SUBSECTION 2.5.0 TABLE OF CONTENTS

2.5 GEOLOGY, SEISMOLOGY, AND GEOTECHNICAL ENGINEERING

This section of the referenced DCD is incorporated by reference with the following departures and/or supplements.

STD DEP 1.1-1 This section is numbered to follow Regulatory Guide 1.206. The COL information items in DCD Subsections 2.5.1 through 2.5.6 are addressed in Subsection 2.5.6.

PTN SUP 2.5-1 This section of the Final Safety Analysis Report (FSAR) presents information on the geology, seismology, and geotechnical engineering characteristics of the site region (200-mile radius), site vicinity (25-mile radius), site area (5-mile radius), and site (0.6 mile radius) of Units 6 & 7. The data and analyses in this section document the evaluation of the suitability of the site. Section 2.5 provides sufficient information to support evaluations of the site-specific ground motion response spectra (GMRS) and provides information to permit adequate engineering solutions to geologic conditions and seismic effects at the site.

Section 2.5 is divided into seven subsections that generally follow the organization of RG 1.206 and NUREG-0800.

- Subsection 2.5.0 Summary
- Subsection 2.5.1 Basic Geologic and Seismic Information
- Subsection 2.5.2 Vibratory Ground Motion
- Subsection 2.5.3 Surface Faulting
- Subsection 2.5.4 Stability of Subsurface Materials and Foundations
- Subsection 2.5.5 Stability of Slopes
- Subsection 2.5.6 Combined License Information

Units 6 & 7 are located within Miami-Dade County, Florida, approximately 25 miles south of Miami, 8 miles east of Florida City, and 9 miles southeast of Homestead, Florida (Figure 2.1-201). The original site is at or near sea level with an existing elevation of –3.2 to 0.8 feet (NAVD 88) and generally flat throughout with the exception of a few isolated vegetated depressions. The local terrain was covered with a thin (2 to 11 feet) veneer of organic muck/peat that overlaid the Pleistocene Miami Limestone.

The vertical datum used for the Units 6 & 7 subsurface investigation is the North American Vertical Datum 1988 (NAVD 88). The vertical datum for references cited in this FSAR is per the cited reference, which include, mean sea level (MSL), NAVD 88, or National Geodetic Vertical Datum 1929 (NGVD 29).

The geological and seismological information presented in this section was developed from a review of published geologic literature, personal communication with experts in the geology and seismotectonics of the site region, aerial photograph analysis, and geologic fieldwork performed as part of the COL Application (including a site subsurface investigation, a geologic field reconnaissance, and a geophysical survey). A list of the references used to compile the geological, seismological and geotechnical information presented in the following sections is provided at the end of each major subsection within Section 2.5.

The review of regional and site geologic, seismic, and geophysical information and an evaluation of the updated earthquake catalog confirm the use of the appropriate seismic sources in the probabilistic seismic hazard analysis (PSHA). Borings at the site provide the geologic and geotechnical data needed to characterize the material properties of the soil and rock.

2.5.0 SUMMARY

This section provides a summary of information presented in detail in FSAR Subsections 2.5.1, 2.5.2, 2.5.3, 2.5.4, and 2.5.5. References are provided in their respective subsections.

2.5.0.1 Basic Geologic and Seismic Information

The geological and seismological information in Subsection 2.5.1 was developed in accordance with the guidance presented in RG 1.206, Subsection 2.5.1, *Basic Geologic and Seismic Information*, NUREG-0800, and RG 1.208, *A Performance-Based Approach to Define the Site-Specific Earthquake Ground Motion*, and is intended to satisfy the requirements of 10 CFR 100.23(c). The geologic and seismotectonic information presented in this subsection is used as a basis for evaluating the detailed geologic, seismic, and man-made hazards at the Turkey Point Units 6 & 7 site. The initial section of Subsection 2.5.1 contains a description of the organization of the subsection and a “roadmap” to discussions of the tectonic evolution of the greater Units 6 & 7 site region.

2.5.0.1.1 Regional Geology

The geologic and seismic information presented in Subsection 2.5.1.1 provides a technical basis for evaluating potential geologic hazards at the Turkey Point Units 6 & 7 site. This subsection summarizes the current physiography, geomorphic processes, stratigraphy, tectonic features, stress regime, and the geologic history of the region within the 200-mile (320-kilometer) radius site region. This subsection also provides similar information about the active plate boundary between North America and the Caribbean Plates located south of the site region. Both local and distant sources contribute to the seismic hazard at the site, including the Updated Charleston Seismic Source and sources associated with the North America-Caribbean Plate boundary, whose closest approach is about 420 miles (675 kilometers) south of the Units 6 & 7 site (Subsections 2.5.1.1.2.2 and 2.5.1.1.2.3.

Subsection 2.5.1.1 describes the regional geology. Subsection 2.5.1.1.1 contains descriptions of the geologic and tectonic characteristics of the 200-mile radius site region. Information describing the geologic and seismic characteristics beyond the 200-mile radius site region is included in Subsection 2.5.1.1.2. The description of characteristics beyond the site region focuses on the North America-Caribbean Plate boundary, including potential seismic and tsunami sources in the Gulf of Mexico and Caribbean that may impact the Units 6 & 7 site.

Subsection 2.5.1.1.2 addresses the geologic and seismic data/information on structures outside the 200-mile radius of the Turkey Point Units 6 & 7 site region that may be relevant to evaluating geologic hazards to the Units 6 & 7 site. The geologic hazards specifically include seismic hazards evaluated in the PSHA of Subsection 2.5.2 and tsunami hazards discussed in Subsection 2.5.1.1.5 and evaluated in Subsection 2.4.6. Subsection 2.5.1.1.2 includes a description of the physiography, stratigraphy, structure, and seismicity of portions of the North America Plate and portions of the Caribbean Plate near its boundary with the North America Plate.

Units 6 & 7 are located within the Atlantic Coastal Plains physiographic region. The ground surface in the region ranges from about 3 feet below sea level to 345 feet above. The geologic and tectonic setting of the region is the product of a complex history of continental collisions and rifting followed by deposition of sediments upon the newly formed Florida platform. Site regional stratigraphy consists of Paleozoic and Mesozoic igneous, metamorphic, and sedimentary basement rock overlain by up to 15,000 feet of additional Mesozoic carbonate and evaporite sedimentary rock units that are in turn overlain by up to 5000 to 6000 feet of Cenozoic carbonate and siliciclastic sediments.

The stratigraphy described in this subsection has been developed from the analysis of surface and subsurface geologic and geophysical investigations performed at the site and reported in peer-reviewed publications. The stratigraphy of southern Florida is characterized by a thick sequence of Jurassic to Holocene sediments that lie unconformably on Jurassic basement volcanic rocks. Although most of the units in the sedimentary sequence are carbonates, deposition of Appalachian derived siliciclastic sediments occurred during the Miocene and Pliocene. The oldest strata exposed at the surface in the southern Florida region is the Miocene-Pliocene Peace River Formation that outcrops in Hardee and Desoto counties.

The site region is located within the Central and Eastern United States (CEUS), a stable continental region characterized by low rates of crustal deformation and no active plate boundary conditions. There is no significant change in the understanding of the static stress in the site region since the publication of the EPRI source models in 1986, and there are no significant implications for existing characterizations of potential activity of tectonic structures. The Mid-Plate stress province is the most likely characterization of the tectonic stress at the site region.

The tectonic history of the site region begins with the late Paleozoic Alleghany orogeny, in which Gondwana (including South America and Africa) and Laurentia (ancestral North America) collided to form the supercontinent Pangea. Pangea was rifted apart during the Triassic and the Florida peninsula became part of North America. In the Jurassic, the southern edge of the North American plate was subducting southwestward beneath the Caribbean plate. In the Eocene Epoch, the Greater Antilles arc collided with the Bahama platform and contractional structures developed north of Cuba to accommodate this strain. After the Eocene, the crustal plate containing Cuba was transferred to the southern edge of the North American Plate, thus ending tectonic activity in the site region.

The Florida peninsula has been a stable carbonate platform since the Eocene. The dominantly carbonate strata of the subsurface Florida peninsula exhibits a series of sedimentary arches, uplifts, basins, and embayments developed in response to minor warping, regional tilting, sedimentary compaction, and sea level changes. These structures are not associated with faulting or tectonic events. No tectonic features younger than Miocene have been identified within the site region. Due to the diverse nature of the geology beyond the site region, further descriptions are deferred to Subsection 2.5.1.1.2.

2.5.0.1.2 Site Geology

Units 6 & 7 are located within the Southern Slopes subprovince of the Atlantic Coastal Plain physiographic province. The site vicinity geology was influenced by sea level fluctuations, processes of carbonate and clastic deposition, and erosion. The Paleogene (early Tertiary) is dominated by the deposition of carbonate rocks while the Neogene (late Tertiary) is more influenced by the deposition of quartzitic sands, silts, and clays. Within the site area the dominate rock types are limestones of the Arcadia Formation, Fort Thompson Formation, Key Largo Limestone, and Miami Limestone, and the sands and silts of the Peace River and Tamiami Formations. Minor units of alluvial soils, organic muck, and silt cover the surface. During the Pleistocene, worldwide glaciation and fluctuating sea levels influenced the geology in the site vicinity. The growth of continental glaciers during glacial advances resulted in the worldwide lowering of sea level. This process increased Florida’s land area significantly, which led to increased erosion and clastic deposition. Warm interglacial periods resulted in a rise in sea level and an increase in nutrient-rich waters leading to a growth in carbonate material. The geology within the site area is dominated by flat, planar bedding in late Pleistocene and older units. No geologic, tectonic, or physiographic structures such as sinkholes have been identified within the site area.

Units 6 & 7 lie on the stable Florida carbonate platform, and no faults or folds are mapped within more than 25 miles. New data include geologic mapping and bedding attitudes derived from lithologic contacts in boreholes. Taken together, these data indicate generally flat, planar bedding in late Pleistocene and older units and an absence of geologic structures within the site area.

Based on the review and updating of the geological, seismological, geophysical, and geotechnical data for the site, nothing was identified that precludes the safe operation of the facilities. The only geologic hazard identified in the site area is potential surface deformation related to carbonate dissolution. Based on records kept by the Florida Geological Survey, sinkholes in the limestone of southeastern Florida are few in number, shallow, broad, and develop gradually (Figure 2.5.1-222).

2.5.0.2 Vibratory Ground Motion

This subsection provides a detailed description of the vibratory ground motion assessment for the site. This assessment uses the guidance in RG 1.208. RG 1.208 incorporates developments in ground motion estimation models; updated models for seismic sources; methods for determining site response; and new methods for defining a site-specific, performance-based earthquake ground motion that satisfy the requirements of 10 CFR 100.23. Identification and characterization of seismic sources lead to the determination of safe shutdown earthquake (SSE) ground motion. This subsection develops the site-specific ground motion response spectrum (GMRS) characterized by horizontal and vertical response spectra determined as free-field motions on the ground surface using performance-based procedures.

The GMRS represents the first part in development of a SSE for a site as a characterization of the regional and local seismic hazard. The GMRS is used to determine the adequacy of the certified seismic design response spectra (CSDRS) for the DCD (RG 1.208). The CSDRS is the SSE ground motion for the site, the vibratory ground motion for which certain structures, systems, and components are designed to remain functional, pursuant to Appendix S to 10 CFR Part 50.

The starting point for the GMRS assessment is the probabilistic seismic hazard analysis (PSHA) conducted by the Electric Power Research Institute (EPRI) for the seismicity owners group (SOG). The EPRI-SOG seismic hazard study is based on the evaluation of seismicity, seismic source models, and ground motion attenuation relationships (Subsection 2.5.2, Reference 201).

Subsections 2.5.2.1 through 2.5.2.4 document the review and update of the available EPRI earthquake catalog, the use of additional earthquake data for the area beyond the 200-mile radius site region, seismic source models, and ground motion characterizations. Subsection 2.5.2.5 summarizes information about the seismic wave transmission characteristics of the site with reference to more detailed description of all engineering aspects of the subsurface in Subsection 2.5.4.

Subsection 2.5.2.6 describes development of the horizontal GMRS ground motion for the site. Following RG 1.208, the selected ground motion is based on the risk-consistent/performance-based approach. Site-specific horizontal ground motion amplification factors are developed using site-specific estimates of subsurface soil and rock properties. These amplification factors are then used to scale the hard rock spectra to develop uniform hazard response spectra (UHRS) accounting for site-specific conditions using Approach 2A of NUREG/CR-6728 (Subsection 2.5.2, Reference 202).

Subsection 2.5.2.6 also describes vertical GMRS, developed by scaling the horizontal GMRS by a frequency-dependent vertical-to-horizontal (V:H) factor.

2.5.0.3 Surface Faulting

Subsection 2.5.3 documents an evaluation of the potential for tectonic and non-tectonic surface deformation within the site vicinity of Units 6 & 7. Information contained in Subsection 2.5.3 was developed in accordance with RG 1.208, *Identification and Characterization of Seismic Sources and Determination of Safe Shutdown Earthquake Ground Motion*, and is intended to demonstrate compliance with 10 CFR 100.23, *Geologic and Seismic Siting Criteria*. RG 1.208 contains guidance on characterizing seismic sources, and it defines a “capable tectonic source” as a tectonic structure that can generate both vibratory ground motion and tectonic surface deformation, such as faulting or folding at or near the earth’s surface, in the present seismotectonic regime.

Subsection 2.5.3 contains information on potential surface deformation associated with capable tectonic sources (Quaternary faults) and potential surface deformation associated with non-tectonic processes, such as collapse structures (karst collapse), subsurface salt migration (salt domes), volcanism, and man-induced deformation (e.g., mining collapse and subsidence due to fluid withdrawal).

The evaluation of this information indicated that there are no capable tectonic sources and there is no potential for tectonic fault rupture within the 25-mile radius site vicinity. A compilation of existing data and literature review did not indicate any tectonic or non-tectonic surface deformation hazards at the site or any faults at the surface on the Florida peninsula within the 200-mile radius site region. Interpretation of aerial photographs identified lineaments within the site area that are associated with planar features identified in core samples and acoustic televiewer data collected during the field investigation. No indication of faulting, displacement, or deformation was identified along any of these features. A review of seismicity data did not indicate that any earthquakes with estimated body wave magnitude (Emb) ≥ 3.0 have occurred within 30 miles of the site. A field and aerial reconnaissance did not locate any evidence of faulting or seismic activity (such as paleoliquefaction features) within the site area. However, this reconnaissance did identify non-tectonic deformation features within the site area. These features appear to be small, localized depressions caused by surface dissolution of carbonate strata.

The data contained in Subsection 2.5.3 were developed as a result of literature and data reviews, interpretations of aerial and satellite imagery, field and aerial reconnaissance, discussions with current researchers, and an analysis of seismicity with respect to geologic structures. These data indicate that there are no Quaternary faults or capable tectonic sources within the site vicinity.

2.5.0.4 Stability of Subsurface Materials and Foundations

The locations of the Units 6 & 7 nuclear islands are shown in Figure 2.5.4-201. A combination of drilling, geophysics, and laboratory testing was used to characterize the subsurface. The results of the initial subsurface investigations and testing are presented in Reference 201. The results of the supplemental subsurface investigations and testing are presented in References 202 and 203.

On average, limestone strata extend from 4 feet below the surface to a depth of approximately 115 feet and are in turn underlain by sandy silty strata that extend to a depth of approximately 450 feet. Below this depth, evaporite-capped carbonate strata continue to basement volcanics at a depth of approximately 15,000 feet.

Karstification resulting from dissolution of carbonate rock can lead to the creation of subsurface voids from which sinkholes might develop when the process occurs at or near the earth's surface. However, based on investigations completed to date, including review of published reports pertaining to karst development in south Florida, geologic field reconnaissance, and a detailed subsurface geotechnical investigation, it is concluded that formation of large subsurface voids with the potential for collapse and development of sinkholes is not likely at the Turkey Point Units 6 & 7 site.

Two types of features related to dissolution of carbonate rock have been identified at the site: (1) vegetated depressions at and near the ground surface and (2) zones of secondary porosity within the underlying limestone. As further discussed in Section 2 of Appendix 2.5AA, the vegetated depressions are thought to be the result of a subaerial, epigenic, gradual process of carbonate dissolution caused by downward seepage of slightly acidic meteoric water following fractures, joints and bedding planes in the near-surface rock. These features have formed either currently (onsite) or during the Wisconsinan glacial stage (on the floor of Biscayne Bay) when continental glaciation had lowered sea level approximately 100 meters and exposed the limestone on the floor of Biscayne Bay to subaerial weathering and dissolution. The vegetated depressions are surficial dissolution features that are not subject to collapse into an underground solution cavity.

Because seawater saturated with calcium carbonate contains far less calcium carbonate than freshwater saturated with calcium carbonate, the combined fluids become undersaturated with respect to calcium carbonate, and dissolution of carbonate rocks (limestone) occurs within the mixing zone at the freshwater/saltwater interface of the two fluids. Carbonate dissolution in paleo-mixing zones of freshwater and saltwater has formed a second type of feature on the site: zones of secondary porosity. These zones of secondary porosity have formed microkarst features of generally centimeter scale in limestone beneath the site and provide pathways of preferential groundwater flow. The microkarst features are thought to have formed by solution enlargement of sedimentary structures in the rock near the contact of the Miami Limestone and Key Largo Limestone and within the Fort Thompson Formation. The zones of secondary porosity were formed during the Pleistocene when periods of continental glaciation lowered sea level and allowed mixing of fresh and saltwater within the stratigraphic intervals of the zones. During these periods, fresh groundwater flowed from inland areas, mixed with seawater near the shoreline, and facilitated dissolution as it flowed through the zones to the sea.

The zones of secondary porosity have developed by solution enlargement of two types of sedimentary structures: “touching-vug porosity” and “moldic porosity” (Subsection 2.5.1.2.4). Touching-vug porosity forms the “upper zone” of secondary porosity on the site that occurs near the contact of the Miami Limestone and the underlying Key Largo Limestone, within the approximate depth interval of 6.1 to 10.7 meters (20 to 35 feet) below the current land surface (Figures 2.5.1-351, 2.5.1-352, and 2.5.1-353). Because the current land surface elevation at the site is approximately 0 meters (0 feet) NAVD 88, this depth interval is also the approximate elevation interval of –6.1 to –10.7 meters (–20 to –35 feet) NAVD 88. This zone will be removed completely during excavation of the nuclear island foundations.

Moldic porosity forms the “lower zone” of secondary porosity on the site and occurs in pockets within the approximate depth interval of –18.3 to –22.9 meters (–60 to –75 feet) NAVD 88 in the Fort Thompson Formation. While both the upper and lower zones of secondary porosity formed in paleo-mixing zones of fresh groundwater and seawater, groundwater in these zones now is saline (Tables 2.4.12-210 and 2.4.12-211) and not conducive to further dissolution of the limestone host rock.

Mixing zones can occur in both surface water as point source discharge and in groundwater as submarine groundwater discharge. An instance of a point source discharge in the vicinity of Turkey Point Units 6 & 7 is the outfall of a drainage canal into Biscayne Bay. Because the closest outfall is more than 1 mile from the site (Figure 2.4.1-203), dissolution of carbonate rocks at the site due to point source discharge is not likely.

Submarine groundwater discharge occurs as shoreline flow or further offshore as deep pore water upwelling. The zones of secondary porosity in limestone at the site are thought to have formed in the past by the process of shoreline flow. Evidence that this process is active or was in the past at several other areas within the site region and why it is not likely to pose a sinkhole hazard at the site is discussed in Subsection 2.5.1.1.1.1.1.1. These areas include a submarine paleokarst sinkhole in the Key Largo National Marine Sanctuary, flank margin caves in the Bahamas, and the cenotes terrane of the Yucatan, Mexico, where shoreline flow was the formative process for karstification. Because groundwater at the site is saline (Tables 2.4.12-210 and 2.4.12-211), the freshwater/saltwater interface is approximately 9.6 kilometers (6 miles) inland from the site (Figure 2.4.12-207), and the long-term sea level rise trend at Miami Beach, Florida, as estimated based on data from 1931 to 1981, is 0.2 meter (0.78 foot) per century (Subsection 2.4.5, Reference 206), carbonate dissolution in a fresh groundwater/saltwater mixing zone by the process of shoreline flow is not likely to develop large underground voids with the potential for collapse and formation of sinkholes at the site.

Evidence of deep pore water upwelling in or near the site region is also discussed in Subsection 2.5.1.1.1.1.1.1. This process occurs within the sea bed on the offshore continental shelf where a layer of relatively impermeable rocks or sediments overlying a confined aquifer is breached by erosion or tectonic action, allowing upwelling of fresh groundwater into the ocean. At the site, the underlying Tamiami Formation and Hawthorne Group combined comprise more than approximately 152 meters (500 feet) of low-permeability rocks and sediments that overlie and confine the Floridan Aquifer (Figures 2.4.12-202 and 2.4.12-204). Deep pore water upwelling generally occurs well offshore, where the slope of the shelf is steeper and erosion of this thickness of confining sediments more likely. For this reason, carbonate dissolution associated with deep pore water upwelling is not likely to pose a threat of surface collapse or sinkhole hazard at the site.

Data from the extensive site geotechnical subsurface investigations for Turkey Point Units 6 & 7 described in References 201 and 202, including a multi-method surface geophysical survey designed to detect subsurface cavities, offer no evidence that karstification of the area has developed cavernous limestone with the potential for collapse and formation of sinkholes (within the limits of the geophysical survey imposed by diminishing resolution with increasing depth, decreasing cavity size, and increasing offset from survey lines). Structure contour and isopach maps for the Key Largo Limestone and Fort Thompson Formation and cross-sections prepared with data from the site subsurface investigation do not suggest the existence of large underground caverns or sinkholes.

The effects of potential changes in sea level and groundwater level during the life of the Turkey Point Units 6 & 7 plant have little potential to induce formation of large underground cavities or sinkholes at the site. Because of the planned method of groundwater control during site construction, no significant change in groundwater level or associated hydrodynamic stress that might lead to formation of sinkholes is anticipated.

2.5.0.5 Stability of Slopes

Subsection 2.5.5 considers nonsafety-related earth structures and slopes. There are no earth slopes at or in the plant area.

2.5.0.6 References

201. MACTEC Engineering and Consulting, Inc., *Final Data Report—Geotechnical Exploration and Testing: Turkey Point COL Project Florida* City, Florida, Rev. 2, included in COL Application Part 11, October 6, 2008.

202. Paul C. Rizzo Associates, Inc., Supplemental Field Investigation Data Report, Turkey Point Nuclear Power Plant Units 6 & 7, Rev. 2, Pittsburgh, Pennsylvania, included in COL Application Part 11, April 15, 2014.

203. Paul C. Rizzo Associates, Inc., Surficial Muck Deposits Field and Laboratory Investigation Data Report, Turkey Point Nuclear Power Plant Units 6 & 7, Rev. 1, Pittsburgh, Pennsylvania, included in COL Application Part 11, April 3, 2014.
