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2.5.3 Surface Faulting

This section evaluates the potential for tectonic surface deformation and non-tectonic surface deformation at the VCS site. Information contained in this section is developed in accordance with RG 1.208 and is intended to demonstrate compliance with 10 CFR 100.23, *Geologic and Seismic Siting Criteria*. Specifically, this subsection addresses the following issues:

- Potential surface deformation associated with active tectonism, including capable seismic sources (faults) and volcanism

- Potential surface deformation associated with growth faults, which do not extend into the crystalline basement beneath the Coastal Plains and, as described in Appendix C of RG 1.208, are not considered to be potential tectonic sources of strong vibratory ground motion

- Potential surface deformation associated with non-tectonic processes such as collapse structures (karst collapse), subsurface salt migration (salt domes), and man-induced deformation (e.g., mining collapse, subsidence due to fluid withdrawal)

In summary, there are no capable faults within the 200-mile VCS site region (see Figures 2.5.1-22 and 2.5.1-25), and there is negligible potential for tectonic fault rupture within 25 miles of the site. The VCS site lies within the regionally extensive Tertiary age Vicksburg growth fault zone along the Texas Gulf Coast (Figure 2.5.1-2). Detailed studies of the site area described in Subsection 2.5.1.2.4.2 provide evidence for the absence of active growth faults whose surface projections lie within the footprint of the VCS plant. These studies further document evidence for localized Quaternary surface deformation above two growth faults, referred to as fault D (or fault GM-D) and fault E (or fault GM-E), within the site area (see Figure 2.5.1-40). The closest approach of the zone of Quaternary surface deformation associated with fault D to the power block area is approximately 509 feet (155 meters) (Figure 2.5.1-43) (see Subsection 2.5.1.2.4.2.3.2). The closest approach of the zone of Quaternary surface deformation associated with fault E to the power block area is approximately 2.6 miles. Detailed studies, including analysis of seismic reflection and LiDAR data, characterize the location, width, and long-term average rate of activity of the more proximal zone of surface deformation associated with fault D, and further indicate that any potential future surface deformation due to growth fault activity will be confined to this zone and thus will not affect the proposed structures. There is no potential for volcanic activity within the site area or vicinity (see Subsection 2.5.1.2.5). There is no potential for other non-tectonic surface deformation within the site area due to processes such as karst collapse, salt migration, or glacial rebound. Based on available information on settlement due to withdrawal of petroleum and/or groundwater in the site vicinity, there is little risk of surface deformation from this source.

The following sections present the data, observations, and references to support these conclusions.

2.5.3.1 Geological, Seismological, and Geophysical Investigations

Available information regarding the potential for permanent surface deformation at the VCS site is documented in several primary sources:

- Geologic mapping published by the U.S. Geological Survey (USGS), the state of Texas, and other researchers (e.g., References 2.5.3-1, 2.5.3-2, 2.5.3-3, 2.5.3-4, and 2.5.3-5)
- Articles published by various researchers in referenced journals and field trip guidebooks (e.g., References 2.5.3-2, 2.5.3-6, 2.5.3-7, 2.5.3-8, and 2.5.3-9)
- Seismicity data compiled and analyzed in published research (e.g., References 2.5.3-10, 2.5.3-11, and 2.5.3-12)

In addition to reviewing this existing information, the following investigations were performed to assess the potential for tectonic and non-tectonic deformation within the 5-mile VCS site area

- Interpretation of aerial photography and remote sensing imagery
- Analysis and interpretation of seismic reflection data
- Detailed analysis of high resolution, LiDAR-derived topographic data
- Aerial and field reconnaissance
- Review of pre- and post-EPRI (Reference 2.5.3-23) seismicity (see Subsection 2.5.2)
- Discussions with current researchers in the area

2.5.3.1.1 Previous Site Investigations

The VCS site is a greenfield site with no existing nuclear facilities or other facilities for which a safety analysis or surface faulting hazard evaluation was performed. The VCS site lies within the Gulf Coastal Plains physiographic province, which has been the subject of regional geologic investigations. Previous geologic studies relevant to the VCS site, and in particular to the potential for permanent ground deformation, were reviewed as part of this ESP application investigation and are summarized in Subsection 2.5.1.

2.5.3.1.2 Regional and Local Geological Studies

The USGS completed a compilation of all active or potentially active Quaternary features (e.g., faults, liquefaction features, young folds, and uplifts) in the central and eastern United States, including the Gulf Coastal Plains region (e.g., References 2.5.3-13, 2.5.3-14, 2.5.3-15, 2.5.3-16, 2.5.3-17, and

2.5.3-18). These compilations do not identify any Quaternary tectonic faults, features, or other evidence of tectonic activity within 25 miles (40 km) of the VCS site (see Subsection 2.5.1.1.4.3.5).

As described in Subsection 2.5.1.1.4.3.5.3, evidence for Quaternary activity in the form of non-tectonic surface deformation has been documented on some growth faults in the Texas Coastal Plains. As noted by Wheeler (Reference 2.5.3-19, Synopsis):

> "The gulf-margin normal faults in Texas are assigned as Class B structures because [of] their low seismicity and because they may be decoupled from underlying crust, making it unclear if they can generate significant seismic ruptures that could cause damaging ground motion."

The definition of a Class B structure, per USGS criteria (Reference 2.5.3-15), is:

> "Class B: Geologic evidence demonstrates the existence of 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."

In contrast, a Class A structure exhibits "geologic evidence (that) demonstrates the existence of a Quaternary fault of tectonic origin, whether the fault is exposed by mapping or inferred from liquefaction or other deformational features" (Reference 2.5.3-15).

The assessment of the USGS (Reference 2.5.3-19) is consistent with studies published since the 1986 EPRI (Reference 2.5.3-23) study (see description in Subsection 2.5.1.2.4.2) that growth faults are shallow upper crustal features confined to the Coastal Plains section and do not extend into the crystalline basement. As described in Subsection 2.5.1.2.4.2, there is a consensus in the informed technical community that the sediments involved in growth faulting do not have the requisite elastic strength to store sufficient strain energy for release in moderate to large earthquakes. The USGS assessment (Reference 2.5.3-19) is consistent with the guidance provided in Section C.2.4 of Appendix C, NRC RG 1.208, which characterizes growth faults as non-tectonic and hence non-capable structures:

> "Non-tectonic structures are those found in karst terrain and those resulting from growth faulting... Large, naturally occurring growth faults such as those found in the coastal plain of Texas and Louisiana can pose a surface displacement hazard, even though offset most likely occurs at a much less rapid rate than that of tectonic faults. They are not regarded as having the capacity to generate damaging vibratory ground motion, can often be identified and avoided in siting, and their displacements can be monitored."

Geologic mapping and analyses of subsurface data relevant to identifying and characterizing growth fault activity in the site vicinity are presented in Subsection 2.5.1.2.4.2.

2.5.3.2 Geological Evidence, or Absence of Evidence, for Surface Deformation

2.5.3.2.1 Bedrock Faults

As shown on Figure 2.5.1-4, no bedrock faults have been mapped within the site area. The entire site vicinity is located in the Texas Gulf Coastal Plains, and the site area specifically is directly underlain by approximately 41,000 feet (equivalent to 7.8 miles or 12.5 km) of Mesozoic and Cenozoic strata deposited within the Gulf of Mexico Basin (Figure 2.5.1-26) (see Subsection 2.5.1.1.4.1.3). Analysis of time-migrated seismic reflection profiles (Figures 2.5.1-45 through 2.5.1-48) for this ESP application documents that all growth faults in the site area that displace Coastal Plains strata in the upper 4000 to 8000 feet (1200 to 2400 meters) of the sedimentary section terminate downward against or above a sub-horizontal detachment horizon within the Coastal Plains section (Subsection 2.5.1.2.4.2.3.1). This observation, along with other stratigraphic and structural relationships that document primary activity of the faults during deposition of the Oligocene Vicksburg Formation, is consistent with the interpretation that the faults are part of the Vicksburg zone of non-tectonic and non-capable growth faults.

2.5.3.2.2 Growth Faults

2.5.3.2.2.1 Previous Studies

As described in Subsection 2.5.1.2.4.2.3, previously published studies and proprietary data documented the presence of five growth faults within the VCS site area. From southeast to northwest, the faults are designated: GM-E, GM-D, GM-K, GM-L, and GM-N (Figure 2.5.1-40). These faults are part of the well-documented Vicksburg growth fault zone (Subsection 2.5.1.2.4.2), which formed and was primarily active in Oligocene time. The growth faults are confined to the Mesozoic and Cenozoic Gulf Coastal Plains stratigraphic section, and do not extend into the underlying crystalline basement. Existing proprietary subsurface mapping (Reference 2.5.3-20) has documented that growth faults GM-E, GM-D, GM-K, GM-L, and GM-N deform marker horizons in the Oligocene-Miocene Frio Formation stratigraphic units overlying the Vicksburg Formation at depths as shallow as about 4000 to 6000 feet (1219 to 1829 meters) (Subsection 2.5.1.2.4.2.1.2). The youngest stratigraphic horizons documented by Geomap (Reference 2.5.3-20) are within the Oligocene-Miocene Frio Formation, and thus the Geomap (Reference 2.5.3-20) dataset provides no evidence to assess activity or non-activity of these growth faults during deposition of sediments younger than the Frio Formation.

2.5.3.2.2.2 Current Investigations

Subsection 2.5.1.2.4.2.3 presents compiled mapping and subsurface data that document the location and geometry of growth faults within the site area. In addition to this compilation effort, an array of four seismic reflection profiles were licensed by Exelon to: (1) document the presence or absence of other growth faults not included in the compilation mapping; (2) elucidate the subsurface geometry of the faults; and (3) assess the stratigraphic and structural relations that document activity or non-activity of the faults. As described in Subsection 2.5.1.2.4.2.1.5, these reflection profiles were processed and interpreted using modern, standard-of-practice techniques. Also, new analyses of air photos and LiDAR data, as well as aerial and field reconnaissance, were performed for this ESP application project to assess whether anomalous topographic features commonly associated with active growth faults exist within the site area and are correlated with growth faults identified in the subsurface. The analyses are described in detail in Subsection 2.5.1.2.4.2.3 and are summarized in the following subsections. Observations and interpretations developed from these analyses that are relevant to assessing activity or non-activity of growth faults in the site area are presented in Subsection 2.5.3.4.2.1.

2.5.3.2.2.2.1 Seismic Reflection Data

Seismic reflection data was used to investigate the subsurface geology of the site area, with the specific goal of identifying and mapping growth faults, documenting their geometry, and analyzing structural and stratigraphic relationships that constrain the timing of their last activity. As described in Subsection 2.5.1.2.4.2.1.5, a total of four 2-D seismic reflection profiles were selected to provide coverage of the site area. The data was licensed from a private broker, processed, and analyzed using industry standard software and techniques.

Based on inspection and interpretation of the time-migrated seismic reflection profiles, the site area is underlain by a series of southeast-dipping listric growth faults, most of which sole into a main detachment horizon at a depth of approximately 3.9 to 4.5 seconds two-way travel time. If it is assumed that the average acoustic velocity for the imaged Gulf Coastal Plains strata is approximately 6000 feet (1829 meters) per second (Reference 2.5.3-21), then the depth to the main detachment is approximately 11,700 to 13,500 feet (3400 to 4100 meters), confirming that the growth-fault system is confined to the upper part of the Coastal Plains stratigraphic section. Through comparison with proprietary Geomap (Reference 2.5.3-20) data, several of the faults interpreted in the seismic data were correlated with previously recognized growth faults GM-E, GM-D, GM-K, GM-L, and GM-N (Figures 2.5.1-45, 2.5.1-46, 2.5.1-47). Several other growth faults not identified in the Geomap (Reference 2.5.3-20) compilation also were recognized and mapped on the seismic lines (e.g., SR-01 and SR-03). In addition to growth faults, four distinct and laterally correlative stratigraphic marker horizons were identified and mapped in the subsurface among all four seismic lines. From oldest to youngest, the marker horizons were designated Horizon 1 (interpreted to be middle Oligocene in age), Horizon 2 (interpreted to be Oligocene to Miocene in age), Horizon 3 (interpreted to be early Pliocene in age), and Horizon 4 (interpreted to be Pliocene to Quaternary in age). The stratigraphic markers were used to assess and document the timing of last activity on the growth faults.

2.5.3.2.2.2.2 LiDAR Derived Topography

As described in Subsection 2.5.1.2.4.2.1.4, LiDAR technology provides extremely detailed imaging of topography. LiDAR data of the Texas coastal regions, including the majority of the VCS site vicinity and all of the site area, was acquired in 2007 by the Texas Natural Resources Information System, in conjunction with the Federal Emergency Management Agency. The LiDAR data for the majority of the site vicinity was analyzed in this site characterization investigation and used to develop high-resolution, shaded relief images of the site vicinity and site area (e.g., Figures 2.5.1-37, 2.5.1-38, 2.5.1-39, 2.5.1-40, 2.5.1-41, 2.5.1-42, 2.5.1-43, and 2.5.1-49). The images were analyzed specifically for lineaments and other anomalous topographic features, in particular those spatially associated with the surface projections of growth faults (see Subsection 2.5.1.2.4.2.2).

2.5.3.2.2.2.3 Stereo Aerial Photography

Stereo-paired aerial photographs (1:20,000 scale), obtained from the United States Department of Agriculture Farm Service Agency, were used to identify topographic, tonal, and vegetation lineaments and assess their spatial relationship, if any, to the surface projections of growth faults within the site area. Features observed in the photos are described in Subsection 2.5.1.2.4.2.3 and include lineaments associated with topographic features and linear tonal and vegetation changes (Figure 2.5.1-37). In several cases, the photo lineaments are coincident with topographic lineaments identified within the LiDAR data (Figure 2.5.1-42).

2.5.3.3 Correlation of Earthquakes with Capable Tectonic Sources

As part of this ESP application, a comprehensive seismicity catalog was compiled for the greater site region (see Subsection 2.5.2.1). The seismicity catalog contains no earthquakes with $m_b \geq 3.0$ within 25 miles (40 km) of the VCS site (Figures 2.5.1-11 and 2.5.1-25), and thus there is no spatial correlation of earthquake epicenters with known faults, postulated faults, tectonic features, or geomorphic features within the site vicinity. In addition, no reported historical earthquake epicenters have been associated with buried bedrock faults, growth faults, or other geologic features within the site vicinity (Figures 2.5.1-11 and 2.5.1-25) (References 2.5.3-10, 2.5.3-11, and 2.5.3-12).

2.5.3.4 Ages of Most Recent Deformation

2.5.3.4.1 Bedrock Faults

As summarized in Subsection 2.5.1.1.4.1, the most recent bedrock deformation within the Texas Gulf Coastal Plains occurred during the Mesozoic Era and is related to rifting that led to development of the Gulf of Mexico basin. As the Gulf of Mexico opened, the basement crust of the Coastal Plains subsided and became part of a passive continental margin. The passive margin crust was progressively buried by Mesozoic and Cenozoic marine deposits of the Gulf of Mexico, and, based on an interpretation of regional gravity data, presently is at a depth of approximately 41,000 feet (equivalent to 7.8 miles or 12.5 km) beneath the VCS site (Figure 2.5.1-26). The basement underlying the site area is part of this extended continental crust. However, as described in Subsection 2.5.1.1.4.1.3, the locations of basement features or faults involved in this extension and rifting are unknown due to the thick sedimentary deposits overlying the deep basement rocks. The current state of knowledge indicates that there is no evidence for capable bedrock faults within the site area, and there is no evidence of fault activity within the basement rocks of the site area since the Mesozoic, if at all.

2.5.3.4.2 Growth Faults

2.5.3.4.2.1 Evidence for Activity and Non-Activity of Growth Faults in the Site Area

As described in detail in Subsection 2.5.1.2.4.2.3.1.4, fault GM-D is the only geologic structure directly imaged by seismic reflection data in the site area that exhibits stratigraphic evidence for late Cenozoic to Quaternary activity. Other subsurface faults (e.g., GM-K, GM-L, GM-M, SR-01, SR-03, SR-04, SR-05, and SR-07) (Figures 2.5.1-40, 2.5.1-45 to 2.5.1-47) are overlain by an undeformed Horizon 3 marker, which provides positive evidence for no activity of these faults since early Pliocene time (from about 5 to 4 million years before present).

Based on interpretation of depth-migrated seismic reflection data, fault GM-D displaces the Pliocene-Quaternary stratigraphic marker Horizon 4 approximately 70 feet down to the southeast. Reflectors at extremely shallow depth above the Horizon 4 marker also appear to be deformed, but primarily by distributed southeast-down tilting or folding within an upward-widening triangular zone, rather than by discrete fault offset. It is important to note that the lateral continuity and imaging of reflectors above Horizon 4 is relatively poor, probably due to a combination of near-shore and relatively energetic late Cenozoic depositional processes (Reference 2.5.3-2) that did not favor the formation of well-defined, laterally continuous horizontal strata, and the fact the seismic data was originally acquired to provide optimum imaging at much greater depths where oil and gas are located. The southeast-down tilting of reflectors above Horizon 4 is interpreted to represent monoclinal fault-propagation folding of the shallow crust in the hanging wall of fault GM-D. As imaged in the seismic line that approaches closest to the plant footprint, the monoclinal fold associated with fault GM-D is interpreted to be about 1600 feet (490 meters) wide in the shallow subsurface. The fold is directly correlated with a LiDAR lineament associated with a distinct southeast-down break in topography, which is also about 1600 feet (490 meters) wide at the ground surface where the seismic line crosses the lineament. Based on these relationships, the LiDAR lineament is interpreted to be a monoclinal fold in the upper surface of the Beaumont Formation related to Quaternary activity of fault GM-D. The closest approach of the zone of monoclinal folding associated with fault GM-D to power block area structures is approximately 509 feet (155 meters), (Figure 2.5.1-43) (see Subsection 2.5.1.2.4.2.3.2).

Fault GM-E is not adequately imaged by reflection data to assess activity or non-activity since deposition of the Horizon 3 and Horizon 4 seismic markers. In lieu of direct seismic imaging, activity or non-activity of fault GM-E was assessed through geomorphic analysis. Subtle topography imaged by LiDAR data indicates that a distinctly linear, southeast-facing slope break associated with the updip projection of fault GM-E is present in the upper surface of the middle to late Pleistocene Beaumont Formation. The lineament can be traced to the southwest where it is present in relatively younger Holocene deposits and landforms of the San Antonio river valley (Figure 2.5.1-39; see Subsection 2.5.1.2.4.2.3). These relationships provide strong evidence that the lineament and associated southeast-facing slope break were not formed by fluvial processes, and that the lineament is clearly post-Beaumont in age where it crosses the Holocene San Antonio River valley deposits. Based on these observations, the lineament is interpreted to be associated with local Holocene activity of growth fault GM-E.

The following sections provide more detailed characterizations of surface deformation associated with faults GM-D and GM-E, and estimates of long-term average activity rates.

2.5.3.4.2.1.1 Fault GM-D

As described in Subsection 2.5.1.2.4.2.3.1.4, fault GM-D is observed to cause down-to-the-southeast displacement of the Horizon 4 marker on all of the seismic profiles (Figures 2.5.1-45, 2.5.1-46, 2.5.1-47, and 2.5.1-48) (Table 2.5.1-4), except 2D Reflection Profile “GSI” Time Mitigated (Figure 2.5.1-46), which crosses the fault at a point where there is no LiDAR or photo lineament indicative of surface deformation. From these relations, it is interpreted that Quaternary activity of fault GM-D is limited to short reaches of the structure that have linear topographic anomalies discernable in LiDAR imagery, and not along the entire fault.

As described in Subsections 2.5.3.4.2.1 and 2.5.1.2.4.2.3.2, the pattern of reflectors in the seismic data suggests that post-Horizon 4 activity of fault GM-D has produced distributed down-to-the-southeast monoclinal tilting or folding of strata within an upward-widening triangular zone in the hanging wall of the fault. Detailed topographic profiles extracted from the LiDAR data across the lineament within the site reveal that the slope break is characterized by a generally uniform increase in surface gradient across a horizontal distance that ranges from approximately 300 to 1600 feet (91 to 488 meters) (Figures 2.5.1-50a through 2.5.1-50c). The broad tilting expressed in the topography is consistent with the interpretation that shallow deformation above Horizon 4 is characterized by monoclinal folding of strata in the hanging wall of fault GM-D. The zone of Quaternary deformation, therefore, is limited to the monoclinal fold in the hanging wall of the fault.

As described in Subsection 2.5.1.2.4.2.3.2, total southeast-down relief on the upper surface of the Beaumont Formation across the monoclinal fold and associated LiDAR lineament at the site is approximately 4 feet (1.2 meters), with minor variability in relief along strike. The slope break is modified in places by post-Beaumont erosion, which locally has reduced the gradient and obscured the monoclinal profile. Even at locations along the LiDAR lineament where the slope break is subdued the southeast-down structural relief on the upper surface of the Beaumont Formation, due to activity on the fault, can be readily determined from analysis of topographic profiles. Through analysis and interpretation of a series of closely spaced topographic profiles across the topographic lineament associated with fault GM-D, the extent of monoclinal surface deformation above the fault was delineated and mapped, and is shown in Figure 2.5.1-43 (see Subsection 2.5.1.2.4.2.3.2). The closest approach of this zone of monoclinal folding to the power block area structures is approximately 509 feet (155 meters) (Figure 2.5.1-43) (see Subsection 2.5.1.2.4.2.3.2).

2.5.3.4.2.1.2 Fault GM-E

Growth fault GM-E is over 2.6 miles (4.2 km) from the power block area, and as such, any activity on the fault will not affect the site. Despite this fact, fault GM-E is still a structure of interest because it is the only fault, besides fault GM-D, that exhibits evidence for Quaternary activity within the site area. As described in Subsection 2.5.1.2.4.2.3.1.3, fault GM-E is not imaged in the seismic reflection data because the seismic profiles do not extend far enough south to cross the fault and provide sufficient imaging resolution of the fault at depth. Despite the lack of direct reflection imaging, the distinct topographic lineament apparent in the LiDAR data and its spatial correlation with the surface projection of fault GM-E strongly suggest that fault GM-E has been active in the Quaternary and formed a monoclinal, southeast-facing slope break in the upper surface of the Beaumont Formation, similar to that associated with fault GM-D.

As described in Subsection 2.5.1.2.4.2.4, fault GM-E crosses a variety of features including the deposits of the Beaumont Formation, younger Holocene stream terrace and floodplain deposits of the San Antonio River, and man-made features (i.e., FM 445, U.S. Highway 77, and SR 239) (Figures 2.5.1-4 and 2.5.1-39). Field reconnaissance of the fault across these features was unable to provide any refinements on the timing of activity other than that movement has occurred since deposition of the Beaumont Formation and younger Holocene sediments of the San Antonio river valley. Topographic profiles of the fault along FM 445 derived from the LiDAR data reveal that the slope break associated with the fault has the same characteristics as the non-eroded profiles of fault GM-D (e.g., Profiles 4 and 8 in Figures 2.5.1-50a and 2.5.1-50b, respectively): a distinct inflection of the ground surface at the location of the lineament with the southeast side down. For fault GM-E, this step has an approximately 4.9 feet (1.5 meters) topographic offset over 980 feet (300 meters), or equivalently a narrow, steepened region with a slope of approximately 0.29 degrees.

2.5.3.4.2.1.3 Long-Term Average Rates of Activity

Long-term average rates of surface deformation associated with growth fault GM-D were estimated from the age of the deformed upper surface of the Beaumont Formation and the total surface offset. Based on analysis of topographic profiles, the separation of the upper surface of the Beaumont

Formation across fault GM-D ranges from approximately 1.5 feet to 4.5 feet (approximately 0.5 meter to 1.5 meters). As described in Subsection 2.5.1.2.3, the precise age of the Beaumont Formation is uncertain. Current estimates of the age of the Beaumont vary between 100,000 and 350,000 years (References 2.5.3-1, 2.5.3-2, 2.5.3-3, 2.5.3-5, and 2.5.3-22). From the extremes in the range of offsets and ages, the corresponding range in long-term average separation rates across fault GM-D is approximately 5.1×10^{-5} inches per year to 5.4×10^{-4} inches per year (see Subsection 2.5.1.2.4.2.3.3). If it is assumed that fault GM-D slips continuously and uniformly at these rates, then the maximum down-to-the-southeast displacement of the land surface across the zone of monoclinal tilting in 100 years will be about 1/18th of an inch (see Subsection 2.5.1.2.4.2.3.2).

Using a similar approach, with topographic relief on the surface of the Beaumont Formation and the Holocene San Antonio River floodplain deposits determined from analysis of LiDAR profiles, the lower-bound Holocene deformation rates for fault GM-E is 5.9×10^{-3} inches per year. This vertical relief and implied range of deformation rates are similar to those observed for fault GM-D. The similarities between the two faults could either be coincidental or may suggest that the mechanisms, rates, and characteristics of growth fault activity within the site area are fairly uniform (see Subsection 2.5.1.2.4.2.4).

2.5.3.4.2.1.4 Seismicity Recurrence

In the last 15 years, there has been wider recognition that seismicity migrates within crustal zones over periods of thousands to tens of thousands of years. Recurrence rates for some seismogenic structures appear to have been nonuniform over long periods of time (e.g., hundreds of thousands of years) (References 2.5.3-25 and 2.5.3-27); and within the Reelfoot Rift aulacogen, large earthquakes appear to have occurred at several different locations over different times throughout the Quaternary.

The combined impact of these observations is stated in Coppersmith (Reference 2.5.3-25), where it is hypothesized that seismicity within the Reelfoot Rift has varied in space and time (i.e., has been non-stationary) during the Quaternary. An implication of this hypothesis is that both geological and seismological observations should be used as the basis for characterizing potential seismic sources in an effort to identify and characterize non-stationary behavior.

With respect to the Reelfoot Rift, the concept of non-stationary seismicity related to tectonic structures does not have an impact on the VCS site because (1) the New Madrid seismic zone (NMSZ) source model used for the site is based on the most recent geologic and seismologic observations of the Reelfoot Rift region (see discussion in Subsection 2.5.2.4.4.1), and (2) hypothetical sources south and north of the NMSZ proper, but within the Reelfoot Rift (References 2.5.3-26 and 2.5.3-28), are too small and at too great a distance from the site to significantly impact site ground motions.

The basis for this conclusion is that: (1) the tectonic setting of the VCS study region is that of a passive continental margin, not an aulacogen; (2) there are no known capable tectonic structures within the site region, and therefore there are no tectonic structures along which large earthquakes may occur in a non-stationary manner similar to that proposed for the Reelfoot Rift (References 2.5.3-26 and 2.5.3-28); and (3) the EPRI-SOG seismic source characterizations (Reference 2.5.3-24) used as the basis for the seismic hazard calculations at the site have been evaluated and updated with respect to the latest geological and seismological observations. Therefore, the ideas presented in the referenced papers, which have not already been incorporated into the seismic hazard model for the site, have no implications for the VCS site.

2.5.3.5 Relationship of Tectonic Structures in the Site Area to Regional Tectonic Sources

The only geologic structures in the site area are growth faults associated with the Vicksburg fault zone, which has been mapped for a minimum of 500 miles along trend in the Gulf Coastal Plains (see description in Subsection 2.5.1.2.4.2.3.2). As described in Subsection 2.5.3.2.2.1, the site area growth faults are confined to approximately the upper 13,000 feet (4000 meters) of the Gulf Coastal Plains stratigraphic section and do not extend into the crystalline basement, which is estimated to lie at a depth of about 41,000 feet (7.8 miles or 12.5 km) beneath the site area, based on interpretation of regional gravity data. As noted in the introduction to Subsection 2.5.3, Section C.2.4 of Appendix C, RG 1.208 states that growth faults are “non-tectonic” and are “not regarded as having the capacity to generate damaging vibratory ground motion.” Given that growth faults are the only geologic structures present in the site area, it is concluded that there are no tectonic structures in the site area. Furthermore, there is no correlation of geologic structures in the site area to regional, capable tectonic sources.

2.5.3.6 Characterization of Capable Tectonic Sources

Based on data presented in Subsection 2.5.1 and previous descriptions in Subsection 2.5.3.4, there are no capable tectonic sources within the VCS site area.

However, as shown in Figure 2.5.1-1, approximately one third of the VCS site region encompasses the Gulf of Mexico including the Texas-Louisiana shelf and slope. These regions are comprised of a thickness of 6.9 to 9.4 miles (11 to 15 km) of Mesozoic sediments underlain by either thin transitional or oceanic crust (see Figures 2.5.1-18 and 2.5.1-19 and discussion in Subsection 2.5.1.1.4.3). As discussed in Subsections 2.5.1.1.4.3, and 2.5.2.2.2.2, no capable faults have been identified within the offshore VCS site region. Growth faults have been identified within the Mesozoic and younger sediments of this region (e.g., see Figures 2.5.1-2, 2.5.1-11, 2.5.1-12 and 2.5.1-42), but these faults are aseismic and are not capable faults (see discussion in Subsection 2.5.1.1.4.3.4.2) (Reference 2.5.3-25).

As outlined in Subsection 2.5.2.2.2.5, the EPRI-SOG source model (Reference 2.5.3-23) comprises the base characterization of seismic potential within the site region. A comprehensive review of all available information and data developed since the EPRI-SOG study was conducted as part of the VCS ESP application effort. One focus of this review was the identification of any information or data that would alter the evaluations of the EPRI-SOG teams with respect to the strong earthquake potential of the site region, including the offshore region. The new information developed since the EPRI-SOG study includes new gravity and magnetic data, refined kinematic models for the opening of the Gulf of Mexico, earthquakes that occurred since the EPRI-SOG study, and revised models of the state of stress within the site region. All of this information is discussed and presented within Subsections 2.5.1.1.4.3 and 2.5.2.2.2.5, and as stated in those sections, none of this information requires or motivates a revision to the EPRI-SOG characterization of seismic potential for the site region with the exception of modifications to the maximum magnitude (Mmax) distribution for some Gulf Coastal Source Zones. These modifications were motivated by two earthquakes that occurred within the Gulf of Mexico with magnitudes greater than the lower-bound Mmax value for some of the EPRI-SOG source zones that contain them (see Subsection 2.5.2.2.2.5). These earthquakes have not been associated with any tectonic structures and are fully accounted for with the Mmax modifications to the EPRI-SOG model (see Subsection 2.5.2.2.2.5).

Given the lack of specific information regarding discrete faults that may be potential seismic sources, the contribution to ground shaking hazard at VCS from the Gulf of Mexico region is modeled by areal source zones, as defined and characterized in the EPRI-SOG study (Reference 2.5.3-23). Therefore, the documentation of the EPRI-SOG source characterizations (Reference 2.5.3-23) is the most comprehensive evaluation for the Gulf of Mexico region. These characterizations are summarized in Subsection 2.5.2.2.2.5 and described in detail in the EPRI-SOG documentation (Reference 2.5.3-23).

As outlined in the introduction to Subsection 2.5.2, the potential for strong ground motion at the VCS site, including the Gulf of Mexico region, is characterized by the seismic source model used in the probabilistic seismic hazard analysis (PSHA) described in Subsection 2.5.2.4. The basis for this source model and PSHA is the EPRI SOG study and additional guidance provided by the NRC as outlined in RG 1.208. This guidance states that the PSHA should be:

> "…conducted with up-to-date interpretations of earthquake sources, earthquake recurrence, and strong ground motion estimation" (RG 1.208, page 3).

RG 1.208 also states that:

> "… seismic sources and data accepted by the NRC in past licensing decisions may be used as a starting point (for the PSHA)" (RG 1.208, page 14).

According to RG 1.208, the EPRI-SOG study (Reference 2.5.3-23) is an acceptable starting-point for source characterization. Therefore, the EPRI-SOG model was adopted as the starting model for VCS.

The EPRI-SOG study provides a comprehensive assessment of seismic hazards for the central and eastern United States (CEUS) that was developed using an expert elicitation process involving six independent earth science teams comprised of scientists recognized as experts in the fields of seismology, geology, and geophysics. Through the expert elicitation process, this study incorporated the range of uncertainty about the occurrence of future earthquakes and seismic sources within the CEUS. Therefore, the resulting seismic source model for the CEUS can be viewed as representing the state of knowledge of the informed expert community at the time of the study with respect to the seismic potential of the CEUS crust, including the crust throughout the VCS site region.

However, RG 1.208 also states that site-specific geological, geophysical, and seismological studies should be conducted to determine if the EPRI-SOG source model adequately describes the seismic hazard for the site of interest given new data developed since acceptance of the original model. The regulatory guidance explicitly states that:

> "The results of these investigations will also be used to assess whether new data and their interpretation are consistent with the information used in recent probabilistic seismic hazard studies accepted by NRC staff. If new data, such as new seismic sources and new ground motion attenuation relationships, are consistent with the existing earth science database, updating or modification of the information used in the site-specific hazard analysis is not required. It will be necessary to update seismic sources and ground motion attenuation relationships for sites where there is significant new information provided by the site investigation" (page C-1).

As outlined in Subsections 2.5.1.1.4.3 and 2.5.2.2.2, a comprehensive review was conducted to determine whether or not any new data or information exists that would require updating the EPRI-SOG source model for the VCS site. All of the updates made to the EPRI-SOG model are described in Subsection 2.5.2.2.2. The changes included:

- Updating the Mmax distributions for source zones within the Gulf coastal region to account for recent earthquakes within these zones that have magnitudes higher than the lower-bound Mmax value for the respective zone (see Subsection 2.5.2.4.3).

- Updating the New Madrid Seismic Zone source model to account for new information developed since the EPRI-SOG study on the recurrence and magnitude of large earthquakes within that region (see Subsection 2.5.2.4.4).

- Revising the smoothing parameters of the Dames & Moore South Coastal Margin source zone to more conservatively represent the hazard at the VCS site (see Subsection 2.5.2.4.5.1).
- Updating the southern extent of the EPRI-SOG source model to ensure that seismicity parameters are defined for the entire site region (see Subsection 2.5.2.4.5).

With these modifications to the original EPRI-SOG source characterizations (Reference 2.5.3-23), the source model used for the VCS PSHA can be viewed as representing the potential for strong earthquake ground motions from sources within the site region, including the Gulf of Mexico, and none of these modifications drastically alter the characterization provided by the EPRI-SOG teams. Therefore, with the exception of the updates made to the EPRI-SOG source model described above, the EPRI-SOG source zones summarized in Subsection 2.5.2.2 and fully presented in the EPRI-SOG report (Reference 2.5.3-23), characterize the seismic potential for the VCS site, inclusive of the Gulf of Mexico region, given the current state of knowledge.

2.5.3.7 Designation of Zones of Quaternary Deformation in the Site Region

There are no zones of Quaternary deformation associated with tectonic faults requiring detailed investigation within the site area.

Interpretation of aerial photography and LiDAR data, coupled with aerial and field reconnaissance, has documented Quaternary surface deformation associated with growth faults GM-D and GM-E in the site area (see Subsection 2.5.1.2.4.2.3). Detailed analysis of seismic reflection and LiDAR data indicate that displacement on faults GM-D and GM-E can be traced upwards to very shallow depths in the stratigraphic section. Displacement on these structures at depth projects updip to distinct lineaments in the LiDAR data that coincide with zones of mappable southeast-side-down monoclinal tilting of the upper depositional surface of the Quaternary Beaumont Formation and the Holocene San Antonio River floodplain deposits. The closest approach of a zone of monoclinal tilting to the power block area is approximately 509 feet (155 meters) (Figure 2.5.1-43) (see Subsection 2.5.1.2.4.2.3.2). The extent of monoclinal surface deformation is discernable from analysis of LiDAR data, and does not require detailed investigations of the type used to characterize potential surface rupture on capable tectonic faults.

2.5.3.8 Potential for Tectonic or Non-Tectonic Deformation at the Site

2.5.3.8.1 Potential for Tectonic Deformation

The potential for tectonic deformation at the site is negligible. There are no capable tectonic faults within the site vicinity.

Based on a review of geologic literature, there is no documented intrusive or extrusive volcanic activity of Tertiary age within the site region, and thus there is no potential for volcanic activity within the site vicinity (see Subsection 2.5.1.2.5). The youngest mapped volcanic and intrusive rocks in the site region are Mesozoic in age, and they primarily crop out to the north and northwest of the site at distances of 60 miles (96 km) or greater (Figures 2.5.1-2 and 2.5.1-9).

2.5.3.8.2 Potential for Non-Tectonic Deformation

2.5.3.8.2.1 Growth Faults

The potential for non-tectonic deformation within the VCS site from movement on growth faults is confined to a narrow zone associated with fault GM-D, as shown in Figures 2.5.1-49 and 2.5.1-43 (see Subsection 2.5.1.2.4.2.3). Any potential future activity on fault D will not extend beneath the footprint of the power block area at the VCS site.

In order to monitor the potential rate of slip associated with growth faults on the VCS site and the potential impacts on structures at the VCS site, a growth fault monitoring program will be implemented at the COL stage. Details concerning the program are outlined below.

The standard-of-practice survey technique within the earth sciences for documenting subtle vertical deformation of the earth's surfaces is tectonic first-order geodetic leveling. This technique is well established and can be used to document vertical displacements as a function of time, by use of repeated surveys of permanent benchmarks installed across a fault. To achieve the accuracy and resolution required to document subtle deformation that may be related to growth fault deformation (on the order of millimeters per year), the surveys will be conducted to the First Order, Class II Standard (Reference 2.5.3-29). This standard is referred to as “tectonic first order precision” (1 ppm) and has an accepted vertical elevation uncertainty of less than or equal to 1.0 mm x L1/2, where L equals the one-way line length in kilometers.

Surveys following this standard require drilling and installation of permanent benchmarks across the fault. The benchmarks act as survey control points and thus require permanence and relative vertical stability with respect to the Earth's crust over the time period of interest (approximately 40 years for an operating license). Benchmarks will be Class A rod marks (Reference 2.5.3-30) consisting of corrosion-resistant metal disks set on long metal rods driven deep into the ground. Rod depths of greater than 1.5 meters to 15 meters are commonly used, and given the relatively unconsolidated soil conditions at the VCS site, appropriate rod depths are likely towards the deeper range. For detailed surveys across active faults, benchmarks are typically spaced 10 to 30 meters. For adequate characterization of Fault D, a minimum line length (i.e., horizontal extent of the benchmarks) of 1.5 km is recommended. With an approximately 30-meter spacing, 50 to 60 benchmarks would be required for a 1.5 km long line. However, exact spacing and the number of benchmarks required for growth fault D will depend on the local site conditions and the goal of the surveys.

Once the benchmarks have been established, an initial survey will be conducted to establish the horizontal and vertical coordinate baseline for the survey line.

Periodic surveys would then be conducted at regular intervals (e.g., on the order of a year or more) and compared to the baseline to determine whether there has been any deformation. A higher density of benchmarks will allow for more precise identification of exactly where any surface deformation has occurred.

2.5.3.8.2.2 Other Potential Sources of Non-Tectonic Deformation

There is no evidence of non-tectonic deformation at the site in the form of glacially induced faulting, collapse structures, salt migration, mining, or subsidence due to petroleum or groundwater extraction:

- All documented faulting within the site vicinity is caused by growth faults, the activity of which is likely related to sediment compaction, dewatering, flow of salt in the subsurface, or fluid withdrawal. There are no documented examples of glacially induced faulting in the site region.
- There are no deposits of limestone or other carbonate rocks at shallow depths within the site area that pose potential karst collapse and surface subsidence hazards.
- No piercement-type salt domes are located within the site vicinity (see Subsection 2.5.1.1.4.3.4.1).
- There are no mining activities within the site area that may produce man-induced surface collapse.
- There is no potential for subsidence due to withdrawal of petroleum and groundwater, as described in Subsection 2.5.1.2.6.4. Further descriptions supporting this statement are found in Subsections 2.4.12 and 2.5.4.

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