen Branch fault segments at the ESP site makes them less favorably oriented for failure in response to the intermediate-depth stress perturbation of N33°E which Moos and Zobach (1992) reported.

Based on its review of the applicant's response to RAI 2.5.1-18, the staff concurs with the applicant that neither of the segments of the Pen Branch fault occurring at the ESP site are favorably oriented to experience displacement in the modern-day stress field. As the applicant indicated, shear failure theory predicts that favorably oriented planes for maximum resolved shearing stress occur at 45° to the maximum horizontal compressive stress direction.

The staff concludes that the applicant presented a thorough and accurate description of the Pen Branch and other faults in the site area in support of the ESP application, as required by 10 CFR 52.17(a)(1)(vi), 10 CFR 100.23(c), and 10 CFR 100.23(d). Furthermore, upon consideration of the information the applicant presented in SSAR Section 2.5.1.2.4, including the applicant's responses to RAI 2.5.1-17 and RAI 2.5.1-18, to support its conclusions about the noncapable nature of the Pen Branch fault, the staff concurs with the applicant that no definitive evidence exists to indicate that the Pen Branch fault (1) shows any surface expression; (2) exhibits Quaternary displacement based on analysis of fluvial terraces and age of stratigraphic units which bound the time of fault displacement; or (3) is a capable tectonic structure. SER Section 2.5.3 contains the staff's complete evaluation of surface faulting near the ESP site in regard to the potential for tectonic deformation and vibratory ground motion due to surface faulting.

The technical bases for the staff's conclusions in regard to site area structural geology, specifically that the Pen Branch fault is not a capable tectonic feature at the ESP site, are related to the evidence which the applicant presented in the SSAR and in its responses to RAIs. The evidence presented by the applicant and summarized below covers information acquired from previous investigations at the SRS and the VEGP site; geomorphic mapping and field reconnaissance, seismic reflection and refraction studies, and investigation of Quaternary fluvial terraces performed by the applicant for the ESP application; and analysis of the regional stress field.

<u>Previous Investigations at the Savannah River Site</u>. History of and evidence from previous investigations of the Pen Branch fault conducted at the SRS, which the applicant outlined in SSAR Section 2.5.1.2.4.1, are summarized as follows:

- Based on seismic data, Snipes et al. (1989) suggested Late Eocene (33.7 mya or older) displacement, but no younger, on the Pen Branch fault and concluded that the fault should not be considered a capable tectonic structure at the SRS.

- Based on a seismic reflection survey designed to investigate the Pen Branch fault, Berkman (1991) reported deformation of the Cretaceous age (144–65 mya) Cape Fear Formation, but no younger units, and concluded that the Pen Branch fault is not a capable tectonic feature.

- A fluvial terrace study performed by Geomatrix (1993) confirmed no tectonic deformation of terrace surfaces overlying the Pen Branch fault within a resolution of 2-3 m (7–10 ft), and Geomatrix (1993) concluded that the Pen Branch is not a capable tectonic feature.

- Snipes et al. (1993) reported that the youngest stratigraphic horizon known from borehole studies to be deformed by fault displacement along the Pen Branch fault is the Dry Branch Formation of Late Eocene (33.7 mya or older) age, and that a Quaternary soil horizon overlying the projected trace of the Pen Branch fault at the SRS showed no offset. The applicant reported this information in SSAR Section 2.5.3.6.

- Based on results of a drilling project designed to investigate the Pen Branch fault using 18 boreholes, Stieve et al. (1994) concluded that the Pen Branch fault is no younger than 50 mya and is not a capable tectonic feature.

- Cumbest et al. (1998) integrated information from more than 60 boreholes and 100 miles of seismic reflection profiling and concluded that no faults on the SRS, including the Pen Branch Fault, are capable tectonic features.

- Based on seismic reflection data, Cumbest et al. (2000) concluded that offset along the Pen Branch fault decreased upward within Coastal Plain sediments to no greater than 9 m (30 ft) at the top of Upper Cretaceous/Lower Paleocene units (i.e., about 66.4 mya).

Previous Investigations at the VEGP Site

Henry (1995) collected and interpreted 115 km (70 mi) of seismic reflection data along the Savannah River, including in the vicinity of VEGP Units 1 and 2, and crossing the projected trace of the Pen Branch fault. Henry (1995) concluded that the Pen Branch fault extended into possibly Eocene age (54.8–33.7 mya) sediments. The applicant summarized this information in SSAR Section 2.5.1.2.4.1.

In SSAR Section 2.5.3.8.2.1, the applicant indicated that an old garbage trench that crossed the trace of the Pen Branch fault in the ESP site area, mapped by Bechtel in 1994, contained only dissolution collapse features and no tectonic structures that resulted from displacement along the Pen Branch fault. The applicant interpreted these dissolution features to be older than Late Pleistocene (i.e., greater than 10,000 years old) based on stratigraphic units exposed in the trench, providing an upper age limit for deformation due to displacement along the Pen Branch fault. More recent investigations, as discussed in the following paragraph, indicate a minimum age for displacement along the Pen Branch fault greater than 33.7 mya.

Seismic Reflection and Refraction Data Collected for the ESP Application

The applicant discussed seismic reflection and refraction data collected for the ESP application in SSAR Section 2.5.1.2.4.2. The applicant defined orientation of the Pen Branch fault in the ESP site area and concluded that a monoclinal fold in the Blue Bluff Marl marks the up-section effects of the Pen Branch fault on stratigraphic units in the site area, indicating no displacement that is post-Eocene (i.e., older than 33.7 mya).

Geomorphic Mapping and Field Reconnaissance for the ESP Application

In SSAR Sections 2.5.1.2.4.3 and 2.5.3.6, the applicant indicated that geomorphic mapping and field reconnaissance performed for the ESP application as preparation for the terrace study showed no surface expression of Quaternary deformation along the Pen Branch fault in the site region.

Terrace Study Performed for the ESP Application

The applicant discussed results of its analysis of the Ellenton fluvial terrace (i.e., terrace Qte) at the SRS, which was performed to assess the capability of the Pen Branch fault in the site area, in detail in SSAR Section 2.5.1.2.4.3. The applicant concluded that no Quaternary deformation of the terrace is indicated due to displacement along the Pen Branch fault within a resolution limit of 1 meter (3 feet). RAIs described in SER Section 2.5.1.3.1 (i.e., RAI 2.5.1-1, RAI 2.5.1-2, and RAI 2.5.1-3) posed questions to address the conclusion that the applicant drew from the analysis of fluvial terrace Qte, since this analysis was cited by the applicant as the most important piece of evidence indicating no Quaternary displacement along the Pen Branch fault. The staff and its USGS advisors also visited the ESP site to gain firsthand knowledge about the accuracy of the terrace analysis, and observations made during the site visit added credence to the applicant's conclusion that this study indicates that the Pen Branch fault does not exhibit Quaternary displacement and is not a capable tectonic feature at the ESP site.

<u>Orientation of the Pen Branch Fault in the Modern-Day Regional Stress Field</u>

In SSAR Section 2.5.1.1.4.2, the applicant stated, based on information from Moos and Zobach (1992), that maximum horizontal regional compressive stress in the modern-day stress field is oriented N50° to 70°E in the upper 640-meter (2100-foot) depth range. Such an orientation of regional stress (the applicant used a reasonable average of N60°E in its response to RAI 2.5.1-18) is subparallel to the measured strike of the Pen Branch fault, even when the fault is divided into segments striking N45°E and N34°E as the applicant discussed in SSAR Section 2.5.1.2.4.1. Shear failure theory predicts that maximum shear stress occurs on a surface oriented at 45° to maximum principal compressive stress; consequently, the Pen Branch fault surface is not oriented as a favorable plane for shear failure and resulting fault displacement.

2.5.1.3.5 Site Area Geologic Hazard Evaluation—Faulting, Earthquakes, and Seismicity

In SSAR Section 2.5.1.2.5, the applicant stated that no geologic hazards, effectively including any related to faulting, earthquakes, and seismicity, occur within the ESP site area. The applicant provided detailed discussions on surface faulting in SSAR Section 2.5.3 and seismic hazards in SSAR Section 2.5.2. The applicant provided results of the detailed analysis of the Pen Branch fault specifically, which demonstrate that the Pen Branch is not a capable structure in the site area, in SSAR Section 2.5.1.2.4. In SSAR Section 2.5.1.2.6.4, the applicant also stated that extensive studies of alluvial terraces and floodplain deposits showed no evidence of post-Miocene (i.e., greater than 5.3 mya) earthquake activity as discussed in SSAR Section 2.5.1.2.4. Based on information presented in SSAR Sections 2.5.1.2.4, 2.5.1.2.5, and 2.5.1.2.6.4, the applicant concluded that the ESP site exhibits no geologic hazards resulting from faulting, earthquakes, or seismicity that occur in the site area. Consequently, the applicant considered the site suitable in regard to geologic hazards related to faulting, earthquakes, and seismicity, including the Pen Branch fault, in the site area. However, the applicant does incorporate new information from other investigators on source geometry and earthquake recurrence rate for the Charleston seismic source into PSHA source models for the ESP site, as discussed in SSAR Section 2.5.2.2.2.4. The staff's evaluation of SSAR Section 2.5.1.2.5 in regard to potential hazards due to faulting, earthquakes, and seismicity is presented below.

Based on its review of the information that the applicant presented in SSAR Sections 2.5.1.2.4, 2.5.1.2.5, and 2.5.1.2.6.4, the staff concludes that the applicant presented a thorough and accurate description of faulting, earthquakes, and seismicity in the site area in support of the ESP application, as required by 10 CFR 52.17(a)(1)(vi), 10 CFR 100.23(c), and 10 CFR 100.23(d). The staff concurs with the applicant that the ESP site exhibits no geologic hazards resulting from faulting, earthquakes, or seismicity that occur in the site area.

2.5.1.3.6 Site Area Nontectonic Deformation Features

In SSAR Section 2.5.1.2.5, the applicant stated that nontectonic surface depressions associated with dissolution of the Utley Limestone member of the Clinchfield Formation which overlies the Blue Bluff Marl do not pose a geologic hazard at the ESP site. The applicant plans to remove this unit from the site excavation, and the Blue Bluff Marl will form the foundation-bearing layer. These units are discussed in SSAR Section 2.5.1.2.3.2, and the surface depressions are discussed in detail in SSAR Section 2.5.3.8.2.1. In SSAR Section 2.5.1.1.1, the applicant indicated that Carolina Bays, which occur in the site area, are related to eolian erosion resulting from strong, unidirectional, southwesterly winds and not from dissolution. The applicant also indicated in SSAR Section 2.5.1.2.5 that any structures founded above the Blue Bluff Marl will require subsurface exploration to define low bearing strength layers associated with dissolution in units overlying the Blue Bluff Marl. Based on information presented in SSAR Section 2.5.1.2.5, the applicant concluded that the ESP site exhibits no hazard resulting from nontectonic deformation features. Consequently, the applicant considered the site suitable in regard to geologic hazards related to these features in the site area. The staff's evaluation of SSAR Section 2.5.1.2.5 in regard to potential hazard from nontectonic deformation is presented below.

Based on its review of the information presented in SSAR Section 2.5.1.2.5 and the SSAR sections (i.e., Section 2.5.3.8.2.1 for dissolution features and 2.5.1.1.1 for Carolina Bays) in which the applicant discussed surface depressions in detail, the staff concludes that the applicant presented a thorough and accurate description of nontectonic deformation features in the site area in support of the ESP application, as required by 10 CFR 52.17(a)(1)(vi), 10 CFR 100.23(c), and 10 CFR 100.23(d). The staff concurs with the applicant that the ESP site exhibits no geologic hazards resulting from nontectonic deformation features.

2.5.1.3.7 Human-Induced Effects on Site Area Geologic Conditions

In SSAR Section 2.5.1.2.6.5, the applicant stated that no mining operations other than borrow of surficial soils, excessive extraction of injection of ground water, or impoundment of water exists in the site area that will detrimentally affect geologic conditions. Based on information presented in SSAR Section 2.5.1.2.6.5, the applicant concluded that the ESP site exhibits no hazard resulting from human-induced effects on site geologic conditions. Consequently, the applicant considered the site suitable in regard to geologic hazards related to human-induced effects in the site area. The staff's evaluation of SSAR Section 2.5.1.2.6.5 is presented below.

Based on its review of the information presented in SSAR Section 2.5.1.2.6.5, the staff concludes that the applicant presented an accurate description of human-induced effects in the site area in support of the ESP application, as required by 10 CFR 52.17(a)(1)(vi), 10 CFR 100.23(c), and 10 CFR 100.23(d). The staff concurs with the applicant that the ESP site exhibits no hazard resulting from human-induced effects on site geologic conditions.

2.5.1.3.8 Site Area Engineering Geology Evaluation

In SSAR Section 2.5.1.2.6, the applicant addressed engineering soil properties and behavior of foundation materials (Section 2.5.1.2.6.1), zones of alteration, weathering, and structural weakness (Section 2.5.1.2.6.2), and deformational zones (Section 2.5.1.2.6.3). The applicant addressed ground water conditions in SSAR Section 2.5.1.2.7. Regarding engineering properties (including index properties, static and dynamic strength, and compressibility), the applicant indicated that this information is discussed in detail in SSAR Section 2.5.4. In regard to zones of alteration, weathering, and structural weakness, the applicant indicated that some dessication of the Blue Bluff Marl is expected and that dessication, weathered zones, and fractures will be mapped and evaluated. Regarding deformational zones, the applicant stated that none were reported from previous studies for VEGP Units 1 and 2, but the applicant will evaluate any such zones detected during excavation mapping. In regard to site ground water conditions, the applicant indicated that a detailed discussion of these conditions is provided in SSAR Section 2.4.12. The staff's evaluation of SSAR Section 2.5.1.6, including SSAR Sections 2.5.1.2.6.1, 2.5.1.2.6.2, 2.5.1.2.6.3, and 2.5.1.2.7, is presented below.

Based on its review of the information that the applicant presented in SSAR Sections 2.5.1.2.6 and 2.5.1.2.7, the staff concludes that the applicant presented an accurate description of site area engineering geology, as far as existing data will allow, in support of the ESP application, as required by 10 CFR 100.23(c). The staff's detailed analysis of engineering properties of soil and rock is presented in SER Section 2.5.4, and the analysis of site ground water conditions is presented in SER Section 2.4.12.

Based on its review of SSAR Section 2.5.1.2 and the applicant's responses to RAIs as set forth above, the staff concludes that the applicant identified and properly characterized all site area geologic features, including the Pen Branch fault. The staff also concludes that SSAR Section 2.5.1.2 provides an accurate and thorough description of site area geologic features, with an emphasis on the Quaternary Period, as required by 10 CFR 52.17(a)(1)(vi), 10 CFR 100.23(c), and 10 CFR 100.23(d).

2.5.1.4 Conclusions

As discussed in SER Sections 2.5.1.1, 2.5.1.2, and 2.5.1.3, the staff carefully reviewed the basic geologic and seismic information submitted by the applicant in SSAR Section 2.5.1. The staff concurs that the data and analyses presented by the applicant in the SSAR provide an adequate basis to conclude that no capable tectonic faults exist in the plant site area that have the potential to generate surface or near-surface fault displacement.

In addition, the staff concludes that the applicant has identified and appropriately characterized all seismic sources significant for determining the SSE for the ESP site, in accordance with the guidance provided in RG 1.70, RG 1.165, and Section 2.5.1 of NUREG-0800. Because ground motion hazard at the ESP site is dominated by the Charleston seismic source, the staff concurs with the applicant's decision to update the EPRI (1986) source model for this seismic source in light of new information on source geometry and earthquake recurrence rate. No capable tectonic feature has as yet been linked to the Charleston seismic source. Based on information from the applicant's thorough review of the literature on regional geology, and the applicant's literature review and geologic, geophysical, and geotechnical investigations of the site vicinity and site area, the staff further concludes that the applicant has properly characterized regional and site lithology, stratigraphy, geologic and tectonic history, and structural geology, as well as subsurface soils and rock units at the site. The staff also concludes that there is no potential for the effects of human activity (i.e., mining activity or ground water injection or withdrawal) that will compromise the safety of the ESP site.

On the basis of the foregoing, the staff concludes that the applicant has provided a thorough and accurate characterization of the geologic and seismic characteristics of the site, as required by 10 CFR 52.17(a)(1)(vi), 10 CFR 100.23(c), and 10 CFR 100.23(d).

2.5.2 Vibratory Ground Motion

SSAR Section 2.5.2 describes the applicant's determination of the SSE ground motion at the ESP site from potential earthquakes in the site area and region. SSAR Section 2.5.2.1 describes the earthquake catalog used for the ESP site, SSAR Section 2.5.2.2 summarizes the geologic structures and tectonic activity that could potentially result in ground motion at the ESP site, and SSAR Section 2.5.2.3 describes the correlation of earthquake activity with geologic structures or tectonic provinces. SSAR Section 2.5.2.4 describes the earthquake potential for seismic sources in the region surrounding the ESP site, SSAR Section 2.5.2.5 describes the seismic wave transmission characteristics of the site, SSAR Section 2.5.2.6 provides the SSE ground motion spectrum, SSAR Section 2.5.2.7 provides the vertical SSE, and SSAR Section 2.5.2.8 discusses the operating-basis earthquake ground motion spectrum.

The applicant stated that the information provided in SSAR Section 2.5.2 of the ESP application uses the procedures recommended in RG 1.165, issued March 1997, for performing the PSHA for the ESP site. Rather than using the reference-probability approach described in RG 1.165 for determining the SSE, the applicant used the performance-based method described in RG 1.208 issued March 2007. In addition, the applicant used the 1986 EPRI Project (EPRI NP-4726) seismic source model for the CEUS as an input for its seismic ground motion calculations. RG 1.165 indicates that applicants may use the seismic source interpretations developed by LLNL (1993) or 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 the ESP site.

To determine whether an update of the seismic source and ground motion models used in the 1989 EPRI PSHA (EPRI NP-6395-D) was necessary, the applicant reviewed the literature published since the mid-to-late 1980s. This literature review identified the need for changes to the source characterization parameters of the Charleston seismic zone. In addition, the applicant determined that the ground motion models used for the 1989 EPRI PSHA needed to be updated.

2.5.2.1 Technical Information in the Application

2.5.2.1.1 Seismicity

SSAR Section 2.5.2.1 describes the development of a current earthquake catalog for the ESP site. The applicant started with the EPRI historical earthquake catalog (EPRI NP-4726-A 1988), which is complete through 1984. To update the earthquake catalog, the applicant used information from the Advanced National Seismic System (ANSS) and the South Eastern United States Seismic Network (SEUSS).

The EPRI catalog covers the time period from 1627 to 1984 and contains earthquakes that occurred within the CEUS. Earthquakes comprising the EPRI catalog are characterized by a variety of different size measures, including local magnitude (M_L), surface-wave magnitude (M_S), duration or coda magnitude (M_d or M_c), body-wave magnitude (m_{bLg}), felt area (FA), and epicentral Modified Mercalli (MM) intensity (I_o). Earthquake measures such as M_L, M_S, M_d, M_c, and m_{bLg} are based on characteristics of instrumentally recorded events. M_d and M_c are related to the duration of a recorded earthquake, while M_L, M_S, and m_{bLg} are related to the amplitude of a recorded earthquake. FA and I_o, are based on qualitative descriptions of the effects of the earthquake at a particular location (Kramer 1996).

All earthquakes comprising the EPRI catalog are described in terms of m_b. The applicant converted all earthquakes that were not originally characterized by m_b to best, or expected, estimates of m_b ($E[m_b]$) using conversion factors developed in EPRI NP-4726-A (1988). EPRI NP-4726-A (1988) developed these conversion factors from regression models relating m_b to M_L, M_S, M_d or M_c; FA; and I_o. In addition, the 1988 EPRI study calculated a uniform magnitude (m_b*) from E_{mb} and the variance of m_b (σ^2_{mb}) in order to account for the uncertainty in estimating m_b.

The applicant only selected earthquakes from the EPRI historical catalog that occurred within the site region (320-kilometer (km) or 200-mile (mi) radius). In addition, the applicant updated the EPRI historical seismicity catalog to incorporate earthquakes that have occurred within the site region since 1984. To update the EPRI earthquake catalog, the applicant used information from the ANSS and the SEUSS. Of these two catalogs, the applicant primarily used the SEUSS catalog for the period from 1985 to 2005. Events in the SEUSS and ANSS catalogs that have occurred since 1985 are primarily reported as m_{bLg}, M_L, M_c, and M_d. To be consistent with the m_b estimates provided in the EPRI catalog, the applicant converted the magnitudes given in both the SEUSS and ANSS catalogs to $E[m_b]$. The applicant included a total of 61 events with $E[m_b]$ magnitude greater than 3.0 in the update of the EPRI NP-4726-A (1988) seismicity catalog. The applicant also calculated m_b* using $E[m_b]$ and σ^2_{mb} (estimated from the ANSS and SEUSS catalogs).

As shown in Figure 2.5.2-1 of this SER, a comparison of the geographic distribution of earthquakes contained in the EPRI catalog (1627–1984) and the earthquakes contained in the updated catalog (1985–2005) shows a very similar spatial distribution. The cluster of events along the coast of South Carolina is related to the Charleston Seismic Zone, while the cluster of events in eastern Tennessee is associated with the ETSZ. The ETSZ extends from southwest Virginia to northeast Alabama.

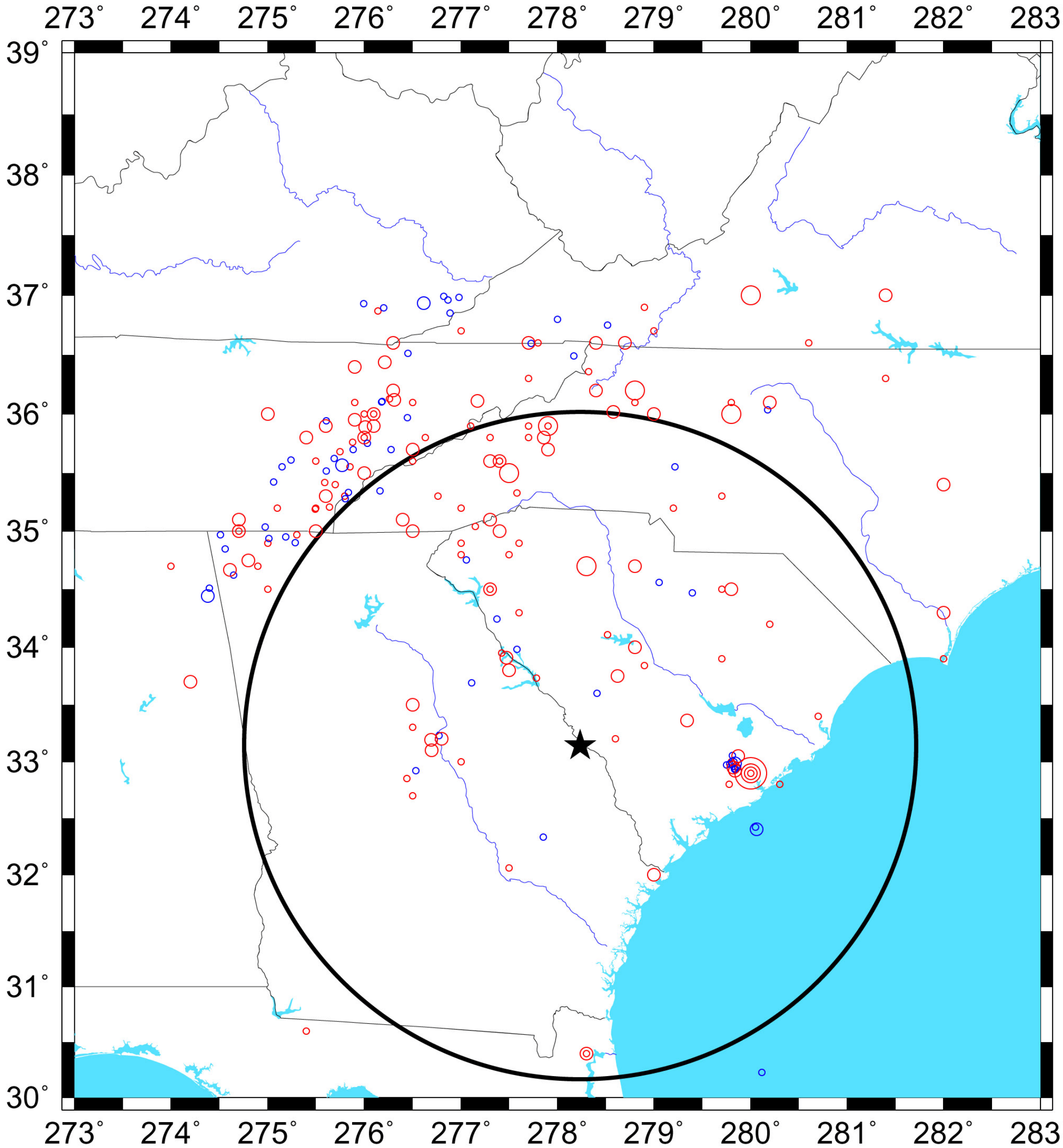

Figure 2.5.2-1 - A comparison of events (m_b greater than 3) from the EPRI historical catalog (depicted by blue circles) with events from the applicant's updated catalog (depicted by red circles). The star corresponds to the location of the ESP site and the large black circle corresponds to the 200-mi site radius.

2.5.2.1.2 Geologic and Tectonic Characteristics of the Site and Region

SSAR Section 2.5.2.2 describes the seismic sources and seismicity parameters that the applicant used to calculate the seismic ground motion hazard for the ESP site. Specifically, the applicant described the seismic source interpretations from the 1986 EPRI Project (EPRI NP-4726 1986), relevant post-EPRI seismic source characterization studies, and its updated EPRI seismic source zone for the Charleston area based on more recent data.

Summary of EPRI Seismic Sources

The applicant used the 1986 EPRI seismic source model for the CEUS as a starting point for its seismic ground motion calculations. The 1986 EPRI seismic source model is comprised of input from six independent earth science teams (ESTs), which included the Bechtel Group, Dames and Moore, Law Engineering, Rondout Associates, Weston Geophysical Corporation, and Woodward-Clyde Consultants. Each team evaluated geological, geophysical, and seismological data to develop a model of seismic sources in the CEUS. The 1989 EPRI PSHA study (EPRI NP-6395-D 1989) subsequently incorporated each of the EST models. SSAR Sections 2.5.2.2.1.1 through 2.5.2.2.1.6 provide a summary of the primary seismic sources developed by each of the six ESTs. As stated in SSAR Section 2.5.2.2.1, the 1989 EPRI seismic hazard calculations implemented a screening criteria to include only those sources with a combined hazard that exceeded 99 percent of the total hazard from all sources for two ground-motion measures (EPRI NP-6395-D 1989).

Each EST representation of seismic source zones affecting the ESP site region differs significantly in terms of total number of source zones and source characterization parameters such as geometry and maximum magnitudes (and associated weights). For example, the total number of primary source zones identified by each EST ranged from 2 (Rondout Associates team) to 15 (Law Engineering team). However, all teams identified and characterized one or more seismic source zones or background sources that accounted for seismicity in the vicinity of the ESP site. In addition, all of the ESTs identified and characterized one or more seismic source zones to account for the occurrence of Charleston-type earthquakes.

SER Table 2.5.2-1 provides the sources that account for Charleston-type earthquakes. The largest maximum magnitudes (M_{max}) assigned to the Charleston source zone by each team ranged from m_b 6.8 (Law Engineering, with a weight of 1) to m_b 7.5 (Woodward-Clyde, with a weight of 0.33). This corresponds to a moment magnitude (M) range of 6.8 to 8.0.

Table 2.5.2-1 - Summary of EPRI EST Charleston Seismic Sources (Based on Information Provided in SSAR Tables 2.5.2-2 to 2.5.2-7)

EPRI EST	Source	Description	Probability of Activity	M_{max} (m_b) and Weights
Bechtel	H	Charleston Area	0.50	6.8 [0.20] 7.1 [0.40] 7.4 [0.40]
	N3	Charleston Faults	0.53	6.8 [0.20] 7.1 [0.40] 7.4 [0.40]
Dames & Moore	54	Charleston Seismic Zone	1.00	6.6 [0.75] 7.2 [0.25]
Law Engineering	35	Charleston Seismic Zone	0.45	6.8 [1.0]
Rondout	24	Charleston	1.0	6.6 [0.20] 6.8 [0.60] 7.0 [0.20]
Weston	25	Charleston Seismic Zone	0.99	6.6 [0.90] 7.2 [0.10]
Woodward-Clyde	30	Charleston (includes NOTA)	0.573	6.8 [0.33] 7.3 [0.34] 7.5 [0.33]
	29	S. Carolina Gravity Saddle (Extended)	0.122	6.7 [0.33] 7.0 [0.34] 7.4 [0.33]
	29A	S. Carolina Gravity Saddle No. 2 (Combo C3)	0.305	6.7 [0.33] 7.0 [0.34] 7.4 [0.33]

Post-EPRI Seismic Source Characterization Studies

SSAR Section 2.5.2.2.2 focuses on the Charleston seismic source zone. The applicant described several PSHA studies that were completed after the 1989 EPRI PSHA, which involved the characterization of seismic sources within the ESP site region. These PSHA studies developed models of the Charleston seismic source that differed from those used in the 1989 EPRI PSHA study because they incorporated recent paleoliquefaction data. The applicant also provided its justification for not updating the EPRI seismic source parameters for the ETSZ, which is situated at the edge of the 320-km (200-mi) site region radius.

Charleston Seismic Source Zone

SSAR Section 2.5.2.2.2 describes three post-EPRI (1989) PSHA studies that characterized the seismic sources within the ESP site region. These studies include the USGS National Seismic Hazard Mapping Project (Frankel et al. 1996, 2002) and the South Carolina DOT (SCDOT) seismic hazard mapping project (Chapman and Talwani 2002). Unlike the EPRI study, these PSHA studies developed models of the Charleston seismic source that incorporated recent paleoliquefaction data.

Abundant soil liquefaction features induced by the 1886 Charleston earthquake, as well as other large prehistoric earthquakes that date back to the mid-Holocene (at least 5000 years), are preserved in geologic deposits at numerous locations within the 1886 meizoseismal area and along the South Carolina coast. In 2001, Talwani and Schaeffer (2001) reevaluated all of the liquefaction data previously compiled for the Charleston area and, based on recalibrated radiocarbon dates for liquefaction features, provided an estimate of earthquake recurrence for the region. Talwani and Schaeffer (2001) reinterpreted radiocarbon dates for previously published liquefaction features documented along the coast of South Carolina. Radiocarbon dates are useful in providing contemporary, minimum, and maximum limiting ages for liquefaction features. Talwani and Schaeffer (2001) recalculated previously compiled age data to account for fluctuations in atmospheric carbon-14 over time. They used the calibrated data to correlate ages of past individual earthquakes and then to estimate earthquake recurrence. Talwani and Schaeffer (2001) also identified individual earthquake episodes based on samples with a “contemporary” age constraint that had overlapping calibrated radiocarbon ages at the 68 percent (1-sigma) confidence interval. They calculated the estimated age of each earthquake from the weighted averages of overlapping contemporary ages. Talwani and Schaeffer (2001) identified a total of eight events from the paleoliquefaction record, including the 1886 Charleston event. These events are referred to as 1886, A, B, C, D, E, F, and G (in order of increasing age).

Talwani and Schaeffer (2001) proposed two scenarios to explain the distribution and timing of paleoliquefaction features (shown in SSAR Table 2.5.2-13). In Scenario 1, they interpreted events A, B, E, and G to be large Charleston-type events, while they interpreted events C, D, and F to be smaller, moderate magnitude (~**M** 6) events. In Scenario 2, Talwani and Schaeffer (2001) interpreted all events as large, Charleston-type events. In addition, they combined events C and D into a large event C’ based on the observation that the calibrated radiocarbon ages that constrain the timing of Events C and D are indistinguishable at the 95 percent (2-sigma) confidence interval.

In 2002, the USGS updated the seismic hazard maps for the contiguous United States based on new seismological, geophysical, and geologic information (Frankel et al. 2002). The 2002 USGS update included modifications to the geometry, recurrence, and M_{max} of the Charleston seismic source zone. In its update, the USGS represented Charleston-type earthquakes by two equally weighted areal sources. One of these seismic source zones envelops most of the tectonic features and liquefaction data in the greater Charleston area, while the other source envelops the southern half of the southern segment of the ECFS. Frankel et al. (2002)

adopted a mean paleoliquefaction-based recurrence interval of 550 years for Charleston-type earthquakes which ranged from **M** 6.8 to 7.5.

The SCDOT model (Chapman and Talwani 2002) characterized Charleston-type earthquakes by using a combination of three equally weighted line and area sources. The SCDOT model comprises a coastal South Carolina areal source zone that includes most of the paleoliquefaction sites, a source that captures the intersection of the Woodstock and Ashley River faults, and a source that represents the southern ECFS source zone. For Charleston-type earthquakes, which ranged from **M** 7.1 to 7.5, Chapman and Talwani (2002) also adopted a mean paleoliquefaction-based recurrence interval of 550 years.

The applicant briefly mentioned the TIP study in the SSAR. However, the applicant did not explicitly include the findings of this study in the SSAR because the TIP study primarily focused on the implementation of the Senior Seismic Hazard Advisory Committee (SSHAC) methodology, rather than the actual seismic hazard estimation.

<u>**Eastern Tennessee Seismic Zone**</u>

In SSAR Section 2.5.2.2.2.5, the applicant concluded that no new information regarding the ETSZ has been developed since 1986 that would require a significant revision to the original EPRI seismic source model. The applicant noted that despite being one of the most active seismic zones in Eastern North America, no evidence for larger prehistoric earthquakes, such as paleoliquefaction features, has been discovered. The largest earthquake recorded in the ETSZ was a magnitude 4.6 and occurred in 1973. The applicant also noted that a much higher degree of uncertainty is associated with the assignment of M_{max} for the ETSZ than for other CEUS seismic source zones where values of M_{max} are constrained by paleoliquefaction data.

The 1986 EPRI seismic source model (EPRI NP-4726 1986) included various source geometries and parameters to represent the seismicity of the ETSZ. All of the EPRI ESTs, except for the Law Engineering team, represented this area of seismicity with one or more local source zones. The Law Engineering team's Eastern Basement source zone included the ETSZ seismic source zone. With the exception of the Law Engineering team's Eastern Basement source, none of the other ETSZ sources contributed more than 1 percent to the site hazard, and thus were excluded from the final 1989 EPRI PSHA hazard calculations (EPRI NP-6452-D 1989).

Upper-bound maximum values of M_{max} developed by the EPRI teams for the ETSZ ranged from **M** 4.8 to 7.5. The applicant found that M_{max} estimates for the ETSZ in more recent studies fall within the range of magnitudes captured by the EPRI model. Bollinger (1992) estimated an M_{max} of **M** 6.3, while the USGS hazard model (Frankel et al. 2002) assigned a single M_{max} value of **M** 7.5 for the ETSZ.

<u>**Updated EPRI Seismic Sources**</u>

Based on the results of several post-EPRI PSHA studies (Frankel et al. 2002; Chapman and Talwani 2002) and the availability of paleoliquefaction data (Talwani and Schaeffer 2001), the applicant updated the EPRI characterization of the Charleston seismic source zone as part of the ESP application. SSAR Section 2.5.2.2.2.4 describes how the applicant used post-EPRI information to recharacterize the source geometry, M_{max}, and magnitude recurrence for the Charleston seismic source zone. The applicant updated the Charleston seismic source zone using the guidelines provided in RG 1.165. Specifically, the applicant performed an SSHAC Level 2 study to incorporate current literature and data and the understanding of experts into an update of the Charleston seismic source model. The applicant referred to the updated model in the SSAR as the UCSS model. Bechtel (2006) describes the development of the UCSS model in greater detail.

UCSS Geometry

To represent the Charleston seismic source, the applicant developed four mutually exclusive source zone geometries. The applicant based the geometries of these four source zones, referred to as A, B, B', and C, on the following information:

- current understanding of geologic and tectonic features in the 1886 Charleston earthquake epicentral region
- the 1886 Charleston earthquake shaking intensity
- distribution of seismicity
- geographic distribution, age, and density of liquefaction features associated with both the 1886 and prehistoric earthquakes
- SER Figure 2.5.2-2, reproduced from SSAR Figure 2.5.2-9, depicts the geometries of the applicant's four source zones. As shown in SER Figure 2.5.2-2, Geometry A is an approximately 100 x 50 km, northeast-oriented area centered on the 1886 Charleston meizoseismal area and envelops the following:
- the 1886 earthquake MMI X (severe damage) isoseismal (Bollinger 1977)
- the majority of identified Charleston-area tectonic features and inferred fault intersections
- the area of ongoing concentrated seismicity
- the area of greatest density for the 1886 and prehistoric liquefaction features

Based on the available geologic and seismologic evidence, the applicant concluded that Geometry A defines the area where future Charleston-type earthquakes will most likely occur. For this reason, the applicant assigned a weight of 0.70 to Geometry A in the UCSS model. However, in order to capture the uncertainty that future events may not be entirely restricted to Geometry A, the applicant developed three additional geometries, referred to as B, B', and C, that were each assigned a weight of 0.1.

As shown in SER Figure 2.5.2-2, Geometry B is a coast-parallel source, with an area of approximately 260 x 100 kilometers (161.6 x 62.1 miles), that incorporates all of Geometry A.

The elongation and orientation of Geometry B roughly parallels both the regional structural grain as well as the elongation of the 1886 isoseismals (damage contours). Paleoliquefaction features mapped by Amick (1990), Amick et al. (1990a, 1990b), and Talwani and Schaeffer (2001) define the northeastern and southwestern extents of Geometry B. In addition, Geometry B extends to the southeast to include the offshore Helena Banks fault zone; offshore earthquakes in 2002 (m_b 3.5 and 4.4) suggest a possible spatial association with the mapped trace of the Helena Banks fault zone. Multiple reflection profiles clearly show the Helena Banks fault, which demonstrates late Miocene (23.8 to 5.3 million years ago (mya)) offset (Behrendt and Yuan 1987).

Geometry B’ is an approximately 260 x 50-km (161.6 x 31.1-mi) source area that is identical to Geometry B with the exception that Geometry B’ does not include the offshore Helena Banks fault system. The applicant excluded the Helena Banks fault system from Geometry B’ because the majority of data and evaluations (e.g., Behrendt and Yuan 1987) suggest that this fault system is no longer active.

Geometry C is an approximately 200 x 30-km (124.3 x 18.6-mi), north-northeast-oriented source area that envelops the southern segment of the ECFS as depicted by Marple and Talwani (2000). Both the USGS hazard model (Frankel et al. 2002) and the SCDOT hazard model (Chapman and Talwani 2002) explicitly incorporate the southern segment of the ECFS as a source zone. However, the USGS hazard model (Frankel et al. 2002) truncated the northern extent of the southern fault segment, while the SCDOT hazard model (Chapman and Talwani 2002) extended the southern segment to include, in part, the liquefaction features in southeastern South Carolina (Chapman 2005). The applicant concluded that the liquefaction features in southeastern South Carolina are captured in source zones B and B’. The applicant further concluded that the truncation of the northern extent of the southern fault segment of the ECFS in the USGS hazard model is not supported by any available data.

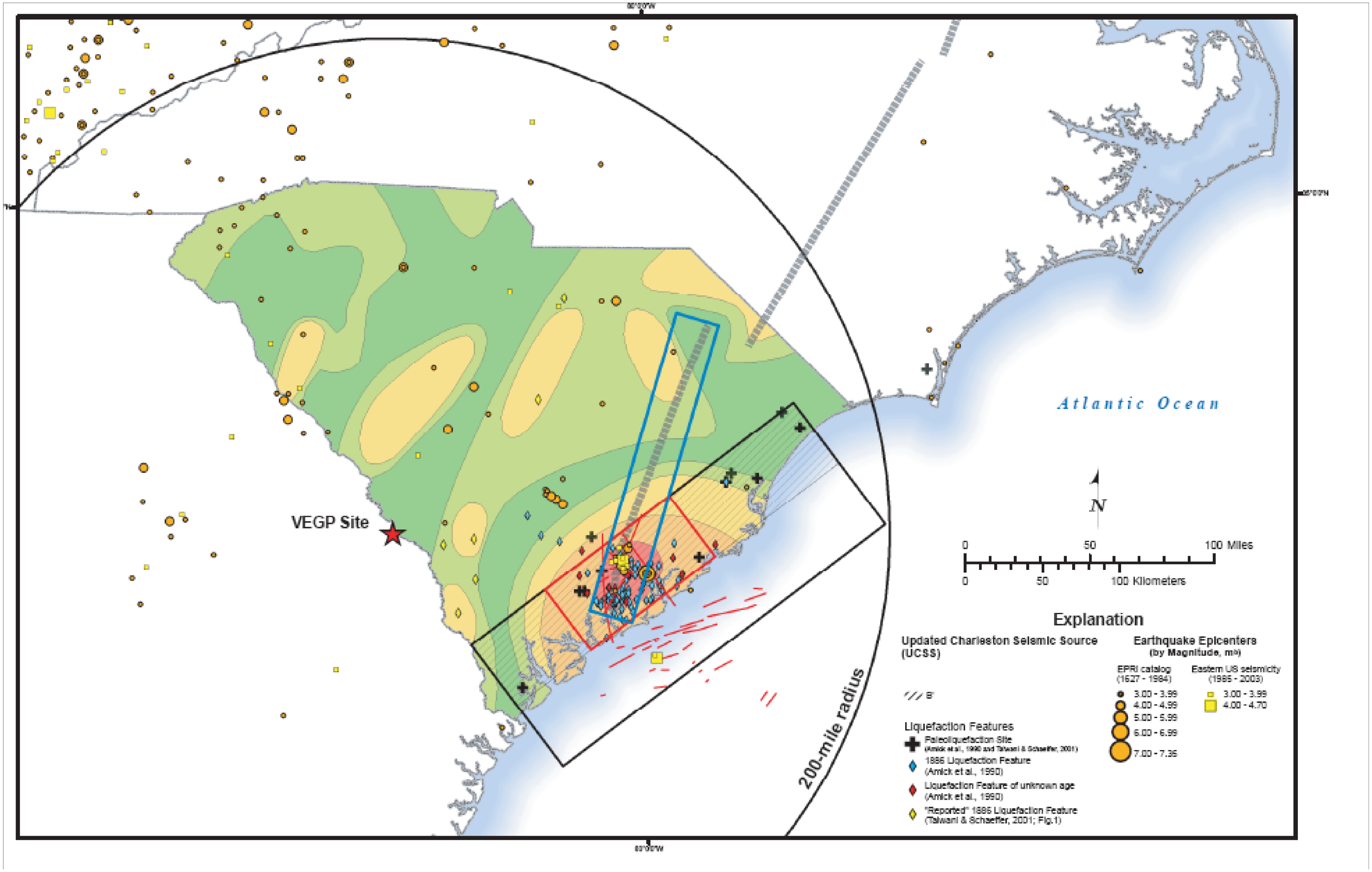

Figure 2.5.2-2 - Alternative geometries comprising the UCSS model updated Charleston seismic source (reproduced from SSAR Figure 2.5.2-9)

UCSS Maximum Magnitude

In order to define the largest earthquake that could be produced by the Charleston seismic source, the applicant developed a distribution for M_{max} based on several post-EPRI (1989) magnitude estimates for the 1886 Charleston earthquake. The applicant modified the USGS hazard model magnitude distribution (Frankel et al. 2002), shown in SER Table 2.5.2-2, to include a total of five discrete magnitude values, each separated by 0.2 **M** units. The applicant's M_{max} distribution included a discrete value of **M** 6.9 to represent the Bakun and Hopper (2004) best estimate of the 1886 Charleston earthquake magnitude, as well as a lower value of **M** 6.7 to capture the probability that the 1886 earthquake was smaller than the Bakun and Hopper (2004) mean estimate of **M** 6.9. In their study, Bakun and Hopper (2004) provide a 2-sigma range of **M** 6.4 to **M** 7.2.

Table 2.5.2-2 - Comparison of Maximum Magnitudes and Weights for the USGS and SCDOT Models with the Applicant's UCSS Model

M_{max} (M)	USGS Model Weight	SCDOT Model Weight	UCSS Model Weight
6.7	—	—	0.1
6.8	0.2	—	—
6.9	—	—	0.25
7.1	0.2	0.2	0.3
7.3	0.45	0.6	0.25
7.5	0.15	0.2	0.1

UCSS Recurrence Model

Most of the available geologic data pertaining to the recurrence of large earthquakes in the South Carolina region were published after 1990. In the absence of these data, the 1989 EPRI study (EPRI NP-6395-D) estimated the recurrence of large Charleston-type earthquakes using a truncated exponential model. The 1989 EPRI study estimated the parameters of this exponential model from historical seismicity. The recurrence of M_{max} earthquakes in the EPRI study was on the order of several thousand years, which is significantly greater than more recently published estimates of about 500 to 600 years that are based on paleoliquefaction data (Talwani and Schaeffer 2001).

To estimate recurrence for earthquakes with **M** less than 6.7, the applicant used an exponential magnitude distribution. The applicant estimated the parameters of this exponential distribution from the earthquake catalog. However, based on paleoliquefaction data, the applicant found that M_{max} earthquakes (**M** greater than 6.7) have occurred more frequently than would be implied by extrapolation of the recurrence of smaller magnitude (**M** less than 6.7) earthquakes within the UCSS. Thus, the applicant treated M_{max} events within the UCSS according to a characteristic earthquake model, which means that this source repeatedly generates earthquakes, known as characteristic earthquakes, similar in size to M_{max}. The applicant estimated the recurrence of these characteristic earthquakes from paleoliquefaction data.

The applicant further reevaluated the data presented by Talwani and Schaeffer (2001) and provided an updated estimate of earthquake recurrence. Talwani and Schaeffer (2001) used calibrated radiocarbon ages with 1-sigma error bands to define the timing of past liquefaction episodes in coastal South Carolina. However, the standard practice in paleoliquefaction studies is to use calibrated ages with 2-sigma error bands (e.g., Sieh et al. 1989; Grant and Sieh 1994; Tuttle 2001) to more accurately reflect uncertainties associated with radiocarbon dating. The applicant determined that the use of 1-sigma error bands by Talwani and Shaeffer (2001) may lead to overinterpretation of the paleoliquefaction record such that more episodes are interpreted than actually occurred. For this reason, the applicant recalibrated the radiocarbon ages presented in Talwani and Schaeffer (2001) and reported the newly recalibrated ages with 2-sigma error bands.

The applicant identified six individual paleoearthquakes, including the 1886 Charleston event, from the UCSS calibrated 2-sigma data. The applicant determined that two earthquake events (C and D) identified in the Talwani and Schaeffer (2001) 1-sigma analysis are not individually distinguishable at the 95 percent (2-sigma) confidence interval, and the applicant defined these two events as a single event, C’. The applicant also suggested that Talwani and Schaeffer (2001) events F and G likely represent a single large event, defined by the applicant as event F’. The applicant interpreted the six large paleoearthquakes (1886, A, B, C’, E, and F’) to represent Charleston-type events that occurred within the past ~5000 years. Furthermore, the applicant determined that results of the 2-sigma analysis suggest there have been four large earthquakes in the most recent ~2000-year (yr) portion of the earthquake record (1886, A, B, and C’).

The applicant calculated two different average recurrence intervals, which represent two recurrence branches on the logic tree shown in SSAR Figure 2.5.2-11. The first average recurrence interval is based on the four events (1886, A, B, and C’) that the applicant interpreted to have occurred within the past ~2000 years. The applicant concluded that this time period represents a complete portion of the paleoseismic record based on published literature (e.g., Talwani and Schaeffer 2001) and feedback from those researchers questioned (Talwani 2005; Obermeier 2005) by the applicant as part of the expert elicitation. The applicant assigned a weight of 0.8 to the logic tree branch representing the recurrence interval calculated for the 2000-yr record. The second average recurrence interval is based on events that the applicant interpreted to have occurred within the past ~5000 years and includes events 1886, A, B, C’, E, and F’. This time period represents the entire paleoseismic record based on available liquefaction data (Talwani and Schaeffer 2001). Published papers and researchers questioned suggest that the older part of the record (i.e., older than ~2000 years) may be incomplete. The applicant noted, however, that it may also be possible that the older record is complete but exhibits longer inter-event times. For this reason, the applicant assigned a weight of 0.2 to the logic tree branch representing the recurrence interval calculated for the 5000-yr record. The 0.80 and 0.20 weighting of the ~2000-yr and 5000-yr paleoliquefaction records, respectively, reflect the incomplete knowledge of both the short- and long-term recurrence behavior of the Charleston source.

The applicant used the methods of Savage (1991) and Cramer (2001) to calculate the mean recurrence interval for both the ~2000-yr and ~5000-yr records. These methods describe the mean recurrence interval with best estimate mean T_{ave} and an uncertainty described as a lognormal distribution with median $T_{0.5}$ and parametric lognormal shape factor $\sigma_{0.5}$. The average recurrence interval for the ~2000-yr record, based on the three most recent inter-event times (1886–A, A–B, B–C'), has a best estimate mean value of 548 years and an uncertainty distribution described by a median value of 531 years and a lognormal shape factor of 0.25. The average recurrence interval for the ~5000-yr record, based on five inter-event times (1886–A, A–B, B–C', C'–E, E–F'), has a best estimate mean value of 958 years and an uncertainty distribution described by a median value of 841 years and a lognormal shape factor of 0.51.

The applicant modeled earthquakes in the exponential part of the distribution as point sources uniformly distributed within the source area, with a constant depth fixed at 10 kilometers. For the characteristic model, the applicant represented source zone Geometries A, B, B', and C by a series of closely spaced, vertical, northeast-trending faults parallel to the long axis of each source zone.

2.5.2.1.3 Correlation of Earthquake Activity with Seismic Sources

SSAR Section 2.5.2.3 describes the correlation of updated seismicity with the EPRI seismic source model. The applicant compared the distribution of earthquake epicenters from both the original EPRI historical catalog (1627–1984) and the updated seismicity catalog (1985–2005) with the seismic sources characterized by each of the EPRI ESTs. Based on this comparison, the applicant concluded that there are no new earthquakes within the site region that can be associated with a known geologic structure. In addition, there are no clusters of seismicity that would suggest a new seismic source not captured by the EPRI seismic source model. The applicant also concluded that the updated catalog does not show a pattern of seismicity that would require significant revision to the geometry of any of the EPRI seismic sources. The applicant further stated that the updated catalog does not show or suggest an increase in M_{max} or a significant change in seismicity parameters (activity rate, b-value) for any of the EPRI seismic sources.

2.5.2.1.4 Probabilistic Seismic Hazard Analysis and Controlling Earthquakes

SSAR Section 2.5.2.4 presents the results of the applicant's PSHA for the ESP site. PSHA is an acceptable method to estimate the likelihood of earthquake ground motions occurring at a site (RG 1.165 and RG 1.208). The hazard curves generated by the applicant's PSHA represent generic hard rock conditions (characterized by a shear- (S-) wave velocity of 9200 feet per second (ft/s)). In SSAR Section 2.5.2.4, the applicant also described the earthquake potential for the site in terms of the most likely earthquake magnitudes and source-site distances, which are referred to as controlling earthquakes. The applicant determined the low- and high-frequency controlling earthquakes by deaggregating the PSHA at selected probability levels. Before determining the controlling earthquakes, the applicant updated the original 1989 EPRI PSHA (EPRI NP-6395 1989) using the seismic source zone adjustments, described in SER Section 2.5.2.1.2, and the new ground motion models described below.

PSHA Inputs

Before performing the PSHA, the applicant updated the original 1989 EPRI PSHA inputs using the seismic source zone adjustments described in SSAR Section 2.5.2.2. In addition, the applicant used the updated 2004 EPRI (EPRI 1009684) ground motion models instead of the EPRI NP-6395-D (1989) ground motion models, which were used in the original 1989 EPRI PSHA.

Seismic Source Model

To update the original EPRI model, the applicant removed all of the sources identified as a Charleston source from each of the six EPRI EST models. SER Table 2.5.2-1 lists these sources. The applicant then incorporated its four UCSS alternative source geometries, M_{max}, and recurrence distributions into each of the six EST models. In most cases this involved replacing a single Charleston source with four alternative Charleston sources.

The applicant used an exponential magnitude distribution to model smaller earthquakes (**M** less than 6.7) within the UCSS. To calculate the activity rate and b-value for this distribution, the applicant used the same methodology and smoothing assumptions that were used in the 1989 EPRI study. However, the applicant calculated these seismicity parameters using the new geometries of the UCSS along with the updated seismicity catalog (through April 2005). Because old and new source geometries are not coincident, the applicant allowed the portions of "old" EPRI sources that fell outside of the new UCSS source geometries to default to the existing EPRI background sources. This ensured that no areas in the seismic hazard model were aseismic. For the unmodified sources of the 1989 EPRI PSHA, the applicant used the original seismicity rates from the 1988 EPRI (EPRI NP-4726-A 1988) earthquake catalog (through 1984) in its seismic hazard calculations.

To determine whether the seismicity rates used in the 1989 EPRI PSHA (EPRI NP-6395-D 1989) are appropriate for the assessment of the seismic hazard at the ESP site, the applicant assessed seismicity rates for two sources in the site region—(1) a small rectangular source around the Charleston seismicity and (2) a triangular-shaped source representing seismicity in South Carolina and a strip of Georgia that incorporates the ESP site. The applicant selected these sources because they contribute the most to the seismic hazard at the ESP site.

The applicant investigated the seismicity rates in the two sources by running the program EQPARAM (from the EPRI EQHAZARD package) first for the original EPRI catalog and then for the updated EPRI catalog (through April 2005). The applicant used the a- and b-values obtained from EQPARAM to calculate the recurrence rates for different earthquake magnitudes. For the rectangular Charleston source, the applicant concluded that the seismicity rates remain the same when the seismicity from 1985 to April 2005 is added. For the triangular South Carolina source, the applicant concluded that the seismicity rates decrease when the seismicity from 1985 to April 2005 is added.

The applicant concluded that, for the rectangular Charleston source, the updated catalog indicates that the seismicity rates are the same. For the triangular South Carolina source, the updated catalog indicates that seismicity rates decrease when the seismicity from 1985 to

April 2005 is added. The applicant concluded that the seismicity recorded since 1984 does not indicate that seismic activity rates have increased in those sources contributing most to the hazard at the ESP site, under the assumptions of the 1989 EPRI PSHA. Based on the review of geological and seismological data published since the 1986 EPRI Project (EPRI NP-4726), presented in SSAR Section 2.5.2, the applicant concluded that, with the exception of the Charleston seismic source, there are no significant changes to the original EPRI M_{max} values. SSAR Section 2.5.2.2.2 discusses the applicant's modifications to M_{max} for the Charleston seismic source.

Ground Motion Models

The applicant used the ground-motion models developed by the 2004 EPRI-sponsored study (EPRI 1009684 2004) for the updated PSHA. For general area sources, the applicant combined 9 estimates of median ground motion with 4 estimates of aleatory uncertainty, which resulted in 36 combinations. For fault sources in rifted regions (which apply to the ECFS fault segments), the applicant combined 12 estimates of median ground motion with four estimates of aleatory uncertainty, resulting in 48 combinations.

The applicant compared the EPRI NP-6395 (1989) ground motion model with the EPRI 1009684 (2004) ground motion models. The differences between the two models are a function of magnitude, distance, and structural frequency. In general, the median ground-motion amplitudes are similar at high frequencies. At low frequencies, the EPRI 1009684 (2004) models show lower median ground motions because these models incorporate the possibility of a double-corner source model. However, the EPRI 1009684 standard deviations are universally higher than those of EPRI NP-6395.

PSHA Methodology and Calculation

For the PSHA calculation, the applicant used the Risk Engineering, Inc. FRISK88 seismic hazard code. The applicant first performed a PSHA using the original 1989 EPRI primary seismic sources and ground-motion models in order to validate FRISK88 against the EPRI software EQHAZARD. The applicant compared the results from FRISK88 with the original EPRI hard rock results. A comparison of the mean hazard curves for peak ground acceleration (PGA) generally agrees to within 5.1 percent for amplitudes up to 1 g.

Using the updated EPRI seismic source characteristics and new ground-motion models as inputs, the applicant performed PSHA calculations for PGA and spectral acceleration at frequencies of 25, 10, 5, 2.5, 1, and 0.5 hertz (Hz). Following the guidance provided in RG 1.165, the applicant performed PSHA calculations assuming generic hard rock site conditions (i.e., an S-wave velocity of 9200 ft/s). The applicant incorporated the effects of the ESP site geology into its calculation of the SSE spectrum, which uses the hard rock PSHA results as a starting point.

PSHA Results

To determine the low- and high-frequency controlling earthquakes for the ESP site, the applicant followed the procedure outlined in Appendix C to RG 1.165. This procedure involves the deaggregation of the PSHA results at a target probability level to determine the controlling earthquake in terms of a magnitude and source-to-site distance. The applicant chose to perform the deaggregation of the mean 10^{-4}, 10^{-5}, and 10^{-6} PSHA hazard results. SER Figure 2.5.2-3 shows the results of the high-frequency (5 to 10 Hz) 10^{-4} hazard deaggregation, while SER Figure 2.5.2-4 shows the results of the low-frequency (1 to 2.5 Hz) 10^{-4} hazard deaggregation. The staff did not show the applicant's deaggregation plots for the 10^{-5} and 10^{-6} mean hazard levels because of their similarity to the 10^{-4} deaggregation plot shown in SER Figures 2.5.2-3 and 2.5.2-4.

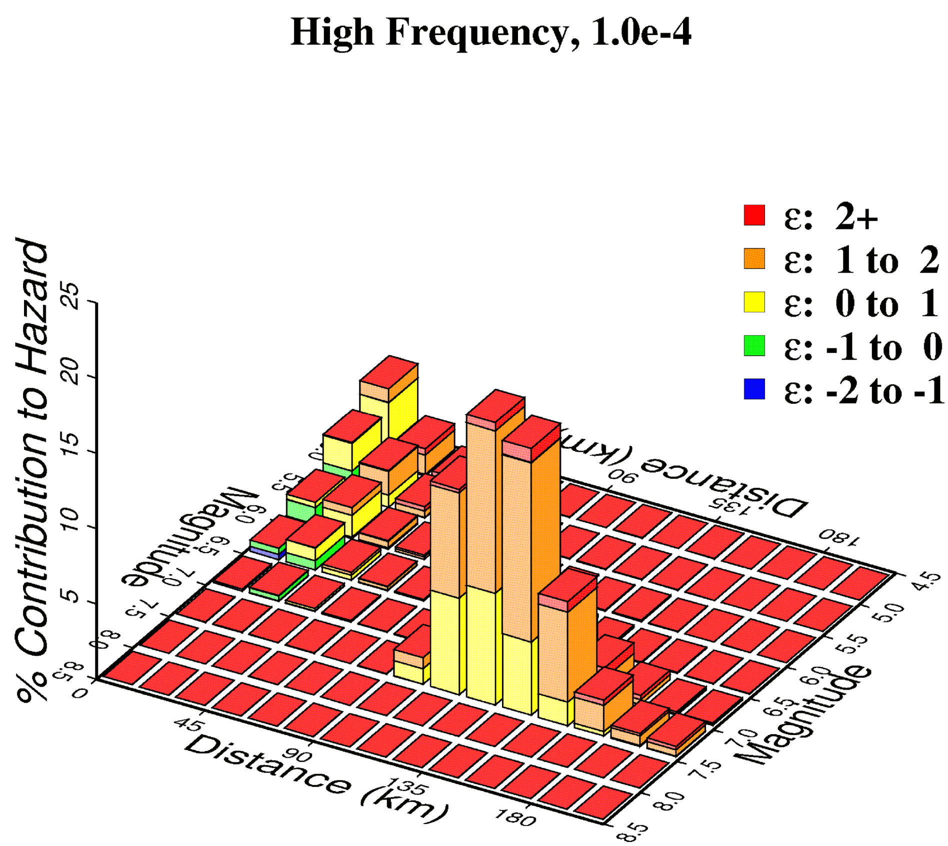

Figure 2.5.2-3 - High-frequency (5 to 10 Hz) 10^{-4} hazard deaggregation (reproduced from SSAR Figure 2.5.2-22)

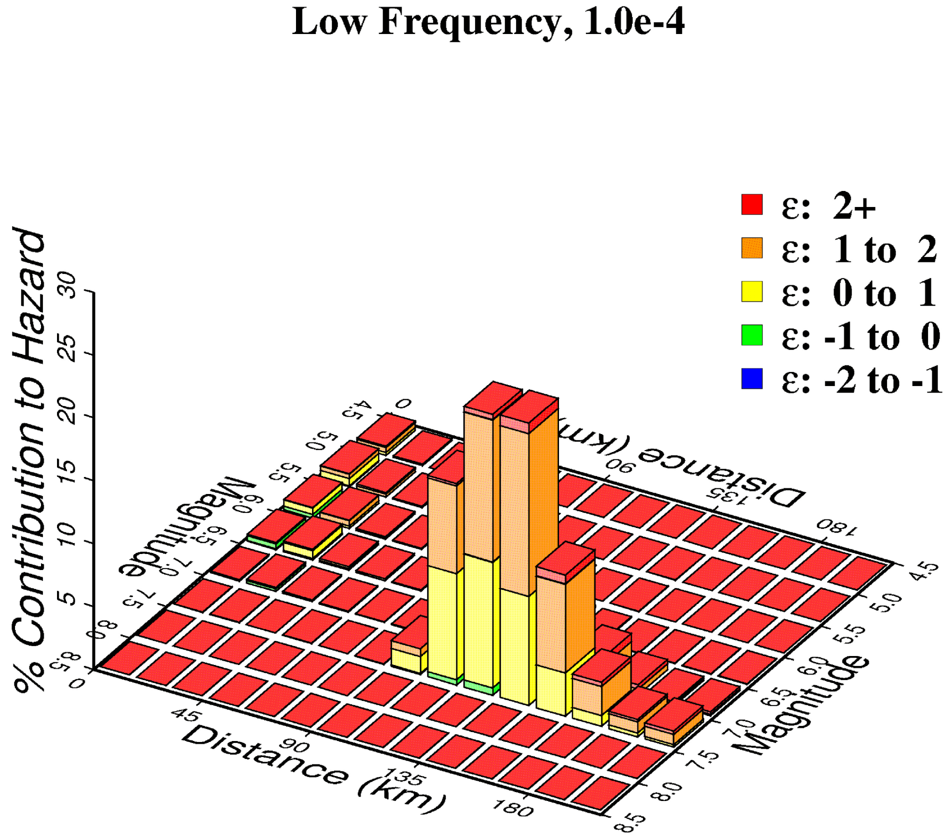

Figure 2.5.2-4 - Low-frequency (1 to 2.5 Hz) 10^{-4} hazard deaggregation (reproduced from SSAR Figure 2.5.2-23)

Because of the similarity of the mean magnitude (Mbar) and mean distance (Dbar) values for the three hazard levels, the applicant selected a single Mbar and Dbar value for each frequency range. SER Table 2.5.2-3 provides the Mbar and Dbar values for the high- and low-frequency controlling earthquakes corresponding to the 10^{-4}, 10^{-5}, and 10^{-6} hazard levels. SER Table 2.5.2-3 also provides the applicant's final Mbar and Dbar values for the high- and low-frequency controlling earthquakes. For the high-frequency mean 10^{-4}, 10^{-5}, and 10^{-6} hazard, the controlling earthquake, based on the final Mbar and Dbar pair, is an **M** 5.6 event occurring at a distance of 12 kilometers (7.5 miles), corresponding to an earthquake from a local seismic source zone. For the low-frequency mean 10^{-4}, 10^{-5}, and 10^{-6} hazard, the controlling earthquake is an M 7.2 event and occurs at a distance of 130 kilometers (80.8 miles). This earthquake corresponds to an event in the Charleston seismic zone.

Table 2.5.2-3 - Computed and Final Mbar and Dbar Values Used for Development of High- and Low-Frequency Target Spectra (Based on the Information Provided in SSAR Table 2.5.2-17)

High Frequency (5 to 10 Hz)				
	39358	39359	39360	Final Values
Mbar (M)	5.6	5.6	5.7	5.6
Dbar	17.6 km (10.9 mi)	11.4 km (7.1 mi)	9.0 km (5.6 mi)	9.0 km (5.6 mi)
Low Frequency (1 to 2.5 Hz)				
	39358	39359	39360	Final Values
Mbar (M)	7.2	7.2	7.2	7.2
Dbar	136.5 km (84.8 mi)	134.3 km (83.5 mi)	133.0 km (82.6)	130 km (80.8 mi)

2.5.2.1.5 Seismic Wave Transmission Characteristics of the Site

SSAR Section 2.5.2.5 describes the method used by the applicant to develop the site free-field soil uniform hazard response spectrum (UHRS). The hazard curves generated by the PSHA are defined for generic hard rock conditions (characterized by an S-wave velocity of 9200 ft/s). According to the applicant, these hard rock conditions exist at a depth of more than 2000 feet below the ground surface at the ESP site. To determine the soil UHRS, the applicant (1) developed soil/rock profile models for the ESP site; (2) selected seed earthquake time histories; and (3) performed the final site response analysis.

<u>**Site Response Model**</u>

The soil profile to a depth of approximately 1049 feet at the ESP site consists of approximately 86 feet of predominantly sands, silty sands, and clayey sands, with occasional clay seams, referred to as the Upper Sand Stratum (Barnwell Group). At the base of this sand unit is a Shelly Limestone (Utley Limestone), which is characterized by solution channels, cracks, and discontinuities. Beneath the Utley limestone is the Blue Bluff Marl (Lisbon Formation), consisting of approximately 64 feet of slightly sandy, cemented calcareous clay. The Blue Bluff Marl is underlain by approximately 900 feet of fine-to-coarse sand with interbedded silty clay and clayey silt, referred to as the Lower Sand Stratum. The Lower Sand Stratum comprises the Still Branch, Congaree, Snapp, Black Mingo, Steel Creek, Gaillard/Black Creek, Pio Nono, and Cape Fear formations.

The rock profile at the ESP site, below approximately 1049 feet, consists of the Dunbarton Triassic (206–24 mya) basin followed by Paleozoic (543–248 mya) crystalline rock. The Dunbarton Triassic basin rock comprises red sandstone, breccia, and mudstone and is characterized by a weathered zone in the upper 120 feet. The Paleozoic crystalline basement is characterized by a high S-wave velocity (greater than 9200 ft/s). The Pen Branch fault forms the boundary between the Dunbarton Triassic basin and the Paleozoic basement rock. As described in SSAR Section 2.5.1, the Pen Branch fault dips to the southeast at an angle of 45° below the ESP site.

The soil/rock profile model used by the applicant for its site response analysis is shown in SSAR Figure 2.5.4-7 and SSAR Table 2.5.4-11. The applicant intends to remove the incompetent Barnwell Group (and the underlying Utley Limestone) because it is susceptible to liquefaction and dissolution-related ground deformation. Furthermore, its S-wave velocity is generally below 1000 ft/s. Therefore, the applicant defined the ESP SSE at the top of the Blue Bluff Marl, which is characterized by an average S-wave velocity of 2354 ft/s. Note that SSAR Figure 2.5.4-7 and SSAR Table 2.5.4-11 do not show the Barnwell Group and Utley Limestone. Instead, the applicant assumes that these have been replaced with 86 feet of structural backfill.

SSAR Figure 2.5.2-7 shows S-wave velocities for each of the different soil and rock layers to a maximum depth of 2275 feet. The applicant based this S-wave velocity profile on the results of suspension primary and secondary (P-S) velocity and seismic cone penetrometer tests (CPTs) performed at the ESP site, as well as deep borehole S-wave velocity data from the SRS (SRS 2005). To represent the variability of the depth to the top of the Paleozoic crystalline basement, where the S-wave velocity is at least 9200 ft/s, the applicant developed six alternative site response profiles. For the six alternative profiles, the depth to the top of the Paleozoic crystalline rock ranged from 1525 feet to 2275 feet. The six alternative site response profiles also accounted for the uncertainty of the S-wave velocity gradient between the top of the unweathered section of the Dunbarton Triassic basin to the top of the Paleozoic crystalline rock. In its site response model, the applicant used the PSHA rock motions at the top of the Paleozoic crystalline rock as input.

The strain-dependent shear modulus and damping relationships used by the applicant for the soil units at the ESP site are based on EPRI TR-102293 (1993). The applicant also used the strain-dependent shear modulus and damping relationships developed for the nearby SRS by Lee (1996). For the Dunbarton Triassic basin and Paleozoic crystalline rocks, the applicant assumed linear behavior during earthquake shaking with 1-percent damping.

Once the applicant determined the appropriate soil and rock dynamic properties, it modeled the variability present in the site data by randomizing the soil and rock S-wave velocity profiles, soil shear modulus reduction and damping relationships, and rock-damping values. For each family of degradation curves (i.e., EPRI or SRS), the applicant generated 60 randomized soil/rock profiles to account for the variability in the site properties. The applicant generated the 60 randomized soil/rock profiles using the stochastic model described in EPRI TR-102293 (1993) and Toro (1996). Inputs to the applicant's stochastic model include the base-case soil and rock profiles provided in SSAR Table 2.5.4-11, as well as the depth to bedrock, which the applicant randomized to account for the range of depths associated with the Pen Branch fault. For each randomized velocity profile, the applicant developed one set of randomized shear modulus reduction and damping curves for the EPRI curves and another set for the SRS curves.

To account for the variability in soil shear strain modulus and material-damping ratio with shearing strain amplitude, the applicant randomized the shear modulus reduction and damping curves used for the site response analysis. For each of the randomized velocity profiles, the applicant developed one set of randomized shear modulus reduction and damping curves for each family of degradation curve (i.e., EPRI or SRS). Inputs to the applicant's model include the base-case shear modulus reduction and damping curves provided in SSAR Tables 2.5.4-12 and 2.5.4-13 and shown in SSAR Figures 2.5.4-9 to 2.5.4-12. The applicant also accounted for the uncertainty in damping ratio for the Dunbarton Triassic basin rock, which is represented by a 5- to 95-percentile range of 0.7 to 1.5 percent.

__Site Response Input Time Histories__

The applicant developed target spectra for two different frequency ranges, high-frequency (5 to 10 Hz) and low-frequency (1 to 2.5 Hz), as defined in RG 1.165. These high- and low-frequency target response spectra represent the Mbar and Dbar values from the deaggregation of the 10^{-4}, 10^{-5}, and 10^{-6} hazard curves. For the high-frequency cases, the applicant considered only those sources less than 105 kilometers to compute the Mbar and Dbar values. To compute the low-frequency Mbar and Dbar values, the applicant only considered sources at distances greater that 105 kilometers. The applicant noted that this distinction was made based on the dominance of the Charleston source for low frequencies and long return periods.

Because of the similarity of the calculated Mbar and Dbar values for the three hazard levels, the applicant selected a single Mbar and Dbar pair to represent the high-frequency controlling earthquake and a single Mbar and Dbar pair to represent the low-frequency controlling earthquake. SER Table 2.5.2-3 provides the final Mbar and Dbar values used for the development of the high- and low-frequency target spectra.

Using the final high- and low-frequency Mbar and Dbar values, described above, the applicant developed target response spectra using the log-average of the single and double corner CEUS spectral shape models of NUREG/CR-6728. The applicant scaled the low-frequency spectral shape to the corresponding UHRS (i.e., 10^{-4}, 10^{-5} or 10^{-6}) at 1.75 and scaled the high-frequency spectral shape to the corresponding UHRS at 7.5 Hz. SER Figure 2.5.2-5 shows the resulting high- and low-frequency target response spectra for the 10^{-4} mean hazard level. The applicant also developed target response spectra for the 10^{-5} and 10^{-6} hazard levels.

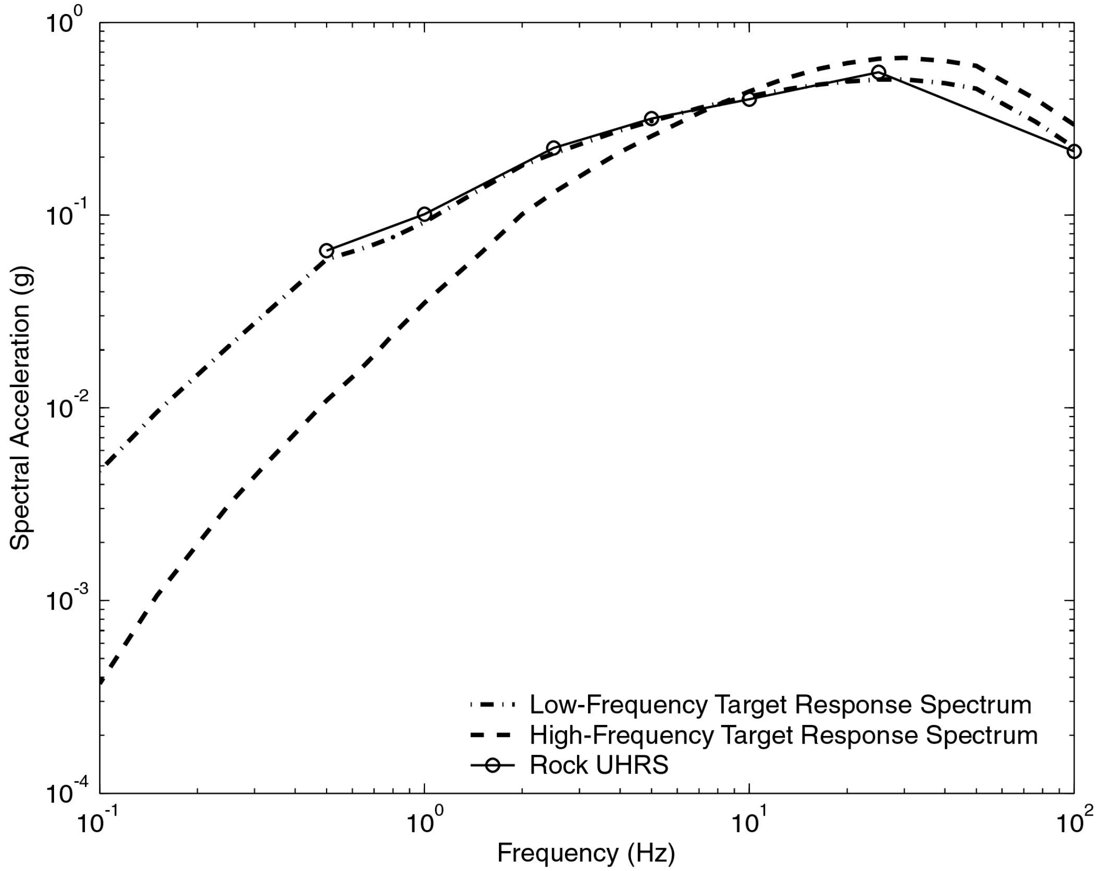

Figure 2.5.2-5 - Low- and high-frequency target response spectra representing the 10^{-4} hazard level. The 10^{-4} rock uniform hazard response spectrum is also shown for comparison (based on the information provided in SSAR Tables 2.5.2-16, 2.5.2-20a, and 2.5.2-20b).

To determine the ESP dynamic site response, the applicant spectrally matched a suite of acceleration time histories to the six target response spectra described above. The applicant selected strong motion acceleration time histories that were recorded at rock-site locations in the Western United States (WUS), Eastern Canada, Turkey, and Japan. Specifically, the applicant selected time histories recorded at sites characterized by S-wave velocities greater than 600 meters per second (m/s) (1968.5 ft/s) in the upper 30 meters (98.4 feet) and similar magnitudes and distances to the final high- and low-frequency Mbar and Dbar values.

The applicant spectrally matched a total of 30 seed time histories to the low-frequency target response spectra corresponding to the 10^{-4}, 10^{-5}, and 10^{-6} mean hazard levels. The applicant spectrally matched a different group of 30 seed time histories to the high-frequency target response spectra representing the 10^{-4}, 10^{-5}, and 10^{-6} mean hazard levels. The applicant used the spectral matching criteria recommended in NUREG/CR-6728 to check the average spectrum from the 30 spectrally matched time histories for a given frequency range and mean hazard level.

<u>Site Response Methodology and Calculation</u>

To determine the final site response, the applicant used the program SHAKE to compute the site amplification functions (AFs) for each of the spectrally matched time histories. As shown in SER Table 2.5.2-4, for each hazard level (10^{-4}, 10^{-5}, and 10^{-6}) and for each deaggregation earthquake (high- and low-frequency), the applicant paired the 60 randomized soil profiles corresponding to the EPRI curves and the 60 randomized soil profiles representing the SRS curves with the 30 spectrally matched time histories. The applicant applied each time history to two of the randomized soil/rock profiles, which resulted in a total of 240 AFs for each of the three mean hazard levels.

Table 2.5.2-4 - Site Response Analyses Performed (Based on the Information Provided in SSAR Table 2.5.2-19)

Mean Hazard Level	10^{-4}		10^{-5}		10^{-6}		Total Number of Analyses
Deaggregation Earthquake	High Freq.	Low Freq.	High Freq.	Low Freq.	High Freq.	Low Freq.	—
Number of Input Time Histories	30	30	30	30	30	30	—
Number of Randomized Soil Profiles (EPRI)	60	60	60	60	60	60	360
Number of Randomized Soil Profiles (SRS)	60	60	60	60	60	60	360
							720

Site Response Results

To obtain the final site AFs, the applicant divided the output response spectrum (defined at the top of the Blue Bluff Marl) by the hard rock input response spectrum for each of the cases shown in SER Table 2.5.2-4. For the 10^{-4} mean hazard level, the applicant computed the mean of the 60 individual AFs corresponding to the high-frequency input time histories and the EPRI-based randomized soil profiles. The applicant repeated this process for the SRS-based randomized soil profiles. The applicant's final high-frequency AF (shown in the upper plot of SER Figure 2.5.4-6) corresponds to the mean of these two results. The applicant developed the final low-frequency AF in a similar manner and this is also shown in SER Figure 2.5.2-6 (lower plot). The ESP site subsurface amplifies the high-frequency input hard rock motion over the fairly wide frequency range of 0.1 to ~25 Hz, with the maximum amplification of 3.8 at a frequency of 0.6 Hz. The low-frequency input hard rock motion is amplified over the frequency range of 0.1 to ~20 Hz, with the maximum amplification of 4.0 at a frequency of 0.6 Hz.

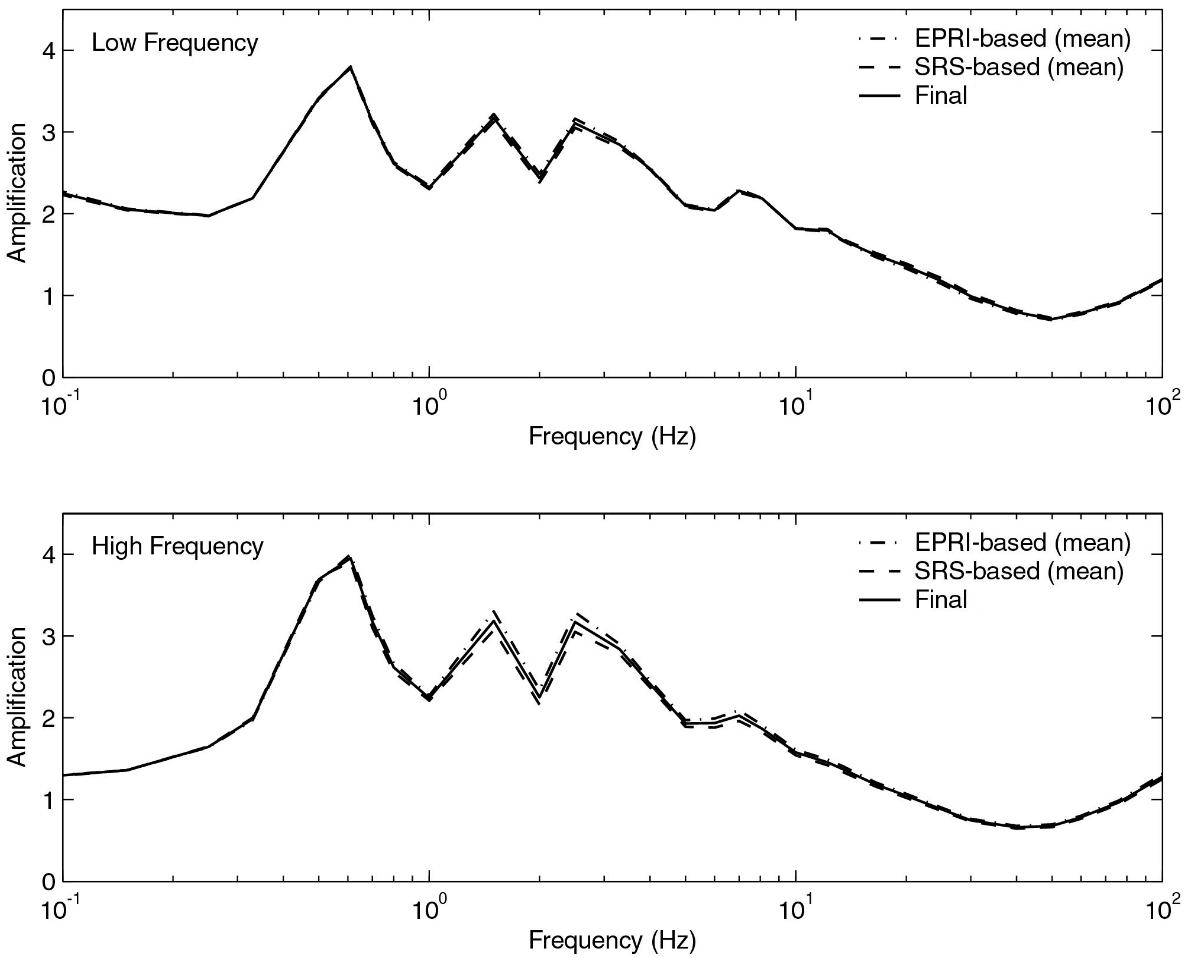

Figure 2.5.2-6 - Final high- and low-frequency AFs for the 10^{-4} hazard level (based on the information provided in SSAR Figures 2.5.2-20a and 2.5.2-20b)

The applicant determined the final 10^{-4} soil surface spectrum for the ESP site by scaling the hard rock UHRS (shown in SER Figure 2.5.2-5) by the final AFs (shown in SER Figure 2.5.2-6). The applicant defined each of the AFs at a total of 300 frequencies, but only defined the hard rock UHRS at 7 structural frequencies. For this reason, the applicant interpolated the hard rock UHRS at values between the 7 structural frequencies using either the high- or low-frequency spectral shapes for hard rock (also shown in SER Figure 2.5.2-5). The applicant's choice of the high- or low-frequency spectral shape for the interpolation depended on the envelope motion. The applicant defined the envelope motion as the envelope of the high- and low-frequency mean output response spectra (defined at the top of the Blue Bluff Marl).

Next, the applicant multiplied the hard rock UHRS (now defined at 300 structural frequencies) by either the high- or low-frequency final amplification factors (shown in SER Figure 2.5.2-6). The applicant multiplied the hard rock UHRS by the low-frequency mean amplification factor if it used low-frequency spectral shape to interpolate the hazard rock UHRS at that structural frequency. If the applicant used the high-frequency spectral shape to interpolate the hard rock UHRS at that frequency, then it multiplied the hard rock UHRS by the high-frequency mean AF.

The applicant repeated the above process for the 10^{-5} hazard level to determine the final 10^{-5} soil UHRS. SER Figure 2.5.2-7 provides the final soil UHRS for the 10^{-4} and 10^{-5} hazard levels.

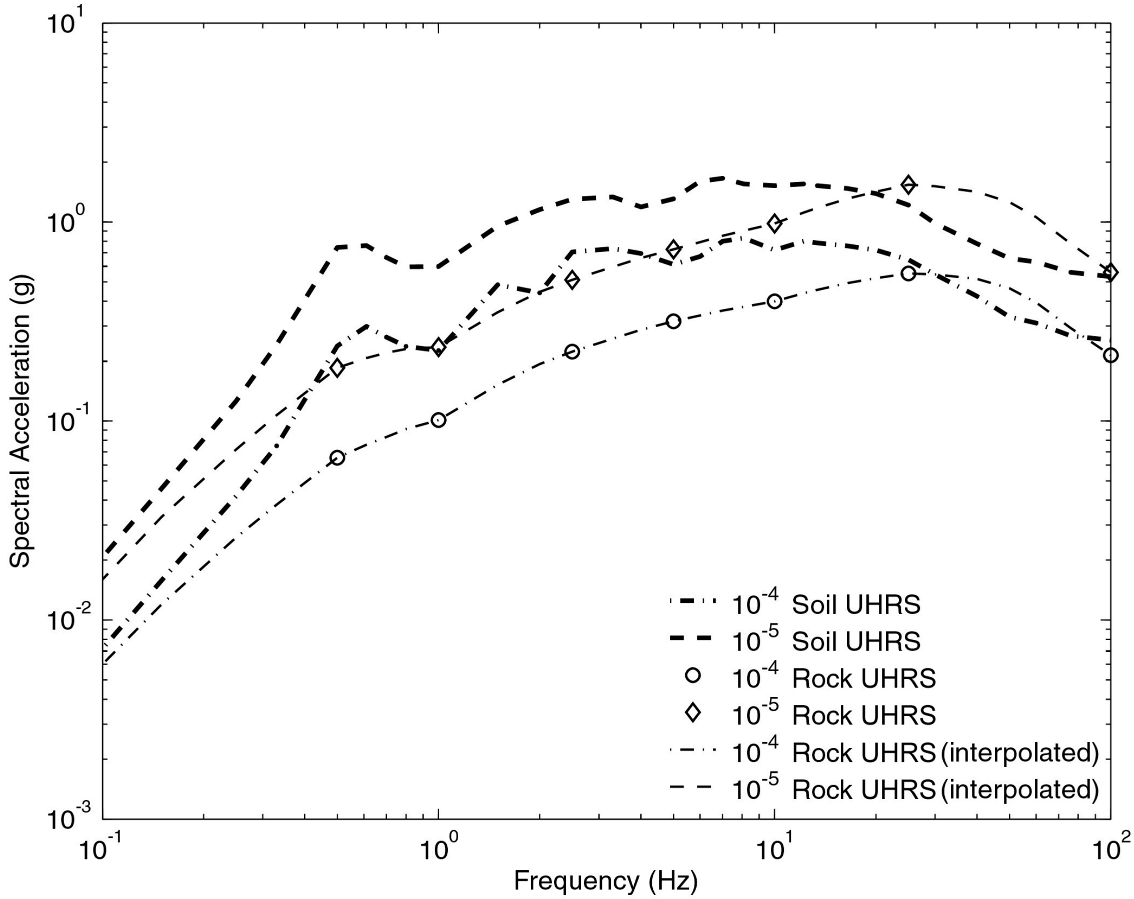

Figure 2.5.2-7 - Horizontal soil-based UHRS for the 10^{-4} and 10^{-5} hazard levels (based on the information provided in SSAR Figures 2.5.2-16 and 2.5.2-21)

2.5.2.1.6 Ground Motion Response Spectra

SSAR Section 2.5.2.6 describes the method used by the applicant to develop the horizontal and vertical site-specific SSE. To obtain the horizontal SSE, the applicant used the performance-based approach described in RG 1.208 and in ASCE/SEI Standard 43-05, "Seismic Design Criteria for Structures, Systems, and Components in Nuclear Facilities and Commentary." The applicant developed the vertical SSE by applying vertical-to-horizontal response spectral (V/H) ratios, based on NUREG/CR-6728 and Lee (2001), to the horizontal SSE.

Horizontal Ground Motion Response Spectrum

The applicant developed a horizontal, site-specific, performance-based SSE using the method described in RG 1.208 and ASCE/SEI Standard 43-05. The performance-based method achieves the annual target performance goal (P_F) of 10^{-5} per year for frequency of onset of significant inelastic deformation. This damage state represents a minimum structural damage state, or essentially elastic behavior, and falls well short of the damage state that would interfere with functionality. The horizontal, site-specific, performance-based ground motion response spectrum (GMRS), which meets the P_F, is obtained by scaling the site-specific mean 10^{-4} UHRS by a design factor (DF):

$$DF = \max\left\{1.0, 0.6\left(A_R\right)^{0.8}\right\} \qquad \text{Equation (1)}$$

where the amplitude ratio, A_R, is given by the ratio of the 10^{-5} UHRS and the 10^{-4} UHRS spectral accelerations for each spectral frequency.

Even though the staff has adopted the use of the GMRS, the applicant refers to this as the SSE. The applicant determined the horizontal performance-based SSE by scaling the 10^{-4} soil UHRS, shown in SER Figure 2.5.2-7, by the DF defined by Equation (1). The applicant's horizontal SSE is shown in SER Figure 2.5.2-8. The applicant smoothed the SSE using a running average filter (above 1 Hz) constrained to go through the seven structural frequencies that define the original rock UHRS (SER Figure 2.5.2-5). The applicant made an exception for the 5-Hz structural frequency because of the trough observed in the 10^{-4} soil UHRS (refer to SER Figure 2.5.2-8) at this frequency. The smoothed 5-Hz SSE value is based on amplitudes at adjacent frequencies. SER Figure 2.5.2-8 also shows the soil UHRS for both the 10^{-4} and 10^{-5} mean hazard levels for comparison.

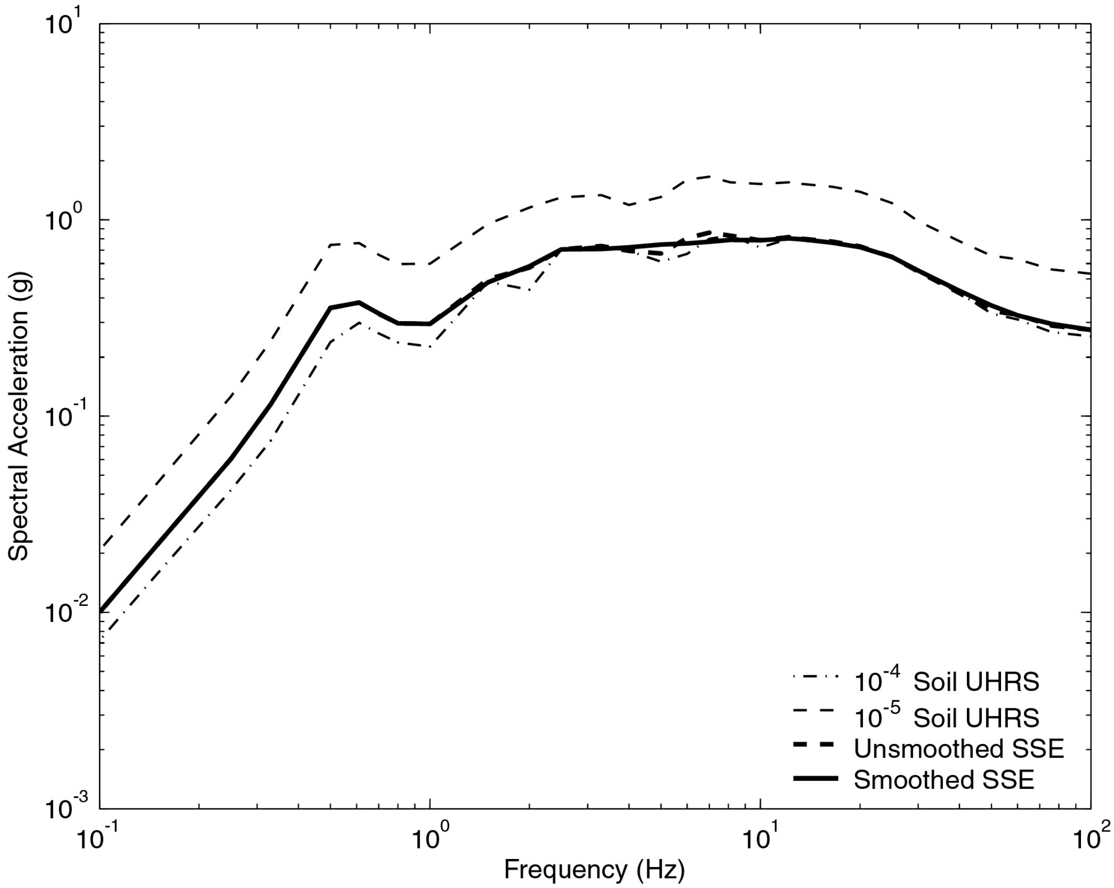

Figure 2.5.2-8 - Horizontal raw and smoothed SSE (based on the information provided in SSAR Table 2.5.2-22)

Vertical GMRS

To determine the vertical SSE, the applicant applied V/H ratios, based on NUREG/CR-6728 and Lee (2001), to the horizontal smoothed SSE shown in SER Figure 2.5.2-8. Since the V/H ratios presented in NUREG/CR-6728 and Lee (2001) are functions of magnitude, source distance, and local site conditions, the applicant developed V/H ratios corresponding to the final low- and high-frequency controlling earthquakes shown in SER Table 2.5.2-3. The low-frequency controlling earthquake corresponds to an M 5.6 event occurring at a distance of 12 kilometers (7.5 miles), while the high-frequency controlling earthquake is represented by an M 5.6 event occurring at a distance of 12 kilometers (7.5 miles).

NUREG/CR-6728 presents V/H ratios for soft rock WUS sites and hard rock CEUS sites. The WUS rock V/H ratios provided in NUREG/CR-6728 are based on an empirical database of WUS strong-motion records. Due to the limited number of available CEUS ground motion recordings, NUREG/CR-6728 uses the WUS ratios and modifies them based on the results of modeling studies to obtain CEUS rock ratios. In addition, Appendix J to NUREG/CR-6728 provides a formula to develop V/H ratios for CEUS soil sites:

$$V/H_{CEUS,Soil} = V/H_{WUS,Soil,Empirical} * \left[V/H_{CEUS,Soil,Model} / V/H_{WUS,Soil,Model} \right] \quad \text{Equation (2)}$$

Because the ESP site is a soil site, the applicant used Equation (2) to determine V/H ratios. The applicant obtained the first term of Equation (2), $V/H_{WUS,Soil,Empirical}$, from the ground motion model of Abrahamson and Silva (1997) which provides horizontal and vertical ground motion relationships for deep soil sites. In NUREG/CR-6728, generic soil columns were used to determine $V/H_{WUS,Soil,Model}$ and $V/H_{CEUS,Soil,Model}$ ratios and provided results for M 6.5 and distances of 1, 5, 10, 20, and 40 kilometers. The applicant obtained the second term of Equation (2) using $V/H_{CEUS,Soil,Model}$ and $V/H_{WUS,Soil,Model}$ ratios corresponding to M 6.5 and 20 kilometers to represent the high-frequency (M 5.6, 12 km) controlling earthquake. In addition, the applicant used the $V/H_{CEUS,Soil,Model}$ and $V/H_{WUS,Soil,Model}$ ratios corresponding to M 6.5 and 40 kilometers to represent the low-frequency (M 7.2, 130 km) controlling earthquake. The applicant considered these magnitude and distance substitutions to be conservative because V/H ratios are observed to decrease with distance for a given magnitude. The applicant assigned a weight of approximately 1:3 to the results representing the high- and low-frequency controlling earthquakes, respectively.

Lee (2001) used the methodology outlined in NUREG/CR-6728 to develop V/H ratios for the MOX Fuel Fabrication Facility at the SRS. However, Lee (2001) developed $V/H_{CEUS,Soil,Model}$ ratios using a site-specific soil model for the SRS, rather than the generic CEUS profile used in Appendix J to NUREG/CR-6728. To obtain V/H ratios corresponding to the high-frequency controlling earthquake (M 5.6, 12 km), the applicant interpolated the results provided in Lee (2001) between M 5.5 at 10 kilometers and 20 kilometers and M 6.0 at 10 kilometers and 20 kilometers. Similarly, to obtain V/H ratios corresponding to the M 7.2, 130-km earthquake, the applicant interpolated the results provided in Lee (2001) between M 7.0 at 100 kilometers and M 7.2 at 100 kilometers. The distance of 100 kilometers was the largest distance considered in Lee (2001). However, the applicant considered the distance substitution of 100 kilometers for 130 kilometers to be conservative because V/H ratios are observed to decrease with distance for a given magnitude. The applicant assigned a weight of approximately 1:3 to the results representing the high- and low-frequency controlling earthquakes, respectively.

SER Figure 2.5.2-9 plots the resulting V/H ratios obtained from NUREG/CR-6728 and Lee (2001), as well as the final V/H ratios. The V/H ratios from Lee (2001) are higher than those derived from the NUREG/CR-6728 results for frequencies greater than about 0.7 Hz. To develop the final V/H ratios, the applicant used an approximate envelope of the two results. The applicant assigned a greater weight to the V/H ratios from Lee (2001) because this study used a site-specific soil model for the nearby SRS. SER Figure 2.5.2-7 also plots V/H ratios from RG 1.60, "Design Response Spectra for Seismic Design of Nuclear Power Plants," Revision 1, issued December 1973. The final V/H ratios are slightly less than those provided in RG 1.60 at all frequencies.

To obtain the vertical SSE, the applicant scaled the horizontal smoothed SSE, shown in SER Figure 2.5.2-8, by the final V/H ratio (shown in SER Figure 2.5.2-9).

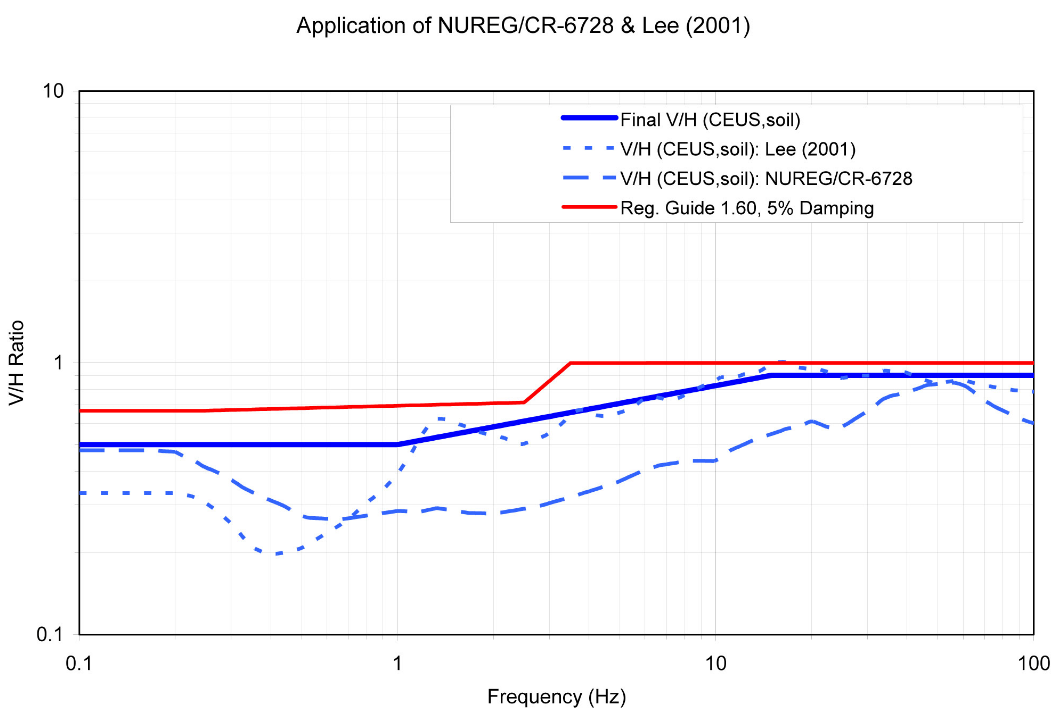

Figure 2.5.2-9 - Final V/H$_{CEUS,Soil}$ ratios (reproduced from SSAR Figure 2.5.2-43)

2.5.2.2 Regulatory Basis

SSAR Section 2.5.2 presents the applicant's determination of ground motion at the ESP site from possible earthquakes that might occur in the site region and beyond. In SSAR Section 1.8, the applicant stated that it had developed the geological and seismological information used to determine the seismic hazard in accordance with regulations listed in SSAR Table 1-2, which includes 10 CFR 50.34; Appendix S, "Earthquake Engineering Criteria for Nuclear Power Plants," to 10 CFR Part 50; and 10 CFR 100.23. The applicant further stated in SSAR Table 1-2 that it developed this information in accordance with the guidance presented in Section 2.5.2 of Revision 3 of NUREG-0800 and RG 1.165. The staff reviewed this portion of the application for conformance with the regulatory requirements and guidance applicable to the determination of the SSE ground motion for the ESP site, as identified below. The staff notes that the application of Appendix S to 10 CFR Part 50 in an ESP review, as referenced in 10 CFR 100.23(d)(1), is limited to defining the minimum SSE for design.

In its application review, the staff considered the regulatory requirements of 10 CFR 52.17(a)(1)(vi) and 10 CFR 100.23(c) and (d), 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 geological, seismological, and engineering characteristics of the proposed site and its environs with sufficient scope and detail to support estimates of the SSE ground motion and to permit adequate engineering solutions to actual or potential geologic and seismic effects at the proposed site. In addition, 10 CFR 100.23(d) states that the SSE ground motion for the site is characterized by both horizontal and vertical free-field ground motion response spectra at the free ground surface. Section 2.5.2 of Revision 3 of NUREG-0800 and RG 1.208 provide guidance concerning the evaluation of the proposed SSE ground motion, and RGs 1.165 and 1.208 provide guidance regarding the use of PSHA to address the uncertainties inherent in the estimation of ground motion at the ESP site.

2.5.2.3 Technical Evaluation

This section of the SER provides the staff's evaluation of the seismological, geological, and geotechnical investigations that the applicant conducted to determine the GMRS for the ESP site. The technical information presented in SSAR Section 2.5.2 resulted from the applicant's surface and subsurface geological, seismological, and geotechnical investigations performed in progressively greater detail as they moved closer to the ESP site. The GMRS is based upon a detailed evaluation of earthquake potential, taking into account regional and local geology, Quaternary (1.8 mya–present) tectonics, seismicity, and specific geotechnical characteristics of the site's subsurface materials.

SSAR Section 2.5.2 characterizes the ground motions at the ESP site from possible earthquakes that might occur in the site region and beyond to determine the site GMRS. According to RG 1.208, applicants may develop the GMRS for a new nuclear power plant using either the EPRI or LLNL PSHAs for the CEUS. However, RG 1.208 recommends that applicants perform geological, seismological, and geophysical investigations and evaluate any relevant research to determine whether revisions to the EPRI or LLNL PSHA databases 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 PSHAs.

2.5.2.3.1 Seismicity

SSAR Section 2.5.2.1 describes the development of a current earthquake catalog for the ESP site. The applicant started with the EPRI historical earthquake catalog (EPRI NP-4726-A 1988), which is complete though 1984. To update the earthquake catalog, the applicant used information from the ANSS and SEUSS.

The staff focused its review of SSAR Section 2.5.2.1 on the adequacy of the applicant's description of the historical record of earthquakes in the site region. In (RAI) 2.5.2-1, the staff asked the applicant to provide electronic versions of the EPRI seismicity catalog (EPRI NP-4726-A 1988) for the region of interest (30° to 37° N, 78° to 86° W), as well as its updated EPRI seismicity catalog. The staff used the catalog data that the applicant provided in response to RAI 2.5.2-1 to compare with its own compilation of recent earthquakes for the site region. The applicant's updated catalog consisted of a total of 61 events. Of these 61 events, there were 56 m_b 3 events and 5 m_b 4 events. In comparison, the staff's list of earthquakes, based entirely on the ANSS earthquake catalog, consisted of 50 m_b 3 events and 3 m_b 4 events.

Because the applicant used the EPRI historical earthquake catalog (EPRI NP-4726-A 1988), which is part of the 1989 EPRI seismic hazard study that the NRC endorsed in RG 1.165, the staff concludes that the seismicity catalog used by the applicant is complete and accurate for the time period 1777–1985. The staff compared the applicant's update of the regional seismicity catalog with its own listing of recent earthquakes and, as a result, concludes that the earthquake catalog used by the applicant is complete and provides a conservative estimate of earthquake magnitudes and locations for the ESP site region.

To determine whether the seismicity rates used in the EPRI study (EPRI NP-6395-D 1989) are appropriate for the assessment of the seismic hazard at the ESP site, the applicant used two areas in the site region—(1) a small rectangular area around the Charleston seismicity and (2) a triangular-shaped area that envelops the seismicity in South Carolina and a strip of Georgia. The applicant concluded that, for the rectangular Charleston source, the updated catalog indicates that the seismicity rates are the same. For the triangular South Carolina source, the updated catalog indicated that seismicity rates decreased when the seismicity from 1985 to April 2005 was added. In RAI 2.5.2-18, the staff asked the applicant to provide a justification for the selection of the geometries used to represent the Charleston source and the South Carolina source. In response to RAI 2.5.2-18, the applicant assessed the seismicity in two additional areas within the site region. The applicant concluded that any region in South Carolina that would affect the seismic hazard at the ESP site would have estimated activity rates that stay constant or decrease, if the new regional earthquake catalog were added to the analysis.

Based on the applicant's evaluation of multiple areas and its determination that seismicity rates in the region have not increased since 1985 for any of these selected areas, the staff concludes that the applicant's use of the EPRI seismicity rates are appropriate and that these rates are appropriate for the assessment of the seismic hazard at the ESP site.

2.5.2.3.2 Geologic and Tectonic Characteristics of the Site and Region

SSAR Section 2.5.2.2 describes the seismic sources and seismicity parameters used by the applicant to calculate the seismic ground motion hazard for the ESP site. Specifically, the applicant described the seismic source interpretations from the 1986 EPRI Project (EPRI NP-4726), relevant post-EPRI seismic source characterization studies, and its updated EPRI seismic source zone for the Charleston area. The staff focused its review of SSAR Section 2.5.2.2 on the applicant's update of the Charleston seismic source zone. The staff also reviewed the applicant's basis for not updating the other EPRI source zones that contribute to the seismic hazard at the ESP site.

Summary of EPRI Seismic Sources

Section 2.5.2.2.1 summarizes the seismic sources and seismicity parameters used in the 1986 EPRI Project and subsequently implemented in the 1989 PSHA (EPRI NP-D 1989). The 1989 EPRI PSHA study expressed M_{max} values in terms of m_b. The applicant noted that most modern seismic hazard analyses describe M_{max} in terms of M and used the arithmetic average of the conversion relations presented in Atkinson and Boore (1995), Frankel et al. (1996), and EPRI TR-102293 (1993) to convert from m_b to M. In RAI 2.5.2-5, the staff asked the applicant to provide its converted M values. In response to RAI 2.5.2-5, the applicant provided a table that listed a range of m_b values and the corresponding converted M values.

To confirm the applicant's magnitude conversions, the staff compared the applicant's converted M values with the M values it obtained using the conversion relations of Frankel et al. (1996) and Johnston (1994), which were provided in Chapman and Talwani (2002). The staff found that the conversion provided in Chapman and Talwani (2002) yields slightly larger M values in the m_b 4.0 to 7.5 range. However, based on the uncertainties associated with magnitude conversions and the applicant's use of the average of three conversion relations, the staff concludes that the applicant's converted M values are adequate.

SSAR Sections 2.5.2.2.1.1 through 2.5.2.2.1.6 provide a summary of the primary seismic sources developed in the 1980s by each of the six EPRI ESTs. Each EST described its set of seismic source zones for the CEUS in terms of source geometry, probability of activity, recurrence, and M_{max}. Each EPRI EST identified one or more seismic source zones that include the ESP site. Although some of the ERPI ESTs assigned M_{max} values as high as M 7.5 for the source zones that make up the Atlantic coastal region, the M_{max} values for the seismic source zones that include the site have a weighted mean of about M. In RAI 2.5.2-6, the staff asked the applicant to explain whether it considered more recent studies on large worldwide earthquakes by Johnston (1994) and Kanter (1994) as possible updates of the earlier EPRI seismic source models.

In response to RAI 2.5.2-6, the applicant stated that the final versions of the Johnston (1994) and Kanter (1994) assessments (included in Volume 1 of the Johnston et al. 1994 study) do not constitute new information that would require an update of the M_{max} values used for the EPRI seismic source models. In its response, the applicant stated that the initial results of the Johnston et al. (1994) study were available to the EPRI ESTs, and the final results of the Johnston et al. (1994) study generally support the initial findings of the study.

The staff reviewed the applicant's response to RAI 2.5.2-6 and concludes that, although many of the EPRI ESTs assigned M_{max} values that reflect the studies of Johnston and Kanter, the applicant did not provide an adequate justification to support the low weights for some of the larger M_{max} values. In particular, the Dames and Moore EST gave fairly low weights to some of its seismic source zones. For example, the two M_{max} values assigned by the Dames and Moore EST for the "Southern Appalachian Mobile Belt" are m_b 5.6 with a weight of 0.8 and 7.2 with a weight of 0.2. These two M_{max} values and weights are similar to those for the other ESTs for the Atlantic coastal margin; however, the Dames and Moore EST also assigned a probability of activity of only 0.26 for this source. Similarly, for its "Southern Cratonic Margin," the Dames and Moore EST assigned a probability of activity of only 0.12. The combined effect of these low probabilities of activity and low weights for the larger magnitudes results in a lower hazard for the ESP site. This result is shown in SER Figures 2.5.2-13 and 2.5.2-14, which are plots of the 1- and 10-Hz PSHA hazard curves for each of the EPRI ESTs. As shown in these two figures, the Dames and Moore seismic hazard curves are substantially lower than those for the other ESTs.

In response to RAI 2.5.2-6, the applicant also stated that the ESP site is located within Kanter's (1994) Piedmont domain 223 in nonextended crust and, as a result, large magnitude earthquakes are not expected in this domain. The staff, however, believes that the ESP site is located within the Mesozoic passive margin. Specifically, the site is on the hanging wall of the southeast-dipping Pen Branch fault (SSAR Figures 2.5.1-2, 2.5.1-29, and 2.5.1-34), which is the main border fault of the Dunbarton Triassic basin (SSAR Figures 2.5.1-2 and 2.5.1-10). In turn, the Dunbarton Triassic basin is a subbasin within the much larger South Georgia basin complex (SSAR Figures 2.5.1-2 and 2.5.1-7). Therefore, the site is in Kanter's Eastern Seaboard domain 218. The rocks beneath the site are Triassic strata of domain 218's rift basins (SSAR Figures 2.5.1-34 and 2.5.1-38). Beneath the Triassic rocks is the Piedmont domain, but the Piedmont rocks have been cut by the Mesozoic extensional faults that bound the rifts. The distinction between the Eastern Seaboard and Piedmont domains depends on the presence or absence of Mesozoic extensional faults, rather than the age of the rocks cut by those faults. Accordingly, the site is subject to the higher M_{max} of the Eastern Seaboard domain of Kanter (1994). The site is in one of the regions that Johnston et al. (1994) found to have hosted all earthquakes of M 7.0 and larger in the world's stable continental regions (SCRs).

SER Figure 2.5.2-10 shows a histogram of magnitudes of the 30 earthquakes that had M 6.5 and larger in the world's extended margin, which is based on the compilation of the largest earthquakes in the world's SCRs by Johnston et al. (1994). The histogram has a large peak at M 6.6 and 6.7. The earthquakes making up the peak come from various SCRs, continents, and plate tectonic settings, indicating that values of 6.6 and 6.7 occur widely in diverse geologic and tectonic settings. This implies that M_{max} is unlikely to be less than these values anywhere in the extended margin of North America. As such, the low weights and low probability of activities assigned by the Dames and Moore EST to larger M_{max} values do not reflect worldwide earthquake activity in extended margins.

In summary, the staff concludes that the applicant did not provide an adequate justification to support the low weights for the larger M_{max} values for the EPRI source zones that include the site. In particular, the staff believes that the low weights and low probability of activities assigned by the Dames and Moore EST to some of its seismic source zones result in hazard curves for the ESP site that do not adequately characterize the regional seismic hazard. In addition, the staff concludes that the site is located within the Mesozoic passive margin, rather than the Piedmont unextended province as stated in the applicant's response. This is **Open Item 2.5-1**.

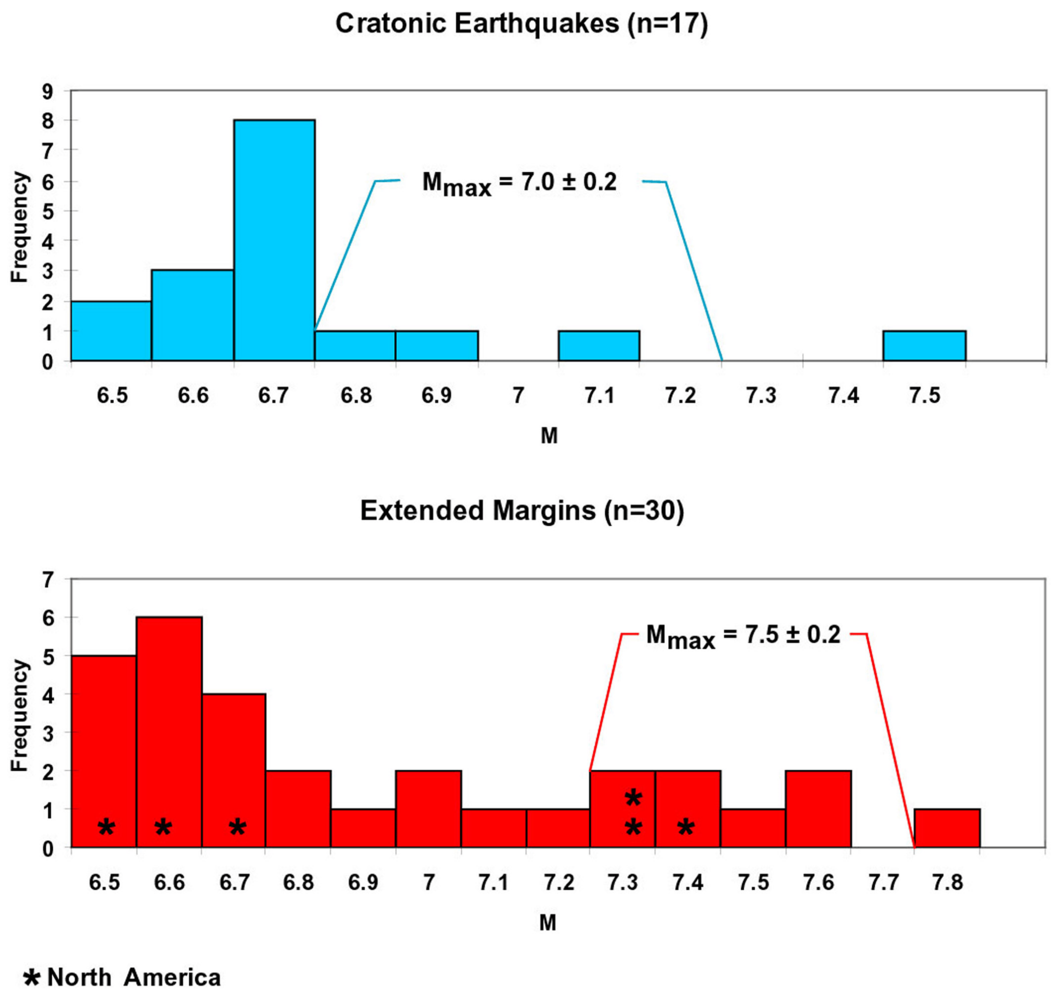

Figure 2.5.2-10 - Histogram showing magnitudes of the 30 earthquakes that had M 6.5 and larger in the world's extended margins (Source: USGS)

Post-EPRI Seismic Source Characterization Studies

SSAR Section 2.5.2.2.2 describes three PSHA studies that were completed after the 1989 EPRI PSHA and which involved the characterization of seismic sources within the ESP site region. These three studies include the USGS National Seismic Hazard Mapping Project (Frankel et al. 1996, 2002), the SCDOT seismic hazard mapping project (Chapman and Talwani 2002), and the NRC TIP study (NUREG/CR-6607, “Guidance for Performing Probabilistic Seismic Hazard Analysis for a Nuclear Plant Site: Example Application to the Southeastern United States”). The applicant provided a description of both the USGS and SCDOT models, as well as the impact of these more recent studies on the EPRI PSHA models. The applicant did not, however, consider the TIP study to be a relevant source of information. The TIP study implemented the PSHA guidelines developed by the SSHAC (NUREG/CR-6372, “Recommendations for Probabilistic Seismic Hazard Analysis: Guidance on Uncertainty and Use of Experts”) and focused on the development of seismic zonation and earthquake recurrence models for the Watts Bar, Tennessee, and Vogtle sites. The applicant stated that it did not explicitly incorporate the results of the TIP study into the SSAR because “the study was more of a test of the methodology rather than a real estimate of the seismic hazard.” Because part of the TIP study focused on the Vogtle site, the staff, in RAI 2.5.2-7, asked the applicant to explain why it concluded that the TIP study was more of a test of the methodology rather than a real estimate of the seismic hazard and why it did not use the TIP study results. In response, the applicant stated the following:

> The TIP study focuses primarily on implementing the Senior Seismic Hazard Advisory Committee (SSHAC) PSHA methodology (SSHAC 1997), however, and was designed to be as much of a test of the methodology as a calculation of seismic hazard. For example, as part of the test of the methodology, Committee members were asked to present opposing arguments, regardless of whether they agreed with the position they were asked to present. As a disclaimer, Kevin Coppersmith prefaced his discussion of the Pen Branch fault with the following statement:
>
> The following white paper—much like a lawyers *(sic)* legal argument—presents a particular position and seeks only to support that position. I have intentionally tried to present an unbalanced case, giving only lip service to counter arguments…Further, I have done a poor job of citing references and providing supporting data to many of my arguments (p. A-51).
>
> The TIP study provides useful discussions, including speculations regarding the Charleston seismic source, seismic hazards of the South Carolina–Georgia region, and Eastern Tennessee. However, the TIP study focuses primarily on methodology. The process-oriented focus of the TIP study is also illustrated in the report presentation, which is very thorough on methodology, but significantly lacking in presenting a summary of seismic source model parameters. For these reasons, the TIP study results are not explicitly incorporated into the VEGP ESP application.

The staff reviewed the applicant’s response to RAI 2.5.2-7, as well as the TIP report, and disagrees with the applicant’s conclusion that the TIP report was more of a test of the methodology rather than a real estimate of the seismic hazard. Furthermore, the staff concludes that the applicant used the disclaimer from Kevin Coppersmith's white paper out of context in order to support its conclusion.

The disclaimer provided in the applicant's response to RAI 2.5.2-7 accompanied a white paper titled, "Include the Pen Branch and Other Local Faults in the PSHA," written by Kevin Coppersmith after the first TIP workshop, which involved a panel of five expert evaluators, the technical facilitator/integrator (TFI) team, and expert proponents and presenters. The workshop comprised a series of technical sessions, which included presentations of recent research and interpretations by the presenters. Each of the technical sessions was followed by a discussion moderated by the TFI team in which key outstanding technical issues were defined. These key issues were then assigned to evaluators as the topics of "white papers" to be written after the workshop. For example, Kevin Coppersmith was assigned to write the white paper in support of "Discrete local fault sources for Vogtle," while Pradeep Talwani was assigned to present a case against "Discrete local fault sources for Vogtle." The TIP report states that "the objective of these papers is to clarify the arguments for and against key interpretations having direct bearing on seismic source characterization in a way that will stimulate interaction among the evaluators." The TIP report also states that "the experts were asked to act as proponents of a certain scientific position and since the issues selected involved dichotomous positions they had to argue for a position that they do not necessarily defend. This has an advantage of forcing the experts, and all the participants, into discovering the positive aspects of scientific concepts other than their own." Thus, Kevin Coppersmith's disclaimer that accompanied his white paper merely reflects his assigned role to provide supporting arguments for a key workshop issue.

The staff concludes that, while the primary objective of the TIP study was to implement the SSHAC PSHA methodology, there is nothing to suggest that the project's final hazard results are not valid. In fact, the seismic hazard results from the TIP triggered a followup NRC-sponsored study, documented in Appendix G to NUREG/CR-6607, which involved a comparison of the TIP hazard results with NUREG-1488, "Revised Livermore Seismic Hazard Estimates for 69 Sites East of the Rocky Mountains." Therefore, although portions of the TIP report may have been focused on implementing the SSHAC methodology, much of the data and results contained in the report are applicable to the ESP site. Thus, the staff does not concur with the applicant's disposition of the TIP study. The staff requests the applicant to provide an evaluation of any information contained in the TIP study that is relevant to the seismic source characterization of the ESP site. This information is necessary in order for the staff to determine whether the applicant provided a thorough characterization of the seismic sources surrounding the site, as required by 10 CFR 100.23. This is **Open Item 2.5-2**.

Northwest of the ESP site, at a distance just beyond 200 miles, is the ETSZ zone. As shown in SER Figure 2.5.2-1, the ETSZ covers a cluster of earthquakes in eastern Tennessee. In SSAR Section 2.5.2.2.2.5, the applicant stated that, despite being one of the most active seismic zones in Eastern North America, the largest recorded earthquake recorded in the ETSZ is a magnitude 4.6, and no evidence for larger prehistoric earthquakes, such as paleoliquefaction features, has been discovered. The applicant also stated that, with the exception of the Law source 17 (Eastern Basement), none of the EPRI EST sources that included the ETSZ contributed more than 1 percent of the total hazard at the ESP site. For this reason, the applicant's hazard calculations did not include the sources that accounted for

ETSZ seismicity, with the exception of Law source 17. The applicant also concluded that no new information regarding the ETSZ has been developed since 1986 that would require a significant revision to the original EPRI seismic source model, specifically with regards to M_{max} for the ETSZ.

In RAI 2.5.2-16, the staff asked the applicant to provide the M_{max} distributions and geographic coordinates defining the geometry of each EST-identified ETSZ. In response to RAI 2.5.2-16, the applicant provided the staff with the requested information and also stated the following:

> None of the EPRI-SOG teams specifically defined a zone identified as "Eastern Tennessee Seismic Zone." Each EPRI-SOG team did define one or more zones that encompass seismicity in eastern Tennessee and, in most cases, the surrounding regions.

The staff concludes that the information provided by the applicant, in response to RAI 2.5.2-16, is complete. SER Table 2.5.2-5 shows the M_{max} distributions for the EPRI EST seismic sources that encompass seismicity in eastern Tennessee, provided by the applicant in its response to RAI 2.5.2-16.

Table 2.5.2-5 - M_{max} Values Corresponding to the EPRI EST Seismic Source Zones That Encompass Seismicity in Eastern Tennessee (Provided by the Applicant In Response to RAI 2.5.2-5)

EPRI EST	Source	Description	Probability of Activity	M_{max} (M) and Weights
Bechtel	24	Bristol Trends	0.25	5.31 [0.10] 5.66 [0.40] 6.06 [0.40] 6.49 [0.10]
	25	NY-AL Lineament	0.3	4.97 [0.10] 5.31 [0.40] 5.66 [0.40] 6.49 [0.10]
	25A	NY-AL Lineament (Alternative)	0.45	4.97 [0.10] 5.31 [0.40] 5.66 [0.40] 6.49 [0.10]
Dames & Moore	4	Appalachian Fold Belt	0.35	5.66 [0.80] 7.51 [0.20]
	0.1666 67	Kinks in Appalachian Fold Belt	0.65	6.82 [0.80] 7.51 [0.20]
Law Engineering	17	Eastern Basement	0.62	5.31 [0.20] 6.82 [0.80]
Rondout	13	Southern NY-AL Lineament	1	4.78 [0.30] 6.06 [0.55] 6.34 [0.15]
	24	Southern Appalachians	0.99	6.49 [0.30] 6.82 [0.60] 7.16 [0.10]
	27	TN-VA Border	0.99	4.78 [0.30] 6.06 [0.55] 6.34 [0.15]
Weston	24	NY-AL Clingman	0.9	4.97 [0.26] 5.66 [0.58] 6.49 [0.16]
Woodward-Clyde	31	Blue Ridge Combo	0.024	5.54 [0.33] 6.06 [0.34] 7.16 [0.33]
	31A	Blue Ridge Combo (Alternative)	0.211	5.54 [0.33] 6.06 [0.34] 7.16 [0.33]

In RAI 2.5.2-17, the staff asked the applicant to justify its rationale for not updating the ETSZ as characterized by the EPRI ESTs and to discuss how the M_{max} distributions developed by each EST compare with more recent M_{max} estimates for the ETSZ included in the USGS hazard model (Frankel et al. 2002) and Bollinger (1992). In addition, the staff asked the applicant to explain whether the contribution to the hazard would change if the EST source zones representing the ETSZ were assigned a single M_{max} of M 7.5, or alternatively, to explain why it believes an M_{max} value of M 7.5 with a weight of 0.5 or higher is not warranted for the ETSZ.

In response, the applicant concluded that the majority of the seismicity that defines the ETSZ is beyond the 200-mi site region. The applicant also noted that its update of the Charleston seismic source model (based on recent paleoliquefaction studies) has increased the relative contribution of the Charleston source to the ESP site and thus served to decrease the relative contribution of more distant sources such as the ETSZ. Furthermore, the applicant stated that there is no historic or prehistoric evidence for large magnitude events occurring in the eastern Tennessee area. In support of the low weights assigned by the EPRI ESTs for this region, the applicant stated the following:

> While the lack of evidence for past large events in ETSZ does not preclude large events from occurring in the future, this fact should influence the weighting of the M_{max} distribution. It is therefore logical that the M_{max} distribution for the ETSZ should have lower weights assigned to the largest magnitudes, in contrast to the Charleston and New Madrid sources, where there is a high confidence that those sources are capable of producing large events since they have occurred in the past.

In response to RAI 2.5.2-17, the applicant concluded that the EPRI EST maximum magnitude distributions for the ETSZ span the range of more recent assessments. The applicant's discussion focused on Bollinger's (1992) source model for the SRS. The applicant stated that Bollinger's (1992) M_{max} of M 6.3, which was given a weight of 95 percent, is close to the mean maximum magnitude of ~M 6.2 of the EPRI study. The applicant also noted that Bollinger (1992) assigned a low weight of 5 percent to an M_{max} of M 7.8, which was calculated based on a low probability that the dimensions of seismogenic structures within the zone may extend along the entire 300-km northeast-trending axis of the zone. The applicant also concluded that the TIP study(NUREG/CR-6607) provided a similarly broad M_{max} magnitude distribution as did the EPRI distribution of M 4.8 to M 7.5 for the ETSZ. The applicant stated that the magnitude distributions for all ETSZ EPRI EST source zone representations ranged from as low as M 4.5 to as high as M 7.5, with the mode of about M 6.5 for almost each distribution (NUREG/CR-6607, pages F-12 to F-19 of Appendix F).

In summary, the applicant concluded the following in its response to RAI 2.5.2-17:

> The ETSZ is characterized by abundant seismicity, but has yet to produce a recorded event greater than M 5, which is about the minimum magnitude used to characterize seismic sources in modern PSHA studies. In our opinion, we believe that there is sufficient uncertainty in the M_{max} potential of the ETSZ that a broad range of magnitudes is appropriate and that the EPRI model sufficiently captures the range of more recent M_{max} distributions for this source. While the ETSZ may be capable of producing a M 7.5, we do not believe that a

weight of 0.5 to 1.0 for this magnitude represents the range of expert opinion reflected in the post-EPRI studies by Bollinger (1992) and Savy et al. (2002). The exception, of course, is the USGS model that assigns a single magnitude of M 7.5.

The staff reviewed the applicant's response to RAI 2.5.2-17 and concludes that the ETSZ EPRI EST M_{max} values do not adequately represent the ETSZ. Even though these EPRI EST sources have M_{max} values as large as M 7.5, the corresponding weights are very low. In addition, the probabilities of activities of many of the ETSZ EPRI EST sources are also low. For example, in SER Table 2.5.2-5, the Dames and Moore Appalachian Fold Belt source has an M_{max} value of M 7.5 and a weight of 0.20, and the probability of activity of this source is only 0.35.

SER Table 2.5.2-6 shows recent M_{max} values for the ETSZ including Frankel et al. (2002), Chapman and Talwani (2002), and Bollinger (1992). A comparison of the two results shows that the EPRI M_{max} values shown in SER Table 2.5.2-5 are significantly lower than more recent studies, as shown in SER Table 2.5.2-6. For example, Chapman and Talwani (2002) assigned a single M_{max} of M 7.0 to the ETSZ. They noted that epicentral locations of the earthquakes define a major northeast-trending seismic zone, over 300 kilometers in length, suggesting the possibility of a major shock, if the zone is viewed as defining a through-going basement fault. Chapman and Talwani (2002) also stated that "focal mechanisms and the spatial locations of seismicity have revealed much information concerning this important issue, but the seismic hazard posed by this seismic zone remains uncertain."

Table 2.5.2-6 - M_{max} Values for the ETSZ for Recent Studies

Study	M_{max} (M) and Weights
Bollinger (1989)	6.2 [1.0]
Johnston and Chiu (1989)	7.2 [1.0]
Bollinger (1992)	5.7 [0.158] 6.1 [0.158] 6.2 [0.317] 6.5 [0.158] 7.2 [0.158] 7.8 [0.050]
Frankel et al. (2002)	7.5 [1.0]
Chapman and Talwani (2002)	7.0 [1.0]

Furthermore, as stated in the applicant's response above, none of the EPRI ESTs specifically defined a zone identified as the "Eastern Tennessee Seismic Zone." Each EPRI EST did define one or more zones that encompass seismicity in eastern Tennessee and, in most cases, the surrounding regions. In more recent studies, the seismicity within the ETSZ is explicitly developed into source geometries to account for the ETSZ (e.g., Frankel et al. 2002; Chapman and Talwani 2002; Bollinger 1992; and NUREG/CR-6607).

To validate the applicant's claim that the ETSZ hazard results are insignificant compared to the Charleston seismic source, the staff did a confirmatory analysis. The staff performed hazard calculations using maximum magnitudes for the ETSZ that ranged from M 6.0 to M 7.8. This magnitude range reflects more recent M_{max} values assigned to the ETSZ, as shown in SER Table 2.2.5-6. SER Figure 2.5.2-11 shows the staff's 1-Hz hazard curves for the ETSZ using this range of M_{max} values. SER Figure 2.5.2-11 also shows the applicant's total mean hazard curve and the Charleston seismic source zone contribution for comparison. The staff's results show that, although the Charleston seismic source zone clearly dominates the 1-Hz hazard, the contribution from the ETSZ for some of the larger M_{max} values (greater than 7.0) may contribute significantly more than 1 percent to the total hazard for the ESP site.

The staff concludes that, despite the uncertainty regarding the potential for large earthquakes within the ETSZ, the results of post-EPRI source characterizations for the ETSZ suggest that the EPRI EST characterization of the ETSZ needs to be updated. The results of the staff's confirmatory analysis do confirm the applicant's assertion that the Charleston seismic source dominates the 1-Hz hazard. However, the staff concludes that the contribution of the ETSZ at the ESP site may be significant enough to warrant inclusion in the applicant's PSHA, if larger M_{max} values are considered. This is **Open Item 2.5-3**.

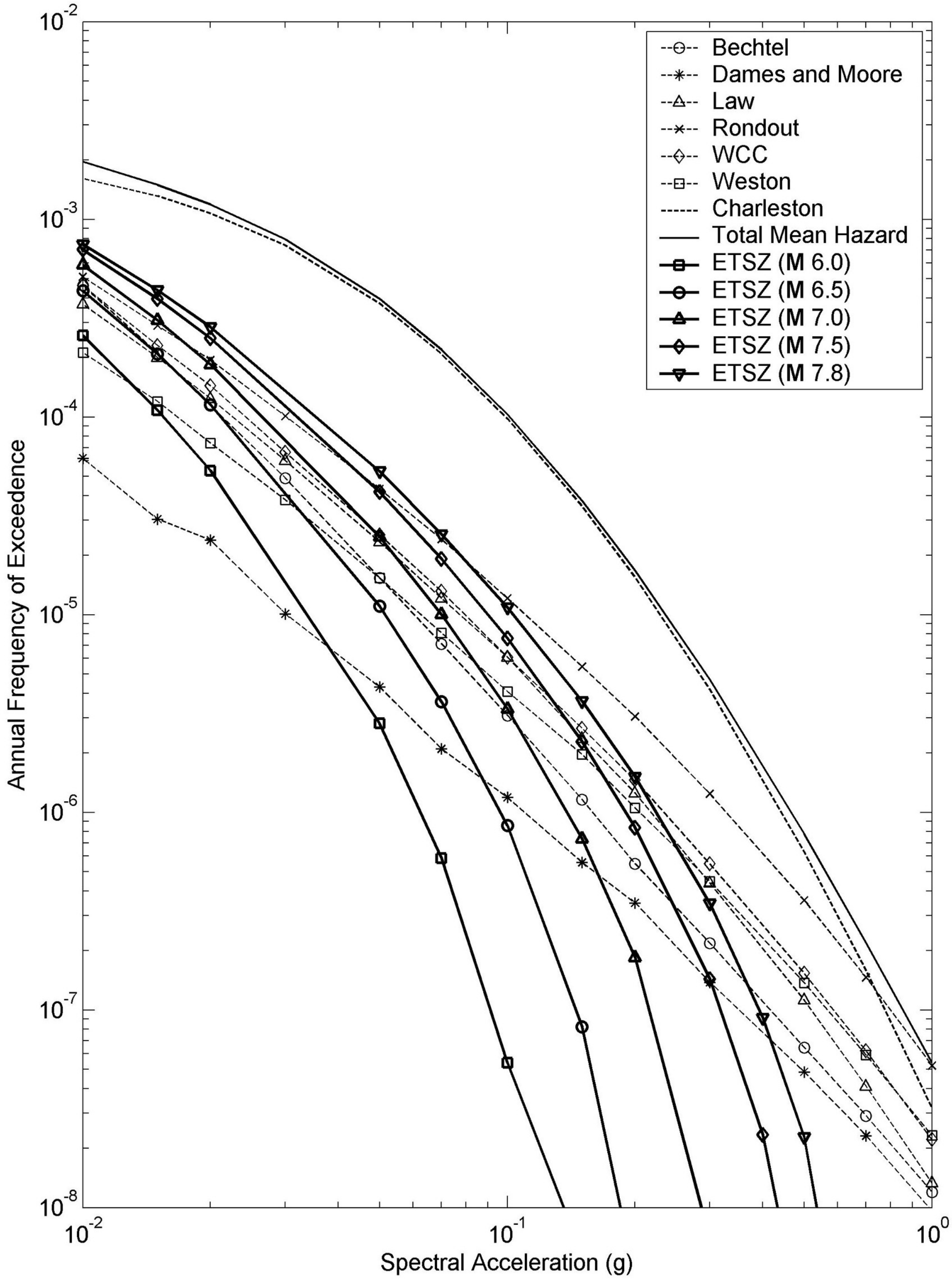

Figure 2.5.2-11 - Comparison of the staff's 1-Hz hazard curves for the ETSZ for magnitudes ranging from M 6.0 to M 7.8

Updated EPRI Seismic Sources

Based on the results of several post-EPRI PSHA studies (Frankel et al. 2002; Chapman and Talwani 2002) and the recent availability of paleoliquefaction data (Talwani and Schaeffer 2001) for the Charleston source zone, the applicant updated the EPRI characterization of the Charleston seismic source zone as part of the ESP application. The applicant referred to its update as the UCSS model. The staff focused its review on the applicant's UCSS geometry, M_{max} values, and recurrence model. The staff also reviewed the methodology that the applicant used to perform this update.

SSHAC Update of the Charleston Seismic Source. In SSAR Section 2.5.2.2.2.4, the applicant noted that the UCSS model is described in detail in a 2006 Bechtel engineering study report. In order to review the applicant's UCSS model, the staff, in RAI 2.5.2-2, requested a copy of the Bechtel (2006) report. In response to RAI 2.5.2-2, the applicant provided the staff with a copy of Bechtel (2006). Based on its review of the Bechtel (2006) report, the staff gained additional insight regarding the applicant's UCSS model.

As described in Bechtel (2006), the applicant performed an SSHAC Level 2 study to incorporate current literature and data, as well as the understanding of experts, into an update of the Charleston seismic source model. An SSHAC Level 2 study uses an individual, team, or company to act as a Technical Integrator (TI), who is responsible for reviewing data and literature and contacting experts who have developed interpretations of or who have specific knowledge about the seismic source. The TI for the update of the Charleston seismic source model consisted of a team of six William Lettis & Associates, Inc. (WLA) personnel (Scott Lindvall, Ross Hartleb, William Lettis, Jeff Unruh, Keith Kelson, and Steve Thompson). The WLA TI team first compiled and reviewed all new information developed since 1986 regarding the 1886 Charleston earthquake and the seismic source that may have produced this earthquake and then compared this new information with the 1986 EPRI EST assessments of the Charleston seismic source. Following the literature review, the TI conducted interviews with experts and researchers familiar with geologic/seismologic data and recent characterizations of the Charleston seismic source. The TI consulted the following seismic and geologic experts:

- Dr. David Amick, Science Applications International Corporation
- Dr. Martin Chapman, Virginia Polytechnic Institute
- Dr. Chris Cramer, U.S. Geological Survey
- Dr. Art Frankel, U.S. Geological Survey
- Dr. Arch Johnston, Center for Earthquake Research and Information, University of Memphis
- Dr. Richard Lee, Los Alamos National Laboratory
- Dr. Joe Litehiser, Bechtel Corporation (original team leader of the 1986 Bechtel EST)

- Dr. Stephen Obermeier, U.S. Geological Survey (retired)
- Dr. Pradeep Talwani, University of South Carolina
- Dr. Robert Weems, U.S. Geological Survey

The TI next integrated this information to develop an updated characterization of the Charleston seismic source that captures the composite representation of the informed technical community.

In RAI 2.5.2-4, the staff asked the applicant to justify its rationale for selecting an SSHAC Level 2 methodology for the UCSS update, as opposed to a higher level update. To support its rationale for using the SSHAC Level 2 methodology, the applicant stated the following:

> SSHAC (1997) describes four levels of study (Levels 1 through 4), in increasing order of sophistication and effort. The choice of the level of a PSHA is driven by two factors: (1) the degree of uncertainty and contention associated with the particular project, and (2) the amount of resources available for the study (SSHAC 1997). SSHAC (1997, Table 3-1) suggests that a Level 2 study is appropriate for issues with "significant uncertainty and diversity," and for issues that are "controversial" and "complex." In a SSHAC Level 2 study, a Technical Integrator (TI) is responsible for reviewing data and literature and contacting experts who have developed interpretations or who have specific knowledge of the seismic source. The TI interacts with experts to identify issues and interpretations, and to assess the range of informed expert opinion. In Level 3 studies, the TI goes a step further by bringing together experts and focusing dialog and interaction between them in order to evaluate relevant issues. In Level 4 studies, a Technical Facilitator/Integrator (TFI) is responsible for aggregating the judgments of a panel of experts to develop a composite distribution of the informed technical community. In a meeting held on July 7, 2005, VEGP ESP Technical Advisory Group (TAG) members Dr. Martin Chapman, Dr. Robert Kennedy, Dr. Carl Stepp, and Dr. Robert Youngs agreed that a Level 2 study is appropriate for updating the Charleston seismic source model.

In RAI 2.5.2-4, the staff also asked the applicant to describe its implementation of the SSHAC Level 2 methodology. Specifically, the staff asked the applicant to describe in more detail how the expert's opinions were integrated into the development of the final UCSS model, how any conflicting opinions between the experts were dealt with, and how the final source model represents the informed consensus of the community beyond those queried for the UCSS update. In response, the applicant stated that, as part of the SSHAC process, the TI contacted 10 experts and researchers familiar with geologic/seismologic data and recent characterizations of the Charleston seismic source. The applicant stated the following:

> These experts were asked a series of questions pertaining to key issues regarding the Charleston seismic source. This was not a formal process of expert interrogation to obtain from each expert all of the specific parameters and weights to be used in the model. Instead, we allowed the experts to speak to their own areas of expertise. It was then the TI's responsibility to combine

> these responses with data from the published literature to capture the range of expert opinion and judgment regarding parameters and weights to be used in the UCSS model.

Regarding the TI integration of the expert's opinion into the development of the final UCSS model, the applicant provided the following information:

> This activity included a two-day workshop held on September 13–14, 2005 to develop the UCSS model at the WLA office in Valencia, California after several weeks of literature and data review. The workshop included the TI team, who integrated Charleston area data and expert interpretations, discussed uncertainties and conflicting expert interpretations, and developed UCSS geometries and the logic tree.

The applicant also stated the following regarding the review of the UCSS model by the TAG panel:

> A Technical Advisory Group (TAG) panel was convened in April 2006 in Frederick, Maryland to critically review the UCSS model and to provide feedback regarding the process and the results of the study. TAG members Chapman, Kennedy, Stepp, and Youngs were in attendance. In addition, Dr. Carl Stepp and Dr. Martin Chapman reviewed written copies of the Engineering Report describing the UCSS and provided written comments on, and approval of, the document.

With regard to how the final source model represents the informed consensus of the community beyond those queried for the UCSS update, the applicant stated, "for the VEGP ESP study, a Senior Seismic Hazard Analysis Committee (SSHAC) Level 2 study was performed to incorporate current literature and data and the understanding of experts into an update of the Charleston seismic source model," and that "the intent of the SSHAC process is to represent the range of current understanding of seismic source parameters by the informed technical community."

Based on its review of SSHAC (1997) and the Bechtel (2006) report provided by the applicant in response to RAI 2.5.2-2, as well as the applicant's response to RAI 2.5.2-4, the staff concludes that the applicant's overall implementation of the SSHAC Level 2 process is adequate. In accordance with an SSHAC Level 2 study, the applicant established a TI, comprising six WLA personnel, to conduct a literature review and contact experts and researchers familiar with geologic/seismologic data and recent characterizations of the Charleston seismic source. As defined in the SSHAC report, a TI is "a single entity (individual, team, or company, etc.) who is responsible for ultimately developing the composite representation of the informed technical community." Also in accordance with SSHAC, the applicant selected a peer review panel to "critically review the UCSS model and to provide feedback regarding the process and results of the study." The applicant referred to its peer review panel as the VEGP ESP TAG. The TAG consisted of Dr. Martin Chapman, Dr. Robert Kennedy, Dr. Carl Stepp, and Dr. Robert Youngs. According to the 1997 SSHAC report, the purpose of the peer review panel is to "assure that the process followed was adequate and to ensure that the results provide a reasonable representation of the diversity of views of the technical community."

The staff also concludes that the applicant's selection of an SSHAC Level 2 study is appropriate for the update of the Charleston seismic source zone. As shown in SER Table 2.5.2-7 (reproduced from Table 3-1 of the 1997 SSHAC report), the SSHAC criteria for deciding on the level of the study is rather subjective. The 1997 SSHAC report suggests that Level 2 studies are appropriate for issues with "significant uncertainty and diversity," and for issues that are "controversial" and "complex," while Level 3 and 4 studies are appropriate for issues that are "highly contentious; significant to hazard; and highly complex." SSHAC (1997) also states that Level 3 and 4 studies "are resource-intensive and are, therefore, most appropriate for large-scale studies for critical facilities." Thus, based on the guidance provided in SSHAC (1997), and because the applicant's study involved the update of a single seismic source zone, the staff agrees with the applicant's decision to use an SSHAC Level 2 study.

Table 2.5.2-7 - Degrees of PSHA Issues and Levels of Study (from SSHAC (1997), Table 3-1, p. 23)

ISSUE DEGREE	DECISION FACTORS	STUDY LEVEL
A Noncontroversial and/or insignificant to hazard	• Regulatory concern • Resources available • Public perception	1 TI evaluates/weights models based on literature review and experience; estimates community distribution
B Significant uncertainty and diversity; controversial; and complex		2 TI interacts with proponents and resource experts to identify issues and interpretations; estimates community distribution
C Highly contentious; significant to hazard; and highly complex		3 TI brings together proponents and resource experts for debate and interaction; TI focuses debate and evaluates alternative interpretations; estimates community distribution
		4 TFI organizes panel of experts to interpret and evaluate; focuses discussions; avoids inappropriate behavior on part of evaluators; draws picture of evaluators' estimate of the community's composite distribution; has ultimate responsibility for project

Although the staff concurs with the applicant's selection and overall implementation of an SSHAC Level 2 method to update the Charleston seismic source model, its review of Bechtel (2006) resulted in several additional questions. For example, the staff was unable to determine the actual questions that each of the experts involved in the SSHAC Level 2 study were asked, the range of expert opinions related to key aspects of the UCSS model (i.e., recurrence, geometry, and maximum magnitude), or the specific process used to combine the expert's opinions and resolve any differing opinions. On June 18, 2007, the applicant supplemented its response to RAI 2.5.2-4 with additional information regarding its SSHAC Level 2 study. Because the staff did not have adequate time to review the information, the staff requires additional time to complete its review. Furthermore, the staff requests that the applicant explain why only two of the four members of the TAG panel reviewed and approved written copies of the engineering report describing the UCSS, as stated in it response to **RAI 2.5.2-4**. The staff requests this information in order to be able to determine whether the applicant has provided an adequate characterization of the seismic sources surrounding the ESP site, as required by 10 CFR 100.23. This is **Open Item 2.5-4**.

<u>Paleoliquefaction features of the Charleston seismic source zone</u>. Abundant soil liquefaction features induced by the 1886 Charleston earthquake, in addition to other large prehistoric earthquakes (dating back to the mid-Holocene), are preserved in geologic deposits at numerous locations within the 1886 meizoseismal area and along the South Carolina coast. SSAR Section 2.5.2.2.2.4.1 states that the characteristics of the 1886 Charleston earthquake, combined with the greatest density of prehistoric liquefaction features, "show that future earthquakes having magnitudes comparable to the Charleston earthquake of 1886 most likely will occur within the area defined by Geometry A. A weight of 0.7 is assigned to Geometry A". Additionally, SSAR Figure 2.5.2-9 indicates no likelihood that an 1886-sized earthquake has occurred inland from the coastal region, except along Geometry C, and then only with a probability of 0.1. In RAI 2.5.2-8, the staff asked the applicant to summarize the age, liquefaction susceptibility, and geographic distribution of liquefiable deposits in the zone that is 50 to 150 kilometers (31 to 93 miles) inland from the coast and explain whether this information supports a negligible probability of large inland earthquakes. In addition, in RAI 2.5.2-8, the staff requested that the applicant reconcile the negligible probability of large inland earthquakes, as indicated in SSAR Figure 2.5.2-9, with the discovery of prehistoric liquefaction features as much as 100 kilometers (62 miles) inland in fluvial deposits of the Edisto River (Obermeier 1996). In response to RAI 2.5.2-8, the applicant stated the following:

> Liquefaction susceptibility is a function of numerous variables including, but not limited to, sediment grain size and sorting, degree of compaction and/or cementation, deposit thickness, depth below ground surface, degree of saturation, and sediment age. Obermeier (1996) suggested that South Carolina Coastal Plain deposits older than about 250 ka have negligible potential for liquefaction due to the effects of chemical weathering. Obermeier (1996) observed that, in general, the region within 30 mi (~50 km) of the coast is highly susceptible to liquefaction. The liquefiable deposits of the about 100 ka Princess Anne Formation, however, are mapped greater than 65 mi inland (McCartan et al. 1984).

> Numerous liquefaction features caused by the 1886 Charleston earthquake and paleoliquefaction features from prehistoric Events A, B, C', E and F' are distributed along a 115 mi stretch of coastal South Carolina from Bluffton in the south to Georgetown in the north. The inland extent of 1886 liquefaction is less well-constrained.
>
> There is no structural, geomorphic, paleoseismic (other than the cited sparse liquefaction data), or historic (i.e., 1886) evidence to suggest a source zone geometry that trends northwest-southeast or extends significantly inland from the 1886 meizoseismal area. The sparse liquefaction features along the Edisto River cited by Seeber and Armbruster (1981), Amick et al. (1990), and Obermeier (1996) likely reflect strong ground shaking in deposits susceptible to liquefaction, and not a localized, inland source.

Although the applicant's response adequately summarized the age, liquefaction susceptibility, and geographic distribution of liquefiable deposits in the zone 50–150 kilometers (31–93 miles) inland from the South Carolina coast, the staff does not believe that the applicant provided substantial evidence to rule out the occurrence of large inland earthquakes, especially given the presence of liquefiable deposits up to 100 kilometers (62 miles) inland from the coast. The occurrence of a large earthquake inland from the coast would necessitate a different Charleston source zone model. This is **Open Item 2.5-5**.

With regard to the size and quantity of earthquakes that produced the Charleston area liquefaction features, SSAR Section 2.5.2.2.2.4.3 suggests that the liquefaction features attributed by researchers to a single large, prehistoric earthquake might actually have been produced by several moderate magnitude earthquakes that are closely spaced in time (SSAR, page 2.5.2-26). In RAI 2.5.2-9, the staff asked the applicant to determine whether Talwani or Obermeier, two recognized experts, have data on the sizes of prehistoric liquefaction craters and whether these or any related data might constrain the possible magnitudes of the prehistoric earthquakes.

In response to RAI 2.5.2-9, the applicant explained that it is possible to compare the 1886 earthquake liquefaction features with liquefaction features attributed to pre-1886 events. The applicant further explained that some pre-1886 features suggest an earthquake magnitude similar to the 1886 Charleston earthquake. The applicant provided the following evidence:

> Obermeier (1996) noted "almost all craters that predate 1886 have a morphology and size comparable to the 1886 craters" (p.345). Moreover, the sizes of individual craters formed during the 600 and 1,250 years BP events are at least as large as those formed during the 1886 earthquake, both in the vicinity of Charleston and farther away (Obermeier 1996). These observations suggest that some prehistoric earthquakes have been at least as large as the 1886 earthquake.

The applicant cited a number of references including Talwani and Schaeffer (2001), Hu et al. (2002a, 2002b), Leon (2003), and Leon et al. (2005), each of which attempted in some degree to estimate earthquake magnitudes associated with liquefaction features over the extended, as well as more limited, areas in the Charleston vicinity. The magnitude estimates based on these studies, vary widely from M 7+ (Talwani and Schaeffer 2001) to M 6.8–7.8 (Hu et al. 2002b) to M 6.9–7.1 and M 5.6–7.2 (Leon et al. 2005) for earthquakes associated with widespread liquefaction features. Magnitude estimates for earthquakes producing liquefaction features over more limited areas vary similarly from M 6+ (Talwani and Schaeffer 2001) to M 5.5–7.0 (Hu et al. 2002b) to M 5.7–6.3 and M 4.3–6.4.

The applicant concluded that, even with the large uncertainties attached to estimating magnitudes from paleoliquefaction data, and in return reflecting broad magnitude estimates for prehistoric earthquake events, the studies cited suggest that at least some of the prehistoric earthquakes have been similar in magnitude to the 1886 Charleston earthquake. Specifically, the applicant's response indicates that pre-1886 liquefaction craters "have a morphology and size comparable to the 1886 craters." This statement indicates that 1886 and pre-1886 liquefaction craters have similar maximum sizes, with ground conditions and hypocentral depths being similar, which implies similar historic and prehistoric earthquake magnitudes.

While the applicant's reasoning does not rule out the occurrence of numerous smaller earthquakes, the staff believes that the applicant made an accurate assumption that earthquake magnitudes for pre-1886 earthquakes in the Charleston area are similar to the magnitude range attributed to the 1886 event based on the documentation of large liquefaction craters induced by both 1886 and pre-1886 earthquakes. As such, the staff concludes that the applicant conservatively assumed that the pre-1886 earthquakes were similar in magnitude to the 1886 event.

In RAI 2.5.2-10, the staff asked the applicant to summarize, for each of the pre-1886 events, the number of liquefaction features and sites that have been documented, the areal extent of liquefaction (i.e., the number of square kilometers affected), the number of dates that have been collected, and how well the features correlate from one site to the next.

In response to RAI 2.5.2-10, the applicant summarized the methods used in the application to constrain the timing of liquefaction-inducing earthquakes and referenced SSAR Table 2.5.2-13 to provide an age comparison of Charleston liquefaction events (Talwani and Schaeffer 2001). The applicant provided the following background information:

> Talwani and Schaeffer (2001) used calibrated radiocarbon ages with 1-sigma error bands in order to define the timing of past liquefaction episodes in coastal South Carolina. The standard in paleoseismology, however, is to use calibrated ages with 2-sigma (95.4% confidence interval) error bands (e.g., Sieh et al. 1989; Grant and Sieh 1994). Likewise, in paleoliquefaction studies, in order to more accurately reflect the uncertainties in radiocarbon dating, the use of radiocarbon dates with 2-sigma error bands (as opposed to narrower 1-sigma error bands) is advisable (Tuttle 2001).

Because Talwani and Schaeffer used calibrated ages with 1-sigma error bands, the applicant recalibrated Talwani and Schaeffer's (2001) radiocarbon data using 2-sigma error bands and presented the new data in the application. The applicant stated that the use of 1-sigma error bands by Talwani and Schaeffer (2001) possibly led to an overinterpretation of the paleoliquefaction record such that they may have interpreted more episodes than what actually occurred. The applicant used the 2-sigma recalibrated data to obtain broader age ranges for pre-1886 earthquake-induced liquefaction events. The applicant provided the following additional information:

> Paleoearthquakes were distinguished based on grouping paleoliquefaction features that have contemporary radiocarbon samples with overlapping calibrated ages. The event ages were then defined by selecting the age range common to each of the samples. For example, an event defined by overlapping 2-sigma sample ages of 100 to 200 cal yr BP and 50 to 150 cal yr BP would have an event age of 100 to 150 cal yr BP. We consider the "trimmed" ages to represent the ~ 95% confidence interval, with a "best estimate" event age as the midpoint between the ~ 95% age range.
>
> The 2-sigma analysis identified six earthquakes (including 1886) in the data presented by Talwani and Schaeffer (2001). As noted by that study, events C and D are indistinguishable at the 95% confidence interval, and together they compose Event C'. Additionally, our 2-sigma analysis suggests that Talwani and Schaeffer's (2001) events F and G may have been a single, large event, which we name Event F'.

The applicant provided a summary of the approximate number of documented liquefaction features, the areal extent of those features, and the number of radiocarbon dates collected for each of the prehistoric earthquake events (A, B, C', E, F') as well as for the 1886 event. SER Figure 2.5.1-11, in response to RAI 2.5.1-10, provides a means of visually correlating liquefaction features from one site location to the next and from one event to another.

Based on its review of the applicant's response to RAI 2.5.1-10, the staff concludes that the applicant adequately summarized the documented liquefaction features associated with 1886 and pre-1886 earthquake events. The data provided by the applicant is useful in evaluating the uncertainty associated with each of the prehistoric earthquake events and in correlating similarities between events in order to better estimate possible magnitudes and source location.

SSAR Section 2.5.2.2.2.4.3 states that paleoliquefaction Event C is defined by features north of Charleston, while Event D is defined by sites south of Charleston. Events C and D are combined into a single large event, C'. In RAI 2.5.2-11, the staff requested the applicant to provide any information on liquefaction features, geographically located between these two areas, that have similar radiocarbon ages which supports the characterization of these events as a single large event rather than two separate events. The staff also asked the applicant to provide justification that there is enough paleoliquefaction data to support a single large event C' from a single source.

In response to RAI 2.5.2-11, the applicant stated that using 2-sigma calibration for evaluating radiocarbon dates associated with Talwani and Schaeffer (2001) events C and D, based on timing alone, provides evidence that these events are indistinguishable at the 95 percent confidence interval. The applicant combined the two events into a single event, C'. Talwani and Schaeffer (2001) themselves interpreted an alternate scenario for these two events, also based on 2-sigma calibration of the data, and referred to a possible single event, C'.

The applicant provided a visual depiction of this information (SER Figure 2.5.2-11) to allow a comparison of liquefaction features associated with Talwani and Schaeffer (2001) events C and D to determine any overlap that could provide further evidence that these two events should be combined into a single event, C'. The applicant stated that liquefaction features associated with events C and D are localized and do not show any spatial overlap and "therefore do not provide definitive geographic evidence for combining these events into a single, large event C'." However, the applicant chose to include a single, large event C' (as opposed to two smaller events C and D) into the updated Charleston seismic source model based on the following three reasons:

1. The two-sigma reanalysis of Talwani and Schaeffer's (2001) age data performed for the VEGP ESP application indicates that the age data constraining the timing of Events C and D overlap one another and therefore the two events are indistinguishable. This observation is consistent with the interpretation of a single, large Event C'.

2. The incorporation of a single, large Event C' into the updated Charleston seismic source model is, in effect, a conservative approach. In developing a recurrence interval for large, characteristic earthquakes in the updated Charleston seismic source model, it was desirable to include the possibility that Events C and D represent a single, large earthquake. Talwani and Schaeffer's (2001) moderate-magnitude (~M 6) earthquakes C and D would be eliminated from the record of large (M_{max}) earthquakes in the updated Charleston seismic source model, thereby increasing the calculated M_{max} recurrence interval and lowering the hazard without sufficient justification.

3. The distribution of paleoliquefaction sites for Event C' is very similar to the coastal extent of liquefaction features from the 1886 earthquake. Moreover, the distribution and number of paleoliquefaction sites for Event C' are very similar to those for Events A and B, the two best documented prehistoric events (see figure following RAI 2.5.1-11 response).

Based on its review of the applicant's response to RAI 2.5.2-11, the staff acknowledges that recalibration of radiocarbon ages shows that the ages of events C and D are indistinguishable at a 95.4% confidence interval and that the applicant's decision to combine the two events into a single larger event, C', is justified. Geographic distribution of liquefaction features associated with a single large event C' is comparable to distribution of features associated with the 1886 Charleston earthquake and prehistoric earthquake events A, B, E and F'. The effect is to decrease the average recurrence interval of 1886-sized earthquakes from what the interval would be if events C and D were two moderate earthquakes. Thus combining C and D is conservative with respect to seismic hazard.

<u>Charleston Seismic Source Zone Geometries</u>. For its update of the Charleston seismic source zone, the applicant developed new source zone boundaries. Specifically, as described in SSAR Section 2.5.2.2.4, the applicant developed four, mutually exclusive source zone geometries, referred to as A, B, B', and C, to represent the Charleston seismic source. These four source zones are shown in SER Figure 2.5.2-2 (reproduced from SSAR Figure 2.5.2-9). SSAR Section 2.5.2.2.2.4.1 states that the width of Geometry B is 80 kilometers (50 miles). However, SSAR Figure 2.5.2-9 (and SER Figure 2.5.2-2) show that

the width of Geometry B is 100 kilometers (62 miles). In RAI 2.5.2-14, the staff asked the applicant to provide the actual dimensions of Geometry B used for the UCSS. In response, the applicant stated that the width of UCSS Geometry B is 100 kilometers and not 80 kilometers, as stated in SSAR Section 2.5.2.2.2.4.1. Based on the applicant's clarification of the width of source zone B, the staff concludes that the source referred to as Geometry B in SSAR Figure 2.5.2-9 is accurate.

SSAR Section 2.5.2.4.4 states that "the new interpretation of the Charleston source indicates that a source of the large earthquakes in the Charleston area exists with weight 1.0…." Although the UCSS update of the Charleston source zone covers a fairly large area, the weighting and source geometries give the largest hazard only inside Zone A (either 0.9 (A, B, B') or 1.0 (A, B, B', C)), which is a relatively small zone. In view of this result, the staff asked the applicant, in RAI 2.5.2-13, to provide justification for the UCSS source geometries and weighting scheme and define what is meant by the "Charleston area." In its response, the applicant concluded that the Charleston source area is "stationary in space and is confined to a relatively restricted area," which it referred to as Geometry A. The applicant provided the following information to support its conclusion that the source area that produced 1886 Charleston-type large magnitude earthquakes is likely relatively restricted in area:

> The updated Charleston seismic source model includes four potential geometries (A, B, B', and C) to represent the source area for the Charleston seismic source zone. The greatest weight is given to a localized zone (Geometry A) that completely incorporates the 1886 earthquake Modified Mercalli Intensity (MMI) X isoseismal (Bollinger 1977), the majority of identified Charleston meizoseismal-area tectonic features and inferred fault intersections, and the majority of reported 1886 liquefaction features. Outlying liquefaction features are excluded because liquefaction occurs as a result of strong ground shaking that may extend well beyond the areal extent of the tectonic source. Data describing the size and spatial distribution of paleoliquefaction features suggest prehistoric earthquakes (Events A, B, C', E, and F') were of similar magnitude and location to the 1886 Charleston earthquake, which produced liquefaction at significant distances northeast and southwest from the meizoseismal area. Lower weights are given for source geometries that envelop specific postulated tectonic features (i.e., Geometry C for the southern segment of the East Coast fault system), or for broader areal distributions that also envelop the localized zone to allow for greater uncertainty in the location and lateral extent of a fault that may have produced the 1886 Charleston earthquake.

The applicant provided the following revision for the term "Charleston area" as used in the third sentence of the first paragraph of SSAR Section 2.5.2.4.4:

> The new interpretation of the Charleston source (see Section 2.5.2.2.2) indicates that a unique source of large earthquakes exists with weight 1.0 and that large magnitude events occur with a rate of occurrence unrelated to the rate of smaller magnitudes.

The applicant's response states that the SSHAC Level 2 TI concluded that the Charleston source area is stationary in space and is confined to a relatively restricted area. Geometry A represents the preferred small source area and it is given a high weight of 0.7 (SSAR 2.5.2.2.2.4.1). Geometry A is based on (1) the 1886 meizoseismal area and greatest density of liquefaction features; (2) the concentration of known and hypothesized tectonic features, mainly faults; (3) the concentration of historical seismicity, chiefly in the Middleton Place-Summerville seismic zone; and (4) the greatest density of prehistoric liquefaction features.

The staff focused its review on the density of prehistoric liquefaction features in relation to Geometry A because the use of a small source area to represent the sources of the 1886 and all previous large earthquakes depends crucially on a demonstration that the largest liquefaction craters of all ages concentrate near Charleston. The staff also reviewed the information presented in Bechtel (2006). Bechtel (2006) briefly references recent studies regarding the geographic distribution, density, and size of liquefaction features produced by the 1886 and prehistoric earthquakes in the Charleston region, specifically Obermeier et al. (1989, 1990, 2001) and Amick et al. (1990).

The staff also reviewed the study of Obermeier et al. (1989). Obermeier et al. (1989) conclude that, "Both the size and relative abundance of pre-1886 craters are greater in the vicinity of Charleston (particularly in the 1886 meizoseismal zone) than elsewhere, even though the susceptibility to earthquake-induced liquefaction is approximately the same at many places throughout this coastal region." Figure 4 of Obermeier et al. (1989), reproduced as SER Figure 2.5.2-12, depicts the sizes of various prehistoric liquefaction features and demonstrates that the largest craters of all ages concentrate near Charleston. The staff notes that the figure cannot exclude the possibility that one (or more) of the large prehistoric earthquakes created its (or their) largest liquefaction features elsewhere. However, Obermeier's (1989) figure shows four size classes of craters, with the largest prehistoric craters (wider than 3 meters) present only in the 1886 meizoseismal area. Only smaller craters are known farther south and north. Obermeier (1989) favors attributing some of these distant, small-to-medium-sized craters to infrequent moderate earthquakes at two separate sources far north and south of Charleston. The epicentral regions of 1886-sized earthquakes should have abundant craters wider than 3 meters, and they have been found only near Charleston. Sparse exposures preclude saying much about crater sizes between Beaufort and the Edisto River, south of Charleston (Obermeier et al. 1989) and south of Geometry A. Thus, it is unlikely, but possible, that the paleoliquefaction record of a large earthquake's meizoseismal region could be concealed south of Geometry A. However, this small probability is accounted for by Geometries B and B', which span most of the length of South Carolina's coast. The absence of known abundant paleoliquefaction features in North Carolina and Georgia, despite searches there (Amick and Gelinas 1991), suggests that Geometries B and B' need not extend beyond South Carolina.

The staff concludes that the applicant's use of a small area to represent the sources of the 1886 and all previous large earthquakes is adequate. Available evidence suggests it is likely that 1886-sized earthquakes occurred mostly or entirely within a small area like Geometry A. However, in RAI 2.5.2-8, the staff asked the applicant to discuss the possibility of large inland earthquakes based on the geographic distribution of liquefiable deposits in the zone 50–150 kilometers (31–93 miles) inland from the coast. The applicant's response to RAI 2.5.2-8 is described above. Based on its review of the applicant's response, the staff does not believe that the applicant provided substantial evidence to rule out the occurrence of large inland earthquakes, especially given the presence of liquefiable deposits up to 100 kilometers

(62 miles) inland from the coast. The occurrence of a large earthquake inland of the coast would necessitate different Charleston source zone models. See Open Item 2.5-5.

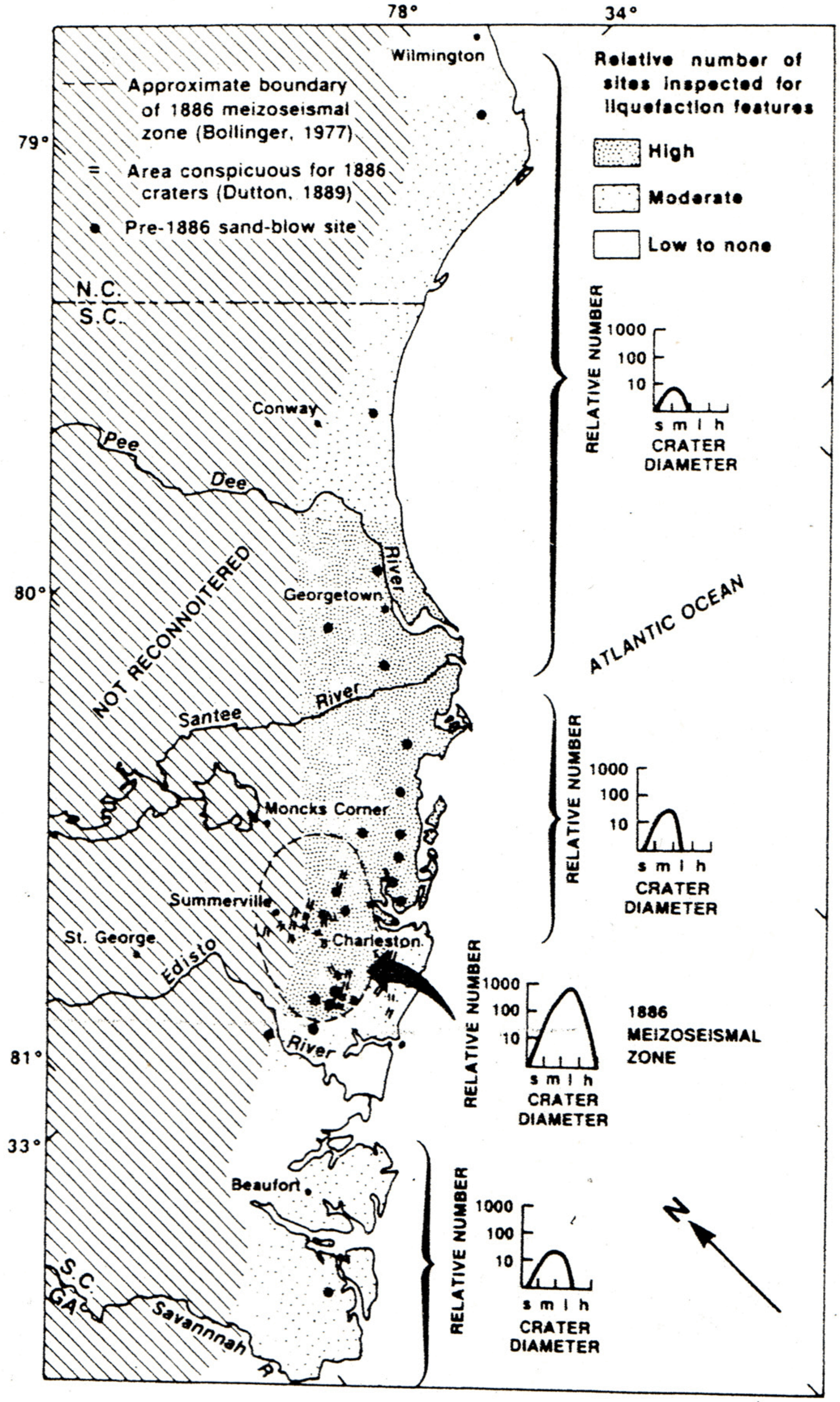

Figure 2.5.2-12 - Relative number of filled craters and crater diameters for pre-1886 sand blows at sites on marine-related sediments. The relative number is a scaling based on comparison with the abundance of craters in the 1886 meizoseismal zone, which has an arbitrary value of 1000. Crater diameters are small (s, less than 1 m), medium (m, 1–2 m), large (l, greater than 3 m) (reproduced from Obermeier et al. 1989).

Offshore of the South Carolina coast in the Charleston area there are several smaller faults (SER Figure 2.5.2-2). These faults correspond to the Helena Banks fault zone. In SSAR Section 2.5.2.2.2.4.1, the applicant concluded that, although the Helena Banks fault zone is clearly shown by multiple seismic reflection profiles and has demonstrable Late Miocene offset (Behrendt and Yuan 1987), there is no evidence to demonstrate the activity of this fault zone. In RAI 2.5.2-15, the staff asked the applicant to explain why the two seismic events (m_b 3.5 and 4.4) in 2002, which occurred in the vicinity of the Helena Bank fault zone, cannot be positively correlated with the fault zone. The association of these two events with the Helena Banks fault zone would indicate that this fault zone is currently active. In response, the applicant stated that it could not positively correlate the two earthquakes with the Helena Banks fault zone for the following reasons:

> The lack of detailed information on these two 2002 offshore earthquakes (poor location, no focal mechanisms) and the lack of additional seismic activity in this offshore area, make it difficult to assign the Helena Banks fault zone as the causative fault. It is possible that the two 2002 earthquakes indicate reactivation of the Helena Banks fault zone, but the fact that these events cannot be positively correlated to the fault suggests otherwise. There are numerous faults in the central and eastern United States located close to a few or more poorly located, small earthquakes, but this simple and very limited spatial association has not typically led researchers to positively correlate them to specific faults and classify these faults as reactivated seismogenic structures.

Based on its review of the applicant's response to RAI 2.5.2-15, the staff concurs with the applicant's conclusion that it could not positively correlate the recent offshore earthquakes with the Helena Banks fault zone because of the uncertainties regarding the exact locations of these two events. However, even though these two events cannot be directly correlated with the Helena Banks fault zone, the applicant's UCSS source zone Geometry B encompasses both the Helena Banks fault zone and the epicenters of these two events.

<u>Recurrence intervals for the Charleston seismic source</u>. In SSAR Section 2.5.2.2.2.4.3, the applicant describes its calculation of recurrence intervals for the updated Charleston seismic source, which is largely based on paleoliquefaction data compiled by Talwani and Schaeffer (2001). The applicant calculated two different average recurrence intervals, which represent two recurrence branches on the logic tree. The first average recurrence interval is based on the four events (1886, A, B, and C') that the applicant interpreted have occurred within the past ~2000 years. The applicant considered this time period to represent a complete portion of the paleoseismic record based on published literature (e.g., Talwani and Schaeffer 2001) and feedback from those researchers questioned (Talwani 2005; Obermeier 2005) by the applicant as part of its expert elicitation. This branch of the logic tree was given a weight of 0.8. The applicant's second average recurrence interval is based on events that the applicant interpreted to have occurred within the past ~5000 years and includes events 1886, A, B, C', E, and F'. This time period represents the entire paleoseismic record based on available liquefaction data (Talwani and Schaeffer 2001). Published papers and researchers questioned by the applicant suggest that the older part of the record (i.e., older than ~2000 years) may be incomplete. The applicant noted, however, that it may also be possible that the older record is complete and exhibits longer inter-event times. For this reason, the

average recurrence interval calculated for the ~5000-yr record (six events) is given a weight of 0.20 on the logic tree.

In RAI 2.5.2-12, the staff asked the applicant to provide more detail regarding its rationale for the weighting of the two recurrence branches on the logic tree. The staff also asked the applicant to justify its use of these two scenarios rather than another case study (e.g., 10 large-magnitude earthquakes occurring at approximately regular intervals during the past 5000 years), including its impact on the hazard calculation. The applicant provided the following response to justify its weighting of the 2000-yr and 5000-yr logic tree branches:

> The relative weighting of these two branches of the logic tree is based on a SSHAC level 2 assessment of completeness of the geologic record of paleoliquefaction events over these two time intervals. Earthquakes in the paleoliquefaction record do not occur at regular intervals, and this may be the result of "temporal clustering of seismicity, fluctuation of water levels, or their evidence having been obliterated" (Talwani and Schaeffer 2001; p. 6640). Talwani and Schaeffer (2001) consider the paleoliquefaction record to be complete for the past 2,000 yrs. Moreover, Prof. Pradeep Talwani (University of South Carolina, pers. comm. 9/8/05) and Dr. Steve Obermeier (U.S. Geological Survey [retired], pers. comm. 9/2/05) consider the 2,000-yr record to represent a complete portion of the paleoseismic record. For these reasons, the average recurrence interval calculated for the most-recent ~2,000 yr portion of the paleoseismologic record is given a relatively high weight of 0.80.
>
> The degree of completeness for the entire ~5,000-yr record of paleoliquefaction events is uncertain. It is possible that all paleoliquefaction events in this time period have been preserved and recognized in the geologic record. Alternatively, it is possible that events are missing from the ~5,000-yr record. Average M_{max} recurrence interval calculated from the entire ~5,000-yr record is greater (i.e., larger average interevent time) than that calculated for the ~2,000-yr record. The decision to give less weight (0.20) to this recurrence estimate is therefore conservative.

Regarding its use of these two scenarios rather than another case study (e.g., 10 large-magnitude earthquakes occurring at approximately regular intervals during the past 5000 years), the applicant stated the following:

> We also considered other scenarios from which to calculate earthquake recurrence, but ultimately decided not to incorporate those that included non-conservative assumptions. For example, Talwani and Schaeffer (2001) include a scenario in which their events C and D are moderate-magnitude, local earthquakes. These moderate-magnitude earthquakes would be eliminated from the record of large (M_{max}) earthquakes, thereby increasing the calculated recurrence interval. This and other permutations of the paleoliquefaction record (and resulting recurrence intervals) could be included, but, if based on nonconservative assumptions, would increase the recurrence interval and lower the hazard without sufficient justification. The given example of "ten large-magnitude earthquakes occurring at approximately regular intervals during the past 5,000 years" was not included in the model because:

(1) it is permissible only if events are assumed to be missing from the geologic record, and (2) the resulting recurrence interval would be very similar to the branch of the logic tree using the ~2,000-yr paleoliquefaction record.

In summary, the applicant assigned the largest weight of 0.8 to the average recurrence interval calculated for the most recent ~2000-yr portion of the paleoseismologic record. The applicant considered this time period to represent a complete portion of the paleoseismic record based on published literature (e.g., Talwani and Schaeffer 2001) and feedback from those researchers questioned (Talwani 2005; Obermeier 2005) by the applicant as part of the expert elicitation. The applicant stated that the 5000-yr time period represents the entire paleoseismic record based on available liquefaction data (Talwani and Schaeffer 2001). However, the applicant only assigned a weight of 0.2 to the 5000-yr branch of the logic tree because the completeness of the ~5000-yr paleoseismic record is uncertain.

Based on its review of the applicant's response to RAI 2.5.2-12, and the information presented by the applicant in SSAR Section 2.5.2.2, the staff concurs with the applicant's logic tree weighting for earthquake recurrence because it reflects all of the available data and uncertainties. Specifically, the applicant assigned the largest weight of 0.8 to the 2000-yr logic tree branch because there is a greater certainty that this portion of the paleoseismologic record is complete. The applicant also used the entire ~5000-yr record to calculate earthquake recurrence. The applicant calculated a recurrence interval of 958 years from the ~5000-yr record. This value is less conservative than the mean recurrence interval of 548 years calculated from the ~2000-yr record. However, the applicant assigned a significantly lower weight of 0.2 to this logic tree branch because there is a greater uncertainty that the ~5000-yr record is complete.

In summary, the staff focused its review of SSAR Section 2.5.2.2 on the applicant's update of the Charleston seismic source model and its basis for not updating the other EPRI seismic source zones that contribute to the seismic hazard at the ESP site. A total of five open items resulted from the staff's review of SSAR Section 2.5.2.2.

Open Item 2.5-1 relates to the M_{max} distributions for the EPRI seismic source zones that include the ESP site. The staff concludes that the applicant did not provide adequate justification for its use of low M_{max} values in comparison to more recent studies and data.

Open Item 2.5-2 relates to the results of the TIP study (NUREG/CR-6607) and is relevant to both the applicant's update of the Charleston seismic source zone as well as the EPRI source zones that include the site and encompass the seismicity associated with the ETSZ. Specifically, the staff disagrees with the applicant's decision not to consider the results of the TIP study in its evaluation of the EPRI seismic source model and requests that the applicant evaluate any information contained in the study that is relevant to the seismic source characterization of the ESP site.

Open Item 2.5-3 relates to the M_{max} distributions for the EPRI seismic source zones that encompass seismicity associated with the ETSZ. The staff concludes that the applicant did not provide adequate justification for its use of low M_{max} values in comparison to more recent studies and data.

Open Items 2.5-4 and 2.5-5 specifically relate to the applicant's update of the Charleston seismic source zone. Open Items 2.5-4 concerns that fact that the applicant's description of the SSHAC Level 2 process lacked several key elements that the staff believes are necessary to completely evaluate the applicant's update. Although the applicant provided additional information related to its SSHAC Level 2 Study as a supplement to its response to RAI 2.5.2-4, the staff requires additional time to complete its review of this information. Furthermore, the staff requests the applicant to explain why only two of the four members of the TAG panel reviewed and approved written copies of the engineering report describing the UCSS model.

Open Item 2.5-5 relates to the adequacy of the evidence needed to rule out the occurrence of large inland earthquakes. The staff concludes that the applicant did not provide adequate evidence, and therefore may need different Charleston source zone models.

Upon resolution of each of the open items described above, the staff concludes that the applicant's update of the 1986 EPRI PSHA sources adequately characterizes the seismic hazard in the region surrounding the site.

2.5.2.3.3 Correlation of Earthquake Activity with Seismic Sources

SSAR Section 2.5.2.3 describes the correlation of updated seismicity with the EPRI seismic source model. The applicant compared the distribution of earthquake epicenters from both the original EPRI historical catalog (1627–1984) and the updated seismicity catalog (1985–2005) with the seismic sources characterized by each of the EPRI ESTs. The applicant concluded that there are no new earthquakes within the site region that can be associated with a known geologic structure and that there are no clusters of seismicity suggesting a new seismic source not captured by the EPRI seismic source model. The applicant also concluded that the updated catalog does not show a pattern of seismicity that would require significant revision to the geometry of any of the EPRI seismic sources. The applicant further concluded that the updated catalog does not show or suggest an increase in M_{max} or a significant change in seismicity parameters (activity rate, b-value) for any of the EPRI seismic sources. The applicant based its conclusions on a comparison of the distribution of earthquake epicenters from both the original EPRI historical catalog and from its updated seismicity catalog with the seismic sources characterized by each of the EPRI ESTs.

In Parts A and B of RAI 2.5.2-1, the staff requested electronic versions of the EPRI seismicity catalog and the applicant's updated EPRI seismicity catalog for the region of interest. In Part C of RAI 2.5.2-1, the staff requested the geographic coordinates of the primary source zones developed by each of the six EPRI ESTs. The staff used the information provided in response to Parts A and B of RAI 2.5.2-1 to compare the applicant's update of the regional seismicity catalog with its own listing of recent earthquakes. Based on this comparison, the staff concurs with the applicant's assertion that the rate of seismic activity has not increased in the ESP region since 1985. Using the information provided in response to Part C of RAI 2.5.2-1, the staff compared the updated earthquake catalog with each of the primary seismic sources developed by each EPRI EST. Based on the spatial distribution of earthquakes in the updated catalog, the staff concurs with the applicant's conclusion that revisions to the existing EPRI sources are not warranted. However, additional worldwide earthquake data may indicate the need for an update of some of the EPRI seismic source models. In addition, recent paleoliquefaction studies predict shorter recurrence intervals for large Charleston-type earthquakes compared to predictions based on the historical seismicity catalog. This paleoliquefaction data also provide information regarding the locations of large prehistoric Charleston-type earthquakes. SER Section 2.5.2.3.2 describes these two issues.

2.5.2.3.4 Probabilistic Seismic Hazard Analysis and Controlling Earthquakes

SSAR Section 2.5.2.4 presents the earthquake potential for the ESP site in terms of the controlling earthquakes. The applicant determined the high- and low-frequency controlling earthquakes by deaggregating the PSHA results at selected probability levels. Before determining the controlling earthquakes, the applicant updated the 1989 EPRI PSHA using the seismic source zone adjustments described in SER Section 2.5.2.1.2 and the new ground motion models described in SER Section 2.5.2.1.4.

The staff focused its review of SSAR Section 2.5.2.4 on the applicant's updated PSHA and the ESP site controlling earthquakes determined by the applicant after completion of its PSHA. While the staff's review of the applicant's update of the EPRI seismic source model is described in SER Section 2.5.2.3.2, this SER section focuses on the review of the application of the updated seismic source model to the hazard calculation at the ESP site.

PSHA Inputs

As input to its PSHA, the applicant used its updated version of the 1989 EPRI seismic source model. The staff's evaluation of the applicant's update is described in SER Section 2.5.2.3.2. The applicant also used the ground motion models developed by the 2004 EPRI-sponsored study (EPRI 1009684 2004) as input to its PSHA. The ESP applications for the Clinton (Illinois), Grand Gulf (Mississippi) and North Anna (Virginia) sites also used the updated EPRI ground motion models. The staff's final SERs for Clinton (ADAMS Accession No. ML0612204890), Grand Gulf (ADAMS Accession No. ML061070443), and North Anna (ADAMS Accession No. ML063170371) provide an extensive review of the updated EPRI ground motion models. Thus, the staff considers the applicant's use of the EPRI 2004 ground motion model to be appropriate.

PSHA Results

In order to determine the adequacy of the PSHA results, the staff, in RAI 2.5.2-1, requested the applicant to provide the 1- and 10-Hz mean hazard curves for each of the six EPRI ESTs, as well as the 1- and 10-Hz mean hazard curves for the UCSS model. In response to RAI 2.5.2-1, the applicant provided the requested hazard curves. SER Figures 2.5.2-13 and 2.5.2-14 show the applicant's 1-Hz and 10-Hz total mean hazard curves, as well as the hazard curves corresponding to each of the six EPRI EST seismic source model inputs. Both figures also show the hazard curves corresponding to the applicant's UCSS model.

The total mean hazard curves, shown in SER Figures 2.5.2-13 and 2.5.2-14, comprise the mean of the six EPRI EST total hazard curves plus the contribution of the UCSS.

As shown in SER Figure 2.5.2-13, for the 1-Hz hazard curves, the Charleston source dominates the overall hazard at the ESP site. In SER Figure 2.5.2-14, for the 10-Hz hazard curves, the contributions from each of the six ERPI seismic source models have a more significant contribution to the overall hazard.

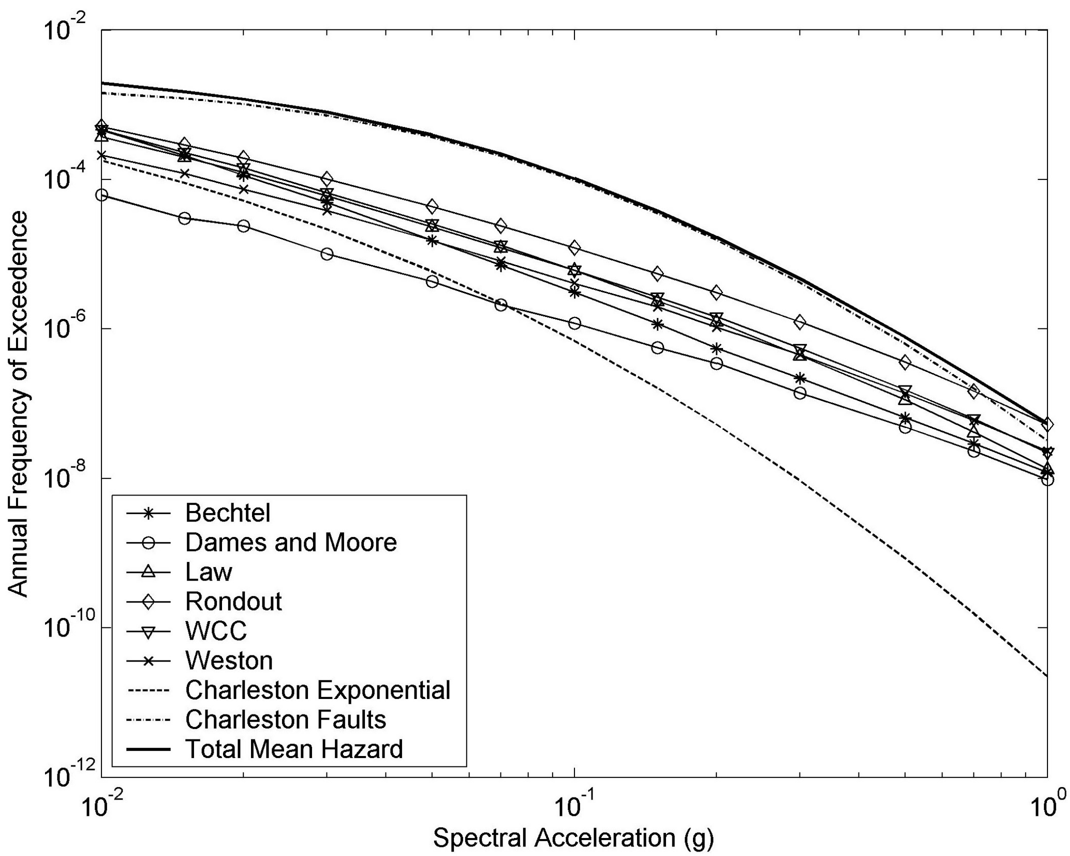

Figure 2.5.2-13 - Plot showing the applicant's 1-Hz total mean hazard curve for the ESP site. This figure also shows the contributions of the applicant's UCSS model, which consists of "Charleston Faults" and "Charleston Exponential," as well as the contributions from each of the six EPRI EST seismic source models.

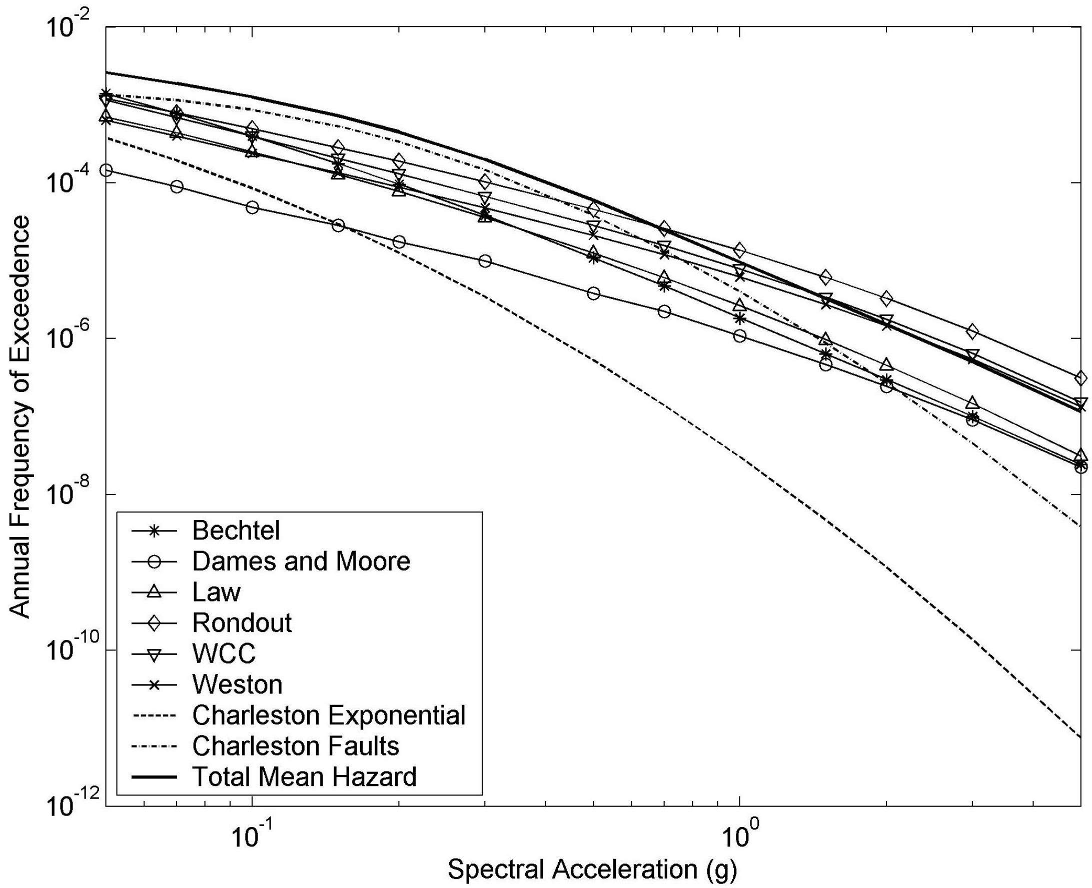

Figure 2.5.2-14 - Plot showing the applicant's 10-Hz total mean hazard curve for the ESP site. This figure also shows the contributions of the applicant's UCSS model, which consists of "Charleston Faults" and "Charleston Exponential," as well as the contributions from each of the six EPRI EST seismic source models.

<u>Controlling Earthquakes</u>. To determine the low- and high-frequency controlling earthquakes for the ESP site, the applicant followed the procedure outlined in Appendix C to RG 1.165. This procedure involves the deaggregation of the PSHA results at a target probability level to determine the controlling earthquakes in terms of magnitude and source-to-site distance. The applicant chose to perform the deaggregation of the mean 10^{-4}, 10^{-5}, and 10^{-6} PSHA results. SER Table 2.5.2-8 shows the low- and high-frequency controlling earthquakes. Because of the similarity of Mbar and Dbar values for the three hazard levels, the applicant selected a single recommended Mbar and Dbar value for each frequency range. For the high-frequency mean 10^{-4} and 10^{-5} and 10^{-6} hazard levels, the controlling earthquake has a magnitude of M 5.6 event occurring at a distance of 9.0 kilometers (5.6 miles), corresponding to an earthquake from a local seismic source zone. In contrast, for the low-frequency mean 10^{-4} and 10^{-5} and 10^{-6} hazard levels, the controlling earthquake has a magnitude of M 7.2 at a distance of 130 kilometers (80.8 miles). This controlling earthquake corresponds to an event in the Charleston seismic source zone.

Table 2.5.2-8 - Computed and Final Mbar and Dbar Values Used for Development of High- and Low-Frequency Target Spectra (Based on Information Provided In SSAR Table 2.5.2-17)

High Frequency (5 to 10 Hz)				
	39358	39359	39360	Final Values
Mbar (M)	5.6	5.6	5.7	5.6
Dbar	17.6 km (10.9 mi)	11.4 km (7.1 mi)	9.0 km (5.6 mi)	9.0 km (5.6 mi)
Low Frequency (1 to 2.5 Hz)				
	39358	39359	39360	Final Values
Mbar (M)	7.2	7.2	7.2	7.2
Dbar	136.5 km (84.8 mi)	134.3 km (83.5 mi)	133.0 km (82.6)	130 km (80.8 mi)

In RAI 2.5.2-21, the staff asked the applicant to explain how it calculated the final Dbar and Mbar values. In its response to RAI 2.5.2-21, the applicant stated that the final low-frequency distance value of 130 kilometers (80.8 miles) is based on the source-to-site distance for the Charleston source, while the final high-frequency value of 9 kilometers (5.6 miles) is equal to the log-average of the three computed values rounded to the nearest kilometer. The applicant also stated that the final magnitude values for the respective high- and low-frequency cases are equal to the linear average of the three magnitude values rounded to the nearest tenth of a magnitude unit. In addition, the applicant provided a comparison between the high-frequency spectral shape using the final magnitude and distance values and the computed magnitude and distance values. The applicant also provided a comparison between the low-frequency spectral shape using the final magnitude and distance values and the computed magnitude and distance values. Based on its comparison, the applicant concluded that the use of the recommended magnitude and distance values in place of the computed magnitude and distance values for each of the three annual probability levels would not significantly change the results of the site response analysis.

The staff concurs with the applicant's final high- and low-frequency Mbar and Dbar values because these final values, and the corresponding spectral shapes, are very similar to the calculated values for the three annual probability levels.

Since the applicant's PSHA results may change depending on the resolution of Open Items 2.5-1 through 2.5-4, which are described in SER Section 2.5.2.3.2, the staff is unable to reach a conclusion concerning the adequacy of the applicant's PSHA seismic source inputs. Furthermore, based on its review of SSAR Section 2.5.2.2, the staff is unable to conclude that the applicant used the methodology recommended in RG 1.165 for performing the PSHA and determining the controlling earthquakes for the ESP site.

2.5.2.3.5 Seismic Wave Transmission Characteristics of the Site

SSAR Section 2.5.2.5 describes the method used by the applicant to develop the ESP site free-field ground motion spectrum. The seismic hazard curves generated by the applicant's PSHA are defined for generic hard rock conditions (characterized by a S-wave velocity of 9200 ft/s). According to the applicant, these hard rock conditions exist at a depth of more than 2000 feet below the ground surface at the ESP site. To determine the site free-field ground motion, the applicant performed a site response analysis. The output of the applicant's site response analysis is site AFs, which are then used to determine the UHRS for three hazard levels (10^{-4}, 10^{-5}, and 10^{-6}). The 10^{-4} and 10^{-5} UHRS are then used to calculate the SSE for the site.

In SSAR Section 2.5.2.5.1.1, the applicant describes the methodology it used to develop the soil UHRS for the 10^{-4}, 10^{-5}, and 10^{-6} hazard levels. The applicant's site free-field soil UHRS is defined at the top of the Blue Bluff Marl. According to the applicant, the top of the Blue Bluff Marl is characterized by an average S-wave velocity of 2354 ft/s. In **RAI 2.5.2-19**, the staff asked the applicant to provide a detailed step-by-step description of the methodology it used to develop the site AFs and the 10^{-4} and 10^{-5} soil UHRS. In response to **RAI 2.5.2-19**, the applicant more completely explained Steps 1 through 6. However, after reviewing the applicant's response, the staff concludes that the applicant's description of Steps 5 and 6 does not provide sufficient detail for the staff to completely evaluate the site response method. In particular, the staff is not clear on the enveloping motion used in Step 5, and the applicant's description in Step 6 appears to differ from that described in SSAR Section 2.5.2.5.1.1. On June 18, 2007, the applicant supplemented its RAI response with additional detail on each of the steps used in the site response analysis; however, the staff has not been able to completely evaluate the applicant's supplemental information. As such, the staff has not been able to reach a conclusion on the adequacy of the applicant's methodology. This is **Open Item 2.5-6**.

SSAR Section 2.5.2.5.1.3 describes the development of low- and high-frequency target spectra based on the low- and high-frequency controlling earthquake magnitudes and distances. To determine the target low- and high-frequency spectra, the applicant used the average of the single and double corner source models provided in NUREG/CR-6728. In RAI 2.5.2-20, the staff asked the applicant why it did not use the EPRI ground motion models (EPRI 1009684 2004) to develop the high- and low-frequency target response spectra since the applicant used these ground motion models for its PSHA. In response to RAI 2.5.2-20, the applicant provided the following information:

> The 2004 EPRI ground motion report (EPRI 1009684) gives equations to estimate spectral acceleration at 7 structural frequencies (100, 25, 10, 5, 2.5, 1, and 0.5 Hz). To properly represent rock motion for input to a site response analysis, it is necessary to interpolate between these 7 structural frequencies to obtain a realistic spectral shape, rather than using linear interpolation. For this task, NUREG/CR-6728 was used, because one of its goals was specifically to develop realistic spectral shapes for the eastern U.S. to use in earthquake ground motion analyses.

The staff concurs with the applicant's use of NUREG/CR-6728 spectral models for the CEUS, since the EPRI 2004 ground motion models only provide 7 structural frequencies. Because the applicant used the NUREG/CR-6728 source models it was able to avoid using linear interpolation and, subsequently, obtained a more accurate estimate of the site response.

A key step in the site response analysis is the selection of actual earthquake records which closely match the low- and high-frequency controlling earthquake magnitude and distance values. The response spectra from these earthquake records, which are generally from the WUS, are matched to the CEUS spectral shapes described in the preceding paragraph. SSAR Section 2.5.2.5.1.4 describes the spectral matching of the selected seed time histories to the target response spectra and states that "the spectral matching criteria given in NUREG/CR- 6728 were used to check the average spectrum from the 30 time histories for a given frequency range (high- or low-frequency) and annual probability level. This is the recommended procedure in NUREG/CR-6728 when multiple time histories are being generated and used." In RAI 2.5.2-22, the staff asked the applicant to verify that it satisfied the NUREG/CR-6728 matching criteria for each individual earthquake time history. In response to RAI 2.5.2-22, the applicant pointed out that item (e) of the NUREG/CR-6728 matching criteria provides guidance for the use of a suite of ground motion records as well as for an individual record. In addition, the applicant stated that it matched the other relevant criteria for both the low-frequency and high-frequency spectra. Since the applicant followed the guidance specified in NUREG/CR-6728 for multiple time histories and also matched the other relevant criteria, the staff concludes that the applicant adequately matched the seed time histories to the CEUS spectral shapes.

In addition to the seed time histories, another important part of the site response analysis is the model of the site subsurface soil and rock properties. In particular, the applicant's site response analysis should incorporate the uncertainty in these properties. Key properties include the shear wave velocities, material damping, and the strain-dependent behavior of each of the soil layers underlying the site. To model the strain-dependent behavior of the soil, the applicant used shear modulus and damping curves developed by EPRI (EPRI TR-102293 1993), as well as curves developed for the SRS (Lee 1996). Besides these soil properties, in RAI 2.5.2-23, the staff asked the applicant to discuss results of its site response calculations in terms of the following:

1. the effects of the six alternative site response profiles in terms of the different depths to the top of the Paleozoic crystalline rocks

2. the possible effects of the Pen Branch fault zone (i.e., as a low-velocity zone or weak zone)

3. the effects of the low-velocity zones within the Blue Bluff Marl and Lower Sand Stratum

In response to RAI 2.5.2-23, the applicant performed additional sensitivity calculations to examine the effects of the different depths to the top of the Paleozoic crystalline rocks using the six base case profiles shown in SSAR Table 2.5.4-11, Part B. In order to represent the Pen Branch fault as a low-velocity zone, the applicant modified the rock S-wave velocities of the six base profiles to include a low-velocity zone and to represent the Pen Branch fault. The applicant concluded that the depth to the Pen Branch fault, and a lower velocity layer for the Pen Branch, does not affect the site response. The applicant observed very small differences between the results. Regarding the effects of the low-velocity zones within the Blue Bluff Marl and Lower Sand Stratum, the applicant stated the following:

> The low velocity zones in the Blue Bluff Marl and in the Lower Sand Stratum were incorporated in the site response calculations, i.e., the site response calculation results inherently reflect the inclusion of these low velocity zones. The calculations were performed using the base case shear wave velocity profile that is based on field measurements, and randomized profiles.

The staff reviewed the applicant's response to RAI 2.5.2-23, as well as the results of its sensitivity calculations, and concludes that the applicant adequately captured the site variability in its site response calculations. The applicant generated randomized soil and rock S-wave velocity profiles and randomly paired them with 60 sets of shear modulus degradation and damping curves. According to RG 1.208, the use of 60 randomized profiles is generally adequate to determine a reliable estimate of the mean and standard deviation of the site response.

To determine the adequacy of the applicant's site response calculations, the staff performed its own confirmatory site response calculations. The staff used a site response methodology similar to that used by the applicant and, like the applicant, the staff used the program SHAKE. The main difference between the two sets of calculations is that the staff did not use multiple input time histories and randomized soil and rock S-wave velocity profiles, soil shear modulus reduction and damping relationships, and rock damping values as the applicant used for its analysis.

SER Figures 2.5.2-15 to 2.5.2-18 show the mean AFs resulting from the staff's confirmatory site response calculations. Each figure plots the mean results of the six alternative subsurface profiles for both the EPRI and SRS shear modulus and damping curves. SER Figures 2.5.2-15 and 2.5.2-16 show the results corresponding to the 10^{-4} hazard levels for the respective high- and low-frequency input motions, while SER Figures 2.5.2-17 and 2.5.2-18 plot the results corresponding to the 10^{-5} hazard levels for the respective high- and low-frequency input motions. SER Figures 2.5.2-15 to 2.5.2-18 also show the applicant's mean AFs for comparison. The applicant's results are similar overall. For each case, the amplification peaks are very similar, and in all cases, the peaks occur at approximately 0.6 Hz. The differences between the results are likely due to the greater variability that the applicant incorporated into its model through the use of randomized profiles and material properties, as well as the use of multiple time histories. This variability is illustrated in SER Figure 2.5.2-19 (reproduced from SSAR Figure 2.5.2-37). As a result of its analysis, the staff was able to confirm the applicant's overall site response results.

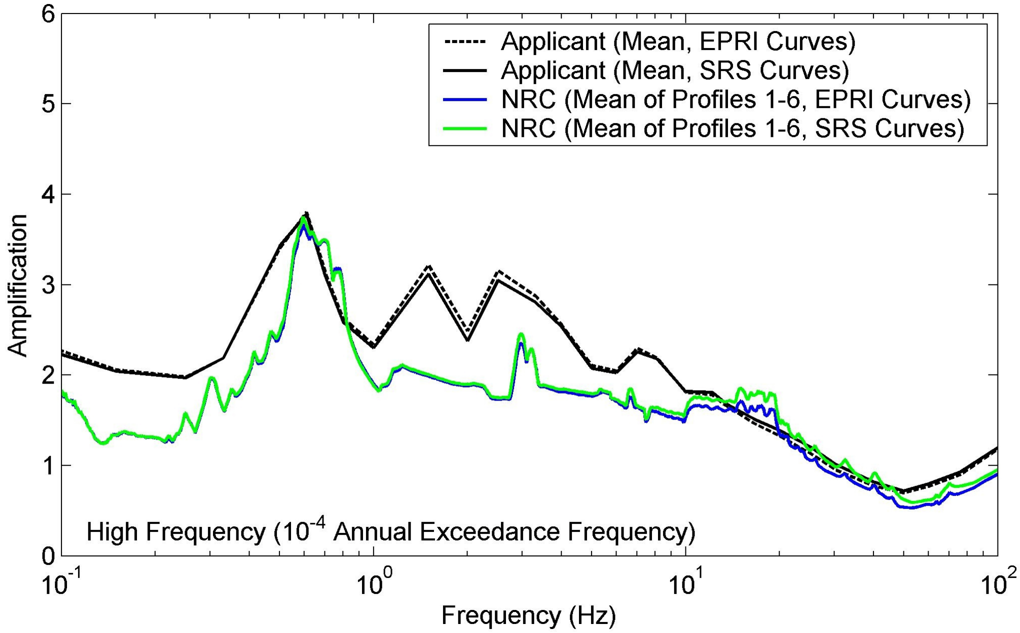

Figure 2.5.2-15 - Results of the staff's site response calculations for high-frequency rock motions for the 10^{-4} hazard level. The applicant's mean results are shown for comparison.

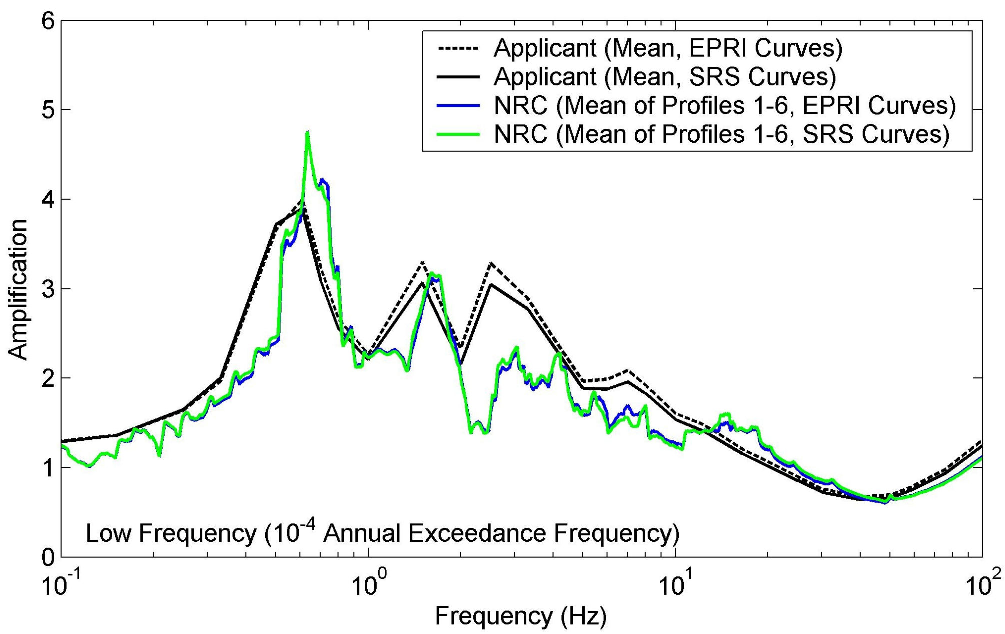

Figure 2.5.2-16 - Results of the staff's site response calculations for low-frequency rock motions for the 10^{-4} hazard level. The applicant's mean results are shown for comparison.

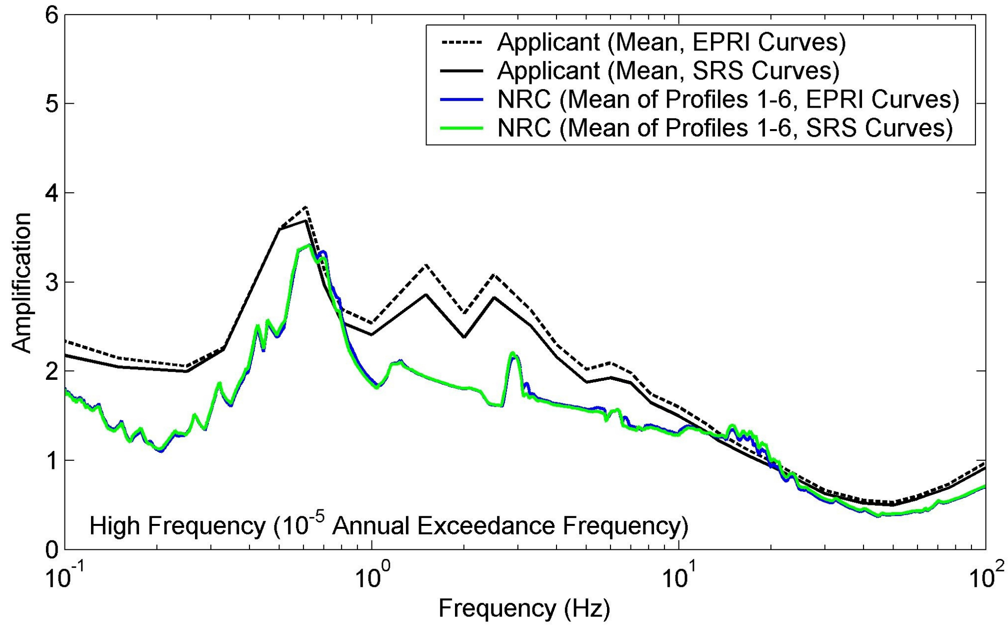

Figure 2.5.2-17 - Results of the staff's site response calculations for high-frequency rock motions for the 10^{-5} hazard level. The applicant's mean results are shown for comparison.

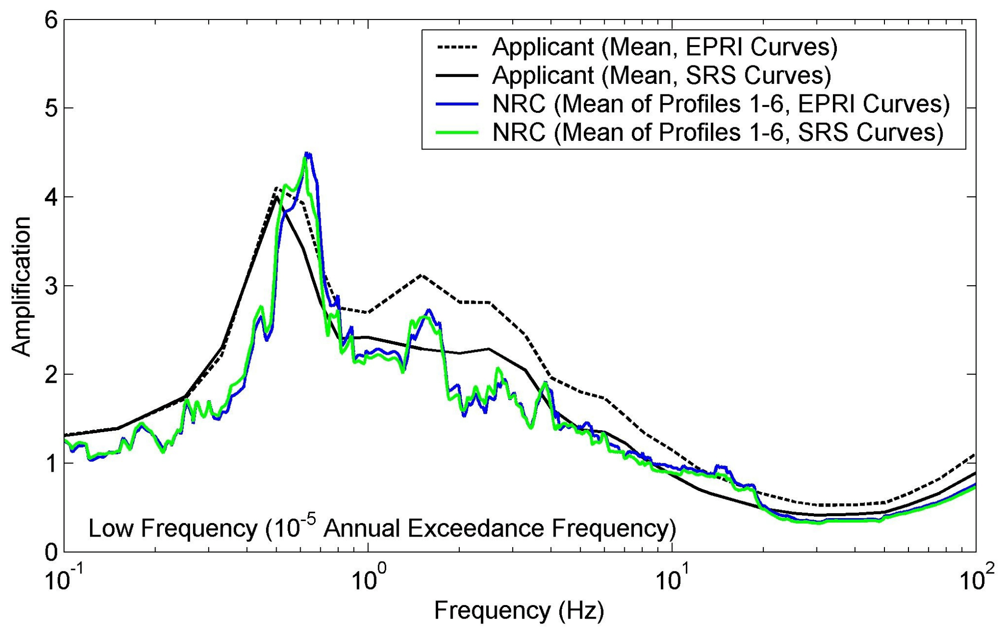

Figure 2.5.2-18 - Results of the staff's site response calculations for low-frequency rock motions for the 10^{-5} hazard level. The applicant's mean results are shown for comparison.

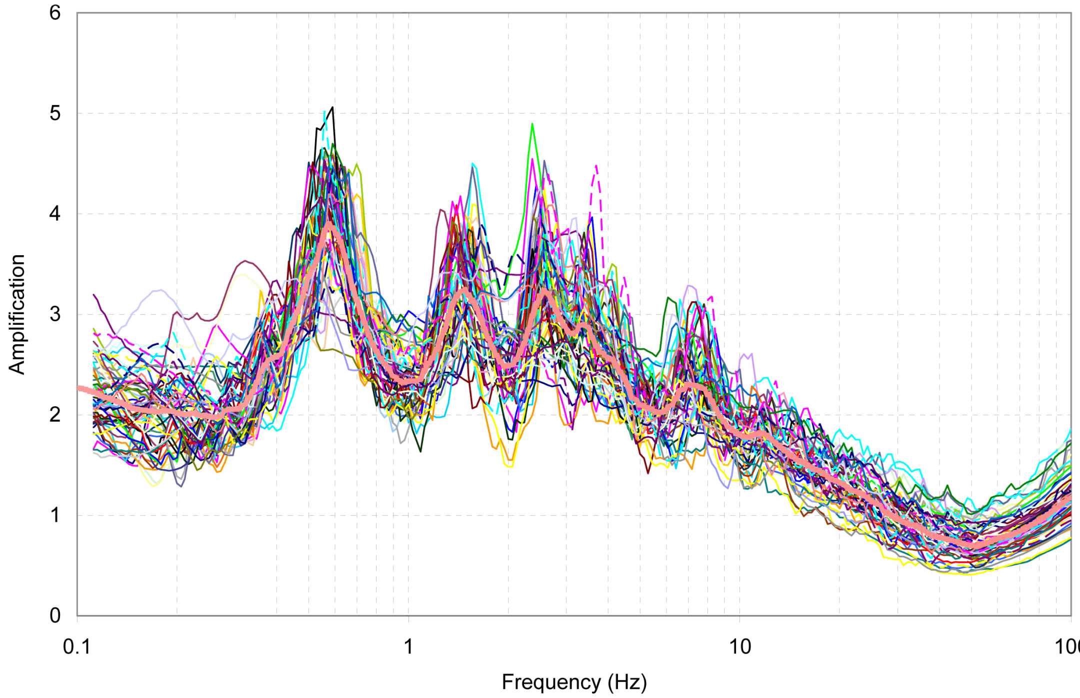

Figure 2.5.2-19 - Results of the applicant's site response calculations for high-frequency rock motions for the 10^{-4} hazard level using the EPRI degradation curves (reproduced from SSAR Figure 2.5.2-37).

In RAI 2.5.2-23, the staff asked the applicant to justify its use of an equivalent-linear approach rather than a nonlinear approach to model the soil nonlinearity at the ESP site. In response, the applicant provided a table containing the maximum shear strains obtained from its SHAKE analyses of the randomized profiles. The applicant's table is reproduced as SER Table 2.5.2-9. In reference to SER Table 2.5.2-9, the applicant stated, "The table shows that the maximum soil strain remained below 0.6%. The equivalent-linear approach is adequate for this low level of soil strain."

Table 2.5.2-9 - Applicant's Maximum Shear Strain Values Provided In Response to RAI 2.5.2-23

Earthquake Probability Level	EPRI Randomized Profiles		SRS Randomized Profiles	
	LF Earthquake	**HF Earthquake**	**LF Earthquake**	**HF Earthquake**
10^{-4}	0.078%	0.067%	0.082%	0.068%
10^{-5}	0.592%	0.300%	0.287%	0.353%

The staff believes that further justification is necessary in order for it to concur with the applicant's assertion that the equivalent-linear approach is suitable for strain levels as high as those for the 10^{-5} probability level. The equivalent-linear modeling approach produces a systematic shift in resonance peaks toward lower frequencies as the level of strain increases and also may predict a more dramatic reduction in AFs at higher frequencies. The applicant is requested to provide further justification for its claim that the equivalent-linear approach is suitable for higher strain levels. This is **Open Item 2.5-7**.

Upon resolution of Open Items 2.5-6 and 2.5-7, the staff concludes that, overall, the applicant's site response methodology and results are acceptable. The applicant followed the general guidance provided in RG 1.208, and the results of the confirmatory site response calculations performed by the staff are similar to the applicant's results. In addition to these two open items, the staff notes that the applicant did not perform any laboratory dynamic testing of the ESP soils, as specified in RG 1.138, "Laboratory Investigations of Soils and Rocks for Engineering Analysis and Design of Nuclear Power Plants," Revision 2, issued December 2003. Instead, as inputs to its site response calculations, the applicant relied on the EPRI and SRS shear modulus degradation and damping curves and assigned equal weights to the results for both sets of curves. This issue is discussed in greater detail in SER Section 2.5.4.3. In Open Item 2.5-19, the staff requests that the applicant justify its use of the EPRI and SRS shear modulus and damping curves in the absence of any dynamic testing of the ESP soils.

2.5.2.3.6 Ground Motion Response Spectra

SSAR Section 2.5.2.6 describes the method used by the applicant to develop the horizontal and vertical site-specific SSE. To obtain the horizontal SSE, the applicant used the performance-based approach described in RG 1.208 and ASCE/SEI Standard 43-05. The applicant developed the vertical SSE by applying V/H ratios to the horizontal SSE. The applicant based these V/H ratios on the information provided in NUREG/CR-6728 and Lee (2001).

Following RG 1.208, the staff has recently adopted new terminology to differentiate between the different types of site and design ground motion response spectra. The staff now refers to the performance-based GMRS as the site-specific GMRS. The GMRS represents the first part of the development of the SSE for a site as a characterization of the regional and local seismic hazard and must satisfy the requirements of 10 CFR 100.23. In accordance with Appendix S to 10 CFR Part 50, during the combined license phase, an additional check of the ground motion is required at the foundation level. Specifically, Appendix S to 10 CFR Part 50 states that the free-field foundation level ground motion must be represented by an appropriate response spectrum with a peak acceleration of at least 0.1 g. The GMRS becomes the site SSE if it exceeds the Appendix S to 10 CFR Part 50 minimum requirements. Otherwise, if any portion of the GMRS falls below the minimum response spectrum, then the site SSE becomes the ground motion spectrum that envelops the GMRS and the minimum response spectrum. As such, the final SSE must satisfy the requirements of both 10 CFR 100.23 and Appendix S to 10 CFR Part 50.

From this point on, the staff will refer to the applicant's SSE as the GMRS. The staff reviewed the applicant's GMRS in terms of meeting the requirements of 10 CFR 100.23 with respect to the development of the SSE.

<u>**Horizontal GMRS**</u>

The ESP applicant for the Clinton, Illinois, site also used the performance-based approach to determine the horizontal GMRS. The staff's final SER for Clinton (ADAMS Accession No. ML0612204890) provides an extensive review and derivation of the performance-based approach. As described in RG 1.208, the performance-based approach combines a conservative characterization of the ground motion hazard with equipment/structure performance (fragility characteristics) to establish a risk-consistent GMRS. The performance-based GMRS is obtained by modifying the 10^{-4} UHRS at the free-field ground surface by a DF. The resulting GMRS meets the target performance goal of 10^{-5} per year for the mean annual probability of systems, structures, and components reaching the limit state of inelastic response. The performance-based approach achieves a relatively consistent annual probability of plant component failure across the range of plant locations and structural frequencies. It does this by accounting for the slope of the seismic hazard curve, which changes with structural frequency and site location.

To verify the adequacy of the applicant's GMRS, the staff, in RAI 2.5.2-3, requested six PSHA hazard curves (1, 2.5, 5, 10, 25, and 100 Hz). The staff received the requested information from the applicant on June 18, 2007 (as supplemental information to RAI 2.5.2-3). Because the staff did not have adequate time to review the information, the staff requires additional time to complete its review. No further information is required at this time. This is **Open Item 2.5-8**.

Vertical GMRS

To compute the vertical GMRS, the applicant used a combination of V/H ratios obtained from NUREG/CR-6728 and Lee (2001). Since the V/H ratios presented in NUREG/CR-6728 and Lee (2001) are functions of magnitude, source distance, and local site conditions, the applicant developed V/H ratios corresponding to the final high-frequency (M 7.2, 130 km) and low-frequency (M 5.6, 12 km) controlling earthquakes described in SSAR Section 2.5.2.4. The applicant referred to these high- and low-frequency controlling earthquakes as “near” and “far” events, respectively.

In Part A of RAI 2.5.2-24, the staff asked the applicant to justify its rationale for assigning the approximate weights of 1:3 to the V/H ratios corresponding to the respective “near” and “far” events. In response to Part A of RAI 2.5.2-24, the applicant concluded that it developed this weighting based on a review of the high- and low-frequency distance deaggregations as well as the relative contributions of the 10^{-4} and 10^{-5} hazard levels to the GMRS. Based on its review of the high-frequency distance deaggregation at the 10^{-4} hazard level (shown in SSAR Figure 2.5.2-30), the applicant concluded that approximately three-fourths of the area under the 10^{-4} hazard probability density curve corresponds to the “far” event, while about one-fourth of the area under the curve corresponds to the “near” event. In comparison, the applicant found that the relative contribution of the “near” and “far” events at the 10^{-5} hazard level is approximately the same. The applicant also reviewed the low-frequency distance deaggregation (shown in SSAR Figure 2.5.2-31) at both the 10^{-4} and 10^{-5} hazard levels and concluded that the hazard is dominated by the “far” event.

As stated in its response to Part A of RAI 2.5.2-24, the applicant focused on the 10^{-4} high-frequency distance deaggregation and the associated weights of 1:3 to determine the relative contributions of the respective “near” and “far” events because the GMRS is generally only slightly higher than the 10^{-4} ground motion. The applicant used the high-frequency distance deaggregation, rather than the low-frequency distance deaggregation, because it concluded “the low-frequency end of the spectrum is not as sensitive to magnitude and distance nor, therefore, to the distinction between ‘near’ and ‘far’ events.”

The staff concludes that the applicant’s use of NUREG/CR-6728 to develop V/H ratios is acceptable because the report considers the effects of magnitude and distance on spectral ratios and is applicable to CEUS soil sites. Previous regulatory guidance (RG 1.60 and NUREG/CR-0098, “Development of Criteria for Seismic Review of Selected Nuclear Power Plants”) recommended that the V/H ratio be fixed at two-thirds, independent of ground motion frequency, earthquake magnitude, distance, and local site conditions. More recent regulatory guidance (RG 1.208) recommends the use of V/H ratios that incorporate magnitude, distance, and local site conditions, such as those found in NUREG/CR-6728. Because of the observed similarity between the SSE to the 10^{-4} soil UHRS, and because V/H ratios are observed to be higher in the near-field region and in the high-frequency range of the response spectrum (e.g., NUREG/CR-6728), the staff concurs with the applicant’s rationale for weighting the relative contributions of the “near” and “far” events based on the 10^{-4} high-frequency distance deaggregation.

In Part B of RAI 2.5.2-24, the staff asked the applicant to discuss the similarities and differences between the site-specific soil profile used by Lee (2001) and the VEGP soil profile.

In response to Part B of RAI 2.5.2-24, the applicant stated that the SRS site-specific soil profile is not published in Lee (2001) so that a comparison with the ESP profile could not be made. The applicant also stated that given the proximity of the ESP site to the SRS, it assumed that the site conditions at the SRS are more comparable to those at the ESP site than the generic CEUS profile used in NUREG/CR-6728.

In Part C of RAI 2.5.2-24, the staff asked the applicant to provide justification for the relative weights assigned to the NUREG/CR-6728 and Lee (2001) results and final smoothing to develop the final V/H ratios for the ESP site. In response, the applicant stated that it used an approximate envelope of the two results. For frequencies between 1 and 100 Hz, the applicant approximated the V/H ratios of Lee (2001) by two log-log line segments. For frequencies less than 1 Hz, the applicant used a constant ratio of 0.5, which is greater than both Lee (2001) and NUREG/CR-6728, and more closely resembles the V/H values in RG 1.60.

For CEUS soil sites, RG 1.208 endorses the procedure provided in NUREG/CR-6728 to determine a WUS-to-CEUS transfer function to modify the WUS V/H ratios. The staff, therefore, concludes that the applicant's use of the formula provided in Appendix J to NUREG/CR-6728 to determine the ESP site V/H ratios is acceptable. However, the formula in Appendix J, shown in Equation (2) in SER Section 2.5.2.6, requires the input of site-specific V/H ratios, $V/H_{CEUS,Soil,Model}$, based on ground motion modeling. For this site-specific V/H ratio, the applicant used the results of Lee (2001), which are applicable to the SRS soil profile, and NUREG/CR-6728, based on a generic CEUS soil profile. SER Figure 2.5.2-9 shows the applicant's final V/H ratios as a function of frequency. At frequencies above approximately 1 Hz, the applicant estimated the V/H ratios of Lee (2001) by two log-log line segments. At frequencies between 1–2 Hz and 10–20 Hz, this log-log line segment is less that the V/H ratios of Lee (2001). The staff concludes that the applicant did not provide adequate justification to support the applicability of either the Lee (2001) or the NUREG/CR-6728 soil V/H ratios at the ESP site. The staff further concludes that the applicant's approximate envelope is arbitrary. For example, the applicant did not provide its rationale for excluding the peaks observed in the Lee (2001) V/H ratios in the 1–2 Hz and 10–20 Hz frequency ranges. In **Open Item 2.5-9**, the staff requests the applicant to provide more detail regarding the applicability of the Lee (2001) and the NUREG/CR-6728 V/H ratios to the ESP site. In addition, the staff requests that the applicant provide its justification for the use of an approximate envelope of the Lee (2001) and NUREG/CR-6728 V/H ratios.

In summary, the staff identified two open items based on its review of SSAR Section 2.5.2.6. In RAI 2.5.2-3, the staff requested the applicant's six hazard curves (1, 2.5, 5, 10, 25, and 100 Hz) in order to verify the adequacy of its horizontal GMRS. Because the staff received the requested information from the applicant on June 18, 2007, it requires additional time to complete its review. This is Open Item 2.5-8. The staff further concludes that the applicant's methodology to determine the ESP site V/H ratios is acceptable because it used the procedure provided in NUREG/CR-6728. However, Open Item 2.5-9 requests that the applicant provide more information regarding the applicability of the Lee (2001) and the NUREG/CR-6728, V/H ratios to the ESP site. In addition, the staff requests that the applicant provide its justification for the use of an approximate envelope.

2.5.2.4 Conclusions

As set forth above, the staff reviewed the seismological information submitted by the applicant in SSAR Section 2.5.2. On the basis of its review of SSAR Section 2.5.2 and upon resolution of Open Items 2.5-1 through 2.5-5, the staff finds that the applicant has provided a thorough characterization of the seismic sources surrounding the site, as required by 10 CFR 100.23. In addition, the staff finds that the applicant has adequately addressed the uncertainties inherent in the characterization of these seismic sources through a PSHA, and this PSHA follows the guidance provided in RGs 1.165 and 1.208. The staff concludes that the controlling earthquakes and associated ground motion derived from the applicant's PSHA are consistent with the seismogenic region surrounding the ESP site. In addition, upon resolution of Open Items 2.5-6 through 2.5-9, the staff finds that the applicant's GMRS, which was developed using the performance-based approach, adequately represents the regional and local seismic hazards and accurately includes the effects of the local ESP subsurface properties. The staff concludes that the proposed ESP site is acceptable from a geologic and seismologic standpoint and meets the requirements of 10 CFR 100.23.

2.5.3 Surface Faulting

In SSAR Section 2.5.3, the applicant evaluated the potential for tectonic and nontectonic surface and near-surface deformation at the VEGP ESP site. The applicant included a review of geologic, seismic, and geophysical investigations in SSAR Section 2.5.3.1.1 to assess the potential for surface deformation that could impact the ESP site. In SSAR Sections 2.5.3.1.2 and 2.5.3.1.4, the applicant assessed geologic evidence, or the absence of evidence, for surface deformation by evaluating known geologic structures in the VEGP site vicinity. SSAR Section 2.5.3.3 provides a review of seismicity within the site vicinity (a 40-km (25-mi) radius of the VEGP site) and addresses any correlation between the seismicity and capable tectonic structures. SSAR Sections 2.5.3.1.4 and 2.5.3.1.5 evaluate the tectonic structures in the site area, how these structures relate to the regional tectonics, and any ages of deformation associated with these structures. The applicant discussed the potential for tectonic and/or nontectonic deformation at the VEGP site in SSAR Section 2.5.3.1.8. On the basis of this evaluation, the applicant concluded that (1) no capable tectonic sources exist within the VEGP site area (within an 8-km (5-mi) radius); (2) the potential for tectonic fault displacement is negligible; (3) only limited potential exists for nontectonic surface deformation within the site area; and (4) the potential for nontectonic surface deformation can be mitigated by excavation of materials.

2.5.3.1 Technical Information in the Application

2.5.3.1.1 Geologic, Seismic, and Geophysical Investigations

In SSAR Section 2.5.3.1, the applicant described the geologic, seismic, and geophysical investigations performed to assess the potential for tectonic and nontectonic surface and near-surface deformation at and within an 8-km (5-mi) radius of the VEGP site. The applicant reviewed previous VEGP site investigations, published geologic mapping, previous SRS investigations, previous seismicity data, previous seismic reflection data, current seismic reflection studies, and current aerial and field reconnaissance. The applicant stated that geologic and geomorphic investigations within and beyond the site vicinity (a 40-km (25-mi) radius) and interpretation of aerial photographs taken within the site area (an 8-km (5-mi) radius) were used to supplement existing information for documenting the presence or absence of features indicative of potential Quaternary (1.8 million years ago (mya) to present) fault activity at or near the site. Based on the information presented in SSAR Sections 2.5.3.1.1 through 2.5.3.1.7, the applicant concluded that no capable tectonic sources occur within the site area and that there is negligible potential for surface or near-surface fault rupture.

Data from Previous Investigations

SSAR Section 2.5.3.1.1 describes previous site area investigations conducted for VEGP Units 1 and 2. SSAR Section 2.5.3.1.2 describes the applicant's review of published geologic maps for analyzing surface deformation within the site area. The applicant reviewed previous SRS investigations (SSAR Section 2.5.3.1.3), including geologic, seismic, hydrologic, and geophysical investigations, and concluded that the Pen Branch fault does not exhibit surface deformation, is not a capable tectonic structure, and is not favorably oriented in the modern-day stress regime to experience displacement. In SSAR Section 2.5.3.1.4, the applicant reviewed historical seismicity and microseismicity data for the site vicinity (within a 40-km (25-mi) radius) and the site area (within an 8-km (5-mi) radius). The applicant stated that no recent earthquake activity has occurred within the site area and that the closest microearthquake to the ESP site is located on the SRS, about 11 km (7 mi) to the northeast of the VEGP. In SSAR Section 2.5.3.1.5, the applicant discussed previous seismic reflection studies and again concluded that the Pen Branch fault is not a capable tectonic structure.

Data from Current Investigations

The applicant described current seismic reflection studies in SSAR Section 2.5.3.1.6 and current aerial and field reconnaissance studies in SSAR Section 2.5.3.1.7. These investigations were performed for the ESP application in order to image the Pen Branch fault beneath the surface and to check for evidence of surface faulting within the ESP site vicinity. The applicant stated that the Pen Branch fault was clearly imaged beneath the ESP site area in the seismic reflection data. The applicant concluded that, based on aerial and field reconnaissance data, no geomorphic features within the site vicinity display evidence for surface rupture, surface warping, or fault offset.

2.5.3.1.2 Geologic Evidence, or Absence of Evidence, for Surface Deformation

In SSAR Section 2.5.3.2, the applicant stated that four bedrock faults are mapped within a 5-mile radius of the VEGP ESP site. These faults, interpreted from seismic reflection, borehole, gravity, and magnetic and/or ground water data, include the Pen Branch, Ellenton, Steel Creek, and Upper Three Runs faults. Of these four faults, only the Pen Branch fault is interpreted to extend beneath the VEGP ESP site area, motivating the applicant to perform a detailed investigation of the Pen Branch fault as it relates to the ESP site. A complete description of the applicant's investigation of the Pen Branch fault is included in SSAR Section 2.5.1.2.4.1. The remaining three faults, mapped in relation to the SRS, are located within a 5-mile radius of the VEGP site, but are not interpreted to extend beneath the site. The applicant concluded that none of the four faults mapped within the site area display evidence of surface rupture and that none of these faults are capable tectonic structures.

Pen Branch Fault

The applicant presented its conclusions regarding the Pen Branch fault in SSAR Sections 2.5.3.2.1 and 2.5.3.5.1. The Pen Branch fault is more than 30 km (greater than 20 mi) in length along its northeastern strike direction and forms the northwest boundary of the Dunbarton Triassic basin. The fault initially accommodated regional crustal extension during the Mesozoic (248 to 65 mya) by normal slip during the Triassic (248 to 206 mya) period to form the Dunbarton Basin, and was reactivated in the Cretaceous (144 to 65 mya) and Tertiary (65 to 2 mya) as a reverse fault. The Pen Branch fault is not exposed or geomorphically expressed at the surface, and borehole and seismic reflection data collected at the SRS show no evidence for post-Eocene slip on the fault. The Ellenton Quaternary terrace (Qte) at the SRS, dated between 350,000 and 1 mya in age, was evaluated for the ESP application and demonstrates no Quaternary tectonic deformation of the terrace surface within a resolution of about 1 m (3 ft). Both previous and more recent investigations to define the presence or absence of surface deformation related to displacement on the Pen Branch fault indicate no evidence of Quaternary (1.8 mya to present) deformation. Based on these findings, the applicant concluded that the Pen Branch fault is not interpreted as a capable tectonic source.

Ellenton Fault

In SSAR Sections 2.5.3.2.2 and 2.5.3.5.2, the applicant summarized geologic evidence for the absence of surface deformation due to slip on the Ellenton fault, located about 7.4 km (4.6 mi) from the VEGP site. As initially mapped by Stieve and Stephenson (1995), the Ellenton fault was a north-northwest striking fault located in the Dunbarton Basin between the Upper Three Runs and Pen Branch faults. The applicant stated that the Ellenton fault likely does not exist because the data used to suggest the existence of this potential structure were acknowledged to be of poor quality; there is no geomorphic expression of this fault at the surface; and the fault does not appear on the most recent SRS fault maps by Cumbest et al. (2000). Therefore, the applicant concluded that this fault could not represent a capable tectonic structure within the site area.

Steel Creek Fault

In SSAR Sections 2.5.3.2.3 and 2.5.3.5.3, the applicant summarized geologic evidence for the absence of surface deformation due to slip on the Steel Creek fault, located about 4.8 km (3 mi) from the VEGP site. This fault is interpreted to be more than 17.7 km (greater than 11 mi) in length, with a northeast strike and a northwest dip, and exhibits reverse slip movement. The Steel Creek fault cuts upward into Cretaceous units, but its uppermost extension remains unresolved. Longitudinal profiles along Quaternary fluvial terraces overlying the surface projection of the fault, with a resolution of 2-3 m (7-10 ft), show no evidence of warping or faulting of the terrace surfaces and therefore provides no evidence for Quaternary (1.8 mya) deformation. Based on a lack of geomorphic surface expression, the applicant concluded that the Steel Creek fault is not a capable tectonic structure within the site area.

Upper Three Runs Fault

In SSAR Sections 2.5.3.2.4 and 2.5.3.5.4, the applicant summarized geologic evidence for the absence of surface deformation due to slip on the Upper Three Runs fault, located about 8 km (5 mi) from the VEGP site. The fault is not included on the more recent fault map of the SRS by Cumbest et al. (2000), but its northernmost trace is roughly parallel to the Tinker Creek fault that is shown on the Cumbest et al. (2000) fault map. Seismic profiles show Coastal Plain sediments are not offset or deformed by this structure, and the fault is interpreted to be confined to basement rocks. Based on these findings and the fact that there is no geomorphic surface expression of this fault, the applicant concluded that it is not a capable tectonic structure within the site area.

2.5.3.1.3 Correlation of Earthquakes with Capable Tectonic Sources

The applicant summarized seismicity data for the VEGP ESP site vicinity in SSAR Sections 2.5.3.3 and 2.5.3.1.4 in order to determine whether any correlation exists between seismicity and capable tectonic structures. Figure 2.5.3-1 of this SER, taken from SSAR Figure 2.5.1-16, shows diffuse microseismic activity recorded by the SRS seismic recording network since 1976 within a 40-km (25-mi) radius of the VEGP site.

Based on the data shown in this figure, the applicant concluded that there is no spatial correlation of earthquake epicenters with known or postulated faults. The applicant reviewed published literature to further conclude that there are no known historical earthquake epicenters associated with bedrock faults or known tectonic structures in the site vicinity. The EPRI catalog of historical seismicity demonstrates that no known earthquake greater than body wave magnitude (m_b) 3 has occurred within the site vicinity, while the SRS seismic recording network documents no recent microseismic activity (m_b less than 3) within an 8-km (5-mi) radius of the VEGP site since 1976. The applicant stated that the nearest microearthquake event to the VEGP ESP site was located about 11 km (7 mi) northeast of the VEGP site on the SRS.

The applicant described three small earthquakes that occurred between 1985 and 1997 with magnitudes ranging between 2.0 and 2.6 and depths ranging from 2.5-6 km (1.5-3.5 mi). In addition to these events, the applicant described a magnitude 3.2 event located north of the SRS in Aiken, South Carolina, and a series of several small events (magnitudes less than or equal to 2.6) that occurred in 2001–2002 within the SRS boundaries. The applicant reviewed the locations of these events with respect to mapped faults in the ESP site vicinity, as well as previous studies of these events by Stevenson and Talwani (2004), Talwani et al. (1985), and Crone and Wheeler (2000), and concluded that there is no spatial correlation of seismicity with known or postulated faults or geomorphic features.

2.5.3.1.4 Ages of Most Recent Deformations

In SSAR Section 2.5.3.4, the applicant stated that, based on information presented in SSAR Section 2.5.3.2, none of the four faults (Pen Branch, Ellenton, Steel Creek, or Upper Three Runs) exhibit Quaternary (1.8 mya to present) displacement. Thus, the applicant concluded that none are considered capable tectonic structures. In particular, the applicant stated that the Pen Branch fault exhibits no post-Eocene (33.7 mya to present) displacement.

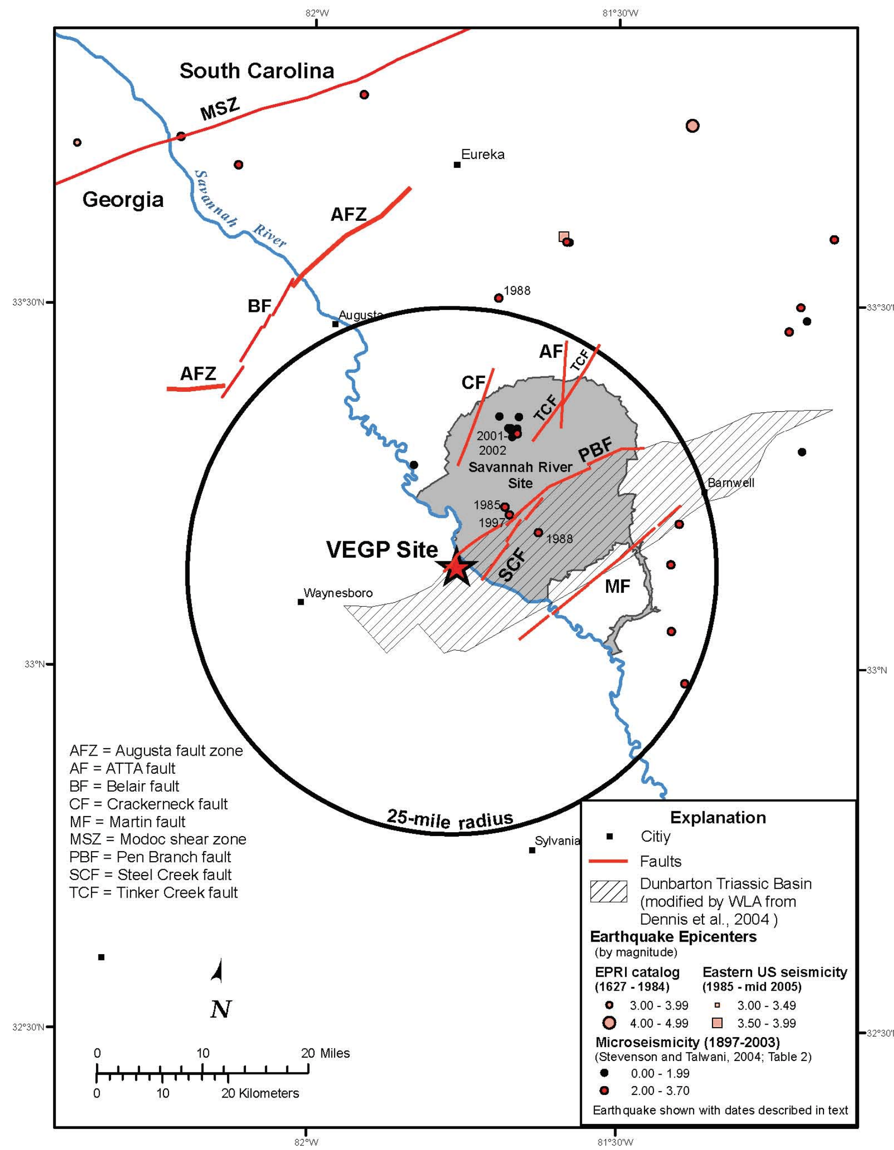

Figure 2.5.3-1 - Site Vicinity Tectonic Features and Seismicity (Reproduced from SSAR Figure 2.5.1-16)

2.5.3.1.5 Relationship of Site Area Tectonic Structures to Regional Tectonic Structures

SSAR Section 2.5.3.5 discusses the four faults identified within the site area and previously discussed in SER Section 2.5.3.1.2. Of these four faults, the applicant stated that only the Pen Branch fault occurs west of the SRS and within the ESP site area. The applicant concluded that, based on a review of all available data, none of these four faults are considered capable tectonic structures and none are associated with any capable regional tectonic structure.

2.5.3.1.6 Characterization of Capable Tectonic Sources

The applicant described characterization of capable tectonic sources in SSAR Section 2.5.3.6 and reiterated that no capable tectonic structures occur within 8 km (5 mi) of the VEGP site based on the following geologic evidence:

1. The Pen Branch fault is not exposed or expressed at the surface. Field reconnaissance and aerial photograph interpretations performed for the ESP study confirmed that there is no surface exposure of the fault or geomorphic expression indicative of Quaternary deformation.

2. Snipes et al. (1993) indicated that there was no displacement of a Quaternary soil horizon overlying the projected trace of the Pen Branch at the SRS, and the youngest horizon offset by fault displacement on the Pen Branch was the Dry Branch Formation of late Eocene age.

3. Geomatrix (1993) evaluated longitudinal profiles of Quaternary fluvial river terraces on the SRS and concluded that no evidence for warping or faulting of the terraces existed within a resolution limit of 2-3 m (7-10 ft).

4. Longitudinal terrace profiles across the now well-located Pen Branch fault also indicated no deformation of the Ellenton terrace (estimated to be 350,000 to 1 million years old) within a resolution limit of 1 m (3 ft).

5. Also as part of the ESP study, geomorphic analysis of the Ellenton terrace, which overlies the surface projection of the Pen Branch, demonstrates a lack of tectonic deformation of this Quaternary surface within a resolution limit of 1 m (3 ft). Details of this ESP study are presented in SSAR Section 2.5.1.2.4.3.

2.5.3.1.7 Designation of Quaternary Deformation Zones Requiring Detailed Investigation

In SSAR Section 2.5.3.7, the applicant concluded that no zones of Quaternary deformation requiring detailed fault investigation exist within the VEGP site area based on the absence of any Quaternary deformation features in the ESP site area.

2.5.3.1.8 Potential for Tectonic or Nontectonic Deformation at the Site

In SSAR Section 2.5.3.8.1, the applicant concluded that the potential for tectonic deformation at the ESP site is negligible and stated that no new information has been reported since the original site studies for VEGP Units 1 and 2 in the early 1970s to suggest the existence of Quaternary surface deformation. Also in SSAR Section 2.5.3.8, the applicant addressed the potential for nontectonic deformation features at the VEGP ESP site, including dissolution collapse features and clastic dikes.

In SSAR Section 2.5.3.8.2, the applicant specifically discussed the potential for nontectonic surface deformation at the ESP site, including interpretation of dissolution collapse features and clastic dikes. Regarding dissolution collapse features, which are discussed in SSAR Section 2.5.3.8.2.1, the applicant indicated that small-scale structures, including warped bedding, fractures, joints, minor fault offsets, and injected sand dikes, identified in the walls of a trench at the VEGP site were local features related to dissolution of the Utley Limestone and subsequent collapse of overlying Tertiary sediments. Age of these features was interpreted to be younger than Eocene-Miocene host sediments and older than the overlying late-Pleistocene Pinehurst Formation. The applicant stated that no late Pleistocene or Holocene dissolution features were identified at the site. The applicant indicated that mitigation of collapse due to dissolution of the Utley Limestone, which overlies the Blue Bluff Marl at the site, could be accomplished by planned excavation and removal of the Utley Limestone to establish the foundation grade of the plant atop the Blue Bluff Marl.

In SSAR Section 2.5.3.8.2.2, the applicant addressed clastic dikes, described as relatively planar, narrow (centimeter-to-decimeter wide) clay-filled features that flare upwards and are decimeters to meters in length. Bechtel (1984) distinguished two types of clastic dikes in the walls of the trench on the VEGP site where dissolution collapse features were found. The first type of clastic dikes was interpreted to be sand dikes that resulted from injection of poorly consolidated fine sand into overlying sediments; the second type was clastic dikes produced by weathering and soil formation processes that were enhanced along fractures that formed during dissolution collapse. Bechtel (1984) concluded the dikes were primarily a weathering phenomenon controlled by depth of weathering and paleosol development in Coastal Plain sediments and subsequent erosion of the land surface. Clastic dike features identified by Bartholomew et al. (2002) within the site area were observed during the ESP field reconnaissance. The applicant interpreted these features to be nontectonic in origin, although Bartholomew et al. (2002) suggested that they might be evidence for paleoearthquakes associated with late-Eocene to late-Miocene faulting, possibly along the Pen Branch fault.

2.5.3.2 Regulatory Evaluation

The acceptance criteria for evaluating the potential for surface or near-surface tectonic and nontectonic deformation are based on meeting the relevant requirements of 10 CFR 52.17 and 10 CFR Part 100.23. The staff considered the following regulatory requirements in reviewing the applicant's discussion of information on surface faulting:

- 10 CFR 53.17(a)(1)(vi), which requires that an ESP application contain a description of the geologic and seismic characteristics of the proposed site.

- 10 CFR 100.23(c), which requires an ESP applicant to investigate geologic, seismic, and engineering characteristics of a site and its environs in sufficient scope and detail to permit an adequate evaluation of the proposed site; to provide sufficient information to support evaluations performed to determine the SSE Ground Motion; and to permit adequate engineering solutions to actual or potential geologic and seismic effects at the proposed site.

- 10 CFR 100.23(d), which requires that geologic and seismic siting factors considered for design include a determination of the SSE Ground Motion for the site; the potential for surface tectonic and non-tectonic deformation; the design bases for seismically-induced floods and water waves; and other design conditions including soil and rock stability, liquefaction potential, and natural and artificial slope stability. Siting factors and potential causes of failure to be evaluated include physical properties of materials underlying the site, ground disruption, and effects of vibratory ground motion that may affect design and operation of the proposed power plant.

The basic geologic and seismic information assembled by the applicant in compliance with the above regulatory requirements should also be sufficient to allow a determination at the COL stage of whether the proposed facility complies with the following requirements in Appendix A to 10 CFR Part 50:

- 10 CFR Part 50, Appendix A, GDC 2, which requires that SSCs important to safety be designed to withstand the effects of natural phenomena such as earthquakes, hurricanes, floods, tsunami, and seiches without loss of capability to perform their safety functions.

- 10 CFR Part 50, Appendix S - IV, “Application to Engineered Design”, which requires that vibratory ground motion (including the Safe Shutdown Earthquake Ground Motion and the Operating Basis Earthquake Ground Motion) and surface deformation be considered in the design of a nuclear power plant.

To the extent applicable in the regulatory requirements cited above, and in accordance with RS-002, the staff applied NRC-endorsed methodologies and approaches (specified in Section 2.5.3 of NUREG-0800) for evaluation of information characterizing the potential for surface or near-surface tectonic and nontectonic deformation at the proposed site as recommended in RG 1.165.

Section 2.5.3 of NUREG-0800 and RG 1.165 provide specific guidance concerning the evaluation of information characterizing the potential for surface and near-surface deformation, including the geologic, seismic, and geophysical data that the applicant needs to provide to establish the potential for surface deformation.

2.5.3.3 Technical Evaluation

This SER section presents the staff’s evaluation of the geologic, seismic, and geophysical information submitted by the applicant in SSAR Section 2.5.3 to address the potential for surface or near-surface tectonic and nontectonic deformation within an 8-km (5-mi) radius of the ESP site (i.e., the “site area” as defined in RG 1.165). The technical information presented in SSAR Section 2.5.3 resulted from the applicant’s surface and subsurface geologic, seismic, and geophysical investigations performed within the site area, supplemented by aerial and field reconnaissance studies undertaken within a 40-km (25-mi) radius of the site (i.e., the “site vicinity” as defined in RG 1.165). Through its review, the staff determined whether the applicant had complied with the applicable regulations and conducted its investigations with an appropriate level of detail in accordance with RG 1.165.

To thoroughly evaluate the geologic, seismic, and geophysical information presented by the applicant, the staff obtained the assistance of the USGS. The staff and its USGS advisors visited the ESP site to confirm interpretations, assumptions, and conclusions presented by the applicant and related to the potential for surface or near-surface faulting and nontectonic deformation.

2.5.3.3.1 Geologic, Seismic, and Geophysical Investigations

In SSAR Sections 2.5.3.1.1 through 2.5.3.1.7, the applicant reviewed and summarized information related to previous VEGP site investigations (Section 2.5.3.1.1), published geologic mapping (Section 2.5.3.1.2), previous SRS investigations (Section 2.5.3.1.3), previous seismicity data (Section 2.5.3.1.4), previous seismic reflection data (Section 2.5.3.1.5), current seismic reflection studies (Section 2.5.3.1.6), and current aerial and field reconnaissance (Section 2.5.3.1.7).

Based on the information presented in SSAR Sections 2.5.3.1.1 through 2.5.3.1.7, the applicant concluded that no capable tectonic sources occur within the site area and that there is negligible potential for surface or near-surface fault rupture. Consequently, the applicant considered the site suitable in regard to the potential for surface or near-surface faulting. The staff’s review of SSAR Sections 2.5.3.1.1 through 2.5.3.1.7 is presented below.

<u>Data from Previous Investigations</u>

The staff focused its review of SSAR Sections 2.5.3.1.1 through 2.5.3.1.5 on the applicant’s descriptions of previous studies and data collected within the site area in order to assess the potential for surface tectonic deformation at the ESP site. In SSAR Section 2.5.3.1.1, the applicant described the results of previous investigations conducted for VEGP Units 1 and 2, which support the concepts that the Pen Branch fault (known to underlie the ESP site) exhibits no surface displacement and is a noncapable tectonic structure and that nontectonic deformation features occur in the site area. In SSAR Section 2.5.3.1.2, the applicant discussed information from published geologic maps documenting the existence of nontectonic deformation features in the site area. SER Section 2.5.3.3.9 provides a more detailed discussion of nontectonic features in the site area. The applicant also stated in SSAR Section 2.5.3.1.2 that Crone and Wheeler (2000) and Wheeler (2005) classified the Pen Branch fault as a Class C feature based on insufficient geologic evidence to document Quaternary displacement along the fault. In SSAR Section 2.5.3.1.3, the applicant cited evidence collected from the SRS that the Pen Branch fault does not exhibit surface displacement, is not a capable tectonic structure, and is not favorably oriented in the modern-day stress field to experience displacement. In SSAR Section 2.5.3.1.4, the applicant stated that no recent earthquake activity has occurred within the site area based on microseismicity data. In SSAR Section 2.5.3.1.5, the applicant discussed previous seismic reflection studies supporting the interpretation that the Pen Branch fault is not a capable tectonic structure.

Based on a review of SSAR Sections 2.5.3.1.1 through 2.5.3.1.5, the staff concludes that the applicant presented thorough and accurate descriptions of previous studies and data collected within the site area. The applicant used this information to assess the potential for tectonic deformation at the ESP site, which is required by 10 CFR 52.17(a)(1)(vi), 10 CFR 100.23(c), and 10 CFR 100.23(d). These five SSAR sections present well-documented geologic information that the applicant derived from published sources. The applicant provided an extensive list of references for these sources which the staff examined in order to ensure the accuracy of the information presented by the applicant in the SSAR.

Data from Current Investigations

The staff focused its review of SSAR Sections 2.5.3.1.6 and 2.5.3.1.7 on the applicant's descriptions of the investigations performed to image the Pen Branch fault at the ESP site using seismic reflection and to look for evidence of surface faulting in the site vicinity using field and aerial reconnaissance. In SSAR Section 2.5.3.1.6, the applicant stated that the Pen Branch fault is clearly imaged beneath the ESP site in the seismic reflection data. In SSAR Section 2.5.3.1.7, the applicant indicated that no geomorphic evidence exists for surface rupture, surface warping, or fault offset. The applicant also reported its reinterpretation of features observed within the site vicinity and initially considered as possible evidence for tectonic activity. The applicant reinterpreted these features as nontectonic in origin.

Based on its review of SSAR Sections 2.5.3.1.6 and 2.5.3.1.7, the staff concludes that the applicant presented thorough and accurate descriptions of data from current investigations within the site area in order to assess the potential for tectonic deformation at the ESP site. This supports the requirements set forth in 10 CFR 52.17(a)(1)(vi), 10 CFR 100.23(c), and 10 CFR 100.23(d). The staff further concludes that the applicant presented adequate evidence to support the conclusions that the Pen Branch fault underlies the ESP site. The staff believes that the applicant also provided adequate evidence that no surface rupture due to displacement along the Pen Branch fault exists in the site area or site vicinity. SER Section 2.5.1.3.4 presents the staff's evaluations and conclusions regarding all new information that was collected by the applicant to assess the Pen Branch fault. This information was used to support the applicant's conclusions that the Pen Branch fault does not exhibit surface rupture or Quaternary (1.8 mya to present) displacement and is not a capable tectonic feature at the ESP site.

2.5.3.3.2 Geologic Evidence for Surface Deformation

In SSAR Section 2.5.3.2, the applicant described four bedrock faults identified within the site area. These structures include the Pen Branch, Ellenton, Steel Creek, and Upper Three Runs faults which the applicant discussed in SSAR Sections 2.5.3.2.1, 2.5.3.2.2, 2.5.3.2.3, and 2.5.3.2.4, respectively. Based on information presented in SSAR Sections 2.5.3.2 and 2.5.1.2.4, the applicant concluded that none of the four faults mapped within the site area show any evidence of surface rupture and that none of the faults are capable tectonic sources. The staff's evaluation of SSAR Section 2.5.3.2, including Sections 2.5.3.2.1, 2.5.3.2.2, 2.5.3.2.3, and 2.5.3.2.4, is presented below.

The staff focused its review of SSAR Section 2.5.3.2 on the applicant's descriptions of the four bedrock faults mapped within the site area. The staff concludes that the applicant presented accurate descriptions of these four faults to enable assessment of the potential for tectonic surface deformation within the site area. This assessment is required by 10 CFR 52.17(a)(1)(vi), 10 CFR 100.23(c), and 10 CFR 100.23(d). Based on a review of the information presented by the applicant in SSAR Section 2.5.3.2, as well as information discussed in SSAR Section 2.5.1.2.4, the staff concurs with the applicant that none of these four faults exhibit surface displacement and none are capable tectonic features.

Rationale for the staff's conclusions in regard to the existence of surface faulting in the site vicinity and at the site, particularly in relation to the Pen Branch fault, is presented in detail in SER Section 2.5.1.3.4, which discusses geology of the site area. Also in this section, the staff presents a summary of the lines of evidence cited by the applicant in the SSAR to indicate that the Pen Branch fault does not exhibit Quaternary displacement and is not a capable tectonic feature.

2.5.3.3.3 Correlation of Earthquakes with Capable Tectonic Sources

In SSAR Section 2.5.3.3, the applicant described the distribution of epicenters for instrumentally recorded earthquakes that have occurred in the site vicinity (within an 8-km (5-mi) radius). The applicant stated that neither historical nor instrumentally recorded earthquake epicenters show a correlation with known or postulated faults in the site vicinity. Based on information presented in SSAR Section 2.5.3.3, as well as in SSAR Section 2.5.1.1.4.3 and SSAR Figure 2.5.1-16, the applicant concluded that no spatial correlation exists between earthquake epicenters and known or postulated faults in the site vicinity or site area. The staff's evaluation of SSAR Section 2.5.3.3 is presented below.

The staff focused its review of SSAR Section 2.5.3.3 on the applicant's description of historical and instrumentally recorded earthquake epicenters and faults that have occurred within the site vicinity. The staff concludes that the applicant presented convincing data and logical interpretations related to a lack of correlation between earthquakes and tectonic sources in support of the ESP application and as required by 10 CFR 52.17(a)(1)(vi), 10 CFR 100.23(c), and 10 CFR 100.23(d). Based on a review of the information presented by the applicant in SSAR Section 2.5.3.3, as well as information presented by the applicant in SSAR Section 2.5.1.1.4.3 and SSAR Figure 2.5.1-16, the staff concurs with the applicant's conclusion that no spatial correlation exists between earthquake epicenters and faults in the site vicinity or site area.

2.5.3.3.4 Ages of Most Recent Deformations

In SSAR Section 2.5.3.4, the applicant discussed information related to ages of the most recent deformations indicated for the four bedrock faults identified within the site area (i.e., the Pen Branch, Ellenton, Steel Creek, and Upper Three Runs faults). Based on information presented in SSAR Sections 2.5.3.4 and 2.5.1.2.4, the applicant concluded that none of these four faults exhibit Quaternary displacement and none are considered capable tectonic structures. For the Pen Branch fault, the applicant stated that there is no evidence indicating this fault has experienced displacement younger than Eocene (i.e., less than 33.7 mya). The Pen Branch fault is of particular concern to the staff because it underlies the ESP site. The staff's evaluation of SSAR Section 2.5.3.4 is presented below.

The staff focused its review of SSAR Section 2.5.3.4 on the applicant's discussion of the ages of most recent deformations indicated for the four bedrock faults mapped within the site area. The staff concludes that the applicant presented accurate descriptions of the ages of deformation for these four faults in order to enable an accurate assessment of Quaternary displacement along faults within the ESP site area and at the ESP site. This assessment is required by 10 CFR 52.17(a)(1)(vi), 10 CFR 100.23(c), and 10 CFR 100.23(d). Based on a review of the information presented by the applicant in SSAR Section 2.5.3.4, as well as information discussed in SSAR Section 2.5.1.2.4, the staff concurs with the applicant's conclusion that none of these four faults exhibit Quaternary displacement.

Rationale for the staff's conclusions in regard to the ages of most recent deformation, specifically for the Pen Branch fault, is presented in detail in SER Section 2.5.1.3.4. Also in this section, the staff presents a summary of the lines of evidence used by the applicant in the SSAR indicating that the Pen Branch fault does not exhibit Quaternary displacement and is not a capable tectonic feature.

2.5.3.3.5 Relationship of Site Area Tectonic Features to Regional Tectonic Structures

In SSAR Section 2.5.3.5, the applicant discussed the four faults identified within the site area. These structures include the Pen Branch, Ellenton, Steel Creek, and Upper Three Runs faults, which the applicant discussed in SSAR Sections 2.5.3.5.1, 2.5.3.5.2, 2.5.3.5.3, and 2.5.3.5.4, respectively. Of these four faults, the applicant indicated that only the Pen Branch fault occurs west of the SRS on the ESP site. Based on information presented in SSAR Section 2.5.3.5, the applicant concluded that none of the four faults is considered a capable tectonic feature within the site area, effectively concluding that none are linked with any capable regional tectonic structure. The staff's evaluation of SSAR Section 2.5.3.5 is presented below.

The staff focused its review of SSAR Section 2.5.3.5 on the applicant's descriptions of these four faults identified within the site area. The staff concludes that the applicant presented accurate descriptions of these four faults to enable assessment of possible linkage with regional tectonic structures in support of the ESP application and as required by 10 CFR 52.17(a)(1)(vi), 10 CFR 100.23(c), and 10 CFR 100.23(d). Based on a review of the information presented by the applicant in SSAR Section 2.5.3.5, as well as information discussed in SSAR Section 2.5.1.2.4, the staff concurs with the conclusions of the applicant that none of the four faults is a capable tectonic feature and none are linked with a capable regional tectonic structure.

2.5.3.3.6 Characterization of Capable Tectonic Sources

In SSAR Section 2.5.3.6, the applicant stated that no capable tectonic sources occur within the site area. The applicant summarized the data supporting a noncapable status for the Pen Branch fault. Based on information presented in SSAR Section 2.5.3.6, the applicant concluded that no capable tectonic sources exist in the site area that would require characterization. The staff's evaluation of SSAR Section 2.5.3.6 is presented below.

The staff focused its review of SSAR Section 2.5.3.6 on the applicant's description of the Pen Branch fault. The staff concludes that the applicant presented an accurate summary to enable assessment of the capability of the Pen Branch fault in support of the ESP application and as required by 10 CFR 52.17(a)(1)(vi), and 10 CFR 100.23(c), 10 CFR 100.23(d). Based on a review of the information presented by the applicant in SSAR Section 2.5.3.6, as well as information discussed in SSAR Section 2.5.1.2.4, the staff concurs with the applicant's conclusion that no capable tectonic sources exist in the site area requiring characterization, including the Pen Branch fault.

Rationale for the staff's conclusions in regard to the noncapability of the Pen Branch fault is presented in detail in SER Section 2.5.1.2.4. Also in SER Section 2.5.1.3.4, the staff presents a summary of the lines of evidence used by the applicant in the SSAR indicating that the Pen Branch fault does not exhibit Quaternary displacement and is not a capable tectonic feature.

2.5.3.3.7 Designation of Zones of Quaternary Deformation for Detailed Investigation

In SSAR Section 2.5.3.7, the applicant concluded that there are no zones of Quaternary deformation within the site area which require detailed investigation. The applicant based its conclusion on data presented in SSAR Sections 2.5.1.2.4, 2.5.3.2, 2.5.3.4, and 2.5.3.5. The staff's evaluation of SSAR Section 2.5.3.7 is presented below.

The staff focused its review of SSAR Section 2.5.3.7 on the applicant's descriptions of faults identified in the site area and discussed in SSAR Sections 2.5.1.2.4, 2.5.3.2, 2.5.3.4, and 2.5.3.5. The staff concludes that the applicant presented accurate descriptions of faults identified in the site area to enable an assessment of Quaternary deformation within the site area and at the ESP site in support of the ESP application and as required by 10 CFR 52.17(a)(1)(vi), 10 CFR 100.23(c), and 10 CFR 100.23(d). Based on a review of this information, the staff concurs with the applicant's conclusion that there are no zones of Quaternary deformation within the site area that require a detailed investigation.

Rationale for the staff's conclusions in regard to a lack of Quaternary deformation in the site area is presented in detail in SER Section 2.5.1.3.4. Also in SER Section 2.5.1.3.4, the staff presents a summary of the lines of evidence cited by the applicant in the SSAR to indicate that the Pen Branch fault does not exhibit Quaternary displacement and is not a capable tectonic feature.

2.5.3.3.8 Potential for Surface Tectonic Deformation

In SSAR Section 2.5.3.8.1, the applicant stated that the Pen Branch fault is noncapable and will not cause surface rupture in the future. The applicant also stated that the nonbrittle folding of the Blue Bluff Marl, interpreted to result from displacement along the Pen Branch fault, indicates near-surface tectonic deformation that is not younger than Eocene (i.e., less than 33.7 mya). Based on information summarized in SSAR Section 2.5.3.8.1, which is discussed in more detail by the applicant in SSAR Section 2.5.1.2.4.2, the applicant concluded that the potential for tectonic deformation at the site is negligible. The staff's evaluation of SSAR Section 2.5.3.8.1 is presented below.

The staff focused its review of SSAR Section 2.5.3.8.1 on the applicant's discussion of near-surface tectonic deformation interpreted by the applicant to result from displacement along the Pen Branch fault more than 33.7 mya. The staff concludes that the applicant presented an accurate discussion of the field data indicating no displacement along the Pen Branch fault younger than Eocene in the site area. This assessment is required by 10 CFR 52.17(a)(1)(vi), 10 CFR 100.23(c), and 10 CFR 100.23(d). Based on a review of the information presented by the applicant in SSAR Sections 2.5.3.8.1 and 2.5.1.2.4.2, the staff concurs with the conclusion of the applicant that the potential for tectonic deformation at the site is negligible.

2.5.3.3.9 Potential for Nontectonic Deformation

In SSAR Section 2.5.3.8.2, the applicant discussed dissolution collapse features (SSAR Section 2.5.3.8.2.1) and clastic dikes (SSAR Section 2.5.3.8.2.2). Based on information presented in SSAR Section 2.5.3.8.2.1, the applicant stated that dissolution collapse features are not tectonic structures or paleoseismic features and concluded that they do not represent a safety issue for the ESP site in regard to nontectonic surface deformation. Based on information presented in SSAR Section 2.5.3.8.2.2, the applicant stated that clastic dikes in the site area are of two types: (1) sand dikes, produced by injection of weakly consolidated fine sand into overlying sediments, and (2) clastic dikes, produced by weathering and soil-forming processes enhanced along fractures. The applicant stated that these dikes are also not tectonic structures or paleoseismic features and likewise concluded that they do not represent a safety issue for the ESP site in regard to nontectonic surface deformation. The staff's evaluation of SSAR Section 2.5.3.8.2 is presented below.

The staff focused its review of SSAR Section 2.5.3.8.2 on the applicant's descriptions of the modes of formation of the dissolution collapse features and clastic dikes (both the injection type and the weathering type discussed above) which the applicant used to conclude that these features resulted from nontectonic deformation. The applicant also referred to "small-scale deformation features" in SSAR Sections 2.5.3.1.2 and 2.5.3.1.7, considered by McDowell and Houser (1983) and Bartholomew et al. (2002) to be possible evidence of tectonic activity. The applicant stated in SSAR Sections 2.5.3.1.2, 2.5.3.1.7, and 2.5.3.8.2.2 that these features are considered to be nontectonic in origin based on observations made by the applicant during field reconnaissance studies performed for the ESP application. The applicant did not fully discuss the field observations and reasoning used to conclude that these small-scale deformation features are nontectonic in origin and did not provide adequate information about the origin of the injection sand dikes and clastic dikes.

In RAI 2.5.3-1, the staff asked the applicant to more clearly describe its logic for concluding that the deformation features mapped and described by McDowell and Houser (1983) and Bartholomew et al. (2002) are nontectonic in origin. In RAI 2.5.3-2, the staff asked the applicant for additional information on field data used by the applicant to conclude that the injection sand dikes and clastic dikes are nontectonic in origin. These clarifications are important since paleoliquefaction features related to the 1886 Charleston earthquake, or other seismic events, are known to occur in the region and because the staff must ensure that none of the features described by the applicant in SSAR Sections 2.5.3.1.2, 2.5.3.1.7, and 2.5.3.8.2.2 are related to Quaternary tectonic deformation.

In response to RAI 2.5.3-1, the applicant stated that, based on reconnaissance of exposures in the site area, certain primary characteristics of clastic dikes suggested an origin consistent with a pedogenic (i.e., related to soil formation) origin for these features. Specifically, (1) the dikes are widely distributed in deeply weathered clayey and silty sands of the Hawthorne Formation and the Barnwell Group formations; (2) the dikes occur in nearly all exposures of the weathered profile, but are in exposures of stratigraphically lower, less weathered sediment; (3) the dikes contain a central zone of bleached host rock bounded by a cemented zone of iron oxide and may contain a clay core; (4) grain-size analyses indicate that the dike contains the same grain-size distribution as the host sediment, but with more silt and clay; and (5) the dikes decrease downward in width and density, usually tapering and pinching out over a distance of 5 to 15 feet. The applicant indicated that the clastic dikes identified by Bartholomew et al. (2002) are syndepositional, as indicated by the presence of marine animal burrows crossing the dikes, and that they developed in a subaqueous marine environment during the Late Eocene (i.e., greater than 33.7 mya). Based on these lines of evidence, the applicant concluded that the clastic dikes observed in the site area are pedogenic and not tectonic in origin. The applicant also concluded that the clastic dikes described by Bartholomew et al. (2002), whether their origin is tectonic or nontectonic, developed more than 33.7 mya.

Based on its review of the applicant’s response to RAI 2.5.3-1, the staff concurs with the applicant that the clastic dikes described by Bartholomew et al. (2002) are older than 33.7 mya. The staff further concludes, in agreement with the applicant, that the clastic dikes observed in the site area are the result of pedogenic processes and are nontectonic in origin.

In response to RAI 2.5.3-2, the applicant indicated that the deformation features (i.e., warped bedding, fractures, small-scale faults, injection sand dikes, and clastic dikes), interpreted by the applicant to be nontectonic in origin, occurred in a garbage trench on the VEGP site mapped by the Bechtel staff in 1984. The trench (now filled but illustrated in SSAR Figures 2.5.3-1 and 2.5.3-2, as well as in Figure 2.5.3-2A accompanying the applicant’s RAI response) contained the uppermost part of a monocline in the Blue Bluff Marl, which is interpreted by the applicant to be related to Eocene displacement along the Pen Branch fault. The monocline is positioned over the subsurface line of intersection with the Pen Branch fault and the contact of basement rock and Coastal Plain sediments.

In response to RAI 2.5.3-2, the applicant also stated that the local spatial relationships of warped bedding, fractures, and small-scale faults with the margins of dissolution depressions clearly demonstrate a nontectonic, dissolution collapse origin for these features. The applicant cited the trench map produced by Bechtel (1984), illustrated in Figure 2.5.3-2A which accompanied its response to RAI 2.5.3-2, as conclusive evidence for this statement. The applicant reiterated the five primary characteristics of clastic dikes presented in its response to RAI 2.5.3-1, which suggested an origin consistent with a pedogenic origin for these features.

In response to RAI 2.5.3-2, the applicant further indicated that the injection sand dikes likely formed by fluid or plastic injection of an underlying source sand and that the close spatial association of the injection dikes with the sides of dissolution collapse depressions suggests this type of dike is also related to a nontectonic, dissolution collapse origin. The applicant also stated that the injection sand dikes likely formed prior to an erosional event which occurred at the end of the Miocene (i.e., more than 5.3 mya), but did not discuss the basis for this statement in detail in the RAI response. The applicant also stated that clastic dikes developed during a weathering event that is older than Late Pleistocene (i.e., greater than 10,000 years ago).

Based on its review of the applicant's response to RAI 2.5.3-1, the staff concurs with the applicant that the clastic dikes described by Bartholomew et al. (2002) are older than 33.7 mya. The staff further concludes, in agreement with the applicant, that the clastic dikes observed in the site area are the result of pedogenic processes and are nontectonic in origin.

Based on its review of the applicant's response to RAI 2.5.3-2, the staff concludes that the response qualifies the timing of the development of warped bedding, fractures, small-scale faults, clastic dikes, and injection sand dikes. The timing of development suggested by information presented by the applicant is as follows:

1. Deposition of Tertiary (i.e., a range of 65 to 1.8 mya in age) sedimentary units, including at least Eocene (54.8 to 33.7 mya) and Miocene (23.8 to 5.3 mya) sediments, with some periods of subaerial (i.e., above water in open air) erosion.

2. Initiation of dissolution of the Utley Limestone (Late Eocene in age) at the base of the Eocene Barnwell Group, with development of incipient depressions and formation of injected sand dikes in Barnwell Unit "D" above the Utley Limestone is illustrated in Figure 2.5.3-2A of the applicant's response to RAI 2.5.3-2. The initiation of dissolution and development of the injected sand dikes occurred after deposition of the sedimentary units in which they are found, and the applicant reported Late Pleistocene (greater than 10,000 years in age) to Holocene (less than 10,000 years in age) sands which do not appear to be deformed overlying the warped bedding, fractures, small-scale faults, and clastic dikes in the trench mapped by Bechtel (1984).

3. Continued and increasing dissolution of the Utley Limestone, with numerous nontectonic dissolution collapse features developed in overlying units, including collapse-generated faulting that cuts, and consequently postdates, the injected sand dikes. Consequently, the injected sand dikes are the oldest of the deformation features mapped which the applicant equated with a response to nontectonic near-surface deformation.

4. Development of nontectonic clastic dikes above the sedimentary units which experienced dissolution collapse, many in the Miocene-age Hawthorne Formation based on Figure 2.5.3-2A of the applicant's response to RAI 2.5.3-2. The clastic dikes do not extend into Late Pleistocene to Holocene-age sands, indicating that the clastic dikes are at least 10,000 years old.

The staff concludes that the evidence presented by the applicant in the response to RAI 2.5.3-2 clearly documents a nontectonic origin for the warped bedding, fractures, small-scale faults, and clastic dikes.

In regard to the origin of the injection sand dikes, the applicant made the case that these features are the oldest structures generated by nontectonic deformation in the site area. That is, the applicant considered that the injection sand dikes are not related to paleoliquifaction resulting from Quaternary tectonic deformation and seismic shaking in the site area. From information presented by the applicant in the SSAR and its response to RAI 2.5.3-2, the staff concludes that the injection sand dikes are the oldest of the observed features, and the age constraints discussed by the applicant appear to limit the youngest timing for development of these features to earlier than Late Pleistocene (i.e., greater than 10,000 years in age) and possibly Pliocene (5.3 to 1.8 mya). This upper age limit for the injection sand dikes is supported by information provided by the applicant in the response to RAI 2.5.3-2, suggesting that the dikes pre-date an erosional event at or near the end of the Miocene (23.8 to 5.3 mya). Consequently, even if the origin of the injection sand dikes were to be related to tectonism (i.e., the result of seismically induced paleoliquefaction), the features are not Holocene (10,000 years to present) in age, although a Pleistocene age (1.8 mya to 10,000 years) is not precluded based on information provided by the applicant in the response to RAI 2.5.3-2.

The staff concurs with the applicant that no evidence exists to indicate any of these features represent a safety issue for the ESP site in regard to nontectonic surface or near-surface deformation. However, timing and origin of the injection sand dikes should be discussed in more detail by the applicant since it was not possible for NRC staff to examine these features in the field during the site visit. The staff considers that the applicant's responses in regard to the injection sand dikes do not provide adequate information to bracket the pre-Miocene upper age limit for development of this feature as suggested by the applicant. The staff notes that stratigraphic information suggests these dikes may be as young as Pleistocene. Furthermore, the staff considers that the applicant did not clearly show that the injection sand dikes are spatially related to what must have been incipient dissolution depressions (i.e., most of the dissolution occurred after development of the injection sand dikes since, as the applicant pointed out, nontectonic small-scale faults associated with dissolution collapse cross cut the injection dikes). In light of the fact that the mechanism described by the applicant to be responsible for the sand injection (i.e., fluid or plastic injection of the source sand) could be associated with seismic shaking and liquefaction, the staff believes a more detailed description of geometry and appearance of the injection sand dikes and the spatial association with dissolution depressions is warranted, including photographs of this feature, if available. This issue is **Open Item 2.5-10**.

With the exceptions noted above in the discussion of Open Item 2.5-10 in relation to injection sand dikes, based on a review of the information presented by the applicant in SSAR Section 2.5.3.8.2 and the applicant's responses to RAI 2.5.3-1 and RAI 2.5.3-2, the staff concurs with the applicant's conclusion that warped bedding, fractures, small-scale faults, and clastic dikes represent nontectonic deformation. The staff concludes that the applicant presented thorough descriptions of these features to enable assessment of nontectonic surface or near-surface deformation within the site area and at the ESP site in support of the ESP application as required by 10 CFR 52.17(a)(1)(vi), 10 CFR 100.23(c), and 10 CFR 100.23(d). The issue related to timing and origin of the injection sand dikes as identified in Open Item 2.5-10 should be discussed in more detail by the applicant.

Based on its review of SSAR Section 2.5.3 and the applicant's responses to RAIs as set forth above, the staff concludes that the applicant properly characterized the potential for surface and near-surface tectonic and nontectonic deformation at the ESP site, including the possibility of Quaternary tectonic deformation along the Pen Branch fault. The staff also concludes that SSAR Section 2.5.3 provides accurate and thorough descriptions of the potential for surface and near-surface tectonic and nontectonic deformation at the ESP site, with emphasis on the Quaternary Period, as required by 10 CFR 52.17(a)(1)(vi), 10 CFR 100.23(c), and 10 CFR 100.23(d).

2.5.3.4 Conclusions

As set forth in SER Sections 2.5.3.1, 2.5.3.2, and 2.5.3.3, the staff carefully reviewed the information on surface faulting submitted by the applicant in SSAR Section 2.5.3. On the basis of its detailed review, as fully described in the above SER sections, the staff concludes that the applicant provided a thorough and accurate characterization of surface and near-surface faulting and nontectonic deformation at the site as required by 10 CFR 52.17(a)(1)(vi), 10 CFR 100.23(c), and 10 CFR 100.23(d). The staff concurs that data and analyses presented by the applicant in the SSAR provide an adequate basis to conclude that there is no evidence to indicate that surface or near-surface faulting or nontectonic deformation presents a hazard for the site area.

Based on information from the applicant's thorough review of the literature on site area geology in regard to surface expression of faulting, and the applicant's literature review and geologic, seismic, and geophysical investigations of the site vicinity and site area, the staff further concludes that the applicant has properly characterized the potential for surface or near-surface faulting and nontectonic deformation at the ESP site.