2.5 GEOLOGY, SEISMOLOGY, AND GEOTECHNICAL ENGINEERING

{This section of the U.S. EPR FSAR is incorporated by reference with the following supplements.

The summary includes a synopsis of FSAR Sections 2.5.1 through 2.5.5, including a brief description of the Site, investigations performed, results of investigations, conclusions and identification of the organization that performed the work.

This section is intended to demonstrate compliance with the requirements of paragraph (c) of 10 CFR 100.23, "Geologic and Seismic Siting Criteria" (CFR, 2007a). Regulatory Guide (RG) 1.208, "A Performance-Based Approach to Define the Site-Specific Earthquake Ground Motion", (NRC, 2007a) is the primary guidance document for the development of the Site Probabilistic Seismic Hazard Analysis (PSHA) and Ground Motion Response Spectrum (GMRS).

The terms Site Region, Site Vicinity, Site Area, and Site are used in this section to describe the specific areas of investigation. These terms correspond to the following areas:

1. The Site Region is that area within 200 miles (320 km) of the Site location (Figure 2.5L-1).

2. The Site Vicinity is that area within 25 miles (40 km) of the Site location (Figure 2.5L-2).

3. The Site Area is that area within 5 miles (8 km) of the Site location (Figure 2.5.1-1).

4. The Site is that area within 0.6 mile (1 km) of the Site location (Figure 2.5.1-2).

2.5.0 SUMMARY

Callaway Plant Unit 2 is located in the southeastern quadrant of Callaway County, Missouri. The Callaway Plant Unit 2 Reactor Building center line is located 0.26 miles (0.42 km) to the northwest of the Callaway Plant Unit 1 Reactor Building center line. Figure 2.5L-3presents the location of Callaway Plant Unit 2, and shows the local topography, the orientation of the plant grid relative to true north, and the placement of Callaway Plant Unit 2 relative to Callaway Plant Unit 1.

FSAR Section 2.5 provides information on the seismic, geologic, and geotechnical characteristics of the Site and the region surrounding the Site. The purpose of this information is to permit an adequate evaluation of the proposed Site, to support evaluations performed to estimate the site-specific ground motion response spectrum (GMRS), and to permit adequate engineering solutions to actual or potential geologic and seismic hazards at the proposed Site. Details of the studies and investigations performed as well as the findings and conclusions are presented in sections 2.5.1 through 2.5.5.

The primary conclusions of Section 2.5 are as follows:

1. Section 2.5.1 Basic Geologic & Seismic Information- The Site lies in a stable geologic region, and no geologic or man-made hazards have been identified within the Site Area. The region has also experienced only minor earthquake activity, with no epicenter of magnitude greater than 3.0 located within 25 miles of the Site.

2. Section 2.5.2 Vibratory Ground Motion – A PSHA was developed in accordance with Regulatory Guide 1.208, using the USGS 2002 data, with background seismicity being dominated by the New Madrid and Wabash Valley seismic source zones. Sensitivity studies which were performed on both the 2002-2007 seismic events and recently evaluated paleoliquefaction features. These studies confirmed the results of the PSHA.

3. Section 2.5.3 Surface Faulting – The Site Vicinity exhibits little evidence of faulting; all of it is non-capable and none is within the Site Area. In addition, a targeted field investigation discovered no evidence of paleoliquefaction features in the Site Area.

4. Section 2.5.4 Stability of Subsurface Materials and Foundations – Subsurface investigations concluded that the Site analysis was bounded by the U.S. EPR FSAR for settlement, bearing capacity, hydraulic gradient and that the subsurface materials are stable with no potential for soil liquefaction. The Nuclear Island will be founded on Graydon Chert Conglomerate, which will be augmented with engineered fill to support the surface founded structures.

5. Section 2.5.5 Stability of Slopes – The Site exhibits limited natural slopes and that the only permanent slopes are those in support of the ESWEMS Retention Pond. All permanent slopes are shown to have adequate stability safety factors.

Additional details are summarized below.

2.5.0.1 Basic Geologic and Seismic Information

2.5.0.1.1 Regional Geology

The Callaway Plant Unit 2 Site lies in an area referred to as the Central Stable Region of the United States. Tectonic features associated with this region were formed from about 300 million years ago to about 100 million years ago.

Seismic activity associated with some of the regional tectonic features has persisted to the present time. The nearest active tectonic features are associated with the Mississippi Embayment, located approximately 200 miles (320 km) to the southeast of the Site.

The Mississippi Embayment is a southwest-plunging sedimentary trough, extending north from the Gulf Coast to the southeast region of Missouri, approximately parallel to the Mississippi River. The area surrounding the northern end of the Embayment is the focus of continued tectonic and seismic activity along linear active zones, specifically the Reelfoot Scarp and the New Madrid Seismic Zone.

In the winter of 1811-1812, four major earthquakes (which have been reclassified by the USGS as three major earthquakes) occurred in the New Madrid Seismic Zone, and the area remains the most seismically active area in central and eastern North America.

The New Madrid Seismic Zone has been determined to be the primary source of the seismic hazard for the Site. The probabilistic Seismic Hazard Analysis for Callaway Plant Unit 2 is discussed in detail in Section 2.5.2.

A large number of faults have been described in the literature as lying within the Site Region; however, the majority of those faults have not been active since pre-Cretaceous time. The active faults-those with known displacements within the Tertiary Period-are located along the southeastern quadrant of the Site Region, and are associated with the fault systems related to the New Madrid Seismic Zone, the Reelfoot Rift and the Ste. Genevieve Fault System. The closest approach of any of these fault systems to the Site is approximately 50 miles (80 km) to the southeast.

2.5.0.1.2 Site Geology

Significant surface and subsurface investigations were conducted for the Callaway Plant Unit 2 Site Area foundation investigation, including field surveys, drilling, and geophysical exploration. Additional

information was obtained from the Callaway Plant Unit 1 FSAR, and from specific discussions with specialists from the MIssouri Department of Natural Resources (MODNR).

The Site is adjacent to the Missouri River at the southern edge of glaciation in North America. The area is characterized by gently rolling upland that has been dissected through down-cutting from the Missouri River and its tributary streams. Glacial and postglacial sediments overlie older unconsolidated deposits and lithified formations of Paleozoic age. Deposits of glacial till and loess buried a bedrock surface of moderate relief and produced a depositional surface of low relief. Deposits representing all of the systems in the geologic column, except Jurassic and Triassic, are found within the study region.

The Callaway Plant Unit 2 Site lies immediately north of the southern boundary of the Dissected Till Plains Physiographic Section within the Central Lowlands Physiographic Province. The Site occupies a portion of a nearly isolated plateau with an area of between 6 and 8 square miles (15 and 20 sq. km) with an average elevation of 846 ft (258 m). The plateau is higher than any surrounding land feature within a radius of 6 miles (10 km). The Missouri River is about 5 miles (8 km) south of the plant, and tributaries to the river have carved deep ravines around the perimeter of the plateau.

The Site geologic history has been quiescent since the end of the Pennsylvanian Period. At that time the central portion of the craton became more stable and tectonic movements became rare. The only disturbance of this quiet state was the advance of several ice sheets in the Pleistocene. However, since the Site is located at the extreme southern limit of the glaciated area, the ice sheets were at their thinnest and any crustal depression or subsequent rebound from the ice load has been minimal.

The sequence of units underlying the Site Area are composed of unconsolidated sediments and lithified deposits of Mississippian and older periods. The unconsolidated materials include glacial deposits of loess and till, as well as reworked Mississippian deposits laid down in the Pennsylvanian Period. The lithified units are principally limestone and dolomite with some sandstone and shale formations interlayered.

Deposits of Quaternary age within the Site Area consist of soils that are associated either directly or indirectly with Pleistocene glaciation. Locally, these deposits are the loess, accretion gley, and till.

Geologic studies to determine the Site structural characteristics have been performed utilizing data obtained from Site borings, excavation mapping and geophysical surveys. In addition, bedrock exposures were mapped throughout the Site Area. A thorough search for faulting and detailed mapping of excavations was previously performed for the Callaway Plant Unit 1 Site. No geologic hazards have been identified.

The Site is located in a region that has experienced only infrequent minor earthquake activity, with only two epicentral locations detected within a 50-mile (80 km) radius of the Site. Both had magnitudes between 3.0 and 3.9 $m_{b.}$ The first epicenter is situated approximately 38 miles (61 km) to the southwest and the second approximately 45 miles (72 km) to the south-southeast.

Investigations at the Site have not revealed any adverse geologic conditions that can't be attributed to man's activity. The addition or withdrawal of subsurface fluids, including ground water, at the Site has not been significant. Material extraction in the Site Vicinity has consisted of minor amounts of surface quarrying of limestone and fire clay. At present, there are no active mining operations within 4.5 miles (7.2 km) of the Site. There has been no mining or petroleum production in the Site Area that would cause any surface or subsurface subsidence.

2.5.0.2 Vibratory Ground Motion

Section 2.5.2 provides a detailed description of the vibratory ground motion assessment that was carried out to develop the Callaway Plant Unit 2 Ground Motion Response Spectra (GMRS). The GMRS is the first

step in defining the Site Safe Shutdown Earthquake (SSE) response spectra. The Site SSE for Callaway Plant Unit 2 is further defined in Section 3.7.1.1.1 after reconciliation with the Certified Seismic Design Spectra (CSDRS) curves. The vibratory ground motion assessment was performed using a Probabilistic Seismic Hazard Analysis (PSHA). The PSHA was conducted in accordance with RG 1.208.

The PSHA process began with the creation of an updated seismic catalog. The United States Geological Service (USGS) "documentation for the 2002 Update of the National Seismic Hazard Maps" was used as a starting point for earthquake catalog selection. The earthquake catalog compiled even in terms of m_b, up to the end of 2001. At the time the analysis was performed, this represented the most complete USGS catalogue of events in terms of m_b.The 2002-2007 seismicity has been incorporated into the analysis as a sensitivity study for the 200 miles (320 km) Site Region.

The Electric Power Research Institute-Seismicity Owners Group (EPRI-SOG) seismic source zones, inclusive of the Wabash Valley area, and the characterization of the New Madrid Seismic Zone (NMSZ) are the main tectonic sources used in the PSHA. The EPRI-SOG PSHA methodology outlined in EPRI NP-4726-A 1988 (EPRI, 1988) was adopted for the selection of the area sources. The hazard contribution of the New Madrid Seismic Zone (NMSZ) was incorporated through a characteristic earthquake model of the New Madrid Fault System (NMFS). The Early Site Permit (ESP) Application for the Clinton NPP (EGC, 2006) submitted to the NRC on April 16, 2006 by Exelon Generation Company (EGC), and USGS new interpretations were included in the development of the NMFS characteristic earthquake model.

The following sources are considered for the PSHA at the Callaway Plant Unit 2 Site:

1. EPRI general area source zones extracted from the 1989 EPRI-SOG study, with updated maximum magnitude for the Wabash Valley source zones,

2. Updated New Madrid Seismic Zone (NMSZ) as a characteristic model earthquake,

3. Background seismicity and updated maximum magnitude (general area source).

Site response analyses were conducted to evaluate the effect of the site geologic conditions on the generic Central and Eastern United States (CEUS) hard rock ground motions. The intent of the analyses is to develop ground motions at the surface that are consistent with the hazard levels defined for the generic rock conditions.

Uniform Hazard Response Spectra (UHRS) at hard rock are derived as well as their corresponding de-aggregation results for 1E-4, 1E-5, and 1E-6 hazard levels. The low frequency controlling event, 1 to 2.5 hertz, and the high frequency controlling event, 5 to 10 hertz, are identified from the de-aggregation results. These controlling events are prescribed in terms of magnitude (M) and distance (R) pairs. From the M-R pair defining each controlling event, the rock motion time histories whose epicenter distance and magnitude are close to the ones of the controlling event are selected.

For each controlling event, a spectral shape is adopted from the shapes for the Central and Eastern United States (CEUS) site according to the corresponding magnitude and distance pair (NUREG 6728). Then the response spectrum is scaled to match the rock UHRS at the spectral frequencies of 1.75 hertz (low frequency controlling event) and 7.5 hertz (high frequency controlling event). Next, the rock motion time histories are scaled to match the corresponding scaled controlling response spectrum. These scaled time histories are utilized as input to the Site Response Analyses.

A best estimate soil profile, with best estimate shear-wave velocity and material stiffness, density, and damping curves, is developed based on the site specific Callaway Plant subsurface geophysical and geotechnical investigation. The site analysis uses randomized material properties and layer thicknesses

based on the best estimate values and their variability. The results are expressed as mean site amplification functions corresponding to each controlling event. These factors are used to calculate the mean soil UHRS. In turn, the mean site amplification functions and the mean soil UHRS are used to derive the GMRS, with the application of the performance approach defined by RG 1.208. Vertical to horizontal ratios are subsequently used to calculate the vertical GMRS.

Two sensitivity analyses were performed as part of the Callaway Plant PSHA: (1) to assess the contribution to the hazard from the 2002-2007 seismicity, and (2) to assess the effects of postulated prehistoric earthquakes including paleo-earthquakes in the vicinity of St. Louis. The first sensitivity study concluded that the 2002-2007 data results in a non-conservative prediction, (i.e., would result in additional margin) of seismic occurrence rates when compared to the USGS 2002 catalog. This would be a non-conservative reduction in the PSHA. The second sensitivity analysis concludes that the use of a maximum magnitude of the background zone of 7.0 M_b constituted a conservative approach for considering the effects of paleo-earthquakes such as the ones postulated in the St. Louis region.

The last portion of Section 2.5.2 provides the Seismic Reconciliation of the GMRS according to the U.S. EPR FSAR seismic reconciliation guidelines, confirming that the peak ground acceleration for the GMRS is less than 0.3g. The development of the PSHA for Callaway Plant Unit 2 utilized a Senior Seismic Hazard Analysis Committee (SSHAC) for the review of the input parameters and overall approach. NUREG/CR-6372 provides guidance on uncertainty and use of experts to incorporate different interpretations and diversity of expert judgment. The SSHAC process focuses on the parameters used as input and the methodologies applied for the calculation of the seismic hazard. Members of the Callaway Plant Unit 2 SSHAC are:

1. Dr. Paul C. Rizzo - Technical Integrator,

2. Dr. Robert Herrmann – Expert in CEUS seismicity,

3. Dr. Robert Kennedy – Expert in PSHA and earthquake design basis, and

4. Dr. Richard Lee – Expert in site amplification analysis and geophysical data interpretation.

The SSHAC agrees with the methodologies utilized in the development of the Callaway PSHA.

2.5.0.3 Surface Faulting

In order to assess the potential or lack of potential for surface rupture in the Site Region, a variety of detailed subsurface and surface investigation tools were employed. A detailed review of existing information was performed, including geologic maps, seismologic survey data, the USGS earthquake catalog, aerial and satellite imagery, local knowledge from the Missouri Department of Natural Resources, and published references. Review of the geotechnical drilling information from the Callaway Plant Unit 1 Site was undertaken to verify the lateral continuity of strata across the Site. In 2007 a surface outcrop survey was carried out within the Site Area. In addition, in October 2008, additional field investigation were performed by geologists and engineers to assess the presence of paleoliquefaction features along waterways within the Site Vicinity, and also to ground-truth the presence and surface expression of nearby Ordovician to Pennsylvanian-age faults.

It has been determined that there is no potential for tectonic rupture and there are no capable tectonic sources within Site Vicinity. Also, there are no surface faults within the Site Vicinity.

Shear wave reflection seismic studies interpreted by Bay Geophysical in 2008 show no indication of offset within the Graydon Chert Conglomerate or the Snyder Creek Formation, which are the local bearing stratum in the Site Area.

There are no documented zones of Quaternary deformation within the Callaway Plant Unit 2 Site Vicinity. No evidence of seismic-related disturbance has been found within the Graydon Chert Conglomerate or glacial and post-glacial deposits.

2.5.0.4 Stability of Subsurface Materials and Foundations

The natural topography at the Callaway Plant Unit 2 Site is gently sloping. The maximum variation in relief is about 19 ft (6 m) across the Site. Average elevation across the Site is about 846 ft (258 m).

The upper 350 ft (107 m) of the Callaway Plant Unit 2 soils was the subject of subsurface investigation. The site geology is comprised of glacial and postglacial soil deposits underlain by bedrock, which is on average 36 ft (11m) below the ground surface. The subsurface is divided into the following stratigraphic units:

- Overburden Soils
  - Modified Loess
  - Accretion-Gley
  - Glacial Till
- Rock Formations
  - Graydon Chert Conglomerate
  - Burlington Formation, Bushberg Formation
  - Snyder Creek Formation, Callaway Formation
  - Cotter-Jefferson City Formation

The Graydon Chert Conglomerate is the bedrock horizon for the Callaway Site, and provides the foundation for the majority of the major plant structures.

The field investigation for the Site was performed in accordance with NRC Regulatory Guide 1.132, "Site Investigations for Foundations of Nuclear Power Plants." A thorough field investigation program was planned and implemented, and included the following:

- Boring Program
  - Wash Rotary Drilling and Standard Penetration Test
  - Rock Coring (NQ Wireline)
- In-Situ Pressure meter Testing
- Geophysical Exploration
  - Downhole Tests
  - PS Suspension Logging Tests
  - Deviation Surveys

- Reflection Surveys

In total, 71 boreholes were completed for the Callaway Plant Unit 2 Site, of which 35 boreholes were located in the vicinity of the proposed Category 1 structures. Three borings were extended to 350 feet (107 m) for detailed core logging and geophysical testing at the location of the reactor building.

A Hydrogeologic Field Investigation collected site-specific data to support a comprehensive hydrogeological evaluation of the plant site and surrounding areas. The data collected were utilized to support the surface hydrology analysis, hydrogeological characterization, and the development of a groundwater flow model.

A comprehensive laboratory testing program was performed on disturbed and undisturbed soil and rock samples, including the following:

1. Index and engineering classification
2. Strength
3. Consolidation
4. Permeability
5. Resonant Column Tortional Shear
6. Free-Free Resonant Column

The number and type of tests performed were consistent with the field investigation findings and the overall uniform conditions found at the Site.

Category 1 Granular Structural Fill for the eventual construction of the plant was identified from local sources and tested to determine the relevant engineering properties to be used in design analyses.

Recommendations of Soil, Fill and Rock properties were developed for all materials based on a combination of field measurements, laboratory testing, engineering analysis and judgment, and reference materials. Recommended properties are summarized in Section 2.5.4.2.5.

Foundation interfaces between the planned structures and site foundation materials were evaluated, and design parameters selected, in accordance with the requirements for COL applicants referencing the U.S. EPR FSAR.

2.5.0.5 Stability of Slopes

The Callaway Plant Unit 2 Site is comprised of generally flat topography in the vicinity of the primary structures and components. The Site is planned to be graded to establish the final grade for the project, resulting in minor cuts and fills, as well as slopes.

The stability of temporary and permanent slopes was evaluated using limit equilibrium methods, resulting in a Factor of Safety for the slope section analyzed.

The ESWEMS Retention Pond slopes are the only permanent slopes planned for Callaway Plant Unit 2. Slope stability analysis results indicate that the pond side slopes have Factor of Safety values ranging from 1.9 to 9.1, indicating that the proposed slope design and configuration is stable under all considered loading conditions.

Temporary cut and fill slopes will exist in dry conditions during construction. Slope stability analysis results indicate the temporary slopes have Factor of Safety values ranging from 2.5 to 3.7 depending upon the slope configuration, indicating that the proposed slope design is stable under all considered loading conditions.}