2.0 SITE CHARACTERISTICS

2.5 Geology, Seismology, and Geotechnical Engineering

This FSAR section describes geologic, seismic, and geotechnical engineering properties of the proposed Fermi 3 site. Following the NRC guidance in RG 1.206, “Combined License Applications for Nuclear Power Plants (LWR Edition),” and in RG 1.208, “A Performance-Based Approach to Define Site-Specific Earthquake Ground Motion,” the applicant defined the following four zones around the Fermi 3 site and conducted investigations within those zones:

- Site region – Area within 320 km (200 mi) of the site location.
- Site vicinity – Area within 40 km (25 mi) of the site location.
- Site area – Area within 8 km (5 mi) of the site location.
- Site location – Area within 1 km (0.6 mi) of the proposed Fermi 3 location.

Since the proposed Fermi 3 is located adjacent to existing Fermi 2, the applicant used the previous site investigations for the Fermi 3 facility as its starting point for the characterization of the geologic, seismic, and geotechnical engineering properties of the site. As such, the material in Fermi 3 FSAR Section 2.5 focuses on any information published since the Fermi 2 FSAR, which was issued in 1985. The material in COL FSAR Section 2.5 also focuses on any recent geologic, seismic, geophysical, and geotechnical investigation performed for the COL site.

The applicant used seismic source models previously published by the Electric Power Research Institute (EPRI 1986, 1989) as the starting point for characterizing potential regional seismic sources and the resulting vibratory ground motion. The applicant then updated these EPRI seismic source and ground motion models in light of more recent data and evolving knowledge pertaining to seismic hazard evaluations in the central and eastern United States (CEUS). The applicant then employed the performance-based approach described in RG 1.208 to develop the ground motion response spectrum (GMRS) for the site.

NRC staff performed an extensive review of Fermi 3 COL FSAR Revision 5 Section 2.5, interacted with the applicant on many occasions through public meetings; and requested additional information to substantiate and support the applicant’s conclusions in the FSAR. Because of the Fukushima Dai-ichi nuclear power plant accident after the Great Tohoku earthquake and the subsequent tsunami in Japan in 2011, the NRC issued an information request letter dated March 12, 2012, requesting all operating nuclear power plants in the U.S. to re-evaluate seismic hazards using the most recent information and methodologies available. The NRC Near-Term Task Force (NTTF) issued a series of recommendations for improving nuclear power plant safety in the U.S. following the Fukushima Dai-ichi accident. The information request letter stated that nuclear power plant sites in the CEUS will be able to use the newly published seismic source model in NUREG–2115, “Central and Eastern United States Seismic Source Characterization for Nuclear Facilities,” to characterize seismic hazards related to their plants. Following the issuance of this information request letter to the operating nuclear power plants, the staff also requested all COL and Early Site Permit (ESP) applicants to address this issue.

The NRC issued RAI 01.05-1 requesting the applicant to provide additional information to address Recommendation 2.1 of the Fukushima NTTF in SECY-12-0025, “Proposed Orders and Requests for Information in Response to Lessons Learned from Japan's March 11, 2011, Great Tohoku Earthquake and Tsunami," as it pertains to the seismic hazard evaluation. The NRC staff asked the COL applicant to reassess the calculated seismic hazard for the Fermi 3 site using the newly published NUREG–2115 seismic source model and to modify its GMRS and the foundation input response spectra (FIRS) as needed. The applicant's initial response to RAI 01.05-1 dated August 24, 2012 (ML12243A455), replaced the EPRI (1986, 1989) base seismic source model used for the seismic hazard analysis with the newly published NUREG–2115 seismic source model. In addition, the applicant committed to address the impact of the RAI 01.05-1 response in conjunction with the site-specific soil-structure interaction (SSI) analyses. On January 25, 2013, the applicant provided a response to RAI 01.05-1 (ML13032A378) that included a revised FSAR Section 2.5. Particularly significant are the calculations in revised FSAR Section 2.5.2, "Vibratory Ground Motion." The applicant then submitted FSAR Revision 5 on February 14, 2013. This change in the base seismic source model made many of the staff's previous RAIs irrelevant. The following sections of this report only focus on FSAR Revision 5. The staff's technical evaluations only discuss those RAIs that remain applicable in the context of the applicant's changes, in addition to new RAIs related to this most recent version of the FSAR.

2.5.1 Basic Geologic and Seismic Information

2.5.1.1 *Introduction*

This FSAR section describes geologic, seismic, and geotechnical information. This technical information incorporates results from surface and subsurface investigations performed in increasing levels of detail for distances closer to the site. These investigations comprised four distinct circumscribed areas corresponding to the previously defined site region, site vicinity, site area, and site location. The primary purposes for conducting these investigations were (1) to determine the geologic and seismic suitability of the site; (2) to provide the bases for the plant design; and (3) to determine whether there is significant new tectonic or ground motion information that could impact the seismic design bases as determined by a probabilistic seismic hazard analysis (PSHA). The basic geologic and seismic information in FSAR Section 2.5.1 addresses the regional and site geology and includes a description of the tectonic setting and the potential for tectonic and non-tectonic deformation, as well as conditions caused by human activities.

2.5.1.2 *Summary of Application*

Section 2.5.1 of the Fermi 3 COL FSAR, Revision 5, describes site-specific geologic, seismic, and geotechnical information. In addition, in FSAR Section 2.5.1, the applicant provides the following:

<u>*COL Item*</u>

- EF3 COL 2.0-26-A — Basic Geologic and Seismic Information in Accordance with SRP 2.5.1

In FSAR Section 2.5.1, the applicant provided information on the geologic and seismic setting for the Fermi 3 site and region. This information included four levels of investigations, each completed with additional scientific data encompassing 320 km (200 mi), 40 km (25 mi), 8 km (5 mi), and 1 km (0.6 mi). FSAR Subsection 2.5.1.1 describes the regional geologic and tectonic setting across a radius of 320 km (200 mi) from the site; and FSAR Subsection 2.5.1.2

describes the site geology and tectonic setting across a radius of 40 km (25 mi), 8 km (5 mi), and 1 km (0.6 mi) from the site.

FSAR Section 2.5.1 is based on information derived from the applicant's review of earlier reports prepared for the Fermi 2 power plant and published geologic literature, in addition to new boreholes drilled for the proposed Fermi 3. The applicant also used recently published literature, reports, and maps to supplement and update existing geologic and seismic information.

Based on these Fermi 3 investigations, the applicant concluded in FSAR Section 2.5.1 that no geologic conditions exist at the site that would negatively impact the construction or operation of safety-related buildings or structures. The applicant further concluded that any hazards at the Fermi 3 site will be mitigated during construction or designed for appropriately. A summary of the geologic and seismic information provided by the applicant in Fermi 3 COL FSAR Section 2.5.1 is presented below.

2.5.1.2.1 Regional Geology

FSAR Subsection 2.5.1.1 discusses the physiography, geomorphology, geologic history, stratigraphy, and tectonic setting within a 320-km (200-mi) radius of the Fermi 3 site. The following subsections summarize the information provided by the applicant in FSAR Subsection 2.5.1.1.

Physiography and Geomorphology

FSAR Subsection 2.5.1.1.1 includes the applicant's descriptions of the regional physiography and geomorphology surrounding the STP site. The applicant stated that the site is located in the Eastern Lake section of the Central Lowlands physiographic province. The applicant explained that the Fermi 3 site region comprises portions of two other physiographic provinces: the Appalachian Plateaus and St. Lawrence Lowlands. Figure 2.5.1-1 in this SER shows the location of the Fermi site in relation to the physiographic provinces.

The applicant stated that the Central Lowlands physiographic province is subdivided into eight sections. The Eastern Lake and Till Plains sections are located in the site region (a radius of 320 km [200 mi]). The Fermi 3 site is located in the Eastern Lake section, which is characterized by glacial landforms and beach and lacustrine (produced or formed in a lake) deposits. The applicant stated that the Fermi 3 site is located in a lake plain formed during the Lake Erie water level fluctuation, and Lake Erie occupies three basins that increase in depth from west to east. The applicant indicated that the western Erie basin extends to depths of 10 to 11 m (33 to 36 ft), the central basin to depths of 24 to 25 m (79 to 82 ft), and the eastern basin to depths exceeding 40 m (131 ft). The Till Plains section is dominated by glacial landforms that include end moraines, ground moraines, recessional moraines, outwash plains, and some lacustrine deposits.

The physiographic province of the Appalachian Plateaus is subdivided into seven sections. Two of those sections, the Kanawha and Southern New York, are within the 320-km (200-mi) radius of the Fermi site. The Kanawha section is described as a dissected plateau containing Pleistocene (2.6 million years ago [Ma] to 10,000 years ago) lacustrine deposits underlain by folded Paleozoic (359 to 251 Ma) sediments. The Southern New York section is dominated by glacial landforms and lacustrine deposits underlain by broadly folded Paleozoic sediments. The applicant described the St. Lawrence physiographic province as low plains with distributed glacial landforms along with beach and lacustrine landforms.

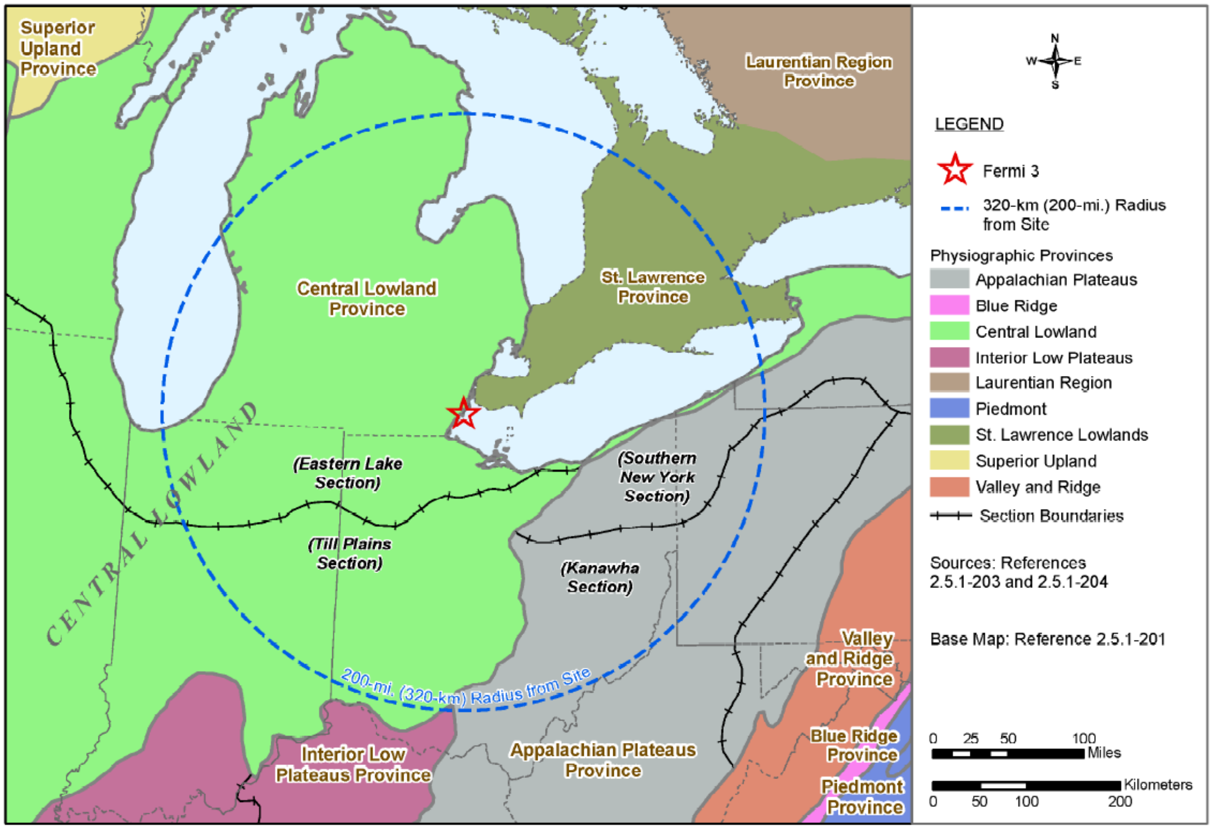

Figure 2.5.1-1 Fermi 3 Site Regional Physiographic Map
(Reproduced from Fermi 3 COL FSAR Figure 2.5.1-202)

Regional Geologic History

In FSAR Subsection 2.5.1.1.2, the applicant described the geologic and tectonic history of the Fermi site region. The applicant stated that the major tectonic events in the site region include several transgressions and regressions of epeiric (inland) seas, widespread subsidence in the continental basins, extensive uplifting in arches, and minimal activity on preexisting basement faults. The applicant stated that the last major tectonic event in the site region was rifting related to the Midcontinent Rift and Grenville Orogeny about 1.2 to 1.0 billion years ago (Ga).

In FSAR Subsections 2.5.1.1.2.3.2 and 2.5.1.1.2.3.3, the applicant described the Mesozoic (252-66 Ma) and Cenozoic (66 Ma to present) geologic history of the site. The applicant explained that no Mesozoic or early Cenozoic rock record is preserved in the site region except for some Jurassic (201 to 145.5 Ma) sedimentary rocks. According to the applicant, the missing rock record, if it did once exist, is likely due to widespread erosion between the late Paleozoic and middle Cenozoic Eras. The applicant stated that the site region is considered tectonically stable during the Cenozoic Era, except for vertical crustal movement associated with glacial isostatic adjustments.

In FSAR Subsection 2.5.1.1.2.3.4, the applicant provided detailed information on the Quaternary (2.6 Ma to present) geologic history of the site region. The applicant explained that the main geologic event in the site region during the Quaternary period is related to the growth and expansion of the continental Laurentide ice sheet. The applicant used the term marine isotope stage (MIS) numbers when referring to major glaciation events and explained that the current interglacial period, the Holocene (12,000 years ago to present), is referred to as MIS 1; whereas the most recent glaciation, the Late Wisconsinan, is referred to as MIS 2. The entire Wisconsinan glacial period (MIS 2 through 5) lasted from approximately 110,000 to 10,000 years ago, with the most significant Wisconsinan ice sheet advances occurring between 25,000 and 12,000 years ago. The Middle and Early Wisconsinan (130,000-25,000 years ago) were periods of low to no ice volume and are recognized as MIS 3 to 5. Finally, the Illinoian glacial period is referred to as MIS 6 and took place around 160,000 years ago. Pre-Illinoian glacial events are only referred to by their MIS number, with even numbers identifying periods of higher ice volumes. The applicant stated that surficial sediments in the site region are mostly composed of Illinoian (MIS 6) and Late Wisconsinan age (MIS 2) glacial sediments, which is further evidence that mostly ice-free conditions existed between MIS 2 and MIS 6.

Regional Stratigraphy

In FSAR Subsection 2.5.1.1.3, the applicant discussed the succession of geologic units in the site region. The applicant stated that no rocks older than the Ordovician period (488 to 444 Ma) are exposed at the surface in the site region. The applicant explained that all of the physiographic provinces in the site region enclose comparable sequences of sedimentary rocks and since the Fermi 3 site is located on the Michigan basin side of the Findlay arch, more emphasis will be given to the stratigraphy of this basin.

The applicant stated that deposition of sediments during the Paleozoic and Mesozoic eras was controlled by several transgressions (high sea levels) and regressions (low sea levels) of epeiric seas (seas on the continental shelf or interior) over the North American Craton (part of the Earth's crust that has attained stability). Each major transgression and regression is referred to as a cratonic sequence, and six cratonic sequences are recognized for the North American Craton starting in the Proterozoic period (greater than 541 Ma) to present time. The applicant explained that five of the six cratonic sequences are identified within the Fermi site region. The rocks that the applicant identified during subsurface investigations for the Fermi 3 site are part of the Tippecanoe cratonic sequence and include rocks of the Salina Group overlain by rocks of the Bass Island Group. The Bass Islands Group is composed of dolomitic rocks with some interbedded shales and provides the foundation rock for the proposed Fermi 3 nuclear island. Both the Salina Group and the Bass Islands Group were deposited during the Silurian period (441 to 419 Ma).

In FSAR Subsection 2.5.1.1.3.3, the applicant discussed the Quaternary stratigraphy of the 320 km (200 mi) in the site region. The applicant explained that Pleistocene (2.6 Ma to 10,000 years ago) features in the site region are incising bedrock valleys and their associated valley fills. Glacial sediments as well as tills of Illinoian age lie on bedrock and were deposited by ice that advanced into the eastern portion of the Lake Erie basin. Glacial lake deposits of the early to middle Wisconsinan age pertaining to the Tyrconnell Formation were deposited in a proglacial lake in the Erie basin. The applicant stated that evidence of a long ice-free period is confirmed by significant soil development in the site region following the Illinoian glaciation and representing the late Wisconsinan glacial period.

Regional Tectonic Setting

In FSAR Subsection 2.5.1.1.4, the applicant described the regional tectonic setting of the Fermi 3 site that is relevant to the characterization of seismic sources used in the development of the Central and Eastern United States Seismic Source Characterization for Nuclear Facilities (CEUS-SSC) project (NUREG–2115) discussed in FSAR Section 2.5.2. Fermi 3 is located within a compressive midplate stress province characterized by a fairly uniform east-northeast compressive stress field, which extends from the midcontinent east toward the Atlantic continental margin and probably into the western Atlantic basin. The applicant explained that glacial isostatic adjustment (GIA) is believed to be the basis of deformation within continental plates and perhaps is a trigger of seismicity in eastern North America and in previously glaciated regions. The applicant stated that these effects on seismicity rates in the site region are not expected to vary significantly in the future due to the GIA. The applicant based this assertion on Mazzotti and Adams (2005) and on modeling of the strain and the resulting changes in seismic stress caused by the GIA in other areas.

Based on historical measurements, Larsen (1985) concluded that the uplift of Lake Erie continues to the present. The applicant explained that the directional trend in the uplift of Lake Erie does not exactly correlate with the isostatic rebound trend (less than 64 mm/century [2.52 in./century]), and that fluctuations in lake levels could be caused by minor climate fluctuations during the Holocene time. The applicant noted that the lake level history was not properly accounted for in previous models that suggest the possible influence of neotectonics on that history. The applicant added that recent GIA observations indicate that the hinge line marking the boundary between regions of vertical rebound to the north and subsidence to the south is close to the northern margin of the site region; and the residual velocity field shows subsidence of 1 to 2 mm/yr (0.039 to 0.078 in/yr) along most of the site region with a possible slight uplift near the western end of Lake Erie. The applicant stated that the monitoring of present-day tilting of the Great Lakes region illustrates uplift in the northeast and subsidence in the south, which indicates a pattern of land tilting upward to the northeast that is consistent with GIA. The applicant also stated that according to the data, the Fermi 3 site and the surrounding region are not characterized by strong vertical gradients or anomalies.

Regional Geophysical Data

In FSAR Subsection 2.5.1.1.4.2.1, the applicant discussed the regional gravity and magnetic data in relation to the Fermi 3 site region. Figure 2.5.1-2 in this SER shows various anomalies covering the site region including the mid-Michigan Gravity Anomaly (MGA), the East Continent Gravity High (ECGH), the Anorthosite Complex Anomaly (ACA), the Seneca anomaly, and the Butler anomaly. The applicant stated that some of these anomalies are associated with the midcontinent rift system (MRS) and the east continent rift system (ECRS).

In FSAR Subsection 2.5.1.1.4.2.2, the applicant provided information on seismic profiles of the midcontinent region using data from the Consortium for Continental Reflection Profiling and some of the seismic line data collected by the Great Lakes International Multidisciplinary Program on Crustal Evolution. The seismic line data collected in the Lake Superior area illustrate a segmented rift structure constituted by inverted, normal faulted asymmetric half grabens. Other features defined by the seismic profile lines were the Granite-Rhyolite province, the Grenville Front Tectonic Zone (GFTZ), and the Grenville Province.

Regional Tectonic Structures

In FSAR Subsection 2.5.1.1.4.3, the applicant stated that the Fermi 3 site is located in the continental region of the North American Craton, which is characterized by low seismic activity and low stress. A transition zone lies between the Michigan interior cratonic basin and the central Appalachian foreland within the 320-km (200-mi) radius of the Fermi site. This transition zone contains structural features that were occasionally active through the Paleozoic period. However, no evidence suggests that a reactivation of Mesozoic structures occurred within the site region. Previous reports for Fermi 2 concluded that there were no capable tectonic faults within the Fermi 2 site region. In addition, the applicant indicated that the CEUS-SSC study did not identify any repeated large-magnitude earthquake (RLME) seismic sources within 320 km (200 mi) of the Fermi 3 site. The applicant discussed the following regional tectonic structures by dividing them into three groups: basins and arches, principal faults, and seismic zones.

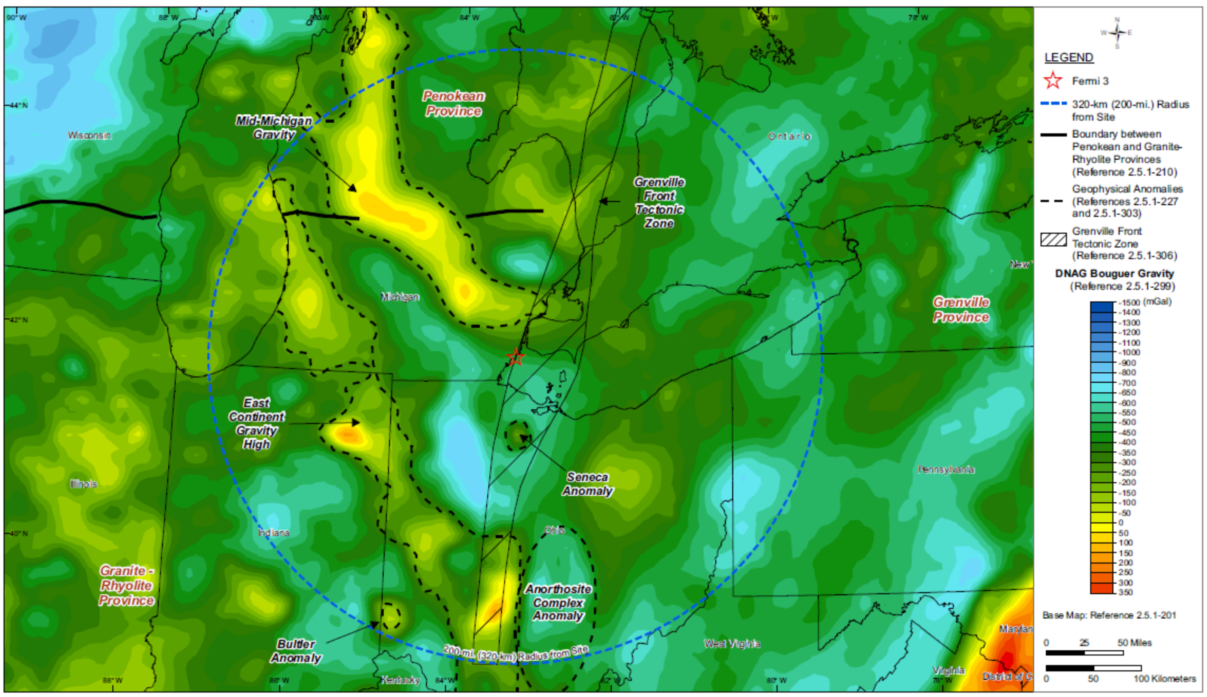

Figure 2.5.1-2 Bouguer Gravity Map of the Fermi 3 Site Region
(Reproduced from Fermi 3 COL FSAR Figure 2.5.1-220)

1. Basins and Arches

In FSAR Subsection 2.5.1.1.4.3.1, the applicant indicated that the most significant basins and arches in the site region are the Michigan basin and the Findlay and Algonquin arches. The applicant stated that the result of a long period of subsidence and deposition is a series of structural features in the basin, which range from closed anticlines to complex horst and grabens. Other structures observed in the basin are differential compaction anticlines and solution collapse features located over covered topographic highs and reefs. The applicant cited Fisher's findings (Fisher 1983) that the main structures in the Michigan basin are the result of vertical tectonics.

The Findlay arch in western Ohio and southeast Michigan and the Algonquin arch in Canada divide the Michigan basin from the Appalachian basin. The applicant explained that the Findlay and Algonquin arches influenced Paleozoic sedimentary deposition into the Middle Devonian.

2. Principal Faults

In FSAR Subsection 2.5.1.1.4.3.2, the applicant described the principal faults and tectonic features in the Fermi 3 site region. The closest faults to the Fermi 3 site area are the Bowling Green (Lucas-Monroe) anticline/fault, the Howell (Howell-Northville) anticline/fault, and the Maumee fault.

a. Bowling Green (Lucas-Monroe) Fault/Monocline

The closest distance of the Bowling Green fault to the site is about 40 km (24 mi). The Bowling Green fault is also known as the Lucas-Monroe monocline or fault and is composed of three segments: central, northern, and southern. The central (Late Cretaceous) segment is called the Bowling Green fault and is an approximately 10-m (33-ft) wide near-vertical zone of heavily sheared rock with secondary faulting. The applicant stated that the central segment of the fault coincides with the GFTZ and the Findlay arch. Citing Onash and Kahle (1991), the applicant stated that recurrent displacement may have occurred on the Bowling Green fault, in response to stress associated with the migration of the Findlay arch during the Acadian or Alleghanian events.

The applicant noted that the southern segment is composed of steeply dipping fault splays in Ohio extending to the southern boundary of Marion County in Michigan, which includes the Outlet and the Marion faults. The Outlet fault zone trends northwest and extends from Wyandot County to Wood County. The applicant stated that based on the sense of folding and the nature of displacement between the Outlet and Bowling Green faults, the Outlet fault is interpreted as a large synthetic shear zone to the Bowling Green fault. The applicant indicated that the vertical displacement on the Outlet fault zone ranges from approximately 6 to 30 m (20 to 100 ft). In addition, the applicant described the Marion fault as one of several small faults recognized on the basis of well data. The applicant indicated that the structural trends of the Marion and other faults are supported by (1) subsurface data on the top of the Trenton limestone, (2) unpublished lineament analyses by the Ohio Geological Survey, (3) an analysis of proprietary seismic data, and (4) anomalies in gravity and magnetic maps.

The northern segment of the fault is also known as the Lucas-Monroe monocline/fault. It consists of steeply dipping to vertical right and left stepping faults that extend from Lenawee and Monroe Counties to Livingstone County, where the segment apparently merges with the Howell anticline.

The applicant stated that a magnitude 3.4 earthquake occurred in 1994 approximately 130 km (90 mi) northwest of the Fermi site. Citting Faust et al. (1997), the applicant stated that the earthquake was on a hypothetical fault associated with the Lucas-Monroe fault or a shallow dipping feature related to the MRS and the Mid-Michigan Gravity High (MMGH). Structure contour maps of Paleozoic units, however, do not sustain the extension hypothesis of the Lucas-Monroe fault because the epicenter and the intense shaking zone of this earthquake were about 25 km (15.5 mi) southwest of the MRS/MMGH margin. Based on this information, the applicant concluded it is not likely that the earthquake is related to the Lucas-Monroe fault. Figure 2.5.1-3 in this SER shows the location of the Bowling Green fault. Figure 2.5.1-4 in this

SER shows a summary of the displacement history of the fault that ranges from Late Ordovician to Post-Middle Silurian.

Figure 2.5.1-3 Fermi 3 Site Region Map of Tectonic Structures
(Reproduced from Fermi 3 COL FSAR Figure 2.5.1-203)

SUMMARY OF DISPLACEMENT HISTORY OF BOWLING GREEN FAULT

Episode	Sense	Displacement	Evidence	Age
I	East-down	32 m	Greater thickness of strata between top of Trenton Ls. and top of Lockport Dol. on east side of fault	Late Ordovician-Early Silurian
II	West-down	50 m	Greater thickness of strata between top of Lockport Dol. and top of Tymochtee Dol. on west side of fault	Early-Middle Silurian
III	Left (?) lateral	?	Slickenlines in Tymochtee Dol. and Bass Islands Gp. in fault zone	Post-Middle Silurian
IV	West-down	>70 m	Slickenlines in Tymochtee Dol. and Bass Islands Gp. in fault zone; offset of Tymochtee-Bass Islands contact	Post-Middle Silurian
V	East-down	Depends on IV	Slickenlines, drag folds, minor fault sense in Tymochtee Dol. and Bass Islands Gp. in fault zone	Post-Middle Silurian
VI	Thrust	<5 m	Slickenlines, offset of bedding in Tymochtee Dol. and Bass Island Gp. in fault zone	Post-Middle Silurian-Cenozoic

Source: Reference 2.5.1-332

Abbreviations:
Dol. = Dolomite
Gp. = Group
Ls. = Limestone
? = uncertain

Figure 2.5.1-4 Summary of Displacement History of Bowling Green Fault
(Reproduced from Fermi 3 COL FSAR Figure 2.5.1-223)

c. Maumee Fault

The applicant described the Maumee fault as a northeast-southwest trending normal fault about 34 km (21 mi) south of Fermi. The applicant stated that the fault is offset (about 2 km [1.2 mi]) left laterally by the Bowling Green fault. The fault also coincides with a moderate lineament formed by the Maumee River.

Seismic Zones

In FSAR Subsection 2.5.1.1.4.3.3, the applicant explained that two seismic zones are within the site region: the Northeast Ohio Seismic Zone and the Anna Seismic Zone. Both seismic zones are classified as Class C structures.

The applicant defined the Northeast Ohio Seismic Zone as a zone of earthquakes south of Lake Erie about 50 km (30.5 mi) long. The largest seismic event in this zone was a magnitude 5 event about 40 km (24.4 mi) east of Cleveland on January 31, 1986, followed by 13 aftershocks within the subsequent 3 months. The applicant stated that the earthquakes and the aftershocks were within 12 km (7.3 mi) of deep waste disposal injection wells that may be associated with the cause of this earthquake and the aftershocks. However, the applicant indicates that the characteristics of these earthquakes would suggest that a natural origin for these events is likely. The applicant discussed events (magnitude 2.3 to 4.5) of a lesser magnitude that occurred from 1987 to 2003 in the Northeast Ohio Seismic Zone. Citing Seeber and Armbruster (1993), the applicant stated that the Northeast Ohio Seismic Zone is associated with the Akron magnetic anomaly or lineament, which could be related to the “Niagara-Pickering magnetic lineament/Central Metasedimentary Belt boundary zone as a continental-scale Grenville-age structure.”

The applicant stated that for the CEUS, the most common types of surficial evidence of large prehistoric earthquakes are liquefaction features and faults that offset young strata. Obermeier (1995) conducted a paleoseismic liquefaction field study along two of the larger drainages in northeast Ohio and documented that no evidence of liquefaction was observed along the river. Crone and Wheeler (2000) later classified the Northeast Ohio Seismic Zone as a Class C feature. Those features have insufficient geologic evidence demonstrating the existence of a tectonic fault, Quaternary slip, or deformation associated with those features. The applicant indicated that the CEUS-SSC model uses broad regional seismic source zones to represent the occurrence of distributed seismicity in the CEUS. In addition, the applicant stated that the Northeast Ohio Seismic Zone appears as an area with higher seismicity rates within the larger regional source zones in which it lies.

The Anna Seismic Zone, also known as the Western Ohio Seismic Zone, has experienced around 40 earthquakes since 1875. The applicant stated that the strongest event recorded occurred in July 1986 with a magnitude of 4.5. Historic records show a maximum magnitude of 5, suggesting that events in this zone are able to produce a magnitude of 6 to 7. The applicant explained that researchers have found no evidence of paleoliquefaction features in the vicinity of Anna, Ohio; or in portions of the Auglaize, Great Miami, Stillwater, and St. Mary's rivers. The Anna Seismic Zone is a Class C feature based on the absence of paleoseismic evidence. The applicant indicated that the Anna Seismic Zone is represented in the CEUS-SSC model as an area of a higher seismicity rate within the larger regional source zones in which it lies.

FSAR Subsection 2.5.1.1.4.4 describes significant seismic sources at a distance greater than 320 km (200 mi) from the site. The applicant described in detail the New Madrid Seismic Zone (NMSZ) and the Wabash Valley Seismic Zone (WVSZ) located 800 km (500 mi) and 500 km (300 mi) from the Fermi 3 site, respectively. The applicant explained the origin of stresses that seem to be driving the active deformation in the CEUS by describing several of the models that includes explanations for the localization of seismicity and the recurrence of large-magnitude events in the NMSZ. The applicant indicated that the CEUS-SSC characterized the RLME seismic sources in the NMSZ and the WVSZ; both of these seismic sources contribute to the seismic hazard at the Fermi 3 site.

Non-Seismic Geologic Hazards

In FSAR Subsection 2.5.1.1.5, the applicant described non seismic geologic hazards—including landslides and karst—within the Fermi 3 site region (320-km [200-mi] radius). The applicant explained that the Kanawha Section of the Appalachian Plateau is an area of moderate to high landslide susceptibility. In the Great Lakes area, landslide susceptibility was moderate and occurred mostly in lacustrine deposits. Landslides were also associated with wave erosion at the base of cliffs.

Karst features in the area are observed in limestones and dolomites of Silurian age (441 to 419 Ma) and consist of fissures, tubes, and caves that are usually less than 300 m (1,000 ft) long. The applicant explained that carbonate rock areas in northwestern Ohio covered by less than 6 m (20 ft) of glacial deposits developed large karstic features. Karst associated with evaporation occurs mostly in the central area of the Michigan basin.

2.5.1.2.2 Site Geology

FSAR Subsection 2.5.1.2 describes the physiography, geologic history, stratigraphy, and structural geology of the site vicinity (40 km [25 mi]); site area (8 km [5 mi]); and site location of

Fermi 3 (1 km [0.6 mi]). In addition, the FSAR includes subsections on site engineering geology and effects of human activity.

Site Physiography and Geomorphology

FSAR Subsection 2.5.1.2.1 states that the Fermi 3 site lies within the Eastern Lake section of the Central Lowlands physiographic province. FSAR Subsection 2.5.1.1.1 describes the regional physiographic provinces. The 1-km (0.6-mi) radius of the site is characterized by lacustrine deposits overlying glacial till, with an elevation that ranges from 173 to 180 m (570 to 590 ft).

The applicant indicated that geomorphic features have been identified and characterized in the western Lake Erie basin using both recent bathymetry and previous results of high-resolution seismic survey studies. The applicant described key geomorphic observations of Holcombe et al. (1987) regarding the lake-floor geomorphology of the western basin of Lake Erie.

Site Area Geologic History

In FSAR Subsection 2.5.1.2.2, the applicant described the site area geologic history during the Paleozoic and Quaternary periods. The applicant explained that units exposed in the site vicinity are from the Silurian and Devonian eras overlain by Quaternary sediments. During the Quaternary time, three ice lobes (Michigan, Saginaw, and Erie) coalesced on the lower peninsula of Michigan. The ice advance of the Port Huron stade affected the site region by creating high lake levels and proglacial lake areas such as the Glacial Lake Whittlesey and Warren Lake. Sedimentary deposits from these two lakes form the bulk of the glacial-age sediments deposited in the site vicinity.

Site Area Stratigraphy

In FSAR Subsection 2.5.1.2.3, the applicant described the site area stratigraphy during the Paleozoic and Quaternary periods. The applicant stated that the stratigraphy in the site vicinity is comparable to the regional stratigraphy, with the exception of sediment deposition associated with the Findlay arch in the Fermi site vicinity.

Paleozoic Stratigraphy of the Site Area

In FSAR Subsection 2.5.1.2.3.1, the applicant stated that three Paleozoic units are observed at the surface in the site vicinity: the Silurian Bass Islands Group, the Devonian Garden Islands Formation, and the Sylvania Sandstone.

The Silurian-age Salina Group is in the center of the Michigan basin and is subdivided into seven units identified as A through G. Unit A is further divided into four additional units: A-1 Evaporite, A-1 Carbonate, A-2 Evaporite, and A-2 Carbonate. The applicant described these units in detail and explained that the Fermi site is located in a region with no halite in the Salina and Bass Island groups. The applicant explained that the Silurian Bass Islands group is the uppermost bedrock unit found during the Fermi 3 subsurface investigation. The Bass Islands Group that the applicant encountered during its subsurface investigations is predominantly dolomite. The Devonian Garden Islands formation is described as dolomitic sandstone, dolomite, and cherty dolomite with a thickness of about 6.1 m (20 ft). The Devonian Sylvania Sandstone is a quartz sandstone cemented with dolomite and has a thickness of 6.1 m (20 ft).

The Sylvania Sandstone overlies the Bois Blanc and Garden Islands formations and is exposed in the (8-km [5-mi] radius) site area.

<u>Quaternary Stratigraphy and Geomorphology</u>

In FSAR Subsection 2.5.1.2.3.2, the applicant described the glacial and postglacial lake strandlines and related geomorphic features, Quaternary deposits and soils in the site vicinity and site area, and the Quaternary stratigraphy of the site location. The applicant stated that the exposed Quaternary surficial geologic units in the site vicinity consist of Wisconsinan age till overlain by a thin mantle of lacustrine and eolian sands or locally thicker beach dune ridge deposits.

The applicant discussed the paleo-shoreline features in the site vicinity associated with Lakes Maumee, Arkona, Whittlesey, Warren, and Wayne. In addition, the applicant discussed the most prominent beach ridges south of Lake Erie. Totten (1982) concluded that before the most recent late Wisconsinan ice advance (Woodfordian), the major activity was wave erosion that formed wave-cut cliffs and terraces. The applicant stated that at the various lake levels following the Woodfordian glaciation, the major geomorphic activity was the deposition of beach and dune ridges rather than cliff and terrace cutting. The applicant indicated that based on the geomorphic position and elevation, the mapped paleoshorelines in the site vicinity are correlated to glacial and postglacial lake levels that postdate the most recent major glacial advance about 14,800 years ago.

1. Quaternary Units

FSAR Subsection 2.5.1.2.3.2.3 describes the glacial till, lacustrine deposits, and fill. The applicant explained that the glacial till overlies the bedrock throughout the entire site location and ranges in thickness from 1.8 to 5.8 m (6 to 19 ft). Glacial till consists of fine grained sediments with variable amounts of sand, gravel, and cobbles.

Lacustrine deposits and shoreline deposits overlie the glacial till in most of the site. The thickness of the lacustrine deposits ranges from 0 to 2.7 m (0 to 8.7 ft) and the deposits consist of laminated silt and clay. The applicant stated that the top of the lacustrine deposits may have been removed and replaced with fill at the Fermi 2 and 3 sites.

<u>Site Area Geologic Structures</u>

In FSAR Subsection 2.5.1.2.4.1, the applicant stated that the major Precambrian structures in the site vicinity are the MRS and the GFTZ. The applicant stated that there no known Quaternary faults in the site vicinity. The applicant explained that the Bowling Green fault and the Maumee fault are bedrock faults mapped within 40 km (25 mi) of the Fermi site. The youngest evidence for displacement on the Bowling Green fault takes place in the Silurian Bass Island Group. The applicant stated the Maumee fault has no geomorphic expression; it is offset in an apparent left lateral sense by the Bowling Green fault. The applicant indicated that offshore of where the Maumee River enters Lake Erie, a linear northeast trending channel was excavated and dredged for shipping traffic entering the Toledo Harbor. The dredged channel includes 11 km (7 mi) of channel on the Maumee River and 29 km (18 mi) on the bay. The applicant also described the Howell anticline and explained that this structure consists of en-echelon folds and other associated faults.

In FSAR Subsection 2.5.1.2.4.2, the applicant explained that recent and previous borings at the Fermi site show that the rocks underlying the site area, the Silurian Salina and Bass Islands Groups, are folded into a wide shallow syncline. FSAR Subsection 2.5.1.2.4.3 states that two joint sets were mapped at a quarry located about 1.6 km (1 mi) from the site and similar trends of joints were observed at quarries and outcrops in Michigan, Ohio, and Ontario, Canada. The applicant explained that some joint sets in the region are related to contemporary stress. Boring data from the Fermi 2 site showed that the Bass Islands dolomite is highly jointed. The applicant described the joints as relatively tight with minor solution activity. During the Fermi 3 subsurface investigations, the applicant observed jointing throughout the Bass Islands Group and Salina Group Unit F. The applicant stated that these joints vary from isolated joints to groups of closely spaced joints with orientations that fluctuate from near horizontal to near vertical and joint apertures up to several inches. The applicant added that joint density decreases below the Salina Group Unit F and only a few joints are observed in Salina Group Units C and B. However, there are joints filled with minerals such as anhydrite even in the deepest formations.

Site Area Geologic Hazard Evaluation

In FSAR Subsection 2.5.1.2.5, the applicant discussed the potential geologic hazards in the 40-km (25-mi) radius of the Fermi 3 site. Based on the Landslide Overview Map of the conterminous United States, the applicant stated that the site area and site location are in a region of moderate landslide vulnerability based on the presence of lacustrine deposits. The lacustrine deposits at the site are about 3 m (9 ft) thick, and the site area is relatively flat with no steep slopes. However, the applicant stated that even though the natural slopes are not landslide prone, “the stability of the lacustrine deposits should be considered in excavation design.”

The applicant stated that some karst features may be present in the site vicinity, site area, and site location. Research performed by Davis et al. (1984) reflects active karst areas near northwestern Ohio that take place in zones where the noncarbonated overburden is less than 6 m (20 ft). The applicant thus concluded that the probability for karst in the 1-km (0.6-mi) radius of the site is low considering that the combined thickness of the till and lacustrine deposits is more than 6 m (20 ft). The applicant stated that there are no sinkholes in the 8-km (5-mi) site area radius, but sinkholes were observed outside of this radius.

The applicant explained that a possible reason for the presence of breccias and soft zones at the site is related to paleokarst occurrences and the associated dissolution of evaporate minerals. The applicant explained that only minor amounts of gypsum and anhydrite and no halite exist at the site. Thus, the potential for modern evaporate karst is small.

Site Engineering Geology Evaluation

FSAR Subsection 2.5.1.2.6 discusses the applicant’s evaluation of the site engineering geology, including potential effects of human activities at the Fermi 3 site. The applicant stated that the engineering behavior of the soils and rock is discussed in FSAR Subsection 2.5.4.2. In FSAR Section 2.5.1.2.6, the applicant explained several engineering aspects of the soil and rocks such as zones of alterations, residual stresses in bedrock, unstable subsurface conditions, deformational zones, and prior earthquake effects.

FSAR Subsection 2.5.1.2.6.7 discusses the effects from human activities in the Fermi site such as oil and gas production, subsurface gas storage, and dissolution mining of salt. The applicant stated that various producing wells are within the Ohio site vicinity. No producing oil wells are within the 8-km (5-mi) radius of the site. The applicant indicated that no subsurface gas storage facilities or salt deposits are within the 8-km (5-mi) radius of the site area, and no mining is anticipated.

The applicant explained that the Fermi site has surface deposits composed of artificial fill that overlies the lacustrine and glacial till, which are less permeable. These less permeable materials formed a confined layer over the Silurian Bass Islands and Salina Groups that are considered bedrock aquifers at the site. The applicant discussed groundwater in more detail in FSAR Section 2.4.12.

2.5.1.3 *Regulatory Basis*

The relevant requirements of the Commission regulations for the basic geologic and seismic information, and the associated acceptance criteria, are in Section 2.5.1 of NUREG–0800. The applicable regulatory requirements are as follows:

- 10 CFR 52.79(a)(1)(iii) as it relates to identifying geologic site characteristics with appropriate consideration of the most severe of the natural phenomena historically reported for the site and surrounding area and with a sufficient margin for the limited accuracy, quantity, and period of time that the historical data were accumulated.

- 10 CFR Part 100, Section 100.23, "Geologic and Seismic Siting Criteria," for evaluating the suitability of a proposed site based on consideration of geologic, geotechnical, geophysical, and seismic characteristics of the proposed site. Geologic and seismic siting factors must include the safe-shutdown earthquake (SSE) ground motion for the site and the potential for surface tectonic and non-tectonic deformation. The site-specific GMRS satisfies requirements of 10 CFR 100.23 with respect to the development of the SSE ground motion.

The related acceptance criteria from Section 2.5.1 of NUREG–0800 are as follows:

- <u>Regional Geology</u>: In meeting the requirements of 10 CFR 52.79 and 10 CFR 100.23, FSAR Subsection 2.5.1.1 will be considered acceptable if a complete and documented discussion is presented for all geologic (including tectonic and nontectonic), geotechnical, seismic, and geophysical characteristics; as well as conditions caused by human activities that are deemed important for the safe siting and design of the plant.

- <u>Site Geology</u>: In meeting the requirements of 10 CFR 52.79 and 10 CFR 100.23 and the regulatory positions in RG 1.208, RG1.132, RG1.138, RG1.198, and RG1.206, FSAR Subsection 2.5.1.2 will be considered acceptable if it contains a description and evaluation of geologic (including tectonic and non- tectonic) features; geotechnical characteristics; seismic conditions; and conditions caused by human activities in appropriate levels of detail within areas defined by circles drawn around the site using radii of 40 km (25 mi) for site vicinity, 8 km (5mi) for the site area, and 1 km (0.6 mi) for the site location.

In addition, the geologic characteristics should be consistent with the appropriate sections from RG 1.208, “A Performance-Based Approach to Define Site-Specific Earthquake Ground Motion”; RG 1.132, Revision 2, "Site Investigations for Foundations of Nuclear Power Plants”; RG 1.138 Revision 2, “Laboratory Investigations of Soils for Engineering Analysis and Design of

Nuclear Power Plants"; RG 1.198, "Procedures and Criteria for Assessing Seismic Soil Liquefaction at Nuclear Power Plant Sites"; and RG 1.206, "Combined License Applications for Nuclear Power Plants - LWR Edition."

2.5.1.4 *Technical Evaluation*

NRC Staff reviewed the information in Section 2.5.1 of the Fermi 3 COL FSAR, Revision 5, related to the site basic geologic and seismic information as follows:

<u>COL Item</u>

- EF3 COL 2.0-26-A Basic Geologic and Seismic Information

NRC staff reviewed the applicant's information on the resolution of COL Item EF3 COL 2.0-26-A related to the evaluation of the geologic, seismic, and geophysical information included under Section 2.5.1 of the Fermi 3 COL FSAR.

The technical information in FSAR Section 2.5.1 was based on the applicant's surface and subsurface geologic, seismic, and geotechnical investigations, which were undertaken in increasing levels of detail for distances closer to the site. The NRC staff reviewed FSAR Section 2.5.1 to determine whether the applicant had complied with the applicable NRC regulations and had conducted investigations with the appropriate levels of detail within the four circumscribed areas designated in RG 1.208. These areas are defined according to various distances from the site specified as 320 km (200 mi), 40 km (25 mi), 8 km (5 m), and 1 km (0.6 mi).

Fermi 3 FSAR Section 2.5.1 contains geologic and seismic information collected by the applicant in support of the vibratory ground motion analysis and the site-specific GMRS in FSAR Section 2.5.2. RG 1.208 recommends that applicants update the geologic, seismic, and geophysical databases and evaluate any new data to determine whether revisions to the existing seismic source models are necessary. Consequently, the staff's review focused on geologic and seismic data published since the mid- to late-1980s to assess whether these data indicate a need to update the existing seismic source models.

During the early site investigation stage, the staff visited the site and interacted with the applicant regarding the geologic, seismic, and geotechnical investigations conducted for the Fermi 3 COL application. To thoroughly evaluate these investigations, the staff obtained additional assistance from experts at the United States Geological Survey (USGS) and participated with the USGS in a site audit at the Fermi 3 site in November 2009 (ML14112A212). The purpose of that visit was to confirm the applicant's interpretations, assumptions, and conclusions related to potential geologic and seismic hazards. The staff's evaluation of the information presented by the applicant in COL FSAR Section 2.5.1 and of the applicant's responses to RAIs is presented below. As discussed earlier under the introduction to Section 2.5 of this SER, the staff had asked several RAIs and had evaluated the responses received earlier in the review process. However, following the issuance of the NRC's NTTF after the Fukushima accident in Japan in March 2011, and the subsequent submissions of an RAI to all COL and ESP applicants, the COL applicant revised the FSAR—including FSAR Section 2.5.1. As part of this FSAR revision, the applicant replaced the EPRI (1986) seismic source models previously used in the seismic hazard calculations with the newly published NUREG–2115 CEUS-SSC model. As a result of this change, some of the earlier RAIs became irrelevant and were closed. The staff's evaluations of some of these earlier RAIs are therefore not discussed in this report. However, several of the original RAIs are still applicable to the staff's review and they are discussed below.

The staff reviewed the resolution to COL Item EF3 COL 2.0-26-A that addresses regional and site-specific geologic, seismic, and geophysical information, as well as conditions caused by human activities included under Section 2.5.1 of the Fermi 3 COL FSAR. The staff's review is provided below:

2.5.1.4.1 Regional Geology

The staff's review of FSAR Subsection 2.5.1.1 focused on the applicant's description of the regional physiography, geomorphology, geologic history, stratigraphy, tectonic setting, and non-seismic geologic hazards within a 320-km (200-mile) radius of the Fermi 3 site. The following SER subsections present the staff's evaluation of the information in FSAR Subsection 2.5.1.1 and the applicant's responses to the staff's RAIs.

Regional Physiography and Geomorphology

In FSAR Subsection 2.5.1.1.1, the applicant described the three physiographic provinces and associated geomorphologies found in the Fermi 3 site region—the Central Lowlands province; the St. Lawrence province; and the Appalachian Plateaus province. The Fermi 3 site lies in the Eastern Lake subprovince of the Central Lowlands province. The staff's review of FSAR Subsection 2.5.1.1.1 focused on the applicant's descriptions of the effects from glaciations and lake level fluctuations on the surrounding landforms. The staff performed an independent review of the published geologic information and concluded that the applicant has provided a thorough and accurate description of the regional physiography and geomorphology surrounding the Fermi 3 site to support the Fermi 3 COL application. The staff found that the applicant's information is in accordance with RG 1.208 and meets the requirements of 10 CFR 100.23.

Regional Geologic History

FSAR Subsection 2.5.1.1.2 describes the Precambrian (greater than 542 Ma), Paleozoic (542 to 251 Ma), Mesozoic (251 to 65.5 Ma), and Cenozoic (65.5 Ma to present) geologic history of the Fermi 3 site region. The applicant's discussions in this subsection concentrated on the early tectonic evolution of the site region before 251 Ma and on the glacial events of the Quaternary period (2.6 Ma to the present). Based on the applicant's descriptions in FSAR Subsection 2.5.1.1.2, the site region has not experienced major tectonic activity in the last 1 to 1.2 billion years (Ga).

The applicant documented that (1) sequences of collisions and rifting events took place before 542 Ma, (2) these sequences contributed to the formation of the basement structure within the site region, and (3) the site region was tectonically stable during the Paleozoic era. The applicant described the formation of the Michigan basin and the Findlay and Algonquin arches that developed in the site region during the Paleozoic era. The applicant documented that only minor sedimentary deposition in the Michigan basin occurred during the Mesozoic era (251 to 65.5 Ma); there is no Tertiary geologic history preserved in the site region; and much of the Quaternary period before about 10,000 years ago was dominated by glacial activity.

The staff's review of FSAR Subsection 2.5.1.1.2 focused on the applicant's descriptions of the Quaternary geologic history of the site region, because this period represents the most recent geologic activity that could affect potential hazards at the site. The staff also focused on the depositional history of the site region, because the geologic units beneath the proposed site also contribute to the safety at the site. The staff performed an independent review of the applicant's data sources and of additional geologic literature to verify the applicant's descriptions and conclusions in the FSAR. The staff concluded that the applicant's documentation of the geologic and tectonic history of the Fermi 3 site region is consistent with the most recent geologic literature. The staff found that there is no major evidence for tectonic activity or deformation in the site region during the Quaternary period. Furthermore, the staff concluded that the applicant has provided a thorough and accurate description of the geologic and tectonic history in the site region to support the Fermi 3 COL application. The staff found that the applicant's documentation is in accordance with RG 1.208 and meets the requirements of 10 CFR 100.23.

Regional Stratigraphy

FSAR Subsection 2.5.1.1.3 describes Precambrian (greater than 542 Ma), Paleozoic (542 to 251 Ma), Mesozoic (251 to 65.5 Ma), and Quaternary (less than 2.8 Ma) sedimentary units in the site region. The applicant focused on those units that make up the Michigan Basin and noted that there are no exposed rocks older than 488 Ma at the surface in the Fermi 3 site region. The applicant documented five Paleozoic-Mesozoic cratonic sequences in the site region that represent sequences of inland sea transgressions and regressions. Of particular interest to the staff are the applicant's descriptions of the Tippecanoe II cratonic sequence that was deposited during the Silurian and early Devonian periods (444-398 Ma) and the 183-m (600-ft) thick Bass Islands Group, which is the foundation unit for the proposed Fermi 3 nuclear island structures and is composed of mostly dolomite with some interbedded salts and shales. The applicant's subsurface investigations for the Fermi 3 site are in FSAR Section 2.5.4. The staff's evaluation of these investigations is in Subsection 2.5.4.4 of this SER and includes the Tippecanoe II sequence rocks.

The staff reviewed FSAR Subsection 2.5.1.1.3 and performed an independent review of the geologic literature describing the regional stratigraphy of the Michigan Basin and surrounding areas. In addition, to verify the applicant's stratigraphic descriptions in the FSAR, the staff visited the Fermi 3 site in November 2009 and evaluated rock core samples obtained during the applicant's subsurface investigations of the Fermi 3 site. Based on this review, the staff concluded that the applicant has provided a thorough and accurate description of the stratigraphic history of the Fermi 3 site region to support the Fermi 3 COL application. The staff found that the applicant's documentation is in accordance with RG 1.208 and meets the requirements of 10 CFR 100.23.

Regional Tectonic Setting

In FSAR Subsection 2.5.1.1.4, the applicant discussed the regional tectonic setting of the Fermi 3 site that includes a description of the regional tectonic stress environment; an overview of the regional gravity, magnetic, and seismic profile data; and descriptions of the regional tectonic structures and seismic zones, in addition to significant seismic sources located beyond the 320-km (200-mi) site radius. Finally, the applicant also discussed regional non-seismic geologic hazards. The topics related to the regional tectonic setting follow, and include both glacial isostatic adjustments and regional tectonic structures.

Glacial Isostatic Adjustments

In FSAR Subsection 2.5.1.1.4.1.1, the applicant discussed the GIA in relation to the local tectonic stress environment. The GIA is also known as the post-glacial rebound and is the response of the earth's surface to glacial changes, such as the melting of large glaciers. The applicant stated that based on GPS measurements, the effects of the GIA on tectonic stress in the Fermi site region are mostly small. The applicant noted minor subsidence throughout most of the site region on the order of 1–2 mm/yr (0.039–0.078 in./yr) and some minor uplifts in the western portion of Lake Erie on the order of 64 mm per hundred years (0.026 in./yr). In RAI 02.05.01-03, the staff asked the applicant to provide additional information on the effects of the GIA in the site region with respect to the potential GIA effects on seismic hazards at the Fermi 3 site.

In the response to RAI 02.05.01-03 dated February 11, 2010 (ML100570306), the applicant referenced the 2005 paper by Mazzotti and Adams (Mazzotti and Adam 2005). According to these authors, research conducted during the previous 25 years documents that the GIA is likely responsible for only a very small number of earthquakes. The applicant's RAI response also includes an explanation and figures documenting the distribution and rates of geodetic strain, which is dominated by the effects of the GIA. The applicant stated that modeled strain rates for parts of the central United States and eastern Canada suggest that seismicity rates will likely remain constant in the next few hundred to thousands of years and will not "vary significantly in the future due to the GIA."

The staff reviewed the applicant's response to RAI 02.05.01-03 and performed an independent assessment of the geologic literature including papers by Mazzotti and Adams (2005), James and Bent (1994), Clark et al. (1994), Grollimund and Zoback (2001), and Sella et al. (2006). The staff concluded that the applicant has adequately evaluated the potential for seismicity in the Fermi 3 site region resulting from the effects of the GIA. In addition, the staff noted that no significant geodetic anomalies exist in the site region when the current deformation field is compared with the deformation field predicted by the GIA models. The staff concluded that the applicant's interpretation that the GIA has little effect on any changes to the regional seismicity is technically defensible. Finally, the staff concluded that there is no evidence in the geologic literature—including available data on strain rates in the central United States and eastern Canada—to suggest a likely increase in the seismic hazard at the proposed Fermi 3 site from future effects of the GIA. Therefore, RAI 02.05.01-03 is resolved and closed.

In RAI 02.05.01-04, the staff asked the applicant to provide additional information on the deformation of old shorelines attributable to the GIA in the Fermi site region—including any evidence for uplift or subsidence along identified old shorelines. In addition, the staff asked the applicant to provide figures or maps to help illustrate deformation attributable to the GIA along old shorelines in the Fermi 3 site region. In the response to RAI 02.05.01-04 dated February 11, 2010 (ML100570306), the applicant referenced its response to RAI 02.05.01-03, which included a figure (FSAR Figure 2.5.1-251) plotting the elevation of versus the distance from the raised and uplifted relict shorelines of multiple lake sequences in the Lake Erie basin within the 320-km (200-mi) site radius. The applicant also provided FSAR Figure 2.5.1-252, which illustrates the location of the Fermi 3 site with respect to areas of higher deformation due to the GIA effects. This figure shows that the Fermi 3 site vicinity is located outside of the uplift zone. The applicant stated that the deformation of relict glacial lake shorelines is consistent with expected deformation due to the GIA.

The staff conducted an independent review of the available geologic literature and noted that the Fermi 3 site is located in an area known as the “zone of horizontality” (or the zone of “zero isobase”), which is away from the hinge line that separates zones of higher uplift due to the GIA. Because of this location, the staff concluded that the Fermi 3 site is more likely to experience minor subsidence rather than uplift and is not expected to experience any significant uplift or deformation attributable to the GIA effects. The staff noted that the applicant had used the USGS 10-m (33-ft) digital elevation model to determine that there is no obvious warping of glacial lake shorelines within the 40-km (25-mile) site vicinity. The staff also noted that the lack of deformation along glacial lake shorelines within the site vicinity is consistent with the geologic literature that assumes little to no deformation in much of the site region related to the effects of GIA. Furthermore, the staff observed that actual GPS measurements described by Sella et al. (2006) and shown in FSAR Figure 2.5.1-253 suggest that the site vicinity may be experiencing subsidence rather than uplift on the order of 0 to 2 mm/yr (0 to 0.078 in/yr).

The staff concluded that the applicant’s response is consistent with the available geologic literature and current state of knowledge. The staff further concluded that there is no geologic evidence to suggest significant deformation attributable to the effects of the GIA at the proposed Fermi 3 site. Therefore, RAI 02.05.01-04 is resolved and closed.

<u>Regional Tectonic Structures</u>

FSAR Subsection 2.5.1.1.4.3 discusses significant geologic structures in the proposed Fermi 3 site region including basins, arches, faults, and seismic zones. The applicant described 14 principal geologic faults and tectonic features in the site region and stated that there is no evidence of Quaternary tectonic faulting in the states of Michigan and Ohio. For most of the 14 structures, the applicant discussed limits on the timing of the most recent deformation.

1. Basins and Arches

FSAR Subsection 2.5.1.1.4.3.1 describes Paleozoic basins and arches, including the Michigan basin and the Findlay and Algonquin arches near the Fermi site. NRC staff reviewed this information and performed an independent review of the available geologic literature. The staff concluded that the applicant has provided a thorough and adequate description of the geologic basins and arches consistent with the current knowledge and available literature. The staff further concluded that there is no geologic evidence to suggest that any of these features represent recent geologic deformation, and therefore they would not be expected to pose a geologic hazard at the site.

2. Principal Faults within the Site Region

FSAR Subsection 2.5.1.1.4.3.2 describes 14 tectonic faults or features in the Fermi 3 site region. FSAR Table 2.5.1-201 summarizes these features and discusses the evidence for geologic deformation associated with each feature. In RAI 02.05.01-06, the staff asked the applicant to further discuss information on the timing of the most recent deformation for three faults in the site region—the Peck fault, the Sharpsville fault, and the Transylvania fault.

In the response to RAI 02.05.01-06 dated February 11, 2010 (ML100570306), the applicant performed a more thorough search of the geologic literature and contacted regional geologic experts concerning these faults. The Peck Fault is located approximately 133 km (82 miles) north of the Fermi 3 site. Although the youngest evidence of deformation is early Mississippian (359-347 Ma), Fisher (1981) concludes that the deformation on this fault may have occurred through the end of the Paleozoic age (252 Ma). However, the applicant noted that there is no evidence in the available geologic literature to suggest that the Peck fault deformed units younger than the Mississippian age. For the Sharpsville Fault, the applicant noted that the youngest deformation is Devonian age (greater than 359 Ma).

The Transylvania Fault Extension comprises multiple geologic structures in the site region. The applicant contacted Mark Baranoski of the Ohio Geological Survey who stated that there was no evidence of Mesozoic or Cenozoic deformation on the Transylvania Fault Extension. This expert noted that although the age of the youngest deformation is not clear, it is likely from the Devonian age. As part of the response to RAI 02.05.01-06 the applicant updated FSAR Table 2.5.1-201; this describes regional tectonic structures within the 320-km (200-mi) radius of the Fermi 3 site region. Based on the staff's review of RAI 02.05.01-06 and the staff's independent literature review, the staff concluded that the applicant's response to RAI 2.5.1-6 adequately resolves the issues surrounding the age of the most recent deformation among the Peck, Sharpsville, and Transylvania faults. The staff noted that there is no documented evidence for a Quaternary deformation along the Peck, Sharpsville, and Transylvania faults or evidence that would contradict the applicant's characterization of these faults. Therefore, RAI 02.05.01-6 is resolved and closed.

The staff noted that FSAR Table 2.5.1–201 summarizes the faults and folds in the Fermi site region, including the youngest faulted or deformed unit for most structures. However, the applicant did not explicitly discuss the oldest unfaulted unit associated with each fault or fold. In RAI 02.05.01-07, the staff asked the applicant to revise FSAR Table 2.5.1-201 and to discuss the oldest unfaulted geologic units associated with each of the major tectonic faults that the applicant described in FSAR Subsection 2.5.1.1.4.3.2.

In the response to RAI 02.05.01-07 dated February 11, 2010 (ML100570306), the applicant revised FSAR Table 2.5.1-201 to reflect a more thorough literature review. The applicant also contacted experts at four state agencies in Michigan, Ohio, and Indiana for additional information. Based on these additional reviews, the applicant concluded that there is no evidence for Quaternary tectonic faulting in the Fermi 3 site region. The applicant also observed an unconformity between the Paleozoic and the overlying Quaternary glacial, fluvial, and lacustrine sediments. In general, the faulted Paleozoic rocks are overlain by Quaternary sediments, which are not known to be faulted in the site region according to information reported in the literature.

The staff reviewed the applicant's response to RAI 02.05.01-07 and noted that not one of the 14 faults that the applicant described in FSAR Subsection 2.5.1.1.4.3.2 shows evidence of Quaternary geologic deformation that would increase the seismic hazard at the proposed Fermi 3 site. The staff also noted that the applicant's descriptions of the faults are consistent with those in the available literature. Furthermore, FSAR Figure 2.5.1-203 illustrates tectonic structures in the Fermi site region. The applicant described most of these tectonic features in FSAR Subsection 2.5.1.1.4.3.2 with the exception of the Outlet, Marian, and Colchester faults.

In RAI 02.05.01-24, the staff asked the applicant to describe the three faults depicted in FSAR Figure 2.5.1-203 but not described in the FSAR text. In the response to RAI 02.05.01-24 dated February 11, 2010 (ML100570306), the applicant explained that the Outlet and Marion faults are part of the Bowling Green fault zone that the applicant described in FSAR Subsection 2.5.1.1.4.3.2.3. The Bowling Green fault zone is located approximately 40 km (25 mi) from the Fermi site at its closest point. There is no evidence of Quaternary age faulting along any of the faults within the Bowling Green system. The applicant revised FSAR Subsection 2.5.1.1.4.3.2.3 to differentiate the different faults in the Bowling Green fault zone.

Also in the response to RAI 02.05.01-24 is the applicant's revision of the FSAR to include a description of the Colchester fault. The Colchester fault shows no evidence of Quaternary geologic faulting. The staff reviewed the applicant's response to RAI 02.05.01-24 and concluded that the applicant has adequately evaluated all known potential fault sources in the Fermi site region based on the most current geologic literature. Following the applicant's response to RAI 02.05.01-24 and the applicant's revision to FSAR Subsection 2.5.1.1.4.3.2 and FSAR Table 2.5.1-201, the staff concluded that the applicant has provided an adequate discussion of known geologic faults in the Fermi site region. Therefore, RAI 02.05.01-24 and RAI 02.05.01-07 are resolved and closed.

<u>NRC Staff's Conclusions Regarding Faults within the Site Region</u>

Based on information in FSAR Subsection 2.5.1.1.4.3.2 and the applicant's responses to the staff's RAIs, the staff concludes that the applicant has provided a thorough and adequate description of known geologic faults in the Fermi 3 site region. The staff concludes that there is no evidence of a Quaternary deformation on these faults to suggest a hazard at the site. Finally, the staff determined that the applicant has provided a sufficient characterization of faults in the site region to support the Fermi 3 COL application. The staff found that the applicant's information is in accordance with RG 1.208 and meets the requirements of 10 CFR 100.23.

2. Seismic Zones within the Site Region

FSAR Subsection 2.5.1.1.4.3.3 describes two seismic zones in the Fermi 3 site region—the Anna and the Northeast Ohio Seismic Zones. In the 2000 USGS Quaternary Fault and Fold Database, Crone and Wheeler (2000) designated these two zones as Class C features. Crone and Wheeler define Class C features as "those for which geologic evidence is insufficient to demonstrate the existence of a tectonic fault, Quaternary slip, or deformation associated with the feature."

a. Northeast Ohio Seismic Zone

The staff noted that FSAR Subsection 2.5.1.1.4.3.3.1 does not discuss earthquake-induced paleoliquefaction studies in the Northeast Ohio Seismic Zone. However, Crone and Wheeler (2000) cite Obermeier's 1995 examination of stream banks in the Northeast Ohio Seismic Zone for liquefaction features. Paleoliquefaction investigations are relevant to evaluating the possibility that magnitude 6 or larger earthquakes may have occurred in the past. Paleoliquefaction information may also indicate the potential for future earthquakes. Given the proximity of the Northeast Ohio Seismic Zone to the Fermi site, an earthquake of magnitude 6 or larger may impact the seismic hazard at the Fermi site. The staff therefore asked the applicant in RAI 02.05.01-10 to describe any paleoseismic investigations conducted in the Northeast Ohio Seismic Zone, including the locations investigated and the level of detail of the investigations.

In the response to RAI 02.05.01-10 dated February 11, 2010 (ML100570306), the applicant described paleoseismic liquefaction field studies that Obermeier had conducted in 1995 along the Grand and Cuyahoga Rivers in northeast Ohio (Obermeier 1995). Dr. Obermeier investigated approximately 25 km (15.5 mi) of stream bank exposures along each of these rivers in search of evidence for earthquake-induced liquefaction features. Obermeier investigated Holocene sediments from the past 8,000 to 10,000 years that he considered to be moderately susceptible to earthquake-induced liquefaction and found no evidence of previously liquefied deposits. The applicant provided a table summarizing the field locations that Obermeier had visited in 1995 in addition to details about the geology, age of deposits, and liquefaction susceptibility for each location. The applicant also described unsuccessful searches for liquefaction evidence in the area near the Perry Nuclear Power Plant in Perry, Ohio. The applicant confirmed through research and through discussions with the Ohio Geological Survey that no additional paleoseismic field investigations have been conducted in northeast Ohio since the 1995 investigations by Obermeier.

The staff reviewed the applicant’s response to RAI 02.05.01-10 and the results of the letter report from Obermeier to the NRC in May 1996 (Obermeier 1996). The staff determined that the applicant’s information adequately describes the extent of paleoseismic investigations conducted in the Northeast Ohio Seismic Zone. RAI 02.05.01-10 is therefore resolved and closed.

FSAR Subsection 2.5.1.1.4.3.3.1 describes a series of earthquakes that occurred between 1987 and 2001 near Ashtabula County, Ohio, and also discusses the proximity of the 1987 earthquakes to an injection well. The staff noted that a series of earthquakes in 2001 were precisely recorded by the Ohio seismic network. However, the applicant did not provide any additional details of the larger 2001 event or the associated smaller events, including their location or the basis for linking the 1987 and 2001 events. The staff also noted that FSAR Figure 2.5.1-207 does not differentiate between the 1987 and 2001 events. In RAIs 02.05.01-12 and 02.05.01-28, the staff asked the applicant to provide additional information describing (1) the linkage between the 1987 and 2001 earthquakes near Ashtabula County; (2) evidence regarding whether or not these earthquakes are related to fluid injection; and (3) the potential for these earthquakes to produce magnitude greater than 5 earthquakes.

In the responses to RAI 02.05.01-12, and RAI 02.05.01-28, both dated February 11, 2010 (ML100570304), the applicant explained that earthquakes occurring between 1987 and 2003 near Ashtabula County, Ohio, are in close proximity to waste fluid injection wells that were active from 1986 to 1994. The earthquake sequences that took place between 1987 and 2003 were recorded by three short-term deployments of portable seismographs and by regional broadband seismographs. Based on an analysis of the recorded seismicity, Seeber et al. (2004) interpreted that these earthquakes had occurred along two existing subparallel faults due to increased pore pressures that are likely associated with the nearby fluid injection. The 1987 and 1992 earthquake sequences likely occurred along a strike slip fault close to the injection well activity. The increased pore pressures propagated outward from the fluid injection source and over time, the pressure led to induced seismicity (associated with the later 2001 and 2003 earthquakes) along a second favorably oriented fault further from the injection source (Seeber et al. 2004). These investigators concluded that the evidence for increased pore pressures along multiple faults provides evidence that these faults would not likely produce earthquakes with a magnitude greater than 5 (Seeber et al. 2004).

As a result of RAIs 02.05.01-12 and 02.05.01-28, the applicant revised FSAR Subsection 2.5.1.1.4.3.3.1 to include a more thorough description of the sequence of earthquakes that occurred near Ashtabula County, Ohio. The applicant provided a more complete description of the evidence linking these earthquakes to nearby fluid injection, as well as evidence linking these earthquakes to multiple pre-existing fault structures. The applicant also updated FSAR Figure 2.5.1-207 to include the timing of earthquakes identified in the Northeast Ohio Seismic Zone. The applicant also added FSAR Figure 2.5.1-266 to show the earthquakes and inferred fault planes associated with the Ashtabula seismic events. The staff reviewed the applicant's responses to RAIs 02.05.01-12 and 02.05.01-28, as well as the evidence and conclusions from Seeber and Armbruster (1993) and Seeber et al. (2004). The staff concludes that the applicant has provided a more thorough characterization of the Ashtabula seismicity in the RAI responses and in the revised FSAR descriptions. Therefore, RAIs 02.05.01-12 and 02.05.01-28 are resolved and closed.

In RAI 02.05.01-11, the staff asked the applicant to identify any other locations in the Fermi site region where large volumes of fluid are being injected or withdrawn. In the response to RAI 02.05.01-11 dated February 11, 2010 (ML100570306), the applicant provided a table of active waste disposal wells located in the site region in Michigan, Ohio, and Indiana. The table identifies when the wells were drilled as well as the depth of the wells and the affected subsurface units. Triggered seismicity is only correlated with the fluid injection wells near Ashtabula County, Ohio. The staff reviewed the applicant's response to RAI 02.05.01-11 and determined that the tables in the applicant's response adequately detail the locations and history of injection wells in the Fermi 3 site region. Accordingly, RAI 02.05.01-11 is resolved and closed.

b. Anna Seismic Zone

FSAR Subsection 2.5.1.1.4.3.3.2 states that Obermeier (1995) performed paleoliquefaction surveys along stream banks surrounding the Anna, Ohio, area to evaluate evidence or the lack of evidence for large historic or prehistoric earthquakes. The applicant stated that Obermeier (1995) discovered no evidence for magnitude 7 earthquakes during the past several thousand years.

In RAI 02.05.01-14, NRC staff asked the applicant to more thoroughly describe Obermeier's paleoliquefaction investigations conducted in the Anna Seismic Zone. In the response to this RAI dated February 11, 2010 (ML100570306), the applicant's detailed description of those investigations included the locations that Obermeier had surveyed. Obermeier investigated more than 100 km (62 mi) of deposits along multiple rivers and streams to the south and southwest of the Fermi 3 site. The applicant also included a figure showing the locations of the rivers in the investigation, most of which are within the 320-km (200-mi) radius of the Fermi 3 site region but at least 100 km (62 miles) from the Fermi 3 site. The applicant also contacted Dr. Stephen Obermeier, USGS geologists Drs. Russ Wheeler and Richard Harrison, and geologists with the Ohio Geological Survey and the University of Indiana who are familiar with the Obermeier studies. The applicant also noted that there are no known surviving maps of Obermeier's field investigations to identify the exact locations of the paleoliquefaction studies.

The staff reviewed the RAI response and performed an independent evaluation of the Obermeier (1995) field investigations, which describe the types of deposits encountered along the rivers that were studied. Obermeier noted that although the quality of the outcrop locations along many of the stream banks was poor, there were sufficient exposures to evaluate the likelihood that larger, magnitude 7, earthquakes had occurred in the Anna Seismic Zone. Obermeier found no such evidence of earthquake activity during his paleoliquefaction field investigations in the Anna Seismic Zone. The staff observed that the Obermeier report does not preclude the possibility that smaller (magnitude 5 or less) earthquakes have occurred the Anna Seismic Zone.

The NRC staff's review found that the applicant's response to RAI 02.05.01-14 provides sufficient information regarding paleoliquefaction evaluations in the Anna Seismic Zone to assure the staff that the applicant had adequately evaluated the potential for large damaging earthquakes in the Fermi 3 site region. Furthermore, the staff concludes that based on published data of field investigations along several rivers in and surrounding the Anna Seismic Zone, there is no paleoliquefaction evidence to suggest that large magnitude earthquakes had occurred in the Anna Seismic Zone. Therefore, RAI 2.5.1-14 is resolved and closed.

NRC Staff's Conclusions Regarding Seismic Zones within the Site Region

Based on information in FSAR Subsection 2.5.1.1.4.3.3, the applicant's responses to the staff's RAIs, and the staff's independent literature investigations, the staff concludes that the applicant has provided a thorough and accurate description of the seismic zones located in the site region to support the Fermi 3 COL application. The staff found that the applicant's information is in accordance with RG 1.208 and meets the requirements of 10 CFR 100.23.

Seismic Zones outside of the Site Region

FSAR Subsection 2.5.1.1.4.4 describes two seismic zones outside of the site region: the NMSZ and the WVSZ. The NMSZ is located approximately 800 km (500 mi) from the Fermi 3 site, while the WVSZ is located approximately 500 km (300 mi) from the site. The applicant indicated that the CEUS-SSC model characterizes both zones as seismic sources of a RLME. The applicant also noted that both of these seismic sources contribute to the seismic hazard at the Fermi 3 site.

New Madrid Seismic Zone

FSAR Subsection 2.5.1.1.4.4.1 discusses the NMSZ, which is located approximately 800 km (500 mi) from the Fermi 3 site. The CEUS-SSC developed an RLME source to represent the central faults in the NMSZ. The applicant described a publication by Forte et al. (2007) proposing a mechanism to explain the occurrence of earthquakes in the NMSZ. Further, staff is aware of additional recent publications proposing other faulting mechanisms in the New Madrid region. In RAI 02.05.01-15, the staff asked the applicant to discuss the mechanisms considered as part of the NMSZ evaluation and to explain whether there is a consensus that favors one mechanism over another.

In the response to RAI 02.05.01-15 dated January 11, 2010 (ML100130382), the applicant explained that there are several proposed models to help explain seismicity in the New Madrid region. The applicant provided a comprehensive description of the many mechanisms various researchers have proposed to explain New Madrid earthquakes and updated the FSAR to include these discussions. The applicant emphasized that there is considerable uncertainty regarding the causative mechanisms and long-term behavior of fault sources in the New Madrid region, and no single hypothesis is widely accepted. What is widely accepted is the evidence of large earthquakes with a magnitude greater than 7 in the NMSZ at various times in the last 2,000 years, regardless of the mechanism.

The staff reviewed the applicant's response to RAI 02.05.01-15, in addition to more than 15 published resources that discuss possible mechanisms for earthquakes in the New Madrid region. The staff concludes that the applicant has performed a thorough review of these mechanisms and the varied possible explanations for NMSZ seismicity. The applicant evaluated the effects of earthquakes in the NMSZ as part of the PSHA for the Fermi 3 site. SER Section 2.5.2 provides the NRC staff's evaluation of the applicant's PSHA for the site. RAI 02.05.01-15 is therefore resolved and closed.

Wabash Valley Seismic Zone

The staff reviewed the applicant's description of the WVSZ in FSAR subsection 2.5.1.1.4.4.2, in addition to published resources that discuss possible mechanisms for earthquakes in the Wabash Valley region. The staff concludes that the applicant has performed a thorough review of these mechanisms and the varied possible explanations for WVSZ seismicity. The applicant evaluated the effects of earthquakes in the WVSZ as part of the PSHA for the Fermi 3 site. SER Section 2.5.2 provides the NRC staff's evaluation of the applicant's PSHA for the site. The staff did not request any additional information from the applicant with respect to the WVSZ.

NRC Staff's Conclusions Regarding Seismic Zones outside of the Site Region

Based on the information in FSAR Subsection 2.5.1.1.4.4 and the applicant's response to RAI 02.05.01-15, NRC staff concludes that the applicant has provided a thorough and accurate description of seismic zones located outside of the site region that have the potential to affect hazards at the Fermi 3 site. The staff found that the applicant's information is sufficient to support the Fermi 3 COL application. The staff concludes that the applicant's description is in accordance with RG 1.208 and meets the requirements of 10 CFR 100.23.

Regional Non-seismic Geologic Hazards

In FSAR Section 2.5.1.1.5, the applicant discussed landslide hazards and the occurrence of karst in the Fermi 3 site region. The staff's review concludes that the applicant has provided an adequate evaluation of non-seismically related geologic hazards in FSAR Subsection 2.5.1.1.5 to support the Fermi 3 COL application. The staff found that the applicant's information is in accordance with RG 1.208 and meets the requirements of 10 CFR 100.23. The staff's evaluation of the potential for landslide and karst hazards at the Fermi 3 site is under the section on "Site Geological Hazards" later in this SER.

2.5.1.4.2 Site Geology

The staff's review of Fermi 3 COL FSAR Subsection 2.5.1.2 focused on the applicant's description of the site physiography, geologic history, stratigraphy, and structural geology within the site vicinity (40-km [25-mile] radius), site area (8-km [5-mile] radius), and site location (1-km [0.6-mi] radius) of the Fermi 3 COL site. The following section presents the staff's evaluation of the applicant's information in FSAR Subsection 2.5.1.2 and the applicant's responses to the staff's RAIs.

Site Physiography and Geomorphology

FSAR Subsection 2.5.1.2.1 discusses the site physiography. The applicant stated that the Fermi 3 site is located in the Eastern Lake section of the Central Lowlands physiographic province. The site vicinity is also located in the St. Lawrence Lowlands physiographic province. These provinces are described in more detail in FSAR Subsection 2.5.1.1.1. The applicant also described the Maumee Lake plains section of the Eastern Lake and the St. Clair Clay Plains section of the St. Lawrence Lowlands.

The staff reviewed the site physiography in FSAR Subsection 2.5.1.2.1 and performed an independent review of the published geologic information. The staff concluded that the applicant has provided a thorough and accurate description of the physiography and geomorphology surrounding the Fermi 3 site to support the Fermi 3 COL application. The staff found that the applicant's information is in accordance with the guidance of RG 1.208 and meets the requirements of 10 CFR 100.23.

Site Geologic History

The applicant discussed the regional geologic history of the Fermi site in FSAR Subsection 2.5.1.1.2. The staff's evaluation of the regional geology is provided above under "Regional Geologic History."

FSAR Subsection 2.5.1.2.2 describes the Paleozoic and Quaternary geologic history, including an unconformity between the Pennsylvanian and Pliocene periods. The applicant also described the glacial history of the Fermi 3 site area and vicinity during the Quaternary and more specifically, during the past 25,000 years. The applicant described the relationships between lake phases, glacial lake shorelines, and ice margin positions in the site vicinity. The applicant also described the predecessor of Lake Erie, Glacial Lake Leverett, whose shoreline may have been within the site vicinity limits.

In RAI 02.05.01-17, the staff asked the applicant to explain any correlations that may exist between mapped glacial shorelines in the site vicinity and possible relict shorelines associated with Glacial Lake Leverett. In the response to RAI 02.05.01-17 dated February 11, 2010 (ML100570306), the applicant summarized the sequence of glacial events affecting the preservation of the Lake Leverett shorelines. The applicant noted that the lake levels associated with Glacial Lake Leverett were affected by subsequent ice advances. These younger ice advances, in addition to subsequent lake level fluctuations from transgressions and regressions, explain the very limited evidence of Lake Leverett shorelines in the Fermi 3 site vicinity.

The staff reviewed the applicant's response to RAI 02.05.01-17 as well as a number of publications that discuss the glacial history of the Great Lakes region. The staff concluded that the applicant's response to RAI 02.05.01-17 is sufficient to clarify that subsequent glacial-related processes have mostly overridden evidence for former Glacial Lake Leverett shorelines. RAI 2.5.1-17 is therefore resolved and closed.

FSAR Subsection 2.5.1.2.2.2 suggests that glacial lakes formed in the last 14,000 years "have surface expression continuity and preserved landforms that document the rebound history of the area." In RAI 02.05.01-18, the staff asked the applicant to describe the post-glacial rebound history in the site vicinity in order to better understand the history of vertical deformation at and near the Fermi site. In the response to RAI 02.05.01-18 dated February 11, 2010 (ML100570306), the applicant referred to the response to RAI 02.05.01-03 that discussed the evidence for vertical deformation of glacial and post-glacial lake shoreline features that record the GIA in the site region. The applicant also referenced its response to RAI 02.05.03-6, which is discussed later in Section 2.5.3 of this SER. The applicant summarized the history of Lake Erie levels during the past approximate 10,000 years based on recent interpretations by Holcombe et al. (2003), whose historic descriptions of Lake Erie post-glacial levels are based on the latest detailed bathymetric and water budget data. The applicant noted that relict shorelines in the site region and vicinity are near the hinge line between uplift to the northeast and a zone of horizontality to the southwest.

The applicant noted that the elevations of lake strand lines in the site vicinity indicate that isostatic adjustments are relatively uniform. The applicant also updated the FSAR to clarify that landforms and features associated with young glacial lakes reflect the “cumulative response of the site vicinity to glacial isostatic adjustments.”

The staff reviewed the applicant’s response to RAI 02.05.01-18. The staff also performed an independent review of the pertinent geologic literature relating to glacial landforms in the Great Lakes region and the vertical deformation of glacial shorelines. The staff concluded that the applicant has provided an adequate description of the glacial rebound history of the Fermi 3 site vicinity. Therefore, RAI 2.5.1-18 is resolved and closed.

NRC Staff’s Conclusions Regarding Site Geologic History

Based on the information in FSAR Subsection 2.5.1.1.2 and the applicant’s responses to the staff’s RAI’s, NRC staff concludes that the applicant has provided a thorough and accurate description of the site geologic history to support the Fermi 3 COL application. The staff found that the applicant’s information is in accordance with RG 1.208 and meets the requirements of 10 CFR 100.23.

Site Stratigraphy

FSAR Subsection 2.5.1.2.3 describes the site area and site location stratigraphy based on the applicant’s subsurface investigations conducted for the Fermi 3 COL application. The staff’s review of FSAR Subsection 2.5.1.2.3 focused on the applicant’s descriptions of the Silurian-age Bass Islands Group and Salina Group units that underlie the proposed Fermi 3 site. In particular, the Bass Islands Group is the foundation-bearing unit for the proposed Fermi 3 nuclear island and is predominantly composed of dolomite with interbedded shale and salt. The applicant also described the Quaternary stratigraphy and geomorphology in the Fermi 3 site vicinity. Glacial and lake deposits overlie the Paleozoic Bass Islands and Salina Groups. The applicant’s descriptions of the stratigraphic and geomorphic history in the Fermi 3 site vicinity correlates with the regional descriptions that the applicant provided in FSAR Subsection 2.5.1.1. FSAR Section 2.5.4 discusses the applicant’s subsurface investigations. The NRC staff’s technical evaluation of FSAR Section 2.5.4 is in SER Subsection 2.5.4.4.

The staff reviewed FSAR Subsection 2.5.1.2.3 and performed an independent review of the geologic literature describing the regional and the site stratigraphy of the Fermi 3 site. In addition, in November 2009, the staff visited the Fermi 3 site and evaluated rock core samples obtained during the applicant’s subsurface investigations of the site to verify the applicant’s stratigraphic descriptions included in the FSAR. Based on this review, the staff concludes that the applicant has provided a thorough and accurate description of the stratigraphic and geomorphic history of the Fermi 3 site vicinity, site area, and site location to support the Fermi 3 COL application. The staff found that the applicant’s information is in accordance with RG 1.208 and meets the requirements of 10 CFR 100.23.

Site Structural Geology

In FSAR Subsection 2.5.1.2.4, the applicant described the structural geology of the site vicinity. FSAR Subsection 2.5.1.2.4.1 states that there is no evidence of Quaternary faulting in the site vicinity. However, the applicant described two mapped bedrock faults in the Fermi 3 site vicinity: the Bowling Green and Maumee faults. The staff also noted that the Howell anticline and the Howell fault lie just outside of the site vicinity within 45 km (28 mi) of the Fermi 3 site.

FSAR Subsection 2.5.1.2.4.1 states that the Maumee fault is a northeast-southwest trending normal fault that follows the Maumee River and extends to the Lake Erie shore. FSAR Figures 2.5.1-230 and 2.5.1-231 show the trend of the Maumee fault and its location with respect to the Lake Erie shoreline while also showing the lake bottom bathymetry, including a northeast-southwest trending linear feature from the mouth of Lake Erie toward the lake basin. In RAI 02.05.01-20, the staff asked the applicant to explain the linear feature shown in the Lake Erie bathymetry with respect to the similar trending Maumee fault. In the response to RAI 02.05.01-20 dated January 11, 2010 (ML100130382), the applicant explained that the linear feature represents an excavated and dredged channel used to facilitate shipping traffic in order to permit barges to enter the Toledo Harbor. The applicant provided additional documentation of the dredging history and annual dredging activity. The staff reviewed the applicant's response to RAI 02.05.01-20 and concludes that the applicant has adequately described the linear feature shown in the Lake Erie bathymetry and has adequately justified that this linear feature is not a likely extension of the onshore Maumee fault. Therefore, RAI 02.05.01-20 is resolved and closed.

During the NRC staff's visit to the Denniston Quarry in Monroe County, Michigan, as part of a November 2009 Fermi 3 COL site audit, the staff noted at least three zones of disrupted bedding exposed in the quarry walls. These disrupted zones suggest possible faulting of the Bass Islands Group. In one location, disrupted bedding exists beneath an interpreted paleokarst feature (located near the top of the geologic section) and suggests that the paleokarst development may be associated with faulting at depth. Figure 2.5.1-5 in this SER shows this paleokarst feature above a zone of disrupted bedding in the Bass Islands Group. In a second quarry location, a zone of disrupted bedding exists with mostly undisturbed bedding on either side. This second zone appears to be at least seven to ten meters wide; contains disrupted bedding from the top to the bottom of the exposed wall; and is flanked by relatively undisturbed bedding on both sides. The third zone of possible disturbed bedding was visible in a distant wall and could be related to vertical offsets within the Bass Islands Group.

RAI 02.05.01-29 asked the applicant to further evaluate the disturbed zones and the apparent offset beds visible at the Denniston Quarry, including a determination of whether or not the disturbed bedding and apparent offsets are fault related. In addition, the staff asked the applicant to evaluate the overlying Quaternary units and to determine whether these younger deposits were deformed by the underlying structures.

In the response to RAI 02.05.01-29 dated February 11, 2010 (ML100570306), the applicant provided a 56-page Technical Memorandum that comprehensively discusses the studies in the Denniston Quarry. The applicant's quarry studies included trenches in the Quaternary deposits across the traces of the faults, sample descriptions of Quaternary deposits, and light detection and ranging (LiDAR) mapping of selected walls in the quarry. The applicant documented all of the evaluations, provided photographs and maps of the exposures, and included information such as a description of the oldest and youngest deformed strata that established the ages of the deformation. In one case, the applicant documented deformation in the Bass Islands Group that was traceable to the top of the bedrock. However, the applicant provided no evidence for faulting or deformation in the overlying Quaternary deposits from the past 12,000 years. The applicant's investigations identified no open caves or modern karst features at the Denniston Quarry that would indicate karst activity within the past 12,000 years. In the response to RAI 02.05.01-29 and as a result of the field investigations at the Denniston Quarry, the applicant updated the FSAR to document the results of the investigations.

The staff reviewed the applicant's response to RAI 02.05.01-29 and the applicant's field investigation report from the Denniston Quarry. The staff concludes that the applicant had conducted a thorough investigation of the evidence for Quaternary faulting and karst activity in the exposures at the Denniston Quarry. Based on this review, the staff noted that the applicant's investigations had revealed no evidence for faulting, deformation due to subsurface faulting, or karst activity in the overlying quaternary sediments at the Denniston Quarry. Based on the applicant's investigations and the information detailed in the applicant's report, the staff concludes that the applicant has provided a thorough characterization of the deformation features at the Denniston Quarry in the response to RAI 02.05.01-29. Therefore, RAI 02.05.01-29 is resolved and closed.

NRC Staff's Conclusions Regarding Site Structural Geology

Based on information in FSAR Subsection 2.5.1.2.4, the applicant's responses to the staff's RAIs, and the staff's independent assessment, NRC staff concludes that the applicant has provided a thorough and accurate description of the structural geology at the site to support the Fermi 3 COL application. The staff found that the applicant's information is in accordance with RG 1.208 and meets the requirements of 10 CFR 100.23.

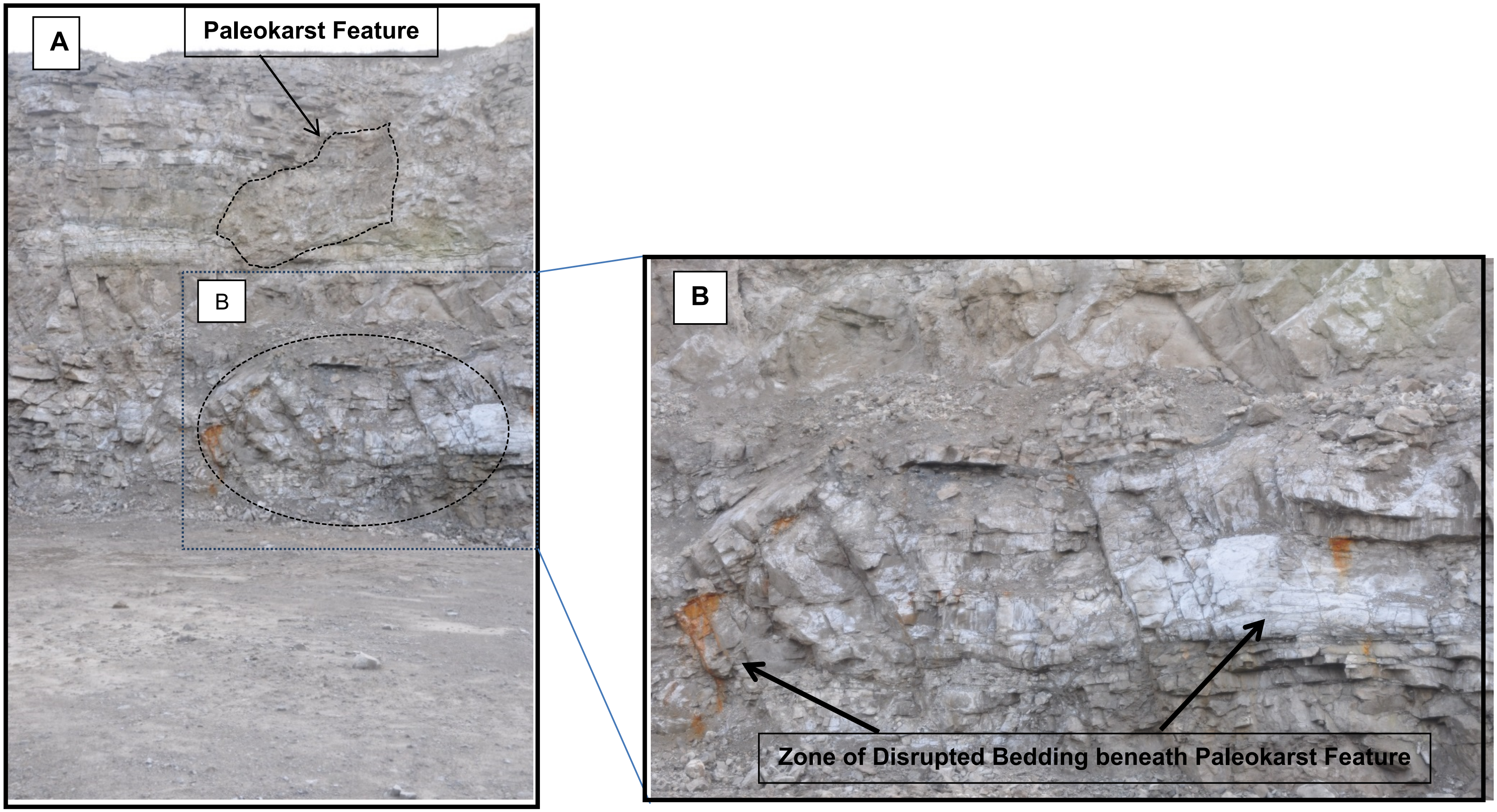

Figure 2.5.1-5 Photographs of Strata in the Denniston Quarry, Monroe, Michigan.

Note: A. Exposure of paleokarst feature in the Bass Islands Group and disrupted bedding beneath the feature.
B. Insert of disrupted bedding beneath paleokarst feature.]

Site Geologic Hazard Evaluation

FSAR Subsection 2.5.1.2.5 describes non-seismically related geologic hazards in the Fermi 3 site vicinity. FSAR Figure 2.5.1-227 illustrates potential landslide hazards in the Fermi 3 site region, and FSAR Figure 2.5.1-228 illustrates the potential for karst in the site region.

1. Site Landslide Hazard Evaluation

FSAR Figure 2.5.1-227 shows a high-incidence landslide area near the Fermi 3 site. In RAI 02.05.01-21, the staff asked the applicant to define the location of the high-incidence landslide probability in relationship to the Fermi 3 site and to explain whether any potential landslide hazards exist at the Fermi 3 site. In the response to RAI 02.05.01-21 dated February 11, 2010 (ML100570306), the applicant noted that the high-incidence landslide zone highlighted in FSAR Figure 2.5.1-227 is located approximately 50 km (31 mi) southwest of the Fermi 3 site, outside of the site vicinity. The applicant stated that the landslide area is associated with steep banks of the Maumee River and thick glacial deposits. The applicant noted, however, that a landslide hazard in the site vicinity is "low incidence, moderate susceptibility." The local relief along the Maumee River that is prone to landslides is approximately 15 m (50 ft) high, but the local relief along the streams near the Fermi 3 site is less than 3 m (10 ft). The applicant noted that this lower relief along the streams close to the site decreases the landslide probability of those stream banks. Based on the applicant's response to RAI 02.05.01-21 and the staff's field visit to the Fermi 3 site and the surrounding area in November 2009, the staff concluded that the applicant has sufficiently considered the potential for landslides. The applicant's response confirmed that the high incidence landslide area is outside of the site vicinity. Furthermore, the staff confirmed that landslide hazard at the site is likely low because of less relief along the stream banks and thinner glacial deposits. Therefore, RAI 2.5.1-21 is resolved and closed.

2. Site Karst Hazard Evaluation

FSAR Subsection 2.5.1.2.5 discusses the probability of karst within the 8-km (5-mile) radius of the Fermi 3 site, with respect to existing karst features in similar Silurian-age rock found in northwestern Ohio. The staff noted that FSAR Figure 2.5.1-228 shows an area of extensive subsidence near the Fermi 3 site. The applicant stated that the probability for karst development is low at the Fermi 3 site because the foundation-bearing Bass Islands Group is covered by more than 6 m (20 ft) of glacial till and lacustrine deposits. The applicant also stated that although the probability for karst is low at the site, karst features in units of a similar age in northwestern Ohio are "large enough to cause engineering problems." In RAI 02.05.01-30, the staff asked the applicant to provide a thorough discussion justifying the applicant's conclusion that the probability of karst at the Fermi 3 site is low.

In the response to RAI 02.05.01-30 dated February 11, 2010 (ML100570307), the applicant provided three lines of evidence to support its conclusion that there is a low probability of karst at the Fermi 3 site. The applicant first noted that karst formation is less likely in areas that have been formerly covered by ice sheets and are now covered by glacial deposits, because glaciers typically eroded away carbonate material or filled in existing karst features. Second, the applicant noted the absence of large voids or cavities due to karst in the subsurface investigations into the Salina and Bass Islands Groups at the Fermi 3 site. Finally, the applicant noted the absence of any large voids and cavities in bedrock exposures at the nearby Denniston Quarry. The applicant further explained that karst features typically form in the site region in Silurian-age carbonate rocks where they are not overlain by thick glacial deposits.

The staff reviewed the applicant's response to RAI 02.05.01-30 and reviewed local and regional karst studies surrounding the Fermi 3 site region. The staff determined that the applicant has adequately justified the conclusion that the evidence supports a low probability of karst formation at the site. The staff also reviewed the subsurface samples collected during the applicant's boring program and evaluated rock units exposed in the Denniston Quarry during a visit to the site in November 2009. The staff did not see any evidence for large cavities or voids due to karst in the subsurface foundation units observed by the staff. As a means of verifying that there are no subsurface faults or deformation features that could cause a hazard to the Fermi 3 site, the staff implemented a geologic license condition requiring the applicant to geologically map and evaluate all excavations for nuclear island structures and to evaluate all excavations for safety-related structures other than the nuclear island. License Condition 2.5.3-1 is defined in Subsection 2.5.3.5 of this SER. The staff's evaluation of cavities and voids in subsurface borings is in Section 2.5.4 of this SER. RAI 2.5.1-30 is therefore resolved and closed.

NRC Staff's Conclusions Regarding Site Geologic Hazard Evaluation

Based on information in FSAR Subsection 2.5.1.2.5 and the applicant's responses to the staff's RAIs, NRC staff concluded that the applicant has provided a thorough and accurate description of the site geologic hazards to support the Fermi 3 COL application. The staff found that the applicant's documentation is in accordance with RG 1.208 and meets the requirements of 10 CFR 100.23.

Site Engineering Geology

FSAR Subsection 2.5.1.2.6 describes the potential for engineering issues within the Fermi 3 site vicinity. The applicant evaluated zones of alteration, weathering, and structural weakness within the Bass Islands and Salina groups. The applicant also evaluated the potential for impacts from unrelieved residual stresses in bedrock and for weak or unstable subsurface conditions. The applicant evaluated deformational zones, the effects of human activities, and site groundwater conditions. The staff reviewed FSAR Subsection 2.5.1.2.6 and concluded that the applicant has adequately characterized potential engineering issues for the Fermi 3 site to support the Fermi 3 COL application. The staff found that the applicant's documentation is in accordance with RG 1.208 and meets the requirements of 10 CFR 100.23.

2.5.1.5 *Post Combined License Activities*

There are no post COL activities related to FSAR Section 2.5.1. However, in SER Subsection 2.5.3.5, the staff identifies a geologic mapping License Condition for Fermi 3 as the responsibility of the applicant and specifies it as License Condition 2.5.3-1.

2.5.1.6 *Conclusion*

NRC staff reviewed the application and confirmed that the applicant has addressed the required information relating to the basic geologic and seismic information, and no outstanding information is expected to be addressed in the Fermi 3 COL FSAR related to this section.

In addition, the staff compared the additional information in the COL application to the relevant NRC regulations, the guidance in Section 2.5.1 of NUREG–0800, and other applicable NRC regulatory guides. The staff's review concluded that the applicant has provided sufficient information to satisfy the requirements of NRC regulations. The staff determined that the applicant has adequately addressed COL Item EF3 COL 2.0-26-A, as it relates to the basic geologic and seismic information.

The staff found that the applicant has provided a thorough characterization of the geologic and seismic characteristics of the Fermi site, as required by 10 CFR 100.23 and 10 CFR 52.79(a)(1)(iii). In addition, the staff concluded that the applicant has identified and appropriately characterized all seismic sources significant to determining the GMRS for the Fermi site, in accordance with NRC regulations in 10 CFR 100.23 and 10 CFR 52.79(a)(1)(iii) and the guidance in RG 1.208. Based on the applicant's geologic investigations of the site vicinity and the site area, the staff determined that the applicant has properly characterized regional and site lithology, stratigraphy, geologic and tectonic history, and structural geology, as well as subsurface soil and rock units at the site. The staff concluded that there is no potential for the effects of human activities (e.g., mining activity or groundwater injection or withdrawal) to compromise the safety of the site. Therefore, the staff concluded that the proposed COL site is acceptable from a geologic and seismologic standpoint and meets the requirements of 10 CFR 100.23.

2.5.1.7 References

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2.5.2 Vibratory Ground Motion

2.5.2.1 *Introduction*

The vibratory ground motion is evaluated based on seismological, geological, geophysical, and geotechnical investigations carried out to determine the site-specific GMRS, which must meet the SSE regulations in 10 CFR 100.23. The GMRS is defined as the free-field horizontal and vertical ground motion response spectra at the plant site. The development of the GMRS is based on a detailed evaluation of earthquake potential that takes into account the regional and local geology, Quaternary tectonics, seismicity, and site-specific geotechnical engineering characteristics of the site's subsurface material. The specific investigations necessary to determine the GMRS include the seismicity of the site region and the correlation of earthquake activity with seismic sources. Seismic sources are identified and characterized, including the rates of occurrence of earthquakes associated with each seismic source. Seismic sources that have any part within 320 km (200 mi) of the site must be identified. More distant sources that have a potential for earthquakes large enough to affect the site must also be identified. Seismic sources can be capable tectonic sources or seismogenic sources. Specific areas covered in the review are (1) seismicity; (2) geologic and tectonic characteristics of the site and region; (3) the correlation of earthquake activity with seismic sources; (4) a probabilistic seismic hazard analysis and controlling earthquakes; (5) seismic wave transmission characteristics of the site; (6) site-specific GMRS; and (7) any additional information requirements prescribed within the "Contents of Application" sections of the applicable subparts to 10 CFR Part 52.

2.5.2.2 *Summary of Application*

Section 2.5.2 of the Fermi 3 COL FSAR, Revision 5, describes potential vibratory ground motion at the Fermi 3 site. In addition, in FSAR Section 2.5.2, the applicant provides the following:

<u>*COL Item*</u>

- EF3 COL 2.0-27-A — Vibratory Ground Motion in Accordance with SRP Section 2.5.2

In FSAR Section 2.5.2, the applicant provided site-specific information in accordance with SRP Section 2.5.2 to address COL Item EF3 COL 2.0-27-A and to confirm that the site-specific foundation input response spectrum is enveloped by the ESBWR DCD design response spectra referenced at the foundation level.

The applicant developed the GMRS using the recommended performance-based approach in RG 1.208. Based on the evaluation, the applicant presented the following details related to the vibratory ground motion information for the Fermi 3 site.

2.5.2.2.1 Seismicity

FSAR Subsection 2.5.2.1 documents that the applicant used the most recent earthquake catalog published as part of NUREG–2115, in the seismic hazard assessment at the Fermi 3 site. The NUREG–2115 earthquake catalog covers earthquakes in the CEUS region from 1568 through 2008. The applicant stated that the NUREG–2115 catalog is the starting point for developing an updated earthquake catalog for the Fermi 3 site region. The applicant developed the updated catalog for the portion of the NUREG–2115 catalog (between latitude 39° and 45°N and longitude 79° and 87.5°W) covering the time period from January 1, 2009, through

December 31, 2012. Furthermore, the applicant followed the process used in NUREG–2115 for developing an earthquake catalog. Consistent with the NUREG–2115 catalog, E[**M**] is the expected value of the true moment magnitude (**M**) and was calculated for all post-CEUS-SSC catalog earthquakes in the updated catalog. The applicant obtained updated earthquake information from the USGS National Earthquake Information Center (NEIC) Web site, the Advanced National Seismic System (ANSS) Web site, the Ohio Seismic Network Web site operated by the Ohio Geologic Survey, as well as the National Earthquake Database (NEDB) operated by the Geologic Survey of Canada.

Figure 2.5.2-1 in this SER shows the seismicity of the Fermi 3 site region and its surroundings. The applicant noted that the earthquakes occurring since 2008 have similar spatial distributions and do not indicate new concentrations of seismicity. In FSAR Subsection 2.5.2.1.2, the applicant noted that several significant earthquakes had occurred beyond the 320-km (200-mi) site radius in the period following the completion of the NUREG–2115 catalog—including the August 23, 2011, E[**M**] 5.73 earthquake near Mineral, Virginia; and the November 6, 2011, E[**M**] 5.66 earthquake in central Oklahoma. The applicant evaluated the impact of these earthquakes on the Fermi 3 seismic hazard is in FSAR Subsection 2.5.2.4.1.2.

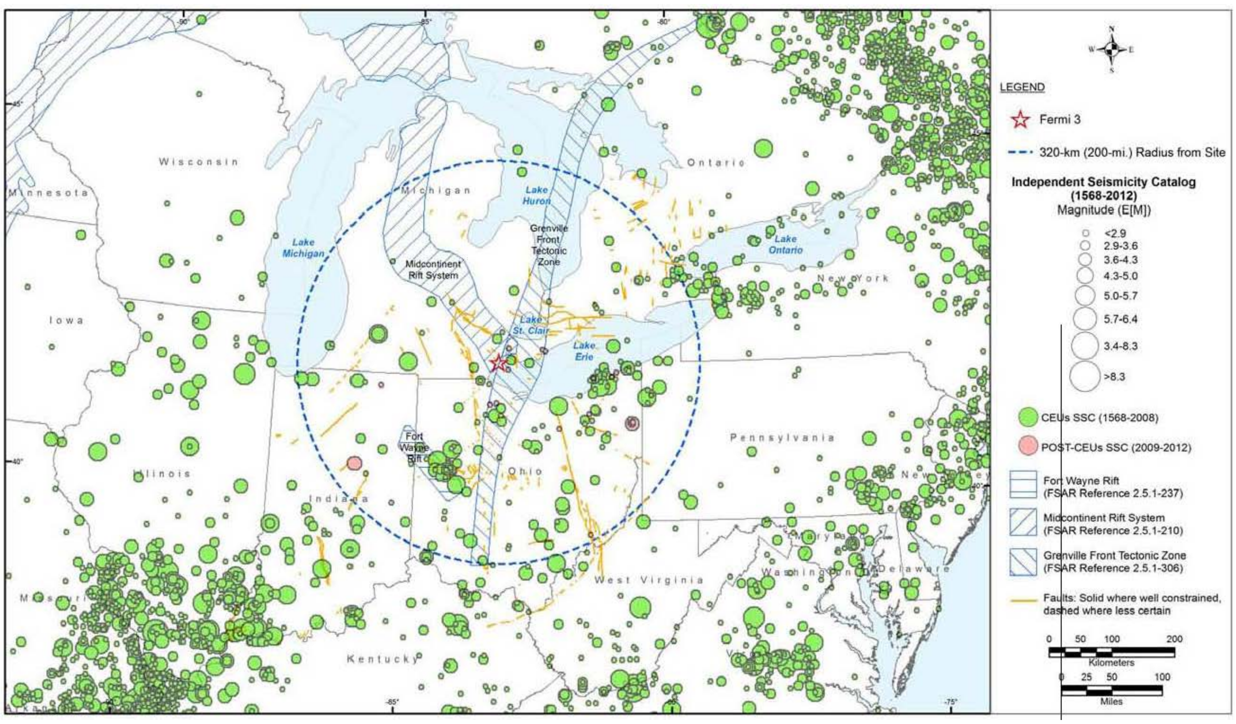


Figure 2.5.2-1 Seismicity of the Site Region of the Fermi 3 Site (taken from COL FSAR markups in the March 15, 2013, response to RAI 01.05-1; Figure 2.5.2-202 [ML13079A493])

2.5.2.2.2 Geologic and Tectonic Characteristics of the Site and Region

FSAR Subsection 2.5.2.2 describes the seismic sources and seismic model parameters that the applicant used to calculate the seismic ground motion hazard at the Fermi 3 site. The applicant used the NUREG–2115 regional seismic source characterization model developed for the

CEUS region as a starting point for its seismic ground motion hazard. It took 3 years to develop the NUREG–2115 seismic source model, which was published in January 2012. The development of the model followed the Senior Seismic Hazard Analysis Committee (SSHAC) Level 3 procedures as outlined in NUREG/CR–6372, "Recommendations for Probabilistic Seismic Hazard Analysis: Guidance on Uncertainty and Use of Experts." It is a regional seismic source model to be used as a starting model in seismic hazard calculations for nuclear facilities in the CEUS region. In FSAR Subsection 2.5.2.4.1, the applicant conducted a review of the CEUS-SSC model to identify which seismic sources are relevant to the assessment of the seismic hazard at the Fermi 3 site and whether there is a need to update any of the seismic sources. Based on this review, the applicant stated that the regional model as published is adequate for use in seismic hazard calculations for the Fermi 3 site. The following summary of the CEUS-SSC model includes the source selection process the COL applicant used.

Summary of the NUREG–2115 Seismic Source Model

The applicant stated that the CEUS-SSC model described in NUREG–2115 contains two types of seismic sources: distributed seismicity sources and RLME sources. While the distributed seismicity sources are based on available earthquake locations and regional geologic/tectonic characterizations, the RLME sources are based on geologic and paleoearthquake records. The RLME source records describe the zones where the occurrence of repeated (two or more) large magnitude earthquakes (**M** > 6.5) are documented.

The CEUS-SSC model categorizes the distributed seismicity sources into two subgroups: M_{max} zones and seismotectonic zones. These subgroups represent uncertainties in source characterizations and differences of opinions regarding the identification of seismic sources in this region. In hazard estimates, the M_{max} and seismotectonics sources are weighted by 40 percent and 60 percent, respectively, to determine their contributions to the total seismic hazard at the site. The M_{max} zones are broad seismic sources that were identified based on limited tectonic information and represent potential seismic sources of future earthquakes. The seismotectonic sources are those that were developed using extensive analyses of regional geology, tectonics, and seismicity for the CEUS region. Both the M_{max} and the seismotectonics zones also include alternative source geometries that accommodate inherent uncertainty in seismic source characterization.

In FSAR Subsection 2.5.2.4.3, the COL applicant stated that the PSHA conducted for the Fermi 3 site includes the contributions from all or parts of each distributed seismicity model (i.e., M_{max} and seismotectonic source zones) that lie within 1,000 km (620 mi) of the site. As a result, the applicant used the following alternative seismic source configurations for the M_{max} zones: the Study Region, NMESE-N, NMESE-W, MESE-N, and MESE-W. The Study Region is the largest seismic source in the CEUS model, and it represents the entire area of the CEUS region. MESE and NMESE represent regions where the Mesozoic-aged tectonic extension did (MESE) or did not (NMESE) take place. The MESE-N, MESE-W, NMESE-N, and NMESE-N represent alternative configurations of these two overall classifications. Narrow "N" or wide "W" extensions represent varying alternative geometries of these sources. The applicant noted that the Fermi 3 site is located in the NMESE M_{max} source zone in both interpretations.

The applicant stated that the following nine seismotectonic source zones are included in the seismic hazard model for the Fermi 3 site: Atlantic Highly Extended (AHEX) Crust; Extended Continental Crust – Atlantic Margin (ECC-AM); Great Meteor Hotspot (GMH); Illinois Basin Extended Basement (IBEB); Midcontinent-Craton (MIDC) including MIDC -A, MIDC-B, MIDC-C, and MIDC-D; Northern Appalachian (NAP); Paleozoic Extended Crust Zone (PEZ) including

PEZ-N and PEZ-W; Reelfoot Rift (RR) and Reelfoot Rift-Rough Creek Graben (RR-RCG); and St. Lawrence Rift (SLR). FSAR Figures 2.5.2-209, 2.5.2-210, 2.5.2-211, and 2.5.2-212 depict these seismotectonic zones. The applicant stated that the region within 320 km (200 mi) of the site is almost entirely contained within the MIDC seismotectonic zone. The MIDC seismic source is a large zone encompassing the regions of the continental interior. Tectonically, the MIDC represents a region with very little or no significant tectonic deformation in the past several hundred million years. Because the MIDC zone boundaries are uncertain, four alternatives define this zone: MIDC-A; MIDC-B; MIDC-C; and MIDC-D. Accordingly, FSAR Figures 2.5.2-211 and 2.5.2-212 show that the PEZ-W falls within a small eastern portion of the 320-km (200-mi) site region radius for the MIDC-C and MIDC-D source zone alternatives. The western boundary of this zone, however, is not well constrained. Therefore, the CEUS-SSC model has two alternative geometries for this source—PEZ-W and PEZ–N—that represent the wide zone geometry and the narrow zone geometry, respectively. Specifically, the PEZ-W alternative geometry falls within the 320-km (200-mi) site region radius, (see Figure 2.5.2-2 in this SER).

The applicant stated that in addition to the alternative geometries, the characterization of the distributed seismicity source zones includes the use of three alternative magnitude ranges for computing seismicity parameters; alternative values for seismogenic crustal thickness; rupture geometry; maximum magnitude distributions for each source; and seismicity parameter distributions for each source. The applicant stated that FSAR Subsection 2.5.2.4.1.2 includes the applicant's evaluation of the impact from earthquakes occurring after the completion of the CEUS-SSC model catalogued with an E[**M**] greater than or equal to 4.3 on the maximum magnitude distributions for the distributed seismicity source zones.

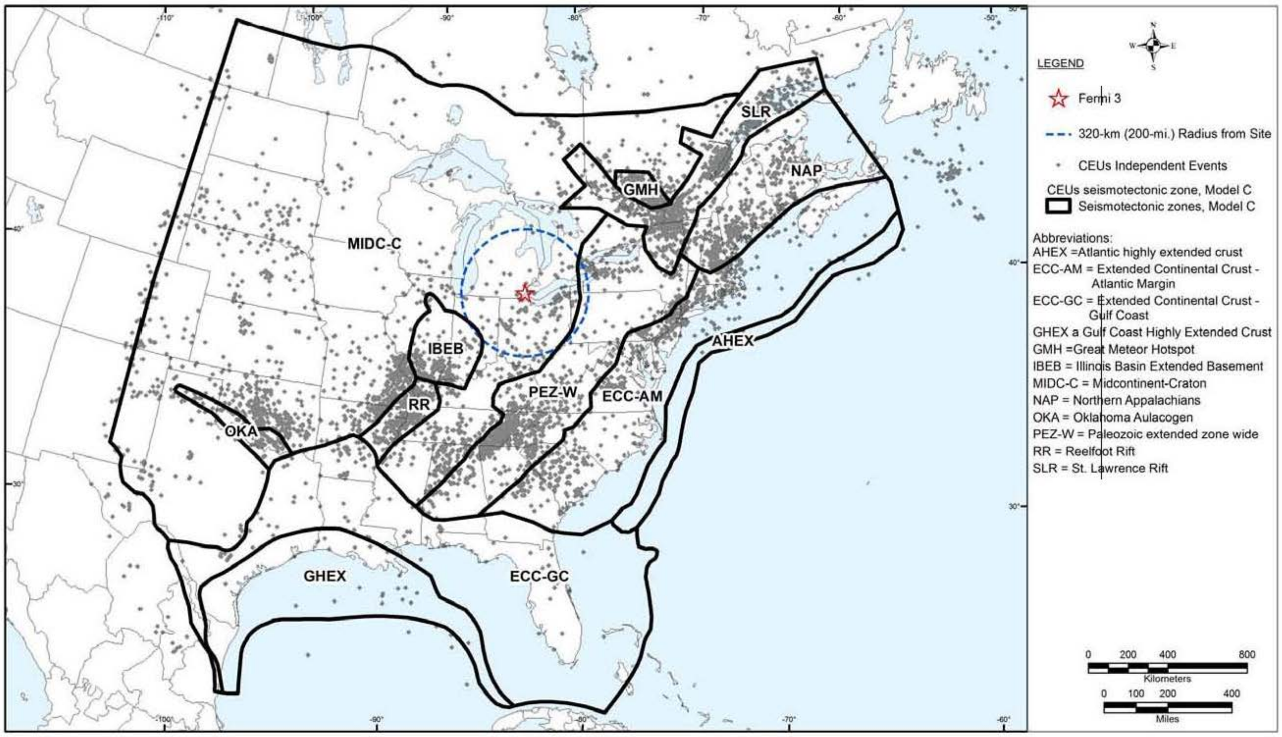


Figure 2.5.2-2 Map Showing the CEUS-SSC Seismotectonic Zones where the Rough Creek Graben Is Not Part of the Reelfoot Rift (RR) and the Wide Paleozoic Extended Crust (PEZ-W)
(taken from COL FSAR markups in the March 15, 2013, response to RAI 01.05-1; Figure 2.5.2-211 [ML13079A493])

[Note: The source configuration shown is one of the four alternative models for the MIDC seismotectonic zone.]

In the response to RAI 01.05-1 dated March 15, 2013 (ML13079A491), revised FSAR Subsection 2.5.2.2.4 summarizes the RLME sources used in the Fermi 3 seismic hazard calculations. The CEUS-SSC model requires contributions from the RLME sources to be added to seismic hazard estimates obtained from the distributed seismicity models. Figure 2.5.2-3 in this SER shows the locations of the RLME sources characterized in the CEUS-SSC model. The applicant identified the following RLMEs that were used in the Fermi Unit 3 seismic hazard calculations and are listed in order of significance to the Fermi 3 site hazard: New Madrid fault system (NMFS), Wabash Valley (WV), Charlevoix (CHV), and Charleston (CHS) RLME seismic sources. FSAR Subsection 2.5.2.4.3.1 provides the details regarding the RLME selection process, which are summarized in Subsection 2.5.2.4 of this SER.

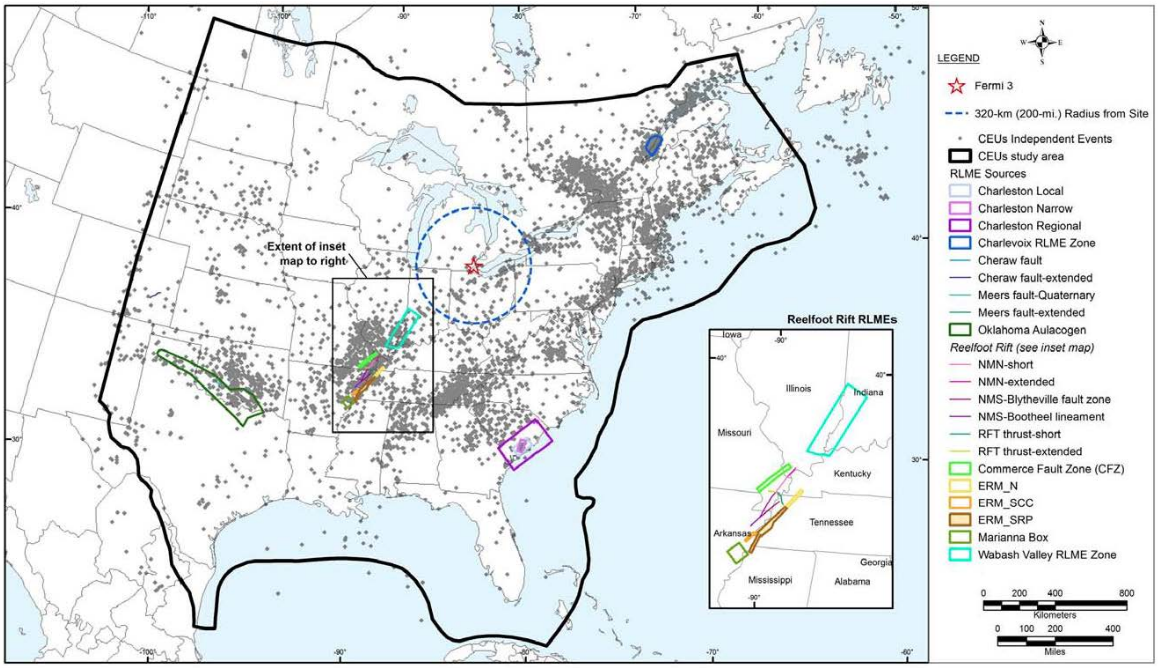


Figure 2.5.2-3 Map Showing the Repeated Large Magnitude Earthquake Sources in the CEUS-SSC Model (taken from COL FSAR markups in the March 15, 2013, response to RAI 01.05-1; Figure 2.5.2-213 [ML13079A493])

[Note: Nine primary RMLE sources and their alternative geometries are shown.]

2.5.2.2.3 Correlation of Earthquake Activity with Seismic Sources

FSAR Subsection 2.5.2.3 describes the correlation between the updated seismicity with the CEUS-SSC model sources. The applicant compared the distribution of earthquake epicenters from the NUREG–2115 earthquake catalog with the CEUS-SSC model sources and also with the updated earthquake catalog. The applicant concluded that the updated catalog does not show a pattern of seismicity that would require a new seismic source or significant revisions to the geometry of the seismic sources defined in the CEUS-SSC model that are in the Fermi 3 site region. The applicant also concluded that the updated CEUS catalog of the site region can be associated with a known geologic structure with the exception of the Anna and Northeast Ohio Seismic Zones, which lie at distances greater than 150 km (90 mi) from the Fermi 3 site. The applicant stated that seismicity in the Anna Seismic Zone occurs near the Ft. Wayne rift and seismicity in the Northeast Ohio Seismic Zone is associated with the Akron Magnetic Boundary; the CEUS-SSC model considers both areas.

2.5.2.2.4 Probabilistic Seismic Hazard Analysis and Controlling Earthquakes

FSAR Subsection 2.5.2.4 describes the applicant's PSHA calculations for the Fermi 3 site. The hazard curves generated by the applicant's PSHA represent the hazard calculated for generic hard rock conditions [characterized by a shear wave velocity (S-wave) of 2.8 km/s (9,200 fps)]. FSAR Subsection 2.5.2.4 also describes the earthquake potential for the Fermi site in terms of the most likely earthquake magnitudes and source-to-site distances, which are referred to as "deaggregation earthquakes." In this subsection, the applicant also determined the low-frequency (1 and 2.5 Hz) and high-frequency (5 and 10 Hz) deaggregation earthquakes by deaggregating the PSHA—in accordance with RG 1.208—at the specified probability levels of 10^{-4} and 10^{-5}.

PSHA Inputs

The applicant's PSHA calculations used the recently published CEUS-SSC model in NUREG–2115 in addition to the ground motion model in EPRI Technical Reports 1009684 and 1014381 (EPRI 2004, 2006).

Seismic Source Model

The applicant stated that the PSHA inputs for the Fermi 3 site consist of the distributed seismicity sources (M_{max} and seismotectonic zones) or portions of these zones that are within 1,000 km (620 mi) of the Fermi 3 site. The applicant conducted PSHA sensitivity calculations to aid in the selection of an appropriate set of RLME sources to include in the PSHA from the CEUS-SSC model. Based on these results, the applicant included CHV, CHS, NMF, and WV RLME sources because they contribute close to or greater than 1 percent to the total mean hazard at the Fermi 3 site. The seismic sources used in the PSHA calculations are summarized earlier under "Geologic and Tectonic Characteristics of the Site and Region" in this SER.

Seismicity Rates

The applicant evaluated the effect of the updated NUREG–2115 earthquake catalog on recurrence estimates within the 320-km (200-mi) site region. According to the applicant, two earthquakes of E[**M**] equal to or greater than 2.9 occurred within 320 km (200 mi) of the Fermi 3 site in the updated catalog (i.e., E[**M**] 3.79 and 3.66). The applicant conducted a one-side exact Poisson test of the hypothesis that the observation of two earthquakes in the 4-year period from 2009 through 2012 is consistent with the earthquake recurrence rates derived from the CEUS-SSC model. The results of the evaluation showed that the two observed earthquakes within 320 km (200 mi) of the Fermi 3 site are consistent with the distribution of earthquake recurrence rates derived from the CEUS-SSC model. Based on these results, the applicant concluded that it is not necessary to update the earthquake recurrence rates for the distributed seismicity source zones of the CEUS-SSC model in the Fermi 3 site region.

Maximum Magnitude Distributions

The applicant stated that FSAR Table 2.5.2-202 lists the earthquakes that have occurred after the completion of the CEUS-SSC model catalog in the time period from 2009 through 2012 with E[**M**] equal to or greater than 4.3. The applicant noted that these earthquakes potentially affect the M_{max} distributions for the following distributed seismicity zones that are applicable to the Fermi 3 PSHA: ECC-AM, GMH, MIDC-A, MIDC-B, MIDC-C, MIDC-D, MESE-N, and NMESE-W. The applicant used the procedure described in Section 5.2.1 of NUREG–2115 to compute the M_{max} distributions for the above source zones and considered the post NUREG–2115 catalog earthquakes listed in FSAR Table 2.5.2-202. The applicant's analysis indicated that forzones ECC-AM, MIDC-A, MIDC-B, MIDC-C, MIDC-D, and NMESE-W, incorporation ofe the updated earthquake catalog data results in a truncation of the lowest magnitude portion of the NUREG–2115 M_{max} distributions. For the NMESE-W and the MIDC zones, there is also an increase in the probability weight in the lower portion of the adjusted distributions. For the MESE-N and GMH zones, the additional earthquake data have an insignificant effect on the computed M_{max} distributions. As described in FSAR Subsection 2.5.2.4.3, the applicant performed sensitivity calculations using the updated M_{max} distributions in FSAR Table 2.5.2-203.

The effect of including these adjusted M_{max} distributions in the hazard calculation produced a 0.3 percent maximum increase in the total mean hazard at 1 Hz and 10 Hz spectral accelerations for the Fermi 3 site. Even though this result indicates that the model does not need to be updated, the applicant conservatively performed the PSHA for the Fermi 3 site using the updated M_{max} distributions.

Ground Motion Prediction Equations

The applicant used the EPRI (2004, 2006) ground motion prediction equations (GMPEs) for the updated PSHA, in addition to the updated aleatory uncertainties and weights. The applicant stated that a number of GMPEs for the CEUS have been published since the completion of the EPRI ground motion median model. In FSAR Figures 2.5.2-239a, 2.5.2-239b, and 2.5.2-239c, the applicant compared these newer GMPEs to the EPRI (2004) 5th, 50th, and 95th percentile 10 Hz and 1 Hz ground motion median models according to the cluster in which they could be assigned. The applicant concluded that the median ground motions obtained using the newer GMPEs—specifically Silva et al. (2003), Atkinson and Boore (2011), and Pezeshk et al. (2011)—produce similar or lower ground motion amplitudes compared to the EPRI (2006) ground motion median models; so they are thus likely to produce lower hazard levels. Therefore, the applicant did not update the EPRI median ground motion models for the purpose of computing the hazard at the Fermi 3 site.

The applicant also discussed the aleatory variability models associated with more recent GMPEs. The applicant noted that the Pezeshk et al. (2011) GMPE uses an average of the Next Generation Attenuation (NGA) aleatory variability values from western North America (WNA). In addition, Atkinson and Boore's (2006) simulation-based aleatory variability value is similar to that for the empirical data in WNA. Atkinson (2013) concluded that aleatory variability models in WNA and central and eastern North America (CENA) should be similar. The applicant thus concluded that it is appropriate to use the EPRI (2006) aleatory variability model in the Fermi 3 PSHA, which is based on empirical ground motion data from active tectonic regions such as WNA.

PSHA Methodology and Calculation

Using the modified CEUS (with modified M_{max} distributions described in FSAR Subsection 2.5.2.4.3) and the EPRI GMPEs (2004, 2006), the applicant performed the PSHA calculations using a fixed lower bound magnitude of **M**5.0 and modeled earthquakes occurring in the CEUS-SSC-distributed seismicity sources as point sources. The applicant applied the EPRI (2004) models for distance adjustment and for additional aleatory variability resulting from the use of point sources (epicenter) to model earthquakes. The models assumed a random rupture location with respect to the epicenter. The applicant modeled earthquakes occurring in the RLME sources as extended ruptures and did not apply the distance adjustment and additional aleatory variability models to these sources. In calculating the magnitude-dependent rupture area of earthquakes for the RLME sources, the applicant made the adjustment to use the 4.35 value instead of 4.366 in Equation H-1 of NUREG–2115.

The applicant performed the above PSHA calculations for peak ground acceleration (PGA) and ground motion frequencies of 25, 10, 5, 2.5, 1, and 0.5 Hz, as described in RG 1.208.

PSHA Results

Figure 2.5.2-4 in this SER shows the mean hard rock uniform hazard response spectra (UHRS) for the 10^{-4},10^{-5}, and 10^{-6} annual frequencies of exceedance that the applicant generated using the PSHA results.

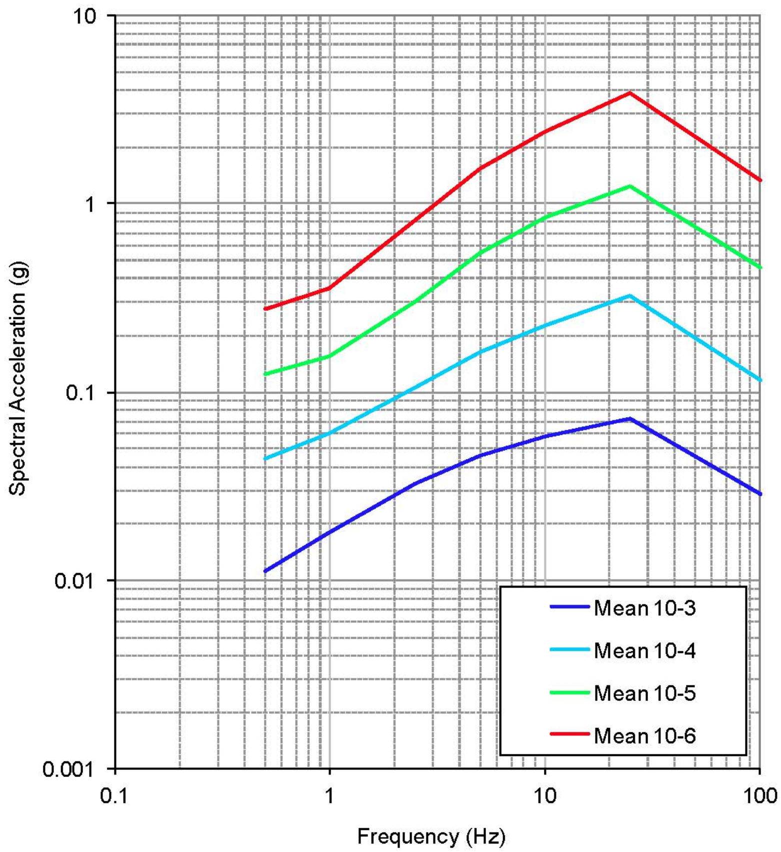


Figure -4 Mean Hard Rock UHRS for the Fermi 3 Site (taken from Fermi COL FSAR markups in the March 15, 2013, response to RAI 01.05-1; Figure 2.5.2-256 (ML13079A491)

To determine the low- and high-frequency controlling earthquakes for the Fermi 3 site, the applicant followed the procedure outlined in RG 1.208, Appendix D. This procedure involves the deaggregation of the PSHA results at a target probability level to determine the controlling earthquake in terms of a magnitude and source-to-site distance. Table 2.5.2-1 in this SER lists the mean magnitudes and geometric mean distances computed for the high- and low-frequency mean 10^{-4}, 10^{-5}, and 10^{-6} hazard results. Following Appendix D of RG 1.208, the applicant selected the controlling earthquake for the low-frequency ground motions from the distance calculation of greater than 100 km (62 mi). The applicant also referred to these controlling earthquakes as reference earthquakes (RE) because Approach 2B was followed for site response analyses described in NUREG/CR–6728, "Technical Basis for Revision of Regulatory Guidance on Design Ground Motions: Hazard- and Risk-Consistent Ground Motion Spectra Guidelines." As part of Approach 2B, the applicant also specified three high-frequency and three low-frequency deaggregation earthquakes (DE) in order to represent the distribution of earthquakes contributing to the hazard. These DEs are also listed in Table 2.5.2-1 in this SER and are designated as DEL, DEM, and DEH for the low-, middle-, and high-magnitude DEs, respectively. Table 2.5.2-1 shows that the high-frequency hazard is dominated by earthquakes with magnitudes of **M**5.5 occurring at short distances. At low frequencies, earthquakes that are several hundreds of kilometers away with magnitudes greater than **M**7 contribute significantly to the hazard.

Table -1 Rock Hazard Reference and Deaggregation Earthquakes (based on information in Fermi COL FSAR markups in the March 15, 2013, response to RAI 01.05-1; Table 2.5.2-212 [ML13079A491])

Reference (Controlling) Earthquakes			Deaggregation Earthquakes			
Mean Hazard	**Magnitude (M)**	**Distance (km)**	**Designation**	**Magnitude (M)**	**Distance (km)**	**Weight**
Mean 10^{-4}, 5, and 10 Hz	6.0	48	DEL	5.5	25.8	0.616
			DEM	6.5	76	0.291
			DEH	7.6	585	0.093
Mean 10^{-4}, 1, and 2.5 Hz	7.4	457	DEL	5.5	22.5	0.172
			DEM	6.6	84	0.117
			DEH	7.6	585	0.711
Mean 10^{-5}, 5, and 10 Hz	5.9	15.1	DEL	5.5	10.8	0.657
			DEM	6.4	22.4	0.286
			DEH	7.4	73	0.057
Mean 10^{-5}, 1, and 2.5 Hz	7.6	468	DEL	5.5	11.5	0.295
			DEM	6.7	37	0.395
			DEH	7.7	594	0.310

The applicant developed smooth response spectra to represent each RE and DE listed in FSAR Table 2.5.2-212 using the EPRI (2004) ground motion models and the EPRI (2006) aleatory variability models, as well as the spectral shape functions (average of the single and double corner spectral shape models for the CEUS) of the ground motions in NUREG/CR–6728. This involved the development of conditional mean spectral shapes based on Baker and Cornell (2006) and Baker and Jayaram (2008) and is described in more detail in FASR Subsection 2.5.2.4.4.3. The applicant also used the average of the single-corner and double-corner spectral shape models developed in NUREG/CR–6728 to (1) smooth the conditional mean spectral shapes between the seven frequencies defined in the EPRI (2004) ground motion models; and (2) extrapolate the EPRI median ground motion model from a frequency of 0.5 Hz down to a frequency of 0.1 Hz, specifically for the DEL and DEM events as well as the high-frequency (HF) RE events.

The applicant used constant velocity scaling to extend the DEH and low-frequency (LF) RE spectra from 0.5 Hz to 0.1 Hz (with a small decrease from constant velocity scaling from 0.2 Hz to 0.1 Hz) based on recently developed ground motion models (Somerville et al. 2001; Pezeshk et al. 2011; Atkinson and Boore 2011; and Silva et al. 2008a and 2008b). The applicant also extended the EPRI (2006) aleatory variability models down to a frequency of 0.1 Hz using a linear increase in aleatory variability with a decreasing log frequency from 0 percent to 0.5 Hz to

14 percent at 0.1 Hz, which was based on ground motion models developed as part of the Pacific Earthquake Engineering Research (PEER) Center's NGA Project (Abrahamson and Silva 2008; Boore and Atkinson 2008; Campbell and Bozorgnia 2008; Chiou and Youngs 2008; and Idriss 2008).

FSAR Figures 2.5.2-262 through Figure 2.5.2-265 shows the resulting DE and RE response spectra.

2.5.2.2.5 Seismic Wave Transmission Characteristics of the Site

FSAR Subsection 2.5.2.5 describes the method the applicant used for develop the Fermi 3 site free-field soil UHRS. Those resulting from the applicant's PSHA are defined for generic, hard rock conditions characterized by an S-wave of 2.8 km/s [9,200 fps]). According to the applicant, these hard rock conditions exist at an elevation of 48 m (156 ft) NAVD 88 at the Fermi 3 site. To determine the near-surface soil UHRS, the applicant first developed soil/rock profile models for the Fermi 3 site; selected representative hard rock ground motions based on a hard rock seismic hazard calculation; and performed site response analyses to obtain the free-field soil UHRS at the competent layer level beneath the Fermi 3 site.

Site Response Model

According to the applicant, the geology at the Fermi 3 site consists of thin layers of fill, lacustrine deposits, and glacial till overlying dolomite of the Bass Islands and Salina groups. The applicant intends to remove the upper ~4 m (13 ft) of fill, ~1.5 m (5 ft) of low velocity lacustrine deposits, and ~3.4 m (11 ft) of glacial till. The applicant also proposed to locate the GMRS at the top of the Bass Islands group, which corresponds to an average elevation of 168.2 m (551.7 ft) NAVD 88. According to the applicant, the glacial till is approximately 3.4 m (11 ft) thick and the measured S-wave velocities range from 286.5 to 350.5 m/s (940 to 1,150 fps)—with a geometric mean of 305 m/s (1,000 fps). The applicant performed P-S (compression [P] - shear [S]) suspension logging, downhole seismic testing, and SASW surveys to obtain an S-wave velocity profile for the Fermi 3 site—as shown in Figure 2.5.2-5 of this SER. The applicant used the P-S suspension logging results to obtain the S-wave velocities of the soil and bedrock units. The applicant also used the downhole seismic test results to obtain bedrock S-wave velocities, while the SASW survey results provided S-wave velocities for the glacial till.

The applicant encountered CEUS generic hard rock conditions (i.e., an S-wave velocity of about 2.8 km/s [9,200 fps]) at a depth of approximately 143.3 m (470 ft) or an elevation of 48 m (156 ft)—which corresponds to the Salina Group Unit B.

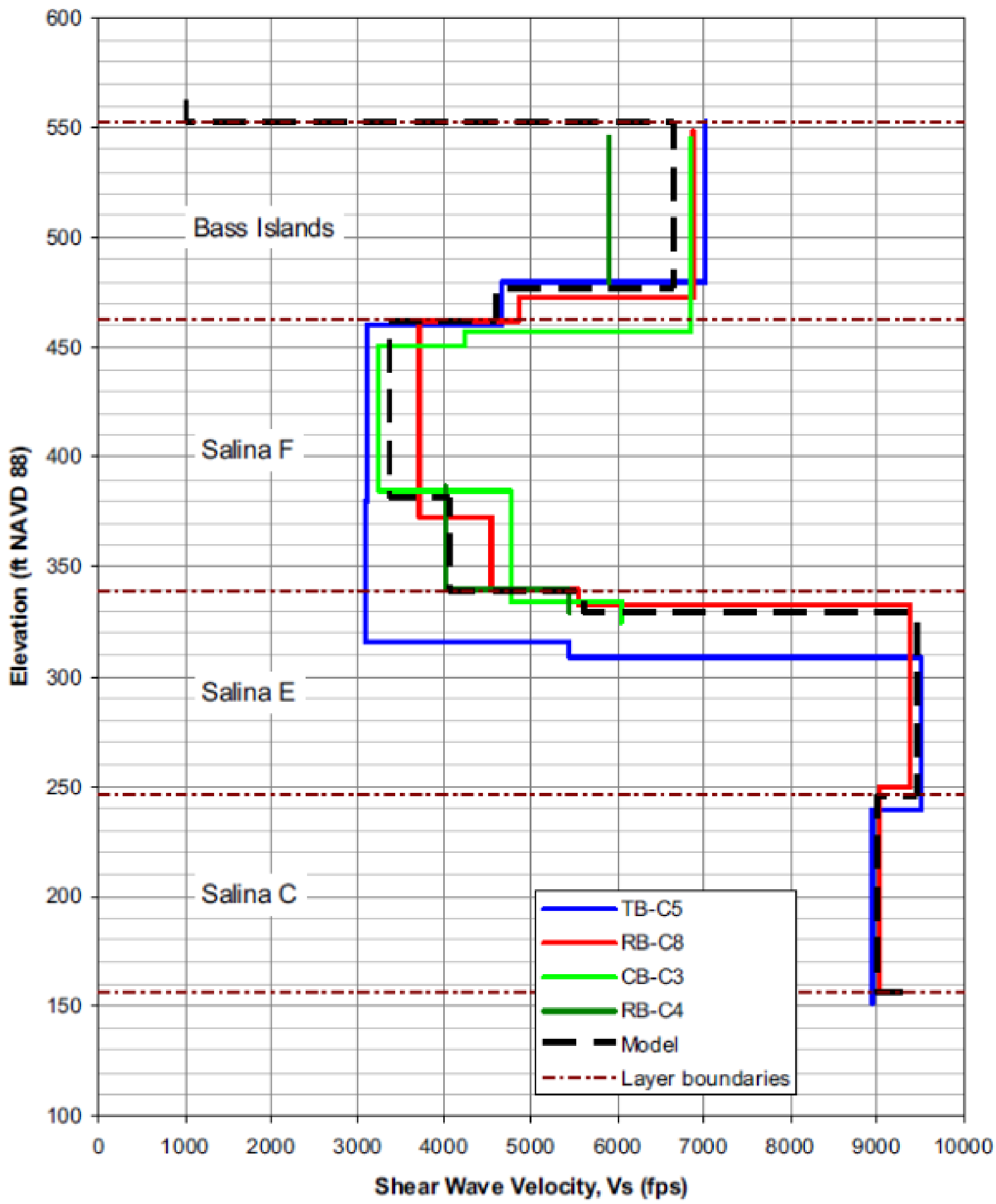


Figure -5 S-Wave Velocity Profile
(taken from Fermi COL FSAR markups in the March 15, 2013, response to RAI 01.05-1: Figure 2.5.2-270 [ML13079A491])

[Note: The curves labeled TB-C5, RB-C8, CB-C3, and RB-C4 corresponds to the mean S-wave velocity profiles developed for each boring. The curve denoted as "Model" corresponds to the geometric mean of the velocity profiles developed for each boring.]

In addition to the S-wave velocity profile, the applicant noted that the other material parameters used as inputs to the site response analysis included material unit weight, shear modulus, and damping. The applicant obtained soil and rock unit weights for the site response profile from laboratory test results and the site characterization. In summary, the applicant stated that unit weights for the rock units beneath the site range from 2,402.8 kg/m^3 to 2,562.95 kg/m^3 (150 pounds per cubic-foot [pcf] to 160 pcf). The applicant assigned a value of 2,707.12 kg/m^3 (169 pcf) to the unit weight of the underlying bedrock.

The applicant stated that the site response profile consists of dolomites and claystones with S-wave velocities exceeding 910 m/s (3,000 fps). The applicant expects the behavior of these materials to remain essentially linear at the expected levels of shaking (as defined by the rock hazard). The applicant determined the damping within these materials using the following procedure involving kappa (κ), a near-surface damping parameter, which is an estimate of the seismic energy dissipation at the site during an earthquake caused by damping within soil/rock layers and waveform scattering at layer boundaries. The applicant used estimates of the kappa to determine an appropriate damping ratio value for the rock layers below the glacial till.

The applicant stated that the kappa is an additive for soil/rock layers and is dependant on the individual layers. The applicant assigned the EPRI CEUS hard rock shallow crustal kappa of 0.006 seconds to shallow crust below an elevation of 48 m (156 ft). The applicant noted that the material above this elevation will contribute an additional damping and will thus add to the total site kappa. The applicant used a relationship between the kappa and the site S-wave velocity from EPRI (2005) to estimate the kappa above an elevation of 48 m (156 ft). Using an average S-wave velocity value of 1,737 m/s (5,700 fps), the applicant obtained a kappa of 0.013 seconds. The applicant then subtracted this value from the hard rock value of 0.006, which yielded a remaining kappa of 0.007 seconds for the top 131 m (396 ft) of dolomite. The applicant's conversion to damping, however, constrained the low strain damping for the Salina Group Unit F to a range of 1 to 3 percent based on values from the literature (Silva et al. 1996; EPRI 2005); and Silva 2007. The applicant then computed the damping values for the remaining rock layers using Equations 1, 2, and 4 in FSAR Subsection 2.5.2.5.1.2. The applicant noted that these assigned damping values add an additional kappa of 0.001 to 0.003 seconds. The applicant's conversion from kappa to material damping, made corrections to account for scattering effects due to velocity reversals present in the velocity model, as well as reversals introduced by randomizing the velocity profiles. The applicant assigned a damping value of 0.1 percent to the halfspace.

The applicant determined the appropriate soil and rock dynamic properties and then modeled the variability in the site data by randomizing the S-wave velocity profile, as well as the shear modulus reduction and the damping relationships for the glacial till. The applicant generated randomized profiles using the S-wave velocity correlation model developed by Silva et al. (1996). The applicant randomized the shear modulus reduction and damping curves for the glacial till according to Silva (2007). The applicant computed the damping in the sedimentary rocks beneath the glacial till using the randomized sedimentary rock layer velocities and thicknesses, as well as the selected kappa values. These artificial profiles represent the soil column from the top of the bedrock (with a bedrock S-wave velocity of 2.8 km/s [9,200 fps]) to the top of the glacial till for calculating the GMRS. The applicant used these randomized profiles as input to the site response calculations, which are summarized below in this SER.

In addition to the GMRS, the applicant developed foundation input response spectra (FIRS) at the base of the RB/FB, the control building (CB), and the fire water service complex (FWSC) that are presented in FSAR Section 3.7.1.

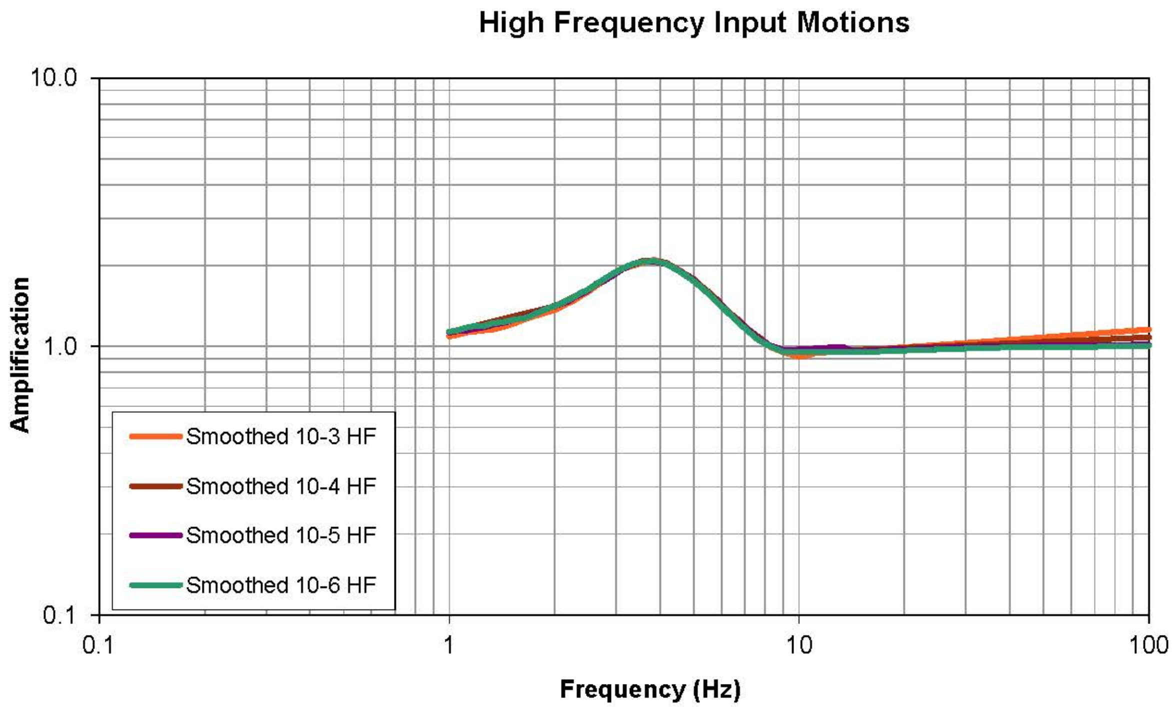
Site Response Input Time Histories

In order to develop rock input time histories for the Fermi 3 site response, FSAR Subsection 2.5.2.5.2 refers to the applicant's response spectra developed for each DE in FSAR Subsection 2.5.2.4.4.3. The applicant stated that 30 time histories were developed for each DE (i.e., three DEs for each HF and LF 10^{-3}, 10^{-4}, 10^{-5}, and 10^{-6} hazard level). The applicant selected time histories from NUREG/CR–6728 and scaled them to approximately match the target DE spectrum using the routine RSPM06, which implements the time domain spectral matching approach developed by Lilhanand and Teng (1988). The applicant concluded that the weak scaling produced records that have, in general, the desired relative frequency content of the DE spectra while maintaining a degree of natural variability.

Site Response Methodology and Results

The applicant used an updated version of the SHAKE computer program to calculate the site response at the Fermi 3 site. To calculate the final site amplification effects of the soil, the applicant divided the response spectrum for the computed surface motion by the corresponding response spectrum for the hard rock input motion. The applicant paired the 60 randomized S-wave velocity profiles with the 60 sets of randomized shear modulus reduction and damping curves (i.e., one S-wave velocity profile with one set of shear modulus reduction and damping curves). The applicant used each of the 30 scaled time histories to compute the response of two profile-soil property curve sets. The applicant then computed the arithmetic mean of the 60 individual response spectral ratios to define the amplification function.

In addition, for each DE, the applicant computed mean amplification functions for the three sets of rock damping values (1, 2, and 3 percent). For each annual exceedance probability level, the results from the three DEs (DEL, DEM, and DEH) are then combined to produce a weighted mean amplification function. The corresponding weights are in FSAR Table 2.5.2-215. FSAR Figure 2.5.2-277 shows the applicant's results for the different rock damping values that were used (1, 2, and 3 percent) for the 10^{-4} exceedance level. The applicant noted that the range in the damping leads to less than a 15 percent difference in the mean amplification at 100 Hz, which is less than a 25 percent difference near 40 Hz and decreases to less than a difference of 6 percent at 10 Hz. This difference continues to decrease for frequencies below 10 Hz. In addition, based on the results in FSAR Figure 2.5.2-278, the applicant concluded that the site amplification functions are insensitive to the differences in the DEs. Figure 2.5.2-6 in this SER plots the resulting high- and low-frequency amplification functions for the 10^{-3}, 10^{-4}, 10^{-5}, and 10^{-6} hazard levels. According to the applicant, the site amplification is insensitive to the level of input motion from the presence of relatively hard rock that is modeled as linear material.



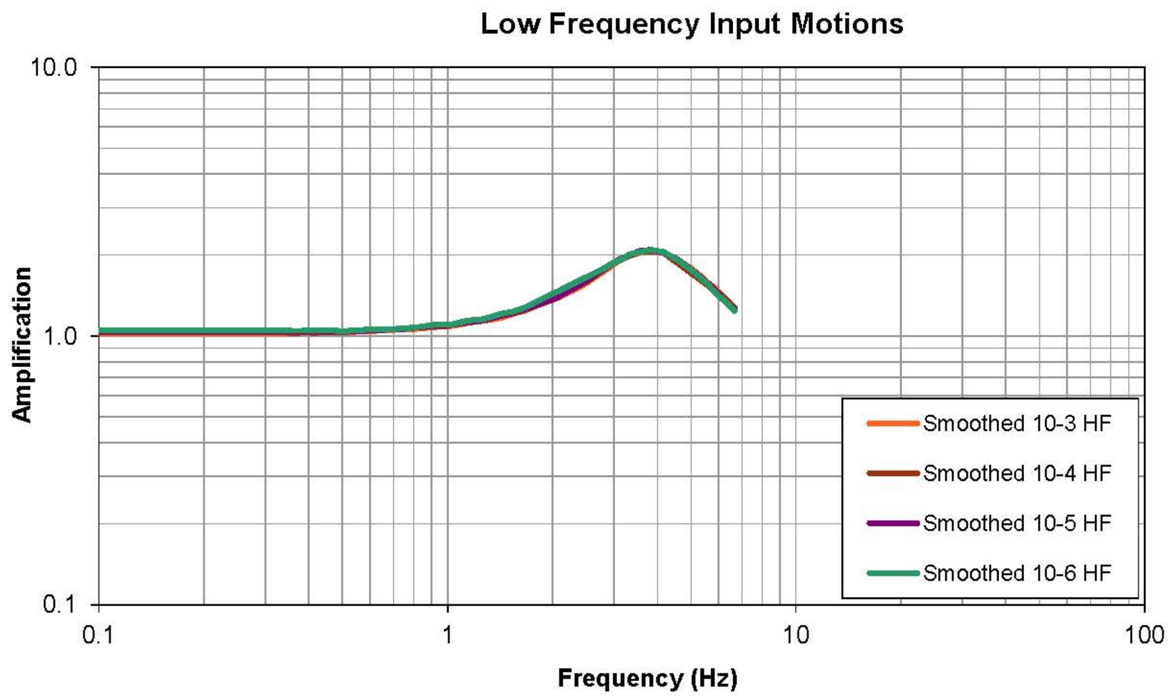


Figure -6 Mean Amplification Functions Corresponding to the Four Levels of Input Motion (i.e., annual probability of exceedance levels of 10^{-3}, 10^{-4}, 10^{-5}, and 10^{-6}) (taken from Fermi COL FSAR markups in the March 15, 2013, response to RAI 01.05-1: Figure 2.5.2-279 [ML13079A491])

2.5.2.2.6 Ground Motion Response Spectra

FSAR Subsection 2.5.2.6 describes the method the applicant used to develop the horizontal and vertical site-specific GMRS. To obtain the horizontal GMRS, the applicant used the performance-based approach in RG 1.208 and in ASCE/SEI Standard 43–05, "Seismic Design Criteria for Structures, Systems, and Components in Nuclear Facilities." The applicant developed the vertical GMRS using vertical-to-horizontal response spectral ratios for generic CEUS hard rock sites in NUREG/CR–6728.

The applicant first described the development of the hazard-consistent surface spectra using the 10^{-4} hazard level ground motions as an example. The applicant defined the surface spectra as free-field outcropping motions at an elevation of 168 m (551.7 ft) NAVD88. In summary, the applicant scaled the high- and low-frequency RE spectra by the appropriate smoothed amplification function. The applicant also scaled the generic hard rock UHRS using the appropriate low- and high-frequency amplification functions. Before applying the amplification functions, the applicant interpolated the rock UHRS between 10 and 100 Hz using the approach in FSAR Subsection 2.5.2.4.4.3. This approach was also summarized earlier in this SER section because there is a sharp peak at 25 Hz, which is an artifact of the PSHA computed for a limited number of frequency values (10, 25, and 100 Hz).

The final surface 10^{-4} UHRS is defined by the smooth envelope of the two spectra described above. The applicant conservatively removed the dip observed in the surface UHRS in the frequency range of 4 to 20 Hz that had resulted from (1) peaks in the site amplification function near 4 Hz from the overall rock profile, and (2) the peak near 25 Hz in the hard rock UHRS.

The applicant repeated the above procedure for the 10^{-5} and 10^{-6} exceedance level motions and then used the resulting surface spectra to develop the Fermi 3 horizontal and vertical GMRS.

<u>Horizontal GMRS</u>

The applicant calculated a horizontal, site-specific, performance-based GMRS using the method in RG 1.208. The performance-based method achieves the annual target performance goal (P_F) of 10^{-5} per year for the frequency of onset of significant inelastic deformation. This damage state (i.e., deformation) represents a minimum structural damage state—or essentially elastic behavior—and falls well short of the damage state that would interfere with functionality. The GMRS was calculated using the following relationship:

$$GMRS = DF^{*}\ UHRS(10^{-4})$$

Where:

$$DF = \max\{1.0,\ 0.6\ (A_R)^{0.8}\}$$

$$A_R = UHRS(10^{-5})/UHRS(10^{-4})$$

The applicant noted that when the value of A_R exceeds 4.2, RG 1.208 specifies that it is appropriate to use a GMRS value equal to 45 percent of the mean 10^{-5} UHRS. The applicant calculated the GMRS using the two approaches and developed the final GMRS from the envelope of the two, which corresponds to the 10^{-4} UHRS multiplied by the DF. Figure 2.5.2-7 of this SER shows the resulting horizontal GMRS.

Vertical GMRS

The applicant obtained the vertical GMRS by deriving V/H ratios and applying them to the horizontal GMRS. The applicant used the V/H spectral ratios for the generic CEUS hard rock sites in NUREG/CR–6728. The applicant justified the use of the generic CEUS hard rock V/H ratios by pointing out that the S-wave velocity of the Fermi 3 site is relatively high, and the kappa value of the assessed site is not significantly greater than the generic hard rock value. Figure 2.5.2-7 in this SER shows the resulting vertical GMRS.

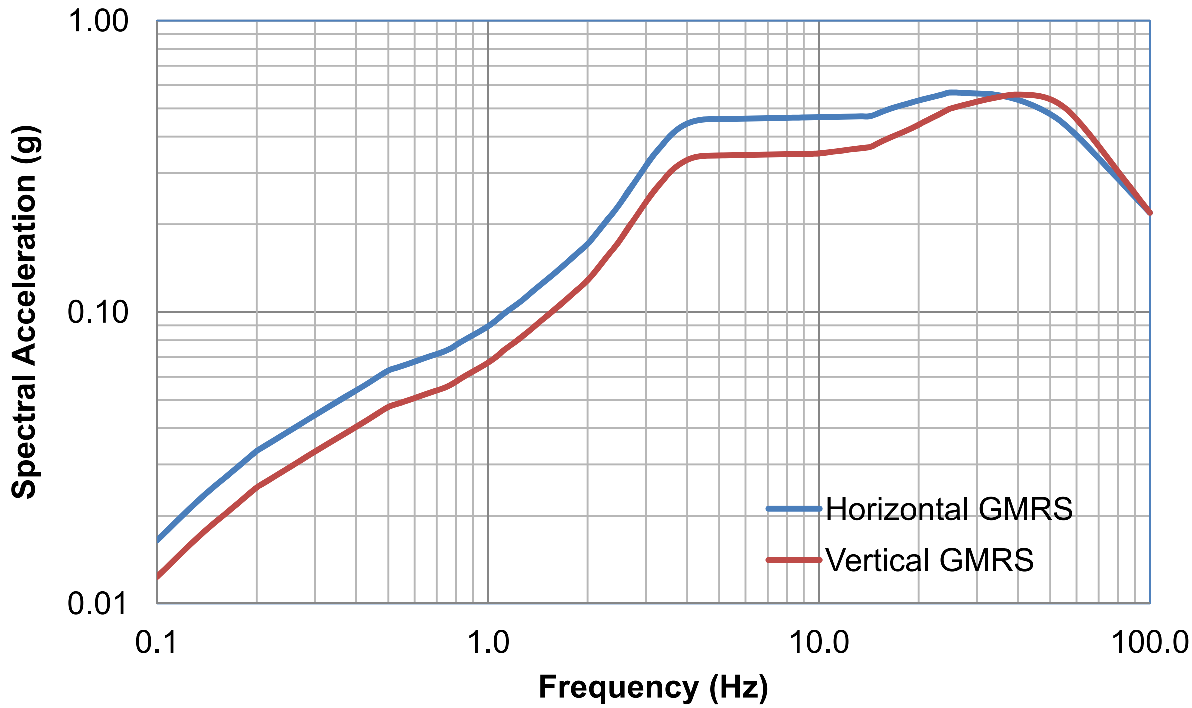


Figure 2.5.2-7 Fermi 3 Horizontal and Vertical GMRS (plot generated from data in Attachment 1 to the response to RAI 01.05-1 dated February 22, 2013 [ML13070A339])

2.5.2.3 *Regulatory Basis*

The relevant requirements of the Commission regulations for the vibratory ground motion, and the associated acceptance criteria, are in Section 2.5.2 of NUREG–0800. The applicable regulatory requirements are as follows:

- 10 CFR 100.23 with respect to obtaining geologic and seismic information necessary to determine site suitability and to ascertain that any new information derived from site-specific investigations does not impact the GMRS derived from a probabilistic seismic hazard analysis. In complying with this regulation, the COL applicant also meets the guidance in RG 1.132 and RG 1.208.

- 10 CFR 52.79(a)(1)(iii) as it relates to considerations of the most severe of the natural phenomena historically reported for the site and surrounding area and with a sufficient margin for the limited accuracy, quantity, and period of time when the historical data were accumulated.

The related acceptance criteria from NUREG–0800, Section 2.5.2, are summarized as follows:

- Seismicity: To meet the requirements in 10 CFR 100.23, this section is accepted when the complete historical record of earthquakes in the region is listed and when all available parameters are given for each earthquake in the historical record.

- Geologic and Tectonic Characteristics of Site and Region: Seismic sources identified and characterized in NUREG–2115 were used.

- Correlation of Earthquake Activity with Seismic Sources: To meet the requirements in 10 CFR 100.23, the acceptance of this section is based on the development of the relationship between the history of earthquake activities and the seismic sources of the region.

- Probabilistic Seismic Hazard Analysis and Controlling Earthquakes: For CEUS sites that rely on the NUREG–2115 seismic source characterization model, the staff will review the applicant's PSHA including the underlying assumptions, how the results of the site investigations are used to update the existing sources in the PSHA, and how these site investigation results are used to develop additional sources or to develop a new database.

- Seismic Wave Transmission Characteristics of the Site: In the PSHA procedure described in RG 1.208, the controlling earthquakes are determined for generic rock conditions.

- Ground Motion Response Spectra: In this section, the staff reviews the COL applicant's procedure for determining the GMRS.

In addition, the geologic and seismic characteristics should be consistent with the appropriate sections in: RG 1.60 Revision 1, "Design Response Spectra for Seismic Design of Nuclear Power Plants"; RG 1.132; RG 1.208; and RG 1.206.

2.5.2.4 *Technical Evaluation*

The staff reviewed the information in COL FSAR Section 2.5.2 related to vibratory ground motion in the response to RAI 01.05-1 as follows:

COL Items

- EF3 COL 2.0-27-A Vibratory Ground Motion

NRC staff reviewed Fermi COL FSAR Section 2.5-2 related to COL Item 2.0-27A. This COL item addresses the provision for site-specific information related to the vibratory ground motion aspects of the site including: seismicity, geologic and tectonic characteristics, the correlation of earthquake activity with seismic sources, a probabilistic seismic hazard analysis, seismic wave transmission characteristics, and the SSE ground motion.

The staff also reviewed the applicant's information that addresses the provision for performing site-specific evaluations, (1) if the site-specific GMRS at the foundation level exceeds the response spectra in DCD Figures 2.0-1 and 2.0-2 at any frequency; or (2) if soil conditions are outside the range evaluated for the ESBWR DCD.

This SER section provides the NRC staff's evaluation of the seismic, geologic, geophysical, and geotechnical investigations carried out by the applicant to determine the site-specific GMRS or the SSE ground motion for the site. The development of the GMRS is based on a detailed evaluation of the potential for an earthquake that takes into account the regional and local geology, Quaternary tectonics, seismicity, and site-specific geotechnical engineering characteristics of the site subsurface material.

During the early site investigation stage, the staff visited the site and interacted with the applicant regarding the geologic, seismic, and geotechnical investigations conducted for the Fermi 3 COL application. To thoroughly evaluate the applicant's geologic, seismic, and geophysical information, the staff obtained additional assistance from experts at the USGS. With the USGS advisors, the staff made an additional visit to the Fermi 3 site in November 2009 (ML14112A212) to confirm the applicant's interpretations, assumptions, and conclusions related to potential geologic and seismic hazards. As discussed in the introduction to Section 2.5 of this SER, the staff had submitted several RAIs to the applicant and had evaluated the responses during the review process conducted during the past several years. However, following the NTTF that the NRC issued after Japan's Fukushima accident in March 2011, and the subsequent submissions of an RAI to all COL and ESP applicants (RAI 01.05-1), the applicant significantly revised the COL FSAR—especially COL FSAR Section 2.5.2 related to seismic hazard calculations. As part of this COL FSAR revision, the COL applicant replaced the previously used EPRI (1986) seismic source models in the seismic hazard calculations with the newly published NUREG–2115 CEUS seismic source characterization model. With this change in the base seismic source model, many of the earlier RAIs became irrelevant and were closed. Therefore, the staff's evaluations of many of these earlier RAIs are not part of this report. However, several of the original RAIs are still applicable to the staff's review. They are discussed below, in addition to the new RAIs that the staff developed in response to the revised COL FSAR.

2.5.2.4.1 Seismicity

FSAR Subsection 2.5.2.1 states that the earthquake catalog used for the Fermi 3 site seismic hazard assessment is the NUREG–2115 earthquake catalog. The earthquake catalog is published as part of the NUREG–2115 seismic source model and covers the entire CEUS region, from 1568 through 2008, and includes a uniform moment magnitude scale for all earthquakes listed in the catalog. The staff recently reviewed the NUREG–2115 earthquake catalog. The staff's technical evaluation of COL FSAR Subsection 2.5.2.1 focused on the applicant's efforts to update the original NUREG–2115 earthquake catalog to use in the PSHA of the Fermi 3 site.

The applicant stated that the NUREG–2115 catalog is the starting point for developing an updated earthquake catalog for the Fermi 3 site region. The applicant developed the updated catalog for the portion of the NUREG–-2115 catalog between latitude 39° and 45°N and longitude 79° and 87.5°W, from January 2009 through December 2012. Furthermore, the applicant followed the process used in NUREG–2115 to develop an updated earthquake catalog that FSAR Figure 2.5.2-202 depicts. According to the applicant, the updated catalog shows that from 2009 through 2012, two earthquakes of E[**M**] equal to or greater than 2.9 occurred within

320 km (200 mi) of the Fermi 3 site. The first of these earthquakes had a magnitude of E[**M**] 3.79; the second had a magnitude of E[**M**] of 3.66. The applicant's updated catalog showed that no significant (E[**M**] ≥ 4) earthquakes have occurred in the 320-km (200-mi) site region. The applicant also evaluated earthquakes that have occurred beyond the 320-km (200-mi) site radius.

As shown in FSAR Table 2.5.2-202 and FSAR Figure 2.5.233, the applicant identified 12 earthquakes in the updated NUREG–2115 catalog with the potential to impact CEUS-SSC distributed seismicity sources (E[**M**] ≥ 4.3). This list included the August 23, 2011, E[**M**] 5.73 earthquake near Mineral (Virginia) and the November 6, 2011, E[**M**] 5.66 earthquake in central Oklahoma.

The staff developed a supplementary earthquake catalog covering the CEUS region from 2009 through 2012, in order to evaluate the completeness of the applicant's updated catalog and subsequent conclusions. The staff used the USGS ANSS, which is in Figure 2.5.2-8 in this SER. The staff compared this recent seismicity with the applicant's updated catalog in FSAR Figures 2.5.2-202 and 2.5.2-203. The staff concluded that the recent seismicity does not show any significant deviations from the applicant's updated seismicity catalog. Therefore, the staff concludes that the Fermi 3 earthquake catalog adequately characterizes the regional and local seismicity through 2012.

<u>NRC Staff's Conclusions Regarding Seismicity</u>

After reviewing FSAR Subsection 2.5.2.1, the staff concludes that the applicant has developed a complete and accurate earthquake catalog for the region surrounding the Fermi 3 site and that the earthquake catalog as described in FSAR Subsection 2.5.2.1 forms an adequate basis for the seismic hazard characterization of the site and meets the requirements of 10 CFR 52.79 and 10 CFR 100.23.

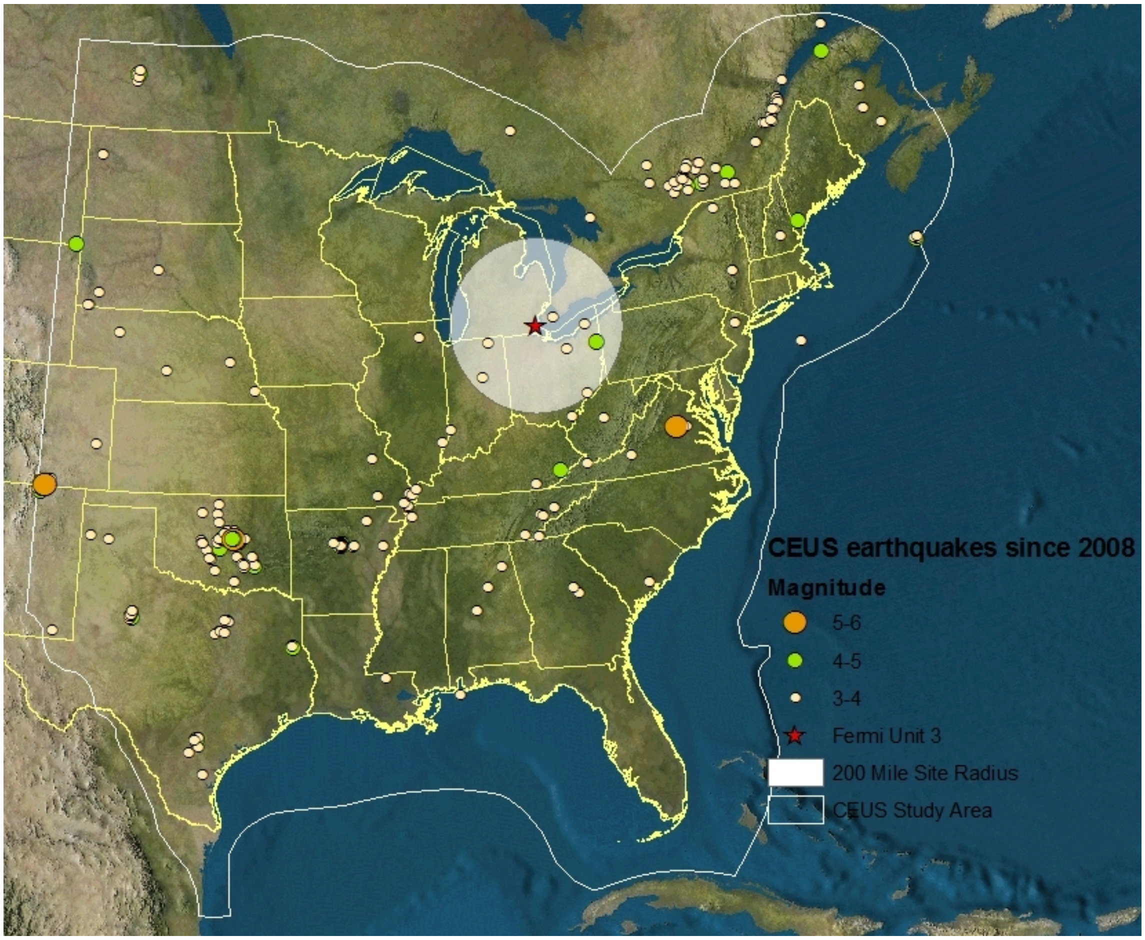


Figure 2.5.2 -8 Earthquakes with Magnitudes Equal to or Greater than 3.0 in the CEUS between 2009 and 2012

2.5.2.4.2 Geologic and Tectonic Characteristics of the Site and Region

FSAR Subsection 2.5.2.2 describes the seismic sources the applicant used to calculate the seismic ground motion hazard for the Fermi 3 site. Specifically, the applicant described the seismic source model published as part of NUREG–2115. The staff previously reviewed the NUREG–2115 seismic source model and approved its use as a starting regional model for nuclear power plant applications. However, NUREG–2115 specifically states that a regional mode should be compared against the local data and information. If needed, there must also be appropriate local adjustments. However, FSAR Subsection 2.5.2.4.1 describes the applicant's investigation of potential local seismic sources and source parameter adjustments to the NUREG–2115 model. The staff's review in this SER section therefore focused on the applicant's selection of the appropriate seismic sources from the CEUS-SSC model. The staff's detailed review of potential local seismic sources and source parameter adjustments to the NUREG–2115 model is in Subsection 2.5.2.4.4 of this SER.

<u>NUREG–2115 Seismic Source Model</u>

The CEUS-SSC model is published as part of NUREG–2115 and contains two types of seismic sources—distributed seismicity sources and RLME sources. The total seismic hazard at a given site is calculated by adding the hazard contributions of the distributed seismicity sources to those obtained using the RLME sources. Whereas the distributed seismicity sources are based on available earthquake locations and regional geologic/tectonic characterizations, the RLME sources are primarily based on geologic and paleoearthquake records. The NUREG–2115 model incorporates uncertainties in source geometries and model parameters by using logic trees and by assigning varying degrees of weights to the branches of the logic trees based on supporting data and evidence.

RLME Sources

The RLME sources describe seismic zones where there are documented occurrences of repeated (two or more) large magnitude earthquakes (**M** > 6.5). There are nine RLME sources defined in the NUREG–2115 model covering the entire CEUS region; they are all depicted in Figure 2.5.2-3 of this SER. These seismic sources are the CHV, CHS, Cheraw fault, Meers fault, NMF system, Eastern Rift margin fault, Marianna, Commerce fault zone (CFZ), and WV seismic sources. The applicant conducted PSHA sensitivity calculations to aid in the selection of an appropriate set of RLME sources to include in the PSHA. The applicant examined six RLME sources closest to the Fermi 3 site: the CFZ, CHS, CHV, Eastern Rift Margin, Marianna, and NMF system. Based on the results of sensitivity calculations, the applicant only included the CHV, CHS, NMF system, and WV RLME sources in the final PSHA because they contribute close to or greater than 1 percent to the total mean hazard at the Fermi 3 site.

The staff evaluated the applicant's rationale for selecting six out of the nine RLME sources for use in the PSHA calculations and finds that the applicant's selection of only the RLME sources that contribute close to or greater than 1 percent of the total mean hazard is adequate for the Fermi 3 PSHA calculations, because the remaining RLME source would not contribute significantly to the total mean hazard.

Distributed Seismicity Sources

The distributed seismicity sources are the second type of seismic sources described in the NUREG–2115 model, which classifies the distributed seismicity sources into two main subgroups: M_{max} zones and seismotectonic zones. These subgroups reflect the fact that there are differing views about seismic source characterizations in the CEUS region. The M_{max} zones represent the view that large magnitude earthquakes may occur anywhere in the CEUS region, and the tectonics of the region contribute minimally to the occurrence of medium and large earthquakes. The M_{max} zones are broad seismic sources with limited tectonic information; they represent areas with potential sources of future earthquakes. Seismotectonic sources represent an alternative view of variations in the occurrence of medium and large magnitude earthquakes based on tectonic environments. The seismotectonic sources result from extensive analyses of regional geology, tectonics, and seismicity in the CEUS region. Both the M_{max} and the seismotectonic zones also include alternative source geometries that accommodate inherent uncertainties in seismic source characterizations. Seismic hazard contributions are calculated for both subgroups, and the results of the M_{max} sources and the seismotectonic sources are weighted by 40 percent and 60 percent, respectively, to determine the total seismic hazard contributions of the distributed seismic sources at a given site.

The applicant included all or parts of each M_{max} source zone that is located within 1,000 km (620 mi) of the Fermi 3 site. Therefore, the applicant's PSHA is comprised of the following five alternative M_{max} seismic source configurations: Study Region, MESE-W, MESE-N, NMESE-W, and NMESE-N. The Study Region seismic source is the largest seismic source in the CEUS model, and it represents the entire area of the CEUS region. The MESE and NMESE sources represent regions where either the Mesozoic-aged (250 million years) or the younger tectonic extension did (MESE) or did not (NMESE) take place. The subgroups of the MESE and NMESE seismic sources—MESE-W, NMESE-N, and MESE-N—represent alternative configurations for each of these sources. The extension "N" represents the "narrow" and the extension "W" represents the "wide" alternative source geometries. The staff confirmed the applicant's choice of the M_{max} sources because they are adequate and satisfy the guidance in RG 1.208, which states that all seismic sources within the 320-km (200-mi) radius of the site should be investigated.

The NUREG–2115 seismic source characterization model also identifies 12 primary seismic sources within the seismotectonic subcategory of the distributed seismicity sources. Because there are uncertainties in source geometry definitions, some of these sources also have defined alternative geometries. The applicant used the same criteria of 1,000 km (620 mi) used for the M_{max} source zone selection, in order to determine which seismotectonic sources to include in the PSHA. Among the 12 seismotectonic-based seismic sources identified in NUREG–2115, the applicant identified the following sources as contributors to the seismic hazard estimates at the Fermi 3 site: AHEX; ECC–AM; GMH; IBEB;,MIDC-A, MIDC-B, MIDC-C, and MIDC-D; NAP; PEZ-N and PEC-W; RR and RR-RCG; and SLR.

The staff reviewed all of the CEUS-SSC seismic sources described in NUREG–2115 that occur within the 1,000-km (620-mi) site radius and confirmed that the applicant's choices of seismic source models are adequate and conform to the guidance in RG 1.208.

NRC Staff's Conclusions of the Geologic and Tectonic Characteristics of the Site and Region

Based on the review of the seismic sources described in the NUREG–2115 model, the staff concluded that the applicant has selected all of the appropriate CEUS-SSC RLME, M_{max}, and seismotectonic sources for inputs into the PSHA of the Fermi 3 site. The staff found that the applicant's has selected all sources that lie well beyond the 320-km (200-mi) site radius and also selected all RLMEs that contribute close to or greater than 1 percent of the total mean hazard. Therefore, the staff concludes that the applicant's seismic source zone model forms an adequate basis for the seismic hazard calculation of the site and meets the requirements of 10 CFR 52.79 and 10 CFR 100.23.

2.5.2.4.3 Correlation of Earthquake Activity with Seismic Sources

FSAR Subsection 2.5.2.3 describes the correlation of updated seismicity with the CEUS-SSC model sources. The applicant compared the distribution of earthquake epicenters in the NUREG–2115 earthquake catalog with the CEUS-SSC model sources and also with its updated earthquake catalog. Based on this comparison, the applicant concluded that the updated catalog does not show a pattern of seismicity that would require a new seismic source or significant revisions to the geometry of the seismic sources defined in the CEUS-SSC model of the Fermi 3 site region. The applicant also concluded that the updated CEUS catalog does not show any earthquakes in the site region that can be associated with a known geologic structure, with the exception of the Anna and Northeast Ohio Seismic Zones, which lie at distances greater than 150 km (90 mi) from the Fermi 3 site. The applicant stated that seismicity in the Anna Seismic Zone occurs near the Ft. Wayne rift, while seismicity in the Northeast Ohio Seismic Zone is associated with the Akron Magnetic Boundary; the CEUS-SSC model considers both areas.

In Subsection 2.5.2.4.1 of this SER, the staff evaluated the completeness of the applicant's updated earthquake catalog and the applicant's subsequent conclusions, by comparing the applicant's earthquake catalog to a compilation catalog derived from the USGS ANSS seismicity catalog. Based on the spatial distribution of earthquakes in the updated catalog, the staff concurred with the applicant's conclusion that significant revisions to the existing CEUS-SSC source geometries are not warranted. The staff found that the applicant has adequately evaluated the potential for new seismic sources or for revisions to existing source geometries based on seismicity patterns. Therefore, the applicant's analysis meets the requirements of 10 CFR 52.79 and 10 CFR 100.23.

2.5.2.4.4 Probabilistic Seismic Hazard Analysis and Controlling Earthquakes

FSAR Subsection 2.5.2.4 presents the applicant's PSHA results and estimates of potential earthquakes for the Fermi 3 site in terms of deaggregation earthquakes. The applicant determined the high- and low-frequency deaggregation earthquakes by deaggregating the PSHA results at selected probability levels, in accordance with the guidance in RG 1.208. Before conducting the PSHA calculations and determining the deaggregation earthquakes, the applicant investigated the local and regional geologic and tectonic features and any potential adjustments to the seismic sources and their model parameters. Subsection 2.5.1.4 of this SER describes the staff's assessments of the local and regional geological features and concludes that no additional updates are needed. Therefore, the staff's review focused on the applicant's PSHA procedures for and the calculation of the Fermi 3 site deaggregation earthquakes.

PSHA Calculation

FSAR Subsection 2.5.2.4.1 states that the applicant used the NUREG–2115 seismic model for the probabilistic seismic hazard calculations of the Fermi 3 site and also outlines the procedures. Because the NUREG–2115 model covers the entire CEUS region, it may be unnecessary to use seismic sources in the PSHA calculations that are farther away and have lower seismicity rates. The applicant first identified seismic sources that will impact the seismic hazard calculations at the Fermi 3 and then used those selected seismic sources and the EPRI (2004, 2006) ground motion model (GMM) to calculate generic hard rock seismic hazard curves at the seven frequencies defined by the EPRI (2004, 2006) GMM. Using the hard rock seismic hazard curves, the applicant obtained uniform hazard response spectra at the annual frequency of exceedances of 10^{-4}, 10^{-5}, and 10^{-6}. Using the procedures outlined in RG 1.208, the applicant also developed the magnitudes and distances of deaggregation earthquakes. The following discussion describes the staff's assessment of the applicant's PSHA calculations and the determination of the deaggregation earthquakes and their parameters.

PSHA Inputs

Among the distributed seismicity sources described in the NUREG–2115 model, Subsection 2.5.2.4.2 of this SER notes that the applicant used those sources with boundaries that are intersected by the 1,000-km (620-mi) site radius—which is well beyond the 320-km (200-mi) region specified by RG 1.208. The applicant also screened the RLME sources based on their potential contribution to the total seismic hazard. Specifically, the applicant included the RLME sources if they contribute close to or greater than 1 percent to the total mean hazard at the Fermi 3 site. RG 1.208 states that if seismic sources are completely beyond the 320-km (200-mi) site region radius but are large enough seismic sources with the potential to contribute to the total seismic hazard, the seismic sources should be considered in the seismic hazard calculations. Thus, the staff concludes that the applicant's source zone selection criteria are adequate.

The applicant used the EPRI (2004, 2006) GMM and the updated aleatory uncertainties and weights for the PSHA. Since the development of the EPRI (2004, 2006) GMM, several GMPEs for the CEUS have been published. In RAI 02.05.02-4, the staff requested the applicant to evaluate the impacts from including more recent GMPEs in the Fermi 3 seismic hazard—such as Tavakoli and Pezeshk (2005) and Atkinson and Boore (2006). Based on comparisons of the newer GMPEs with the EPRI (2004) model, the applicant concluded that the median ground motions obtained using the newer GMPEs—specifically Silva et al. (2003), Atkinson and Boore (2011), and Pezeshk et al. (2011)—produce similar or lower ground motion amplitudes compared to the EPRI (2004) GMMs, and are thus likely to produce lower hazard levels. Therefore, the applicant did not update the EPRI (2004, 2006) GMM for the purpose of computing the hazard levels for the Fermi Unit 3 site.

The staff reviewed the applicant's comparisons of the EPRI (2004, 2006) GMM with more recent GMPEs and determined that the applicant's conclusions are supported by the recently updated EPRI (2004, 2006) GMM (EPRI 2013) conducted in accordance with the SSHAC process. In a letter dated August 28, 2013 (ML13233A102), the NRC determined that the Updated GMM is an acceptable ground motion model to use for CEUS plants in developing plant-specific, ground motion response spectra until the NGA project for eastern North America (NGA-East) is complete and NRC staff has reviewed and approved it (NRC 2013).

Chapter 8 of the EPRI (2013) report provides the results of demonstration hazard calculations performed using the updated EPRI (2004, 2006) GMM and the EPRI (2004, 2006) GMPE for seven test sites; including the Central Illinois test site, which is the closest test site to the Fermi 3 site. The resulting UHRS are in Figures 8.2-1h, 8.2-2h, 8.2-3h, 8.2-4h, 8.2-5h, 8.2-6h, and 8.2-7h in the EPRI (2013) report. All of the test site comparisons show that the updated EPRI (2004, 2006) GMPEs produce equivalent or lower spectral accelerations when compared to the EPRI (2004, 2004) GMPEs. Furthermore, the spectral shapes remain consistent between both the earlier and the updated models, with the exception of very low hazard sites (e.g., the Houston test site) at frequencies below ~1 Hz. The staff therefore concludes that the applicant's use of the EPRI (2004, 2006) GMPEs is adequate for the Fermi 3 PSHA calculation.

PSHA Methodology and Calculation

Using the NUREG–2115 CEUS-SSC model and the EPRI (2004, 2006) GMPEs, the applicant performed PSHA calculations for the PGA and ground motion frequencies of 25, 10, 5, 2.5, 1, and 0.5 Hz, as described in RG 1.208. Before performing the final PSHA calculation for the Fermi 3 site, the applicant first conducted sensitivity calculations in order to (1) determine which set of RLMEs to include in the final calculation; and (2) evaluate the impacts of more recent earthquakes and determine whether or not updates to the associated CEUS-SSC seismic sources are necessary.

In FSAR Subsection 2.5.2.4.3.1, the applicant described the selection process used to identify which RLME sources to include in the PSHA model for the Fermi 3 site. The applicant examined the source contributions at 1 Hz and 10 Hz spectral accelerations for the eight RLME sources closest to the Fermi 3 site (the CFZ, CHS, CHV, Eastern Rift Margin – North [ERM-N], Eastern Rift Margin – South [ERM-S], Marianna Zone [MAR], NMF, and the WV sources). Based on the results of these sensitivity calculations, which are shown in FSAR Figures 2.5.2-240 and 2.5.2-241, the applicant decided to include the NMF, WV, CHS, and CHV RLME sources because they contributed close to or greater than 1 percent to the total mean hazard at the Fermi 3 site. The applicant did not include the remaining RLMEs because they contribute to less than 1 percent of the total mean hazard. The staff reviewed the applicant's results in FSAR Figures 2.5.2-240 and 2.5.2-241 and concurred with the applicant that inclusion of only the NMF, WV, CHS, and CHV RLME sources is adequate, because the remaining RLME sources would not produce a significant contribution to the total mean hazard at the Fermi 3 site.

As described in FSAR Subsection 2.5.2.4.3, the applicant performed PSHA sensitivity calculations using the updated M_{max} distributions shown in FSAR Table 2.5.2-203. These updated M_{max} distributions are based on the earthquakes with an E[**M**] equal to or greater than 4.3 that have occurred after completion of the CEUS-SSC model catalog in the time period from 2009 through 2012. The applicant found that the effect of including these adjusted M_{max} distributions in the hazard calculation produces a 0.3 percent maximum increase in total mean hazard at 1 Hz and 10 Hz spectral accelerations for the Fermi 3 site. Even though this result indicated that the model did not need to be updated, the applicant conservatively performed the PSHA for the Fermi 3 site using the updated M_{max} distributions. Based on the applicant's discussion of the results, the staff concurs that updating the M_{max} distributions did not result in any significant change in the seismic hazard calculation results. Therefore, updates to the CEUS-SSC model source zone are not warranted at the Fermi 3 site.

NRC PSHA Confirmatory Analyses

To determine the adequacy of the applicant's PSHA calculations, the staff performed its own confirmatory PSHA calculation for the Fermi 3 site. The staff used the CEUS-SSC model (NUREG–2115) along with the EPRI (2004, 2006) GMM. The staff conducted the PSHA for the Fermi site using a source distance radius of 1,000 km (620 mi) for the CEUS-SSC-distributed seismicity sources. The staff's calculation did not include the RLME source zones. Therefore, the staff compared its confirmatory 0.5, 1, 2.5, 5, 10, 25, and 100 Hz hazard curve results with the applicant's results for the distributed seismicity sources and determined that the two sets of results are almost identical. This finding is illustrated in Figures 2.5.2-9 through Figure 2.5.2-11 in this SER showing the PSHA hard rock hazard curve results for 1, 10, and 100 Hz, respectively, for the distributed seismicity sources.

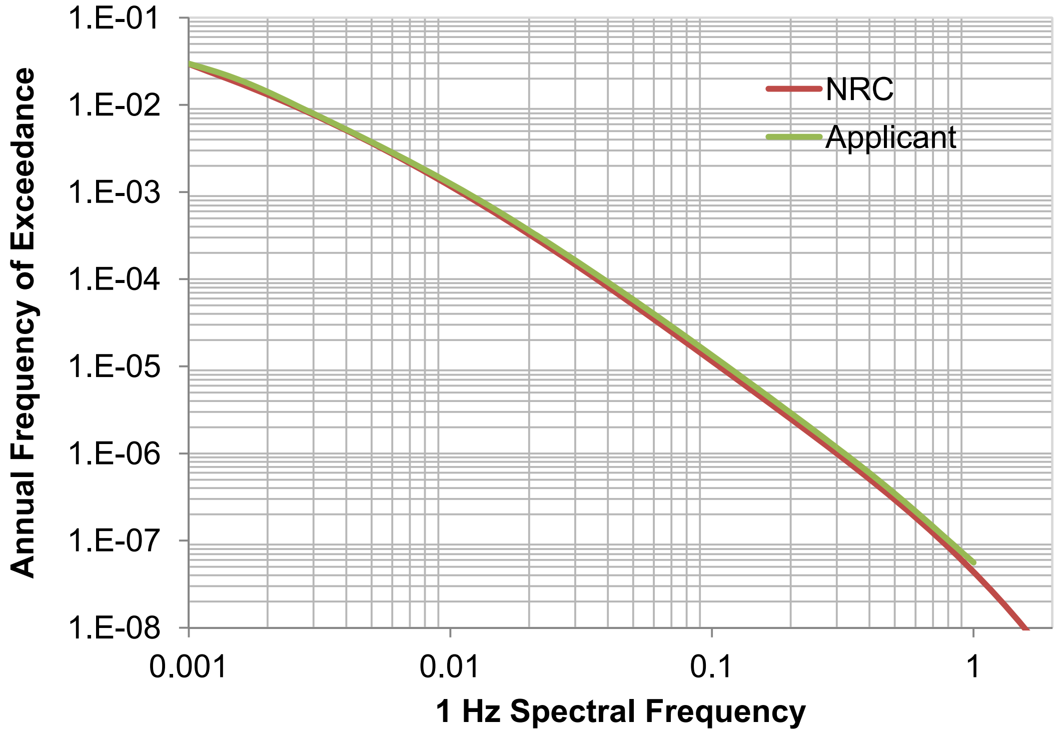


Figure 2.5.2-9 Plot Comparing the Staff's and the Applicant's 1-Hz Total Mean Hazard Curves for the Distributed Seismicity Source Zones

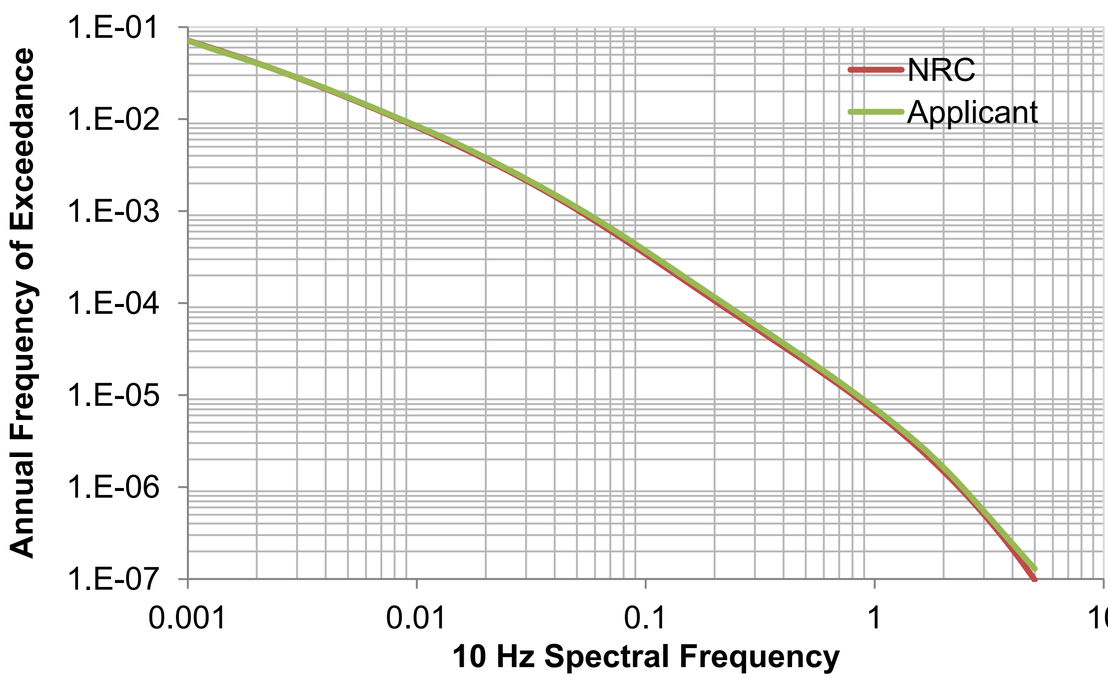


Figure 2.5.2-10 Plot Comparing the Staff's and the Applicant's 10-Hz Total Mean Hazard Curves for the Distributed Seismicity Source Zones

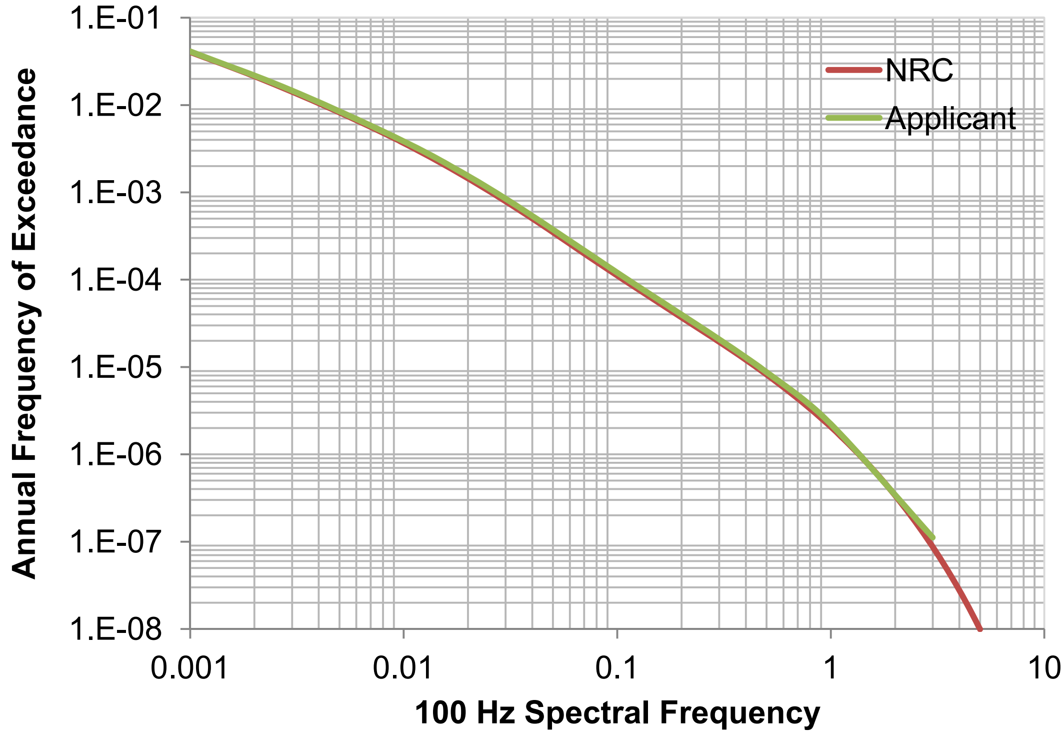


Figure 2.5.2-11 Plot Comparing the Staff's and the Applicant's 100-Hz Total Mean Hazard Curves for the Distributed Seismicity Source Zones

Based on the above assessment, the staff concluded that the applicant's PSHA calculations adequately characterize the seismic hazard at the Fermi 3 site in terms of the contribution from the distributed seismicity sources. Because the staff's calculation did not include the RLMEs, the staff determined that the applicant had selected the appropriate RLME sources (i.e., the NMFS, WA, CHV, and CHS) based on their contribution of 1 percent or greater to the total mean hazard.

Controlling Earthquakes

To determine the low- and high-frequency controlling earthquakes, the applicant used a procedure called deaggregation of the seismic hazard. The applicant followed the deaggregation procedures in RG 1.208, Appendix D. The deaggregation results showed that local seismic sources within approximately 30 km (18.6 mi) of the Fermi site are the primary contributors to the high-frequency seismic hazard at the site, while the NMFS RLME is a significant contributor to the low-frequency seismic hazard at the Fermi site. Table 2.5.2-1 of this SER shows the applicant's deaggregation results for the mean 10^{-4} and 10^{-5} PSHA results. Because the applicant used the guidance in RG 1.208 to determine the reference and deaggregation earthquakes and their magnitudes and distances, the staff concludes that the procedures used by the applicant are adequate and the resultant deaggregation earthquake parameters are representative of the deaggregation earthquakes in this region.

In FSAR Subsection 2.5.2.4.4.3, the applicant also described how it developed smooth response spectra to represent each reference earthquake and deaggregation earthquake listed in FSAR Table 2.5.2-212, for the purpose of developing input time histories for the site response analysis, which is reviewed by the staff in Subsection 2.5.2.4.5 of this SER. The applicant used the EPRI (2004, 2006) GMM as well as the spectral shape functions (specifically, the average of the single and double corner spectral shape models) for CEUS ground motions developed in NUREG/CR–6728. The applicant also used Baker and Cornell's (2006) response spectral correlation method to extrapolate spectral shapes. However, the Baker and Cornell method used worldwide recordings from both the National Earthquake Hazards Reduction Program (NEHRP) B/C (rock/very dense soil and soft rock) type soil boundary and the first story of structures. In RAI 02.05.02-6, the staff thus requested the applicant to (1) explain why the free-field and first-story recordings can be mixed together to predict the correlation; and (2) why the correlation from the B/C boundary can be used to represent the other soil types.

In the response to part (1) of the RAI dated January 11, 2010 (ML100130382), the applicant explained that Baker and Cornell's method requires a model for correlation between response spectral amplitudes at different spectral periods. The applicant used Baker and Jayaram (2008), which uses all of the residuals resulting from the NGA GMPE development (i.e., the correlation model is not specific to the B/C boundary condition). Furthermore, Baker and Jayaram (2008) determined that the correlation is not sensitive to site subsurface conditions.

In the response to part (2) of the RAI, the applicant stated that the NGA GMPE developers included recordings from instrument shelters and first-story recordings in small buildings (i.e., light one-to-two story structures without basements) in their data sets that were used to develop ground motion models for free-field conditions and indicated that recordings in larger buildings are not representative of free-field motions. Furthermore, the applicant stated that it is common practice to include recordings from the first floor of small buildings in data sets used to develop empirically based, free-field ground motions (e.g., Boore et al. 1997; Campbell 1997; Sadigh et al. 1997; Spudich et al. 1997; and Campbell and Bozorgnia 2003).

After reviewing the applicant's responses to both questions in this RAI, the staff agreed with the applicant that because the correlation models are not sensitive to site subsurface conditions and the NGA developers used the instrument recordings from the first story of small buildings, it is appropriate to develop the correlation model using those relevant data sets. Therefore, the staff concludes that the applicant developed appropriate response spectra to represent the reference and controlling earthquakes resulting from the PSHA calculations. Therefore, RAI 02.05.02-6 is closed.

<u>NRC Staff's Conclusions Regarding the PSHA and Controlling Earthquakes</u>

The staff concludes that the applicant's PSHA inputs, methodology, and results (including the resulting reference and deaggregation earthquakes) are acceptable because the applicant's PSHA calculation followed the general guidance in RG 1.208. The staff's confirmatory analysis also indicated that the applicant's results are adequate. Thus, the staff concludes that the applicant's seismic hazard calculation meets the requirements of 10 CFR 52.79 and 10 CFR 100.23.

2.5.2.4.5 Seismic Wave Transmission Characteristics of the Site

FSAR Subsection 2.5.2.5 describes the method the applicant used to develop the Fermi 3 site free-field UHRS. The applicant's seismic hazard curve calculations are defined for generic hard rock conditions characterized by a shear-wave velocity of at least 2.8 km/s (9,200 fps). According to the applicant, these hard rock conditions exist at a depth of about 130 m (425 ft) below the ground surface at the Fermi 3 site. To determine the impact of the soil column between the hard rock and the surface, the applicant performed a site response analysis. The output of the applicant's site response analysis is site amplitude functions (AFs), which are then used to determine the soil UHRS at three hazard levels (10^{-4}, 10^{-5}, and 10^{-6} annual frequency of exceedances).

The Fermi 3 site consists of thin layers of fill, lacustrine deposits and glacial till overlying dolomite of the Bass Islands and Salina groups. The applicant intends to remove the upper ~4 m (13 ft) of fill, ~1.5 m (5 ft) of low-velocity lacustrine deposits, and ~3.4 m (11 ft) of glacial til, and proposed to locate the GMRS at the top of the Bass Islands group, which corresponds to an average elevation of 168.2 m (551.7 ft) NAVD 88. The staff noted that in previous FSAR revisions, the applicant had defined the GMRS at the top of the glacial till. With this change in the GMRS location, several of the staff's earlier RAIs related to glacial till are no longer relevant and were closed. The staff's evaluations of those RAIs are therefore not part of this SER.

Additionally, the staff noted that the applicant's site response calculations for the RB/FB, CB, and FWFC FIRS are in FSAR Section 3.7.1 instead of in FSAR Section 2.5.2, as in earlier revisions of the FSAR. Therefore, the staff's evaluations of RAIs 02.05.02-20 and 02.05.02-21 are in Subsection 3.7.1.4 of this SER. In Subsection 2.5.2.4 of this SER, the staff noted that many earlier RAIs have become irrelevant or closed as a result of the applicant's significant revisions of the COL FSAR as a result of the replacement of the EPRI (1986) seismic source models previously used in the seismic hazard calculations with the newly published CEUS-SSC model. With this change in the base seismic source model, several of the earlier RAI responses related to the applicant's site response calculations also needed to be revised. Instead, however, the staff performed detailed site response confirmatory analyses to determine the adequacy of the applicant's site response inputs and calculations. These calculations are discussed below in Subsection 2.5.2.4.5.2, while Subsection 2.5.2.4.5.1 of this SER presents the staff's evaluation of the original RAIs that are still applicable to the staff's review.

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

FSAR Subsection 2.5.2.5.1 summarizes the applicant's low-strain S-wave velocity, material damping, and strain-dependent properties of the base case soil and rock profile, which the applicant used as the input model for the site response calculations. The applicant performed P-S suspension logging, downhole seismic testing, and spectral analysis of surface wave (SASW) surveys to obtain an S-wave velocity profile for the Fermi 3 site, which is shown in Figure 2.5.2-5 of this SER. The applicant used the P-S suspension logging results to obtain the S-wave velocities of the soil and bedrock units. The applicant also used the downhole seismic testing results to obtain bedrock S-wave velocities, while the SASW survey results provided S-wave velocities for the glacial till. The applicant encountered CEUS generic hard rock conditions (i.e., an S-wave velocity of about 2.8 km/s [9,200 fps]) at a depth of approximately 143.3 m (470 ft) or an elevation of 48 m (156 ft), which corresponds to the Salina Group Unit B.

The applicant stated that the site response profile consists of dolomites and claystones with S-wave velocities exceeding 910 m/s (3,000 fps). The applicant expects the behavior of these materials to remain essentially linear at the expected levels of shaking (as defined by the rock hazard). The applicant determined the damping within these materials by using the following procedure that involved kappa, a near-surface damping parameter that is an estimate of the dissipation of seismic energy of the site during an earthquake due to damping within soil/rock layers and waveform scattering at layer boundaries. The applicant used estimates of kappa to determine an appropriate damping ratio value for the rock layers below the glacial till.

In FSAR Subsection 2.5.2.5.1.2, the applicant stated that ground motion models for the CEUS assume a shallow crustal kappa value of 0.006 seconds, which refers to the point at the elevation of 48 m (156 ft) at the Fermi 3 site. The FSAR further states that the material above this elevation will contribute additional damping and add to the total site kappa value. The applicant used Equation 11 in FSAR Section 2.5.2 Revision 5, (or Equation 5 in the FSAR markups in the March 15, 2013, response to RAI 01.05-1), to calculate an additional kappa value of 0.013 seconds based on an average S-wave velocity of 1,737 m/s (5,700 fps) for the materials above an elevation of 48 m (156 ft). The applicant then subtracted the hard rock kappa value of 0.006, which yielded a remaining kappa of 0.007 seconds. In RAI 02.05.02-13, the staff asked the applicant to confirm whether the kappa value of 0.013 seconds represents an additional damping contribution from the material above the elevation of 48 m (156 ft); and why the two kappa values were then subtracted.

Based on the applicant's response to RAI 02.05.02-13 dated August 6, 2010 (ML102210351), FSAR Equation 5 represents the relationship between the average S-wave velocity and the total site kappa value—not an additional damping contribution from the material above the elevation of 48 m (156 ft). Therefore, a shallow crustal kappa value was subtracted from the total kappa and the difference of 0.007 seconds is the kappa contributed by the materials above an elevation of 48 m (156 ft). The staff concluded that RAI 02.05.02-13 is closed because the applicant has provided adequate clarification regarding how the kappa value was obtained for the materials above an elevation of 48 m (156 ft). Furthermore, the staff calculated a kappa value for the material above an elevation of 48 m (156 ft) and assumed a quality factor, Q_s, of 40 (EPRI 2013). The resulting kappa value of 0.00774 seconds is very similar to the applicant's value of 0.007 seconds. Figure 2.5.2-13 in this SER shows that the effect of using a kappa value based on a Q_s of 40 is similar to the applicant's kappa value in the site response calculations.

The applicant used an updated version of the SHAKE computer program to calculate the Fermi 3 site response. The use of the time series approach is mentioned in RG 1.208 as an acceptable approach given that an appropriate set of earthquake time histories for each of the target response spectra is used, and a sufficient number of time histories are used to obtain a consistent behavior from the dynamic site response analysis. FSAR Subsection 2.5.2.4.4.3 states that the applicant developed 30 time histories for each target DE, which equated to a total of 3 DEs for each HF and LF 10^{-3}, 10^{-4}, 10^{-5}, and 10^{-6} hazard level. The applicant then selected time histories from NUREG/CR–6728 and scaled them to approximately match the target DE spectrum using the routine RSPM06, which implements the time domain spectral matching approach developed by Lilhanand and Teng (1988). The applicant concluded that the weak scaling produced records that have, in general, the desired relative frequency content of the DE spectra, while maintaining a degree of natural variability. The staff performed confirmatory site response calculations in order to determine the adequacy of the applicant's approach. In comparison, the staff used a Random Vibration Theory (RVT) method that characterizes the input rock motion using a Fourier amplitude spectrum, instead of earthquake time histories. The use of the RVT in site response calculations is mentioned in RG 1.208 as an acceptable alternative to the time series approach. As shown in Figure 2.5.2-12 of this SER, the staff's site amplification calculated using RVT is very similar to the applicant's time history-based results.

FSAR Subsection 2.5.2.5.1.3 describes the randomized S-wave velocity profiles used in the site response analyses to account for variations in these profiles. The correlation model described in Silva et al. (1996) is the model developed from analyses of shear wave data taken at the Savannah River site, a relatively deep soil site (composed primarily of sands, silty sands, and silts) of approximately 244 m to 305 m (800 ft to 1,000 ft) depth over hard rock. In RAI

02.05.02-17, the staff asked the applicant to explain why this model is appropriate for use at the Fermi site and to also evaluate the impact on site amplification. In the response to this RAI dated March 1, 2012 (ML12065A194), the applicant stated that since the principal geologic units that immediately underlie the Fermi 3 site are relatively flat-lying sedimentary rocks that have not been subject to severe deformation, the current correlation structure for S-wave velocities is expected to reflect the correlation structure present when the sediments were first deposited. For this reason, the applicant selected the correlation model described in Silva et al. (1996) for USGS Category C, a relatively deep soil site, rather than the model for rock sites —USGS Category A. In Figure 1 of the RAI response, the applicant compared the predicted correlations between the natural log of the S-wave velocity in two adjacent layers for the stiff soil site model used in FSAR Subsection 2.5.2.5.1.3 with those predicted by the model developed by Silva et al. (1996) for rock sites (USGS Category A). The applicant stated that the USGS Category C model used in the FSAR shows higher correlations than the rock site model for USGS Category A. Furthermore, the applicant stated that a fully correlated model is not supported by the subsurface S-wave velocity data collected at the Fermi 3 site. The applicant added that Figure 2 in the RAI response, which shows velocity profiles for the four borings in which the individual P-S suspension log data were used to compute hyperbolic mean (travel time averaged) velocities for individual sublayers, shows that the S-wave velocity profiles cross each other frequently indicating that the Fermi 3 site profile is not fully correlated.

The staff also performed confirmatory site response calculations in order to investigate the effect of using a fully correlated model. The staff performed calculations comparing the correlation model for USGS Category C and USGS Category A, which are shown by the red and purple curves, respectively, in Figure 2.5.2-13 in this SER, and found that the resulting amplification functions are very similar. As shown in Figure 2.5.2-13 in this SER, differences in mean amplification observed in the frequency range of 4 to 6 Hz is less than 7 percent. Thus, the staff concluded that RAI 02.05.02-17 is closed, because the staff's sensitivity calculations demonstrated that the correlation model used does not significantly impact the amplification functions when compared to a fully correlated model.

<u>NRC Site Response Confirmatory Analyses</u>

To determine the adequacy of the applicant's site response calculations, the staff performed confirmatory site response calculations. As input, the staff used the static and dynamic soil properties in FSAR Section 2.5.4 and summarized in FSAR Table 2.5.2-213. The staff performed site response calculations using the RVT methodology with 7 spectral frequencies and 11 input rock amplitudes. The use of RVT in site response calculations is mentioned in RG 1.208 as an acceptable alternative to the time series approach. The staff's site amplification function results are compared with the applicant's results in Figure 2.5.2-12 in this SER.

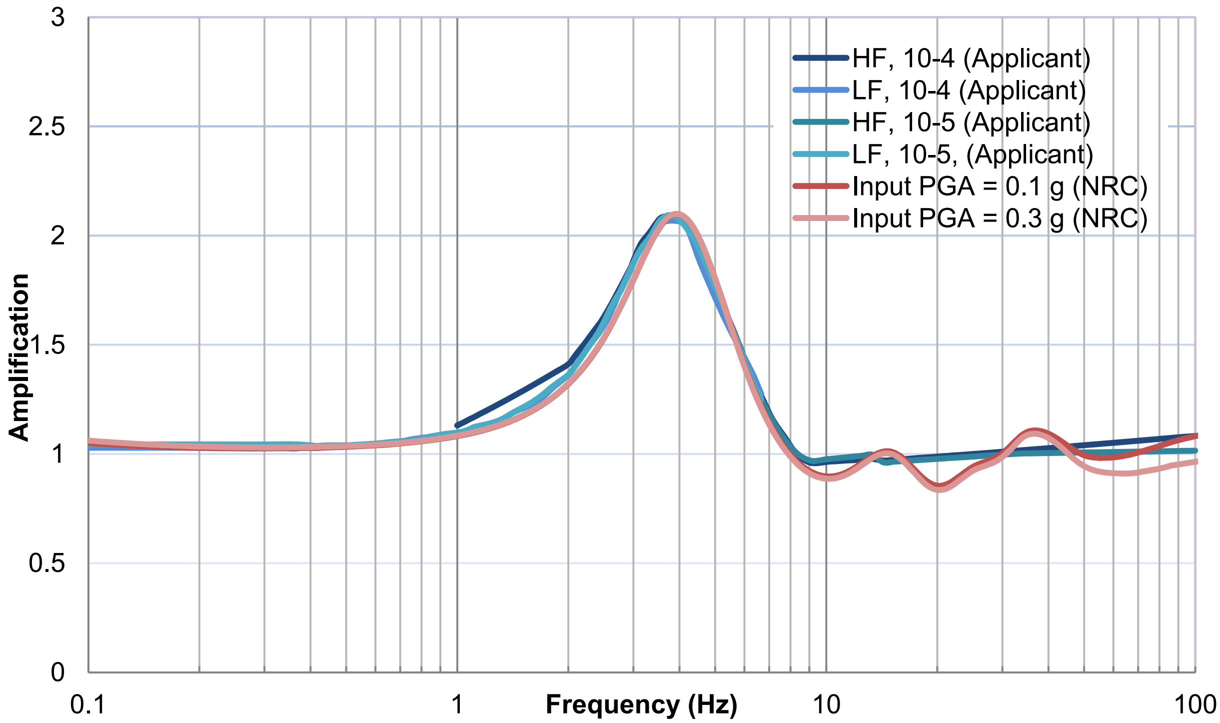


Figure 2.5.2-12 Comparisons of the Staff's Site Response Amplification Functions with the Amplification Functions Determined by the Applicant

[Note: The staff's amplification functions for respective input PGA values of 0.1 g and 0.3 g are depicted by the light and dark red lines, and the COL applicant's results are depicted by the blues lines.]

As Figure 2.5.2-12 in this SER shows, the applicant's amplification functions are similar to the staff's confirmatory calculations; and the very small difference observed between ~1 and 100 Hz are within the limits of uncertainties. Similar to the applicant's results, the staff's confirmatory calculations also show that the Fermi 3 site response is not strongly sensitive to the level of input motion. Figure 2.5.2-12 also shows that there are only small differences in the site amplification (at frequencies greater than ~40 Hz) using input PGAs of 0.1 g and 0.3 g.

In addition to confirming the applicant's calculations, the staff conducted an additional sensitivity calculation to confirm the applicant's selected damping values in FSAR Table 2.5.2-214. Figure 2.5.2-13 in this SER compares the staff's amplification functions calculated using the applicant's damping values, with the staff's amplification functions calculated assuming a shear-wave quality factor, Q_s, of 40. Because the average S-wave velocity of the material above an elevation of 48 m (156 ft) is 1,737 m/s (5,700 fps), and the thickness of these materials is only ~121 m (396 ft), the kappa contributed by the profile can be computed by assuming a Q_s of 40 according to EPRI Report 1025287, "Seismic Evaluation Guidance," (EPRI 2012). As illustrated in Figure 2.5.2-13 of this SER, the staff's amplification functions calculated by assuming a Q_s of 40 is only slightly higher than the staff's calculated amplification functions that used the damping values developed by the applicant between frequencies of ~3 to 5 Hz and at frequencies above 30 Hz.

The staff's results are slightly higher than the applicant's at frequencies between 3 and 5 Hz. However, these differences are less than 10 percent.

Based on the above assessment, the staff concludes that the applicant's site response calculations adequately characterize the Fermi 3 site effects.

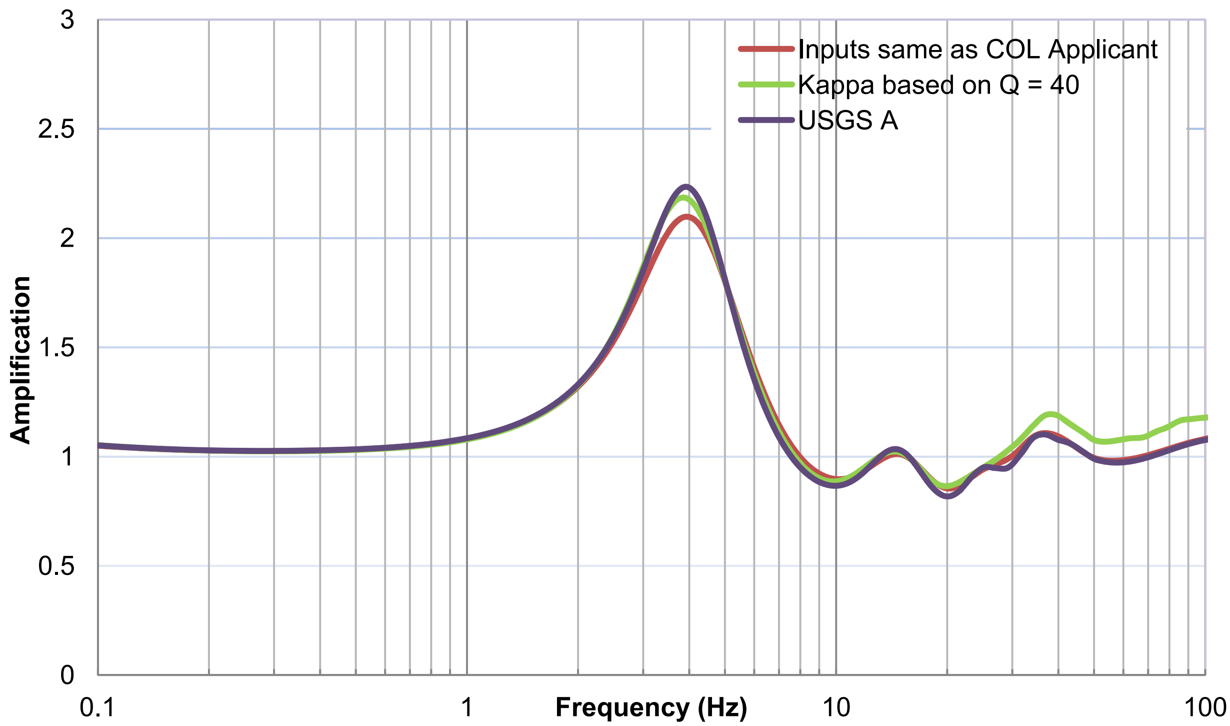


Figure 2.5.2-13 Comparisons of the Staff's Site Response Amplification Function Using Damping Values Selected by the Applicant with the Staff's Site Response Amplification Functions Based on a Q_s of 40 and also Using a Correlation Model for USGS Category A

[Note: The staff's amplification functions using the same inputs as COL applicant used are depicted by the red lines; and the staff's amplification functions based on a Q_s of 40 and a correlation model for USGS Category A are depicted by the green and purple lines, respectively.]

<u>NRC Staff's Conclusions Regarding Seismic Wave Transmission Characteristics of the Site</u>

The staff concludes that the applicant's site response methodology and results are acceptable, because the applicant has followed the general guidance in RG 1.208 in the site response calculations and used an adequate range of input parameters. The staff's confirmatory analysis also indicates that the COL applicant's results are adequate.

2.5.2.4.6 Ground Motion Response Spectra

FSAR Subsection 2.5.2.6 describes the method the applicant used to develop the horizontal and vertical, site-specific GMRS. As stated in Subsection 2.5.2.1 of this SER, RG 1.208 defines the GMRS as the site-specific SSE to distinguish it from the CSDRS (certified seismic design response spectra), the design ground motion for the ESBWR certified design.

FSAR Subsection 2.5.2.6 describes the method the applicant used to develop the horizontal and vertical site-specific GMRS. To obtain the horizontal GMRS, the applicant used the performance-based approach in RG 1.208 and ASCE/SEI Standard 43-05. FSAR Subsection 2.5.2.6 states that the horizontal GMRS (for each spectral frequency) is obtained by scaling the soil 10^{-4} UHRS by the design factor specified in RG 1.208. To develop the vertical GMRS, the applicant multiplied the horizontal GMRS by V/H ratios for generic CEUS hard rock sites in NUREG/CR–6728. Because the S-wave velocity of the Fermi 3 site is relatively high, and the assessed site kappa value is not much greater than the generic hard rock value, the staff concludes that the applicant's use of V/H ratios for generic CEUS hard rock sites is appropriate.

NRC Staff's Conclusions Regarding the Ground Motion Response Spectra

The applicant used the standard procedures outlined in RG 1.208 to calculate the final horizontal and vertical GMRS. The staff thus concludes that the applicant's GMRS adequately represents the site ground motion, and the applicant's calculated GMRS meets the requirements of 10 CFR 100.23.

2.5.2.5 *Post Combined License Activities*

There are no post COL activities related to this section.

2.5.2.6 *Conclusion*

NRC staff reviewed the COL application and confirmed that the applicant has adequately addressed the required information, and no outstanding information is expected to be addressed in the COL FSAR related to this section.

In addition, the staff compared the additional information in the COL application to the relevant NRC regulations, the guidance in Section 2.5.2 of NUREG–0800, and applicable NRC regulatory guides. The staff's review concludes that the applicant has provided sufficient information to satisfy the requirements of NRC regulations. The staff determined that the applicant has adequately addressed COL Item COL Item EF3 2.0-27-A related vibratory ground motion.

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2.5.3 Surface Faulting

2.5.3.1 *Introduction*

This FSAR section describes the potential for surface deformation due to faulting, and addresses the following topics related to surface faulting: geologic, seismic, and geophysical investigations; geologic evidence, or absence of evidence, for tectonic surface deformation; correlation of earthquakes with capable tectonic sources and characterization of those sources; ages of most recent deformation; relationships between tectonic structures in the site area and regional tectonic structures; designation of zones of Quaternary (less than 1.8 Ma) deformation in the site region; and the potential for surface deformation at the site. The applicant collected the information during site characterization investigations.

2.5.3.2 *Summary of Application*

Section 2.5.3 of the Fermi 3 COL FSAR, Revision 5, describes the potential for tectonic and non-tectonic surface faulting at the Fermi 3 site. In addition, in FSAR Section 2.5.3, the applicant provided the following:

<u>COL Item</u>

- EF3 COL 2.0-28-A — Surface Faulting In Accordance with SRP 2.5.3

To address this COL item, the applicant developed FSAR Section 2.5.3 based on reviews of relevant published geologic literature; aerial photographic interpretations; lineament analyses; interviews with experts familiar with the geology, seismology, and tectonics of the site region; a review of seismicity data; and geologic field investigations. The applicant performed field investigations that included geologic field reconnaissance, aerial reconnaissance, and geologic mapping of rock units and Quaternary deposits at the site. Also, the applicant used the previous UFSAR for the existing Fermi 2 (DTE 2006); in addition to construction reports and interactions with involved personnel to supplement recent geologic and seismic investigations on the site.

In the context of these efforts, the applicant concluded that there are no capable tectonic sources within the 8-km (5-mi) site area radius. The applicant also concluded that there is no evidence for Quaternary tectonic surface fold deformation or faulting within the 1-km (0.6-mi) radius of the Fermi site.

2.5.3.2.1 Geologic, Seismic, and Geophysical Investigations

In FSAR Subsection 2.5.3.1, the applicant described the investigations performed to evaluate the potential for surface deformation at the Fermi 3 site. The applicant compiled and reviewed existing data from the investigations for the operating Fermi 2 site, as well as published and unpublished literature regarding tectonics and geomorphology for southeast Michigan and northwest Ohio. The applicant also analyzed previous and updated seismicity data for the site vicinity, analyzed and interpreted aerial photographic and remote sensing imagery for the Fermi 3 site vicinity, and conducted multiple field and aerial reconnaissance investigations at and surrounding the site. Finally, the applicant contacted experts at the Ohio, Michigan, and Canadian geological surveys to obtain the most current information related to geologic investigations within the Fermi 3 site region.

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

FSAR Subsection 2.5.3.2 discusses the geologic evidence, or absence of evidence, for tectonic and non-tectonic surface deformation in the Fermi 3 site area. The applicant concluded that there are no faults at or close to the ground surface in the Quaternary sediments within 40 km (25 mi) of the site. Using boring and geophysical data, the applicant indicated that the faults in the subsurface of the site vicinity are in Paleozoic rocks; the closest tectonic features to the site are (1) the Bowling Green fault and the Maumee fault (40 km [25 mi]), (2) the Howell anticline and associated fault (40 km [25 mi]), (3) a series of folds in the subsurface bedrock units along the southeastern trend of the Howell anticline and two possible fault trends located on the southwestern flank of these folds that are possibly associated with oil and gas pools, and (4) shorter faults located in southwestern Ontario (one of which is possibly associated with oil and gas fields). The applicant observed two minor faults in the Silurian Bass Islands Group at the Denniston Quarry 16 km (10 mi) south of the Fermi 3 site; each fault has a displacement of less than 1.4 m (4.6 ft). The applicant stated that the second fault extends to the top of the Bass Island Group, but the latest Pleistocene (approximately 13–12 thousand years ago [ka]) Quaternary till and lacustrine deposits overlying the projected trends of both faults are not deformed. The applicant indicated that only one possible fault extends within the 8-km (5-mi) radius of the site, and that fault trend is associated with the New Boston Pool mapped in 1962 by Ells (Ells 1962). However, there is no supporting documentation regarding the existence of this structure, and no faults were identified within the basement rocks or overlying sediments at the Fermi 2 site.

The applicant stated that non-tectonic deformation agents, such as glacial and periglacial processes, sometimes look like surface tectonic fault ruptures. However, there is no evidence of surface deformation in the site associated with these non-tectonic processes. The applicant explained that other observed non-tectonic deformation processes in the Michigan basin are associated with the dissolution and subsequent collapse of carbonate rock, and there are reports of karst-related problems within the 320-km (200-mi) radius of the site.

In FSAR Subsection 2.5.3.2.3, the applicant described the lineaments in the Fermi 3 site and explained that most apparently coincide with paleoshorelines as well as with linear stream segments. The applicant concluded that no evidence indicates the presence of post-glacial surface faulting or continuing tectonic deformation.

2.5.3.2.3 Correlation of Earthquakes with Capable Tectonic Sources

In FSAR Subsection 2.5.3.3, the applicant concluded that there is no record of earthquakes or earthquake alignments within 40 km (25 mi) of the Fermi 3 site that could be associated with mapped bedrock faults.

2.5.3.2.4 Ages of Most Recent Deformations

In FSAR Subsection 2.5.3.4, the applicant concluded that the major bedrock deformation in the site vicinity occurred during the Paleozoic epoch. The applicant also stated that limited geologic history exists in the site region during the Mesozoic era, and no Mesozoic pluton or rift-related sediments are present to suggest that the Mesozoic extension affected the site region. The applicant concluded that there is no evidence of paleoliquefaction or deformation on the lacustrine plain that overlies the postulated faults within the site vicinity.

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

In FSAR Subsection 2.5.3.5, the applicant stated that folding occurred in the Silurian and Devonian rocks on the Fermi site. Folds are recognized along the southeastern margin of the Michigan basin and they coincide with the mid-Michigan gravity high, which is associated with the mid-continent rift system.

2.5.3.2.6 Characterization of Capable Tectonic Sources

In FSAR Subsection 2.5.3.6, the applicant stated that the mapped bedrock faults within a 40-km (25-mi) radius and the lineaments within the 8-km (5-mi) radius of the site are not considered capable tectonic sources. The applicant based this conclusion on the study of geomorphic evidence, determination of surface or near-surface deformation of landforms or geologic deposits, evaluation of the association with one or more moderate earthquakes and the structural association with capable tectonic structures.

2.5.3.2.7 Designation of Zones of Quaternary Deformation in the Site Region

In FSAR Subsection 2.5.3.7, the applicant stated that no zones of Quaternary tectonic deformation exist in the Fermi 3 site region.

2.5.3.2.8 Potential for Surface Tectonic Deformation at the Site

In FSAR Subsection 2.5.3.8, the applicant stated that no capable tectonic faults exist in the Fermi 3 site vicinity. The applicant added that there is no evidence of potential deformation associated with non-tectonic deformation such as glacially induced faulting, salt migration, and dissolution collapse associated with karst.

2.5.3.3 *Regulatory Basis*

The relevant requirements of the Commission regulations for the surface faulting, and the associated acceptance criteria, are in Section 2.5.3 of NUREG–0800. The applicable regulatory requirements are as follows:

- 10 CFR 52.79(a)(1)(iii) as it relates to identifying geologic site characteristics with appropriate consideration of the most severe natural phenomena historically reported for the site and surrounding area and with a sufficient margin for the limited accuracy, quantity, and period of time that the historical data were accumulated.

- 10 CFR 100.23 as it relates to determining the potential for surface tectonic and non-tectonic deformations in the region surrounding the site.

The related acceptance criteria from Section 2.5.3 of NUREG–0800 are as follows:

- Geologic, Seismic, and Geophysical Investigations: To meet the requirements of 10 CFR 100.23 and the guidance in RG 1.208, RG 1.132, and RG 1.198, this area of review is acceptable if the discussions of Quaternary tectonics, structural geology, stratigraphy, geo-chronologic methods used for age dating, paleoseismology, and geologic history of the site vicinity, site area, and site location are complete, compare well with the studies conducted by others in the same area, and are supported by detailed investigations performed by the applicant.

- Geologic Evidence, or Absence of Evidence, for Surface Tectonic Deformation: To meet the requirements of 10 CFR 100.23 and the guidance in RG 1.208, RG 1.132, RG 1.198, and RG 4.7 "General Site Suitability Criteria for Nuclear Power Stations," this area of review is acceptable if the applicant's discussion about sufficient surface and subsurface provides information that includes the site vicinity, site area, and site location to confirm the presence or absence of surface tectonic deformation (i.e., faulting) and if present, to demonstrate the age of the most recent fault displacement and the ages of previous displacements.

- Correlation of Earthquakes with Capable Tectonic Sources: To meet the requirements of 10 CFR 100.23, this area of review is acceptable if all reported historical earthquakes within the site vicinity are evaluated with respect to accuracy of hypocenter location and source of origin, and if all capable tectonic sources that could, based on fault orientation and length, extend into the site area or site location are evaluated with respect to the potential for causing surface deformation.

- Ages of Most Recent Deformation: To meet the requirements of 10 CFR 100.23, this area of review is acceptable if every significant surface fault and feature associated with a blind fault, or any part of which lies within the site area, is investigated in sufficient detail to demonstrate or to allow relatively accurate estimates of the age of the most recent fault displacement and to identify geologic evidence for previous displacements (if such evidence exists).

- Relationship of Tectonic Structures in the Site Area to Regional Tectonic Structures: To meet the requirements of 10 CFR 100.23, this area of review is acceptable if the discussion includes the structural and genetic relationships between site area faulting or other tectonic deformation and the regional tectonic framework.

- Characterization of Capable Tectonic Sources: To meet the requirements of 10 CFR 100.23, this area of review is acceptable is the applicant's investigative techniques are sufficiently sensitive to identify all potential capable tectonic sources, such as faults or structures associated with blind faults, within the site area; and the discussion provides the fault geometry, length, sense of movement, amount of total displacement and displacement per faulting event, age of latest and any previous displacements, recurrence rate, and limits of the fault zone for each capable tectonic source.

- Designation of Zones of Quaternary Deformation in the Site Region: To meet the requirements of 10 CFR 100.23 regarding the designation of zones of Quaternary deformation in the site region, the discussion is acceptable if the zone (or zones) designated by the applicant as requiring detailed faulting investigations is of sufficient length and width to include all Quaternary deformation features potentially significant to the site, as described in Regulatory Guide 1.208.

- Potential for Surface Tectonic Deformation at the Site Location: To meet the requirements of 10 CFR 100.23, this subsection must take into account potential for surface tectonic deformation if the applicant's field investigations reveal a surface or near-surface tectonic deformation along a known capable tectonic structure (i.e., a known capable tectonic feature related to a fault or blind fault).

In addition, the geologic characteristics should be consistent with the appropriate sections from: RG 1.208, RG 1.132, RG 1.198, and RG 1.206.

2.5.3.4 *Technical Evaluation*

NRC staff reviewed the information in Section 2.5.3 of the Fermi 3 COL FSAR, Revision 5, related to surface faulting as follows:

COL Item

- EF3 COL 2.0-28-A Surface Faulting

The staff reviewed the applicant's information in FSAR Section 2.5.3 addressing COL Item EF3 COL 2.0-28-A. Fermi 3 COL FSAR Section 2.5.3 addresses the potential for surface or near-surface tectonic and non-tectonic deformation within an 8-km (5-mi) radius of the Fermi 3 site.

The technical information in FSAR Section 2.5.3 resulted from the applicant's surface and subsurface geologic investigations performed for the site area and supplemented by aerial and field reconnaissance studies of the site vicinity, or within a 40-km (25-mi) radius of the site. The staff reviewed Fermi 3 COL FSAR Section 2.5.3 to determine whether the applicant had complied with the applicable regulations and had conducted investigations with an appropriate level of detail in accordance with the guidance in RG 1.208.

The staff's review focused on FSAR Section 2.5.3, which include the applicant's descriptions of previous studies and data collection and the applicant's own investigations conducted within the site area to assess the potential for surface tectonic deformation at the site. During the early site investigation stage, the staff visited the site and interacted with the applicant regarding the geologic, seismic, and geotechnical investigations conducted for the Fermi 3 COL application. To thoroughly evaluate the applicant's geologic, seismic, and geophysical information, the staff obtained additional assistance from experts at the USGS. The staff and the USGS advisors made an additional visit to the Fermi 3 site in November 2009 to confirm the applicant's interpretations, assumptions, and conclusions related to the potential for surface or near-surface faulting and non-tectonic deformation.

The staff's review of Fermi 3 COL FSAR Section 2.5.3 is presented below.

2.5.3.4.1 Geologic, Seismic, and Geophysical Investigations

NRC staff reviewed the applicant's descriptions of the site geologic, seismic, and geophysical investigations in FSAR Subsection 2.5.3.1. The staff verified the results of the applicant's field investigations as well as the applicant's interpretations of existing aerial photographic and remote sensing imagery. Specifically, the staff evaluated core borings and subsurface investigation reports in addition to field imagery; the visit included field locations at and near the site during a site audit in November 2009 (ML14112A212). After reviewing FSAR Subsection 2.5.3.1 and verifying current literature and findings from observations made during the November 2009 site audit, the staff concluded that the applicant has performed adequate investigations to evaluate the potential for surface deformation at the Fermi 3 site. The staff further concluded that the applicant's information in FSAR Subsection 2.5.3.1 is adequate to support the Fermi 3 COL application. The applicant's information is in accordance with the guidance in RG 1.208 and meets the requirements of 10 CFR 100.23.

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

NRC staff reviewed the applicant's evaluations and conclusions described in FSAR Subsection 2.5.3.2 regarding geologic evidence, or absence of evidence, for surface deformation at the Fermi 3 site. The staff's review of FSAR Subsection 2.5.3.2 focused on evidence to support the applicant's conclusion that there is no record of faulting or fault-related deformation in Quaternary age (less than 2.6 Ma) sediments within the site vicinity. To verify the applicant's results, the staff performed an independent literature review; reviewed the results of the applicant's lineament analysis; and visited locations in and around the Fermi 3 site, including the Denniston Quarry. The staff also reviewed the applicant's analysis of Paleozoic age faults identified within the site vicinity (including the Bowling Green and Maumee faults), in order to verify that there is no evidence for Quaternary deformation associated with these faults.

The staff noted that although FSAR Revision 1 Subsection 2.5.3.2.1 contained a brief description of the Quaternary stratigraphy at the site, the description did not provide details of field observations that relate to deformation or lack of deformation of Quaternary deposits revealed in stratigraphic exposures. Therefore, in RAI 02.05.03-3, the staff asked the applicant to describe any field observations of the local stratigraphic exposures that would assist in constraining any post-glacial deformation that may have occurred in the last 10,000 years in the site vicinity, especially with respect to lake deposits.

The response to RAI 02.05.03-3 dated February 11, 2010 (ML100570307), identified publications, reports, maps, and available electronic data the applicant had compiled and used as the basis for evaluations of the stratigraphy and geomorphology at the site. The applicant used this information to determine locations for conducting field and aerial reconnaissance investigations. Part of the applicant's response to RAI 02.05.03-3 also included a collection of maps, field photographs, and soil profiles the applicant had used as part of the site evaluation of the stratigraphy. The applicant explained that good exposures to view Quaternary stratigraphic relationships in the site vicinity are limited by the low-relief topography, incision by local streams, and thick vegetation covering stream banks. The applicant evaluated more than 244 m (800 ft.) of continuous lateral exposure of Quaternary deposits at the nearby Denniston Quarry. The applicant conducted three backhoe excavations at the quarry in December 2009 after the staff's visit to the site. During the November 2009 visit, NRC staff identified deformations in the underlying Paleozoic Bass Islands Group. As a result of RAI 02.05.01-29, which is discussed in Subsection 2.5.1.4 of this SER, the applicant provided a technical report that comprehensively evaluated the applicant's field studies at the Denniston Quarry. The applicant identified no evidence for deformation of Quaternary age sediments in the exposures at the Denniston Quarry.

The staff reviewed the information in the applicant's responses to RAI 02.05.03-3 and RAI 02.05.01-29, including the applicant's detailed description of the exposed Quaternary deposits in the Fermi 3 site vicinity. The staff visited a number of field exposures, including local streams and the Denniston Quarry, and found no evidence at or near the site for Quaternary deformation on the field visits or in the applicant's Denniston Quarry field investigation. Based on the review of the applicant's response to RAI 02.05.03-3, the staff's independent literature review, and the staff's visit to field locations surrounding the Fermi 3 site, the staff determined that the applicant had adequately evaluated evidence for Quaternary deformation based on stratigraphic exposures at or near the Fermi 3 site. The applicant also provided a more thorough description of the Quaternary deposits at and surrounding the Fermi 3 site, including the most recent post-glacial lake deposits. Therefore, RAI 02.05.03-3 is resolved and closed.

FSAR Revision 1 Subsection 2.5.3.2.3 discussed a lineament analysis that the applicant conducted to evaluate evidence for surface deformation in the site vicinity. As part of the analysis, the applicant used the USGS 10-m (33-ft) digital elevation model to identify topographic and linear stream segments in the site vicinity. In RAI 02.05.03-4, the staff asked the applicant to discuss the vertical accuracy of the digital elevation model data and the suitability of the data in a geologic environment with low strain rates and young surficial deposits. In the response to RAI 02.05.03-4 dated February 11, 2010 (ML100570307), the applicant referenced Gesch (2007) and stated that the relative vertical accuracy of the USGS digital elevation model data is 1.64 m (5.38 ft) and the absolute vertical accuracy is 2.44 m (8.0 ft). The applicant further stated that the objective in performing the lineament analysis was to identify linear anomalies in the site topography that may have developed as a result of tectonic or non-tectonic deformation at or near the surface. The applicant expected that the surface rupture due to faulting would be expressed at the surface as erosional remnants or vegetation anomalies. The applicant was confident that the digital elevation model data would be suitable to identify topographic anomalies if they did exist. The applicant found no evidence of surface disruption above two postulated subsurface faults (the Sumpter Pool and the New Boston Pool faults). In addition, the applicant supplemented the digital elevation model analysis with field and aerial investigations.

The staff also asked the applicant in RAI 02.05.03-4 to discuss the availability of light detection and ranging (LiDAR) high-resolution topographic data sets for the site vicinity and whether these data would be useful for evaluating post-glacial deformation at or near the site. The applicant stated that at the time of the Fermi 3 field studies, there were no LiDAR data sets available for the site vicinity. The applicant also stated that although a small strip of LiDAR data now exists along the Lake Erie shoreline, the data would not be useful for adequately evaluating geomorphic features in the site vicinity. Additional LiDAR data were being collected for various counties surrounding the site that may be useful in future evaluations once the data become available. The applicant noted that the USGS 10-m (33-ft) digital elevation model was the highest resolution topographic data available for analyzing surface lineaments at the time that the field investigations were conducted for the Fermi 3 site.

The staff evaluated the applicant's response to RAI 02.05.03-4 and the applicant's lineament analysis conducted in support of the Fermi 3 COL application. In November 2009, the staff visited multiple locations surrounding the Fermi 3 site to verify the geomorphic features identified in the applicant's lineament analysis and in field and aerial reconnaissance investigations. The staff determined that the applicant had adequately evaluated potential surface deformation features at the site using multiple means of verification. The staff found the resolution of the USGS topographic digital elevation model to be an adequate source for evaluating potential deformation in the Fermi 3 site vicinity. RAI 02.05.03-4 is therefore resolved and closed.

In RAI 02.05.03-5, NRC staff asked the applicant to discuss any relevant marine seismic and bathymetric data for Lake Erie as a basis for evaluating the presence or absence of recent tectonic deformation in the site region. The response to RAI 02.05.03-5 dated February 11, 2010 (ML100570304), stated that the applicant had relied on the highest-resolution bathymetric data available for Lake Erie to characterize the Fermi 3 site. The U.S. NOAA and the Canadian Hydrographic Service developed the bathymetric data using 1-m (3.3-ft) contour intervals. The applicant also described the results of high-resolution seismic reflection data collected in the western basin of Lake Erie by the Geological Survey of Canada in cooperation with the Ohio Geological Survey. Finally, the applicant discussed seismic reflection surveys conducted in the Ohio waters of Lake Erie. These high-resolution seismic surveys focused on mapping bedrock topography, sediment thickness, and stratification. The applicant stated that the present lake bottom topography results from the latest Pleistocene and Holocene glacial and lacustrine processes and added that there is no evidence suggestive of tectonic activity. The applicant stated that the most prominent features visible in the western Lake Erie basin topography are related to shipping and dredging activities. In the response to RAI 02.05.03-5, the applicant also updated FSAR Subsections 2.5.1.1.1 and 2.5.1.2.1 with additional topographic and geomorphic information based on the bathymetric and high-resolution seismic reflection data analyses relevant to Lake Erie.

The staff reviewed the applicant's response to RAI 02.05.03-5 and performed an independent evaluation of the references cited in this response and other available literature. Based on the applicant's information in response to RAI 02.05.03-5 and the applicant's FSAR updates, the staff determined that the applicant had adequately evaluated the presence or absence of deformation features in the Lake Erie site vicinity and region. Therefore, RAI 02.05.03-5 is resolved and closed.

In FSAR Revision 1 Subsection 2.5.3.2.3, the applicant stated that paleoshoreline features in the Fermi 3 site vicinity cross possible subsurface fault trends with no apparent disruption. In RAI 02.05.03-6, the staff asked the applicant to provide additional details regarding the basis for the conclusion that paleoshoreline features do not display evidence for deformation due to faulting. The staff also asked the applicant to discuss whether there is evidence of broad-scale regional deformation expressed in the paleoshoreline data. In the response to RAI 02.05.03-6 dated February 11, 2010 (ML100570307), the applicant stated that strandlines (former shorelines) and related features such as wave-cut bluffs and beach ridges provide important geomorphic information for evaluating vertical deformation in the past several thousand years and more. The applicant referenced the response to RAI 02.05.01-3 for a discussion of regional glacial-related deformation. The applicant focused the response to RAI 02.05.03-6 on geomorphic characterizations of paleoshorelines in the site vicinity.

The applicant clarified that the mapped paleoshorelines in the Fermi 3 site vicinity correlate with glacial and post-glacial lake levels from the past 14,800 years, or since the last major glacial advance. The applicant's response to RAI 02.05.03-6 systematically described the shoreline features associated with each significant lake-level phase for seven lakes identified within the Fermi 3 site vicinity—Lake Maumee, Lake Arkona, Lake Whittlesey, Lake Warren, Lake Wayne, Lake Grassmere and Lake Lundy. The applicant used the USGS 10-m (33-ft) digital elevation model to evaluate evidence for possible vertical deformation of paleoshoreline features within the Fermi site vicinity. The applicant used the digital elevation model data to construct a series of topographic profiles across the locations of mapped possible faults. Specifically, the applicant focused on the possible subsurface Sumpter Pool and New Boston Pool faults. The applicant's analyses of the paleoshoreline profiles and the digital elevation model data in combination with the applicant's lineament analyses identified no evidence for tilting or deformation along paleoshorelines located in the site vicinity. The applicant's conclusion regarding the lack of deformation on these features further confirms earlier published observations that concluded there was a lack of evidence for deformation along paleoshorelines in southeast Michigan. In this response, the applicant also provided extensive revisions to the FSAR as well as supporting figure updates documenting the paleo-shoreline analysis.

NRC staff reviewed the applicant's response to RAI 02.05.03-6, conducted an independent literature review, visited paleoshoreline locations evaluated by the applicant near the Fermi 3 site, and reviewed the applicant's lineament analysis. The staff determined that the applicant has conducted a thorough and systematic review of paleoshoreline features within the site vicinity, in order to evaluate the potential for surface deformation at the site. The staff also determined that the applicant has provided sufficient information to address the staff's questions in RAI 02.05.03-6. Therefore, RAI 02.05.03-6 is resolved and closed.

Based on the review of the information in FSAR Subsection 2.5.3.2 and the applicant's responses to the staff's RAIs, the staff concluded that the applicant has adequately evaluated evidence of surface deformation at the Fermi 3 site. The staff found that the applicant has presented thorough and accurate descriptions of information related to geologic evidence, or lack of evidence, for surface deformation from tectonic or non-tectonic processes within the site vicinity to support the Fermi 3 COL application. The applicant's information is in accordance with the guidance in RG 1.208 and meets the requirements of 10 CFR 100.23.

2.5.3.4.3 Correlation of Earthquakes with Capable Tectonic Sources

In FSAR Subsection 2.5.3.4.3, the applicant stated that there is no evidence in the seismic record for earthquakes that can be associated with bedrock faults mapped within the Fermi 3 site vicinity. The applicant referenced FSAR Subsection 2.5.2.1 for a discussion of the regional seismic history. The staff reviewed FSAR Subsection 2.5.3.4.3 in combination with the applicant's review of regional and site tectonic descriptions in FSAR Subsections 2.5.1.1.4.3 and 2.5.1.2.4, and the applicant's description of the local seismicity in FSAR Subsection 2.5.2.1. Based on this review, the staff determined that the applicant has adequately evaluated the correlation of earthquakes with possible tectonic sources. The applicant's conclusion that there is no correlation between earthquakes and known faults of any geologic age within the site vicinity is reasonable. The staff concluded that the applicant has provided sufficient information in FSAR Subsection 2.5.3.3 to support the Fermi 3 COL application. The applicant's information is in accordance with the guidance in RG 1.208 and meets the requirements of 10 CFR 100.23.

2.5.3.4.4 Ages of Most Recent Deformations

In FSAR Subsection 2.5.3.4, the applicant concluded that there is no evidence for surface deformation from at least the last 200 million years within the site vicinity. The applicant also stated that there is no evidence for earthquake-induced paleoliquefaction and no geomorphic expression of surface deformation across the broad surface or along paleoshoreline features. The staff noted that throughout much of the central and eastern United States, large earthquakes tend not to produce fault ruptures at the surface but may produce liquefaction features in potentially suitable areas. The staff also noted that the combination of a high water table and the presence of interbedded fine-grained and sandy sedimentary deposits in the site vicinity could indicate optimal conditions for liquefaction.

In RAI 02.05.03-2, the staff asked the applicant to provide additional bases for the determination that there is no evidence for paleoliquefaction in the Fermi 3 site vicinity. Specifically, the staff asked the applicant to describe paleoliquefaction investigations conducted in the site vicinity to support the applicant's conclusion that such features do not exist. In the response to RAI 02.05.03-2 dated January 11, 2010 (ML100130382), the applicant stated that paleoliquefaction investigations were conducted in the Fermi 3 site region. However, there are no published or unpublished reports documenting paleoliquefaction investigations in the site vicinity. The applicant confirmed the findings with the Ohio and Michigan Geological Survey staffs. The applicant stated that favorable geologic conditions to support the formation, preservation, or recognition of liquefaction features are not present in the Fermi 3 site vicinity, and this conclusion was verified through the applicant's observations during field reconnaissance investigations. Furthermore, the applicant identified several key field observations that provide the basis for its conclusion—including overall low relief across the site vicinity as well as shallow, over-vegetated stream banks.

NRC staff reviewed the applicant's response to RAI 02.05.03-2 and visited multiple field locations at and surrounding the Fermi 3 site in November 2009. The staff visited floodplain and stream locations in the site vicinity to observe stratigraphic exposures and noted unfavorable conditions for conducting paleoliquefaction investigations. The staff also reviewed the applicant's field investigation results and lineament analysis and concluded that the site conditions are not conducive to the development of liquefaction features. The staff determined that the combination of limited and poor exposures, relatively shallow bedrock, and unsuitable Quaternary stratigraphy contribute significantly to the difficulty in relying on paleoliquefaction studies to evaluate strong ground shaking in the Fermi 3 site vicinity. Accordingly, the applicant provided an adequate response to RAI 02.05.03-2. Therefore, this RAI is resolved and closed.

Based on the information in FSAR Subsection 2.5.3.4, the applicant's response to RAI 02.05.03-2, the staff's independent literature review, and observations made during the staff's visit to the site in November 2009, the staff determined that the applicant has adequately evaluated the evidence for the most recent deformations at the Fermi 3 site. The staff found that the applicant's conclusion of a lack of evidence for Quaternary tectonic and non-tectonic surface deformation is reasonable, as is the conclusion that the ages of the most recent deformations in the site vicinity are older than the Quaternary Period. The staff concluded that the applicant has provided sufficient information in FSAR Subsection 2.5.3.4 to support the Fermi 3 COL application. The applicant's information is in accordance with the guidance in RG 1.208 and meets the requirements of 10 CFR 100.23.

2.5.3.4.5 Relationship of Tectonic Structures in the Site Area to Regional Tectonic Structures

NRC staff reviewed the applicant's information in FSAR Subsection 2.5.3.5 related to the correlation of Paleozoic subsurface structures in the site area with regional tectonic structures. The staff independently reviewed the geologic literature referencing Paleozoic and Precambrian structures in the site region. The applicant provided a reasonable basis to conclude that tectonic structures in the site area are related to regional tectonic structures, which preserve deformation that occurred before the Quaternary Period. The staff concluded that the applicant has provided sufficient information in FSAR Subsection 2.5.3.5 to support the Fermi 3 COL application. The applicant's information is in accordance with the guidance in RG 1.208 and meets the requirements of 10 CFR 100.23.

2.5.3.4.6 Characterization of Capable Tectonic Sources

NRC staff reviewed FSAR Subsection 2.5.3.6 and the applicant's basis for concluding that no capable tectonic sources exist in the Fermi 3 site vicinity in accordance with criteria defined in RG 1.208. The applicant noted that Paleozoic rocks older than 250 million years are overlain by glacial and lacustrine (lake) deposits that are younger than 30,000 years. The applicant identified no geomorphic evidence for deformation in the overlying glacial and lacustrine deposits.

In RAI 02.05.03-7, the staff asked the applicant to provide a more detailed discussion of the basis for concluding in FSAR Subsection 2.5.3.6 that no bedrock faults within the Fermi 3 site vicinity are capable tectonic sources. In the response to RAI 02.05.03-7 dated February 11, 2010 (ML100570311), the applicant explained the use of multiple observations to assess the capability of postulated faults within the site vicinity. The applicant's analyses focused on evaluating the evidence for deformation associated with two possible bedrock faults that extend into the Fermi 3 site area—the New Boston and the Sumpter Pool faults. The applicant analyzed well log data for 20 oil wells within the vicinity of these two possible structures that were useful for providing elevation constraints across the tops of Paleozoic subsurface formations. The applicant determined that there was no evidence for vertical displacement across either of these postulated faults in the Devonian age (~359 Ma) top of bedrock units associated with the Dundee Formation.

The applicant also relied on analyses of the overlying Quaternary sediments in the Fermi 3 site vicinity to evaluate the potential for surface deformation above the postulated faults. The applicant explained that a series of late-glacial lakes occupied the entire site vicinity about 12,000 to 13,000 years ago. Geomorphic and stratigraphic indicators associated with glacial lake levels are useful indicators of and evidence for vertical displacement and deformation. The applicant analyzed the lake level deposits across the site vicinity and determined that there is no evidence for deformation within these units. The results of these analyses strongly suggest a lack of deformation in the site vicinity within at least the past 13,000 years. The applicant stated that neither of these possible faults within the site vicinity shows any evidence of activity in the past 12,000 years, and the low rate and scattered pattern of seismicity further supports a conclusion that the possible New Boston and Sumpter Pool faults are not capable tectonic structures. As a result of RAI 02.05.03-7, the applicant provided Fermi 3 FSAR updates that more thoroughly document the analyses of the New Boston and Sumpter Pool faults.

NRC staff reviewed the applicant's response to RAI 02.05.03-7, the applicant's analysis of well logs, and the applicant's revisions to FSAR Sections 2.5.1 and 2.5.3. The staff determined that the applicant's response provides a thorough analysis of evidence for capable tectonic structures within the site vicinity. The applicant also clarified unclear statements in previous FSAR versions related to analyzing surface and near-surface deposits in the site vicinity. The staff concluded that the applicant's discussion in the response to RAI 02.05.03-7, including markups of the updated FSAR, adequately address the staff's concerns and provide a more thorough basis to support the applicant's conclusions. Therefore, RAI 02.05.03-7 is resolved and closed.

Based on the information in FSAR Subsection 2.5.3.6, the applicant's response to RAI 02.05.03-7, the staff's independent review, and the staff's observations during a visit to the Fermi 3 site in November 2009, the staff determined that the applicant has adequately characterized capable tectonic sources within the Fermi 3 site vicinity. The applicant provided sufficient information to support the conclusion that tectonic faults in the site vicinity have not experienced deformation since at least the Quaternary Period, thus demonstrating that these faults should not be considered capable tectonic sources. The staff concluded that the applicant has provided sufficient information in FSAR Subsection 2.5.3.6 to support the Fermi 3 COL application. The applicant's information is in accordance with the guidance in RG 1.208 and meets the requirements of 10 CFR 100.23.

2.5.3.4.7 Designation of Zones of Quaternary Deformation in the Site Region

In FSAR Subsection 2.5.3.7, the applicant concluded that there are no zones of Quaternary deformation in the Fermi 3 site region. Based on the staff's independent reviews of the FSAR and the applicant's various RAI responses related to FSAR Sections 2.5.1 and 2.5.3, literature cited in the FSAR, and the results of the field investigations performed by the applicant for the Fermi 3 site, as well as direct field observations made by staff during a site visit in November 2009, the staff determined that the applicant adequately evaluated the Fermi site region for evidence of Quaternary deformation zones. The staff finds that the applicant's conclusion that no zones of Quaternary deformation exist in the site region is reasonable. Therefore, the staff concludes that the applicant provided sufficient information in FSAR Subsection 2.5.3.7 to support the Fermi 3 COL application, and that this information is in accordance with regulatory guidance in RG 1.208 and regulatory requirements in 10 CFR 100.23

2.5.3.4.8 Potential for Surface Deformation at the Site

In FSAR Subsection 2.5.3.8, the applicant concluded that the potential for tectonic or non-tectonic surface deformation at the Fermi 3 site is negligible. The NRC staff reviewed the information in FSAR Sections 2.5.1 and 2.5.3 and the applicant's response to the staff's RAIs as the basis for the applicant's conclusions that negligible tectonic or non-tectonic surface deformation potential exists at the site. Based on the staff's review of the FSAR, the staff's independent literature review, the staff's review of the applicant's field investigations in the Fermi 3 site vicinity, and the staff's observations during a site visit in November 2009, the staff determined that the applicant has adequately evaluated the Fermi 3 site for evidence of tectonic or non-tectonic surface deformation. The staff found that the applicant's conclusion that Quaternary tectonic and non-tectonic surface deformation are absent at the site is reasonable, as is the conclusion that existing structures represent deformation processes that occurred before the Quaternary Period. Thus, the applicant has reasonably supported the conclusion that there is a negligible potential for future surface deformation at the site. It is the responsibility of the applicant to perform detailed geologic mapping of the Fermi 3 excavation for nuclear island structures, to examine and evaluate geologic features in excavations for other safety-related structures, and to inform the NRC once the excavations are open for examination by NRC staff. In Subsection 2.5.3.5 of this SER, the staff defines this responsibility as License Condition 2.5.3-1. The staff concluded that the applicant has provided sufficient information in FSAR Subsection 2.5.3.8 to support the Fermi 3 COL application. The applicant's information is in accordance with the guidance in RG 1.208 and meets the requirements of 10 CFR 100.23.

2.5.3.5 *Post Combined License Activities*

The staff identified the following geologic mapping license condition as the responsibility of the COL licensee:

> License Condition (2.5.3-1) – The applicant shall perform detailed geologic mapping of excavations for safety-related structures; examine and evaluate geologic features discovered in those excavations; and notify the Director of the Office of New Reactors,

or the Director's designee, once excavations for safety-related structures are open for examination by NRC staff.

2.5.3.6 *Conclusion*

The NRC staff reviewed the application and confirmed that the applicant has addressed the required information, and no outstanding information is expected to be addressed in the COL FSAR related to this section.

In addition, the staff compared the additional information in the COL application to the relevant NRC regulations, the guidance in Section 2.5.3 of NUREG–0800, and applicable NRC regulatory guides. The staff's review concludes that the applicant has provided sufficient information to satisfy the requirements of NRC regulations. The staff determined that the applicant has adequately addressed COL Item EF3 COL 2.0-28-A, as it relates to the surface faulting.

As set forth above, the staff found that the applicant has provided a thorough characterization of the potential for surface deformation at the Fermi 3 site, as required by 10 CFR 100.23 and 10 CFR 52.79(a)(1)(iii). The staff considered the information gathered by the applicant during the regional and site-specific investigations. Therefore, the staff concludes that the applicant had performed these investigations in accordance with the requirements of 10 CFR 100.23 and 10 CFR 52.79(a)(1)(iii) by following the guidance in RG 1.208. The staff concludes that the applicant has provided an adequate basis to establish that there is no potential for surface tectonic or non-tectonic deformation that may affect the design and operation of the proposed nuclear power plant. The staff concludes that the site is suitable from the perspective of surface deformation and meets the requirements of 10 CFR 100.23 and 10 CFR 52.79(a)(1)(iii).

2.5.3.7 *References*

Detroit Edison Fermi Unit 2 Updated Safety Analysis Report, Revision 14, November 2006.

Ells, G.D., "Structures Associated with the Albion-Scipio Oil Field Trend," Michigan Geological Survey Open-File Report 62-1, 1962.

Gesch, D.B.,"The National Elevation Dataset, in Maune, D., ed., Digital Elevation Model Technologies and Applications" The DEM User's Manual, 2nd Edition: Bethesda, Maryland, American Society for Photogrammetry and Remote Sensing, pp. 99-118, 2007.

2.5.4 Stability of Subsurface Materials and Foundations

2.5.4.1 *Introduction*

This FSAR section presents the stability of subsurface materials and foundations that relate to the Fermi 3 site. The properties and stability of the soil and rock underlying the site are important to the safe design and siting of the plant. The information in this FSAR section addresses (1) geologic features in the site vicinity; (2) static and dynamic engineering properties of soil and rock strata underlying the site; (3) the relationship of the foundations for safety-related facilities and the engineering properties of underlying materials; (4) results of seismic refraction and reflection surveys, including in-hole and cross-hole explorations; (5) safety-related excavation and backfill plans and engineered earthwork analyses and criteria;

(6) groundwater conditions and piezometric pressure in all critical strata as they affect the loading and stability of foundation materials; (7) responses of site soils or rocks to dynamic loading; (8) liquefaction potential and consequences of liquefaction of all subsurface soils, including the settlement of foundations; (9) earthquake design bases; (10) results of investigations and analyses conducted to determine foundation material stability, deformation, and settlement under static conditions; (11) criteria, references, and design methods used in static and seismic analyses of foundation materials; (12) techniques and specifications to improve subsurface conditions, which are to be used at the site to provide suitable foundation conditions, and any additional information deemed necessary in accordance with 10 CFR Part 52.

2.5.4.2 *Summary of Application*

Section 2.5.4 of the Fermi 3 COL FSAR describes the stability of subsurface materials and foundations. In addition, in FSAR Section 2.5.4, the applicant provides the following:

COL Item

- EF3 COL 2.0-29-A — Stability of Subsurface Materials and Foundations in Accordance with SRP 2.5.4

In FSAR Section 2.5.4, the applicant provides site-specific information in accordance with SRP Section 2.5.4 to address COL Item EF3 COL 2.0-29-A. Specifically, the information addresses the (1) localized liquefaction potential under other than Seismic Category I structures; and (2) settlement and differential settlement.

2.5.4.2.1 Geologic Features

FSAR Subsection 2.5.4.1 refers to FSAR Section 2.5.1 for a complete description of the regional and site geology, including discussions of the potential for surface and subsurface weathering and deformation.

2.5.4.2.2 Properties of Subsurface Materials

FSAR Subsection 2.5.4.2 presents the static and dynamic engineering properties of subsurface materials based on the applicant's field investigation and sampling program and on laboratory testing. Table 2.5.4-1 of this SER summarizes the engineering properties of subsurface materials at the Fermi 3 site.

Table 2.5.4-1 Summary of Engineering Properties of Soils and Bedrocks
(Reproduced from Fermi COL FSAR Table 2.5.4-202)

Stratum	Quarry Fill	Lacustrine Deposits	Glacial Till	Bass Islands Group	Salina Group Unit F	Salina Group Unit E	Salina Group Unit C	Salina Group Unit B
USCS Symbol	GP/GW	CL/CH	CL	-	-	-	-	-
Total Unit Weight kg/m^3 (pcf)	2,002 (125)	2,082 (130)	2,162 (135)	2,402 (150)	2,402 (150)	2,402 (150)	2,402 (150)	2,402 (150)

Fines Content, %	-	93	68	-	-	-	-	-
Natural Water Content, %	-	27	15	0.1	0.4	3.9	0.9	0.2
Atterberg Limits								
Liquid Limit %	-	44	29	-	-	-	-	-
Plastic Limit %	-	17	15	-	-	-	-	-
Plasticity Index %	-	27	14	-	-	-	-	-
Adjusted SPT N60-value, bpf	11	7	47	-	-	-	-	-
Undrained Shear Strength kPa (ksf)	-	43 (0.9)	129 (2.7)	-	-	-	-	-
Effective Shear Strength Parameters								
Effective Cohesion kPa (ksf)	0	0	0	-	-	-	-	-
Effective Friction Angle	36	29	31	-	-	-	-	-
Rock Quality Designation	-	-	-	54	13	72	97	97
Unconfined Compressive Strength MPa (ksf)	-	-	-	89 (1,870)	45 (940)	84 (1,760)	86 (1,800)	73 (1,540)
Poisson Ratio	0.35	0.35/0.49	0.35/0.49	0.33	0.39	0.30	0.28	0.29
Modulus of Elasticity based on Hoek-Brown criterion								
Upper Bound Modulus MPa (ksf)	-	-	-	5,242 (109,500)	1,517 (31,700)	23,560 (492,100)	29,830 (623,000)	63,430 (1,324,700)
Mean Modulus MPa (ksf)	-	-	-	3,863 (80,700)	1,160 (24,200)	20,310 (424,200)	26,780 (559,300)	58,810 (1,228,400)
Lower Bound Modulus MPa (ksf)	-	-	-	2,868 (59,900)	924 (19,300)	16,710 (349,000)	23,080 (482,100)	52,800 (1,102,700)

Modulus of Elasticity based on Laboratory Test MPa (ksf)	-	-	-	43,030 (898,600)	25,340 (529,200)	32,150 (671,500)	36,540 (763,200)	72,050 (1,504,800)
Modulus of Elasticity based on V_s MPa (ksf)	-	-	-	26,630 (556,200)	6,350 (132,600)	36,190 (755,800)	48,240 (1,007,600)	55,390 (1,156,900)
Average V_s m/s (fps)	-	-	243 to 350 (800 to 1,150)	2,042 to 2,225 (6,700 to 7,300)	975 to 1,219 (3,200 to 4,000)	2,407 to 2,773 (7,900 to 9,100)	2,712 to 2,743 (8,900 to 9,000)	2,895 to 3,017 (9,500 to 9,900)
Average V_p m/s (fps)	-	-	-	4,023 to 4,389 (13,200 to 14,400)	2,438 to 2,865 (8,000 to 9,400)	4,663 to 4,937 (15,300 to 16,200)	4,846 to 4,907 (15,900 to 16,100)	5,334 to 5,577 (17,500 to 18,300)
Shear Modulus at very small strain levels, G_{max} MPa (ksf)	-	-	129 (2,700)	10,010 (209,100)	2,283 (47,700)	13,920 (290,700)	18,850 (393,600)	21,470 (448,400)
bpf = blows per foot; fps = foot per second; kg/m^3 = kilograms per cubic-meter; kPa = kilopascal; ksf=kip (1000 pound force) per square-foot; m/s= meters per second; MPa= megapascal; pcf = pounds per cubic-foot								

Engineering Properties of Subsurface Materials

FSAR Subsection 2.5.4.2.1 provides an overview of the subsurface soil and rock at the Fermi 3 site. The applicant stated that there are approximately 9.0 m (30 ft) of overburden material consisting of fill, lacustrine deposits, and glacial till overlying the bedrock at the site. The applicant described plans to remove all overburden material beneath and adjacent to Seismic Category I structures during excavation. The bedrock unit below the overburden consists of the Bass Islands Group and Units F, E, C, and B (from the top to the bottom) of the Salina Group. The applicant noted that the site is relatively flat with an average elevation of 177 m (581 ft) NAVD 88. Table 2.5.4-2 of this SER summarizes the approximate elevation ranges and average thickness for each of the subsurface layers. FSAR Appendix 2.5DD lists a total of 68 borings, which the applicant performed to obtain the engineering properties of both soils and rocks.

Table 2.5.4-2 Approximate Elevation Ranges for Each Subsurface Material Encountered at Fermi 3
(Reproduced from Fermi COL FSAR Table 2.5.4-201)

Subsurface Material	Approximate Range in Elevation NAVD 88, m (ft)	Average Thickness, m (ft)
Fill	177 to 173 (581 to 568)	3.9 (13)
Lacustrine Deposits	173 to 171 (568 to 563)	1.5 (5)
Glacial Till	171 to 168 (563 to 552)	3.3 (11)
Bass Islands Group	168 to 141 (552 to 462)	27 (90)
Salina Group Unit F	141 to 103 (462 to 339)	37 (123)
Salina Group Unit E	103 to 75 (339 to 246)	28 (93)
Salina Group Unit C	75 to 47.5 (246 to 156)	27 (90)
Salina Group Unit B	47.5 to * (156 to *)	*
*The bottom of the Salina Group Unit B was not encountered during the geophysical investigations. ft= foot; m = meter		

Engineering Properties of Soils

FSAR Subsection 2.5.4.2.1.1 discusses the engineering properties of the upper 30 m (90 ft) of overburden materials present at the Fermi 3 site. The applicant stated that the overburden is comprised of fill, lacustrine deposits, and glacial till, all of which will fully excavate beneath and adjacent to all Seismic Category I structures.

The applicant further stated that although the fill and lacustrine deposits are not suitable for foundation support or structural backfill, their static engineering properties are suitable for the stability analysis and design of temporary excavation support systems and slopes. Since the fill and lacustrine deposits will be removed at the site, the applicant did not consider the dynamic engineering properties of these materials in the GMRS.

Finally, the applicant considered the static and dynamic properties of the approximately 3.4-m (11-ft) thick glacial till at the base of the overburden; because this material may be used to support non-Seismic Category I structures. The applicant noted that shear wave velocity (V_s) measurements of the glacial till range from 244 to 351 m/s (800 to 1,150 fps). The applicant used these values to calculate the shear modulus behavior of the glacial till and considered the glacial till the uppermost competent material present at the Fermi 3 site.

Engineering Properties of Bedrock

FSAR Subsection 2.5.4.2.1.2 describes the characteristics, properties, and classification of the two primary bedrock units beneath the Fermi 3 site: the Bass Islands Group and Units F, E, C, and B of the Salina Group. FSAR Subsections 2.5.1.2.3.1.2 and 2.5.1.2.3.1.1 provide detailed descriptions of these units. The applicant estimated the strength and deformation characteristics of the bedrock units using the Hoek-Brown criterion (Hoek 2007).

1. Bass Islands Group

The applicant stated that it will found the Fermi 3 Seismic Category I structures on the Bass Islands Group, or on fill concrete overlying the Bass Islands Group, the uppermost bedrock unit with an elevation of approximately 168 to 141 m (552 to 462 ft) NAVD 88. Based on field testing, the applicant stated that the average rock quality designation (RQD)—a measure of the rock's integrity—is 54 percent. The applicant lab-tested 20 intact rock samples and determined an average unconfined compressive strength (q_u) and elasticity modulus (E) of 89.5 megapascals (MPa) (1,870 kips per square-foot (ksf)) and 43,000 MPa (898,600 ksf), respectively. The applicant based the Poisson's ratio, which varies from 0.33 to 0.34, on the mean V_s and compression wave velocity (V_p), which varies from 2,012 to 2,225 m/s (6,600 to 7,300 fps) and 4,023 to 4,389 m/s (13,200 to 14,400 fps), respectively.

2. Salina Group

FSAR Subsections 2.5.4.2.1.2.2 through 2.5.4.2.1.2.5 describe the general characteristics for Salina Group Units F, E, C, and B. The applicant described Salina Group Unit F as bedrock localized at an elevation of 140 to 103 m (492 to 339 ft) NAVD 88, with an average RQD of 13 percent. In order to determine the characteristics of the intact bedrock, the applicant performed thirteen unconfined compression (UC) laboratory tests to obtain an average q_u of 45 MPa (940 ksf) and an average E of about 25,300 MPa (529,300 ksf). The applicant performed an in situ pressuremeter test and obtained an average E of 996 MPa (20,800 ksf). The applicant calculated a Poisson's ratio of 0.39 to 0.40 from the mean Vp of 2,438 to 2,865 m/s (8,000 to 9,400 fps) and the mean Vs of 975 to 1,219 m/s (3,200 to 4,000 fps).

The applicant observed the Salina Group Unit E between elevation 103 and 75 m (339 and 246 ft) NAVD 88, with an average RQD of 72 percent. The applicant performed UC laboratory tests on eight intact bedrock samples with an average q_u and E of 84 and 32,100 MPa (1,750 and 671,400 ksf), respectively. The applicant calculated a Poisson's ratio of 0.27 to 0.32 based on the mean V_s and V_p that vary from 4,115 to 4,938 m/s (15,300 to 16,200 fps) and 2,408 to 2,774 m/s (7,900 to 9,100 fps), respectively.

FSAR Subsection 2.5.4.2.1.2.4 states that the Salina Group Unit C was found between elevations of 75 to 47.5 m (246 to 156 ft) NAVD 88, with an average RQD of 97 percent. The applicant noted that only two borings penetrated Unit C. The applicant performed an UC laboratory test on two intact bedrock samples, and the resultant q_u and E had averages of 86 MPa and 36,542 MPa (1,790 ksf and 763,200 ksf), respectively. The applicant calculated a Poisson's ratio of 0.26 to 0.28 from the mean V_p of 4,846 to 4,907 m/s (15,900 to 16,100 fps) and the mean V_s of 2,713 to 2,743 m/s (8,900 to 9,000 fps).

FSAR Subsection 2.5.4.2.1.2.5 specifies that the top of Salina Group Unit B is at an elevation of 47.5m (156 ft), but the bottom was not found during the subsurface investigation. The applicant noted that the average RQD was 97 percent and considered an average q_u of 74 MPa (1,540 ksf) and an average E of 72,000 MPa (1,504,800 ksf) to be representative of the engineering behavior of the rock mass of Salina Group Unit B. The applicant used the mean V_p, which varied from 5,334 to 5,578 m/s (17,500 to 18,300 fps); and the mean V_s, which varied from 2,896 to 3,018 m/s (9,500 to 9,900 fps), to calculate a Poisson's ratio of 0.29.

Field Investigations

FSAR Subsection 2.5.4.2.2 states that the applicant conducted field investigations in accordance with an approved quality assurance program. The applicant used two phases to complete the investigation: a hydrogeological phase and a geotechnical phase.

Hydrogeological Investigation Program

The applicant conducted a hydrogeological investigation that consisted of piezometers and monitoring wells installation, packer and slug testing, downhole geophysics and sampling, and groundwater testing. The applicant's investigation focused on the unconfined surficial groundwater and the confined Bass Islands Group aquifer. The applicant installed 17 shallow and 11 deep piezometers and monitor wells east and west of the overflow canal. The applicant utilized the shallow wells to monitor the unconfined groundwater and the deeper wells to monitor the confined Bass Islands Group aquifer. FSAR Section 2.4.12 discusses the existing Fermi piezometers and monitoring wells in greater detail. The applicant recorded the groundwater or drilling fluid level at the start of each workday for borings in progress and at the completion of drilling, in accordance with the guidance in RG 1.132. The groundwater levels were measured monthly for a period of 1 year. The applicant performed downhole logging in areas of poor bedrock core recovery to aid in the selection of packer test zones, understand the hydrology, and correlate the bedrock geology across the site. The applicant referred to FSAR Section 2.4.12 for the results of packer and slug testing performed to estimate the permeability of selected intervals of bedrock and the hydraulic conductivity in the overburden, respectively.

FSAR Subsection 2.5.4.2.2.1.7 presents the types of chemical testing conducted on the groundwater and surface water samples to establish baseline conditions at the site.

Geotechnical Investigation Program

The applicant conducted a geotechnical investigation to obtain surface information, characterize site conditions, develop site specific seismic design criteria, and evaluate the potential for geotechnical hazards.

In accordance with RG 1.132, the applicant collected soil samples at depth intervals no greater than 1.5 m (4.92 ft). The applicant used a combination of split–barrel samplers, thin-walled tubes, or sonic sampling depending on the soil type. The applicant concluded that because it will found all safety-related structures at the Fermi 3 site on bedrock or fill concrete over bedrock, the continuous sampling requirement was satisfied by the continuous sonic sampling from the ground surface to the top of the bedrock and by continuous rock coring in bedrock.

The applicant conducted P-S suspension logging, downhole seismic testing and SASW surface geophysics to obtain a V_s profile to use in a seismic response analysis of the site.

FSAR Subsection 2.5.4.2.2.2.5 describes the procedure and results of additional pressuremeter testing the applicant performed at the Salina Group Unit F location to provide a direct in situ measurement of the E for Unit F. The applicant selected rock pressuremeter locations in Boring RB-C6, at the location planned for the reactor, to test a range of bedrock qualities and types to provide a range of E values for Unit F. The applicant stated that the material being tested was a very complex geological unit consisting of interbedded limestone, dolomite, claystone, siltone, shale and breccias with variable degrees of induration. Even with the limitation of full classification of interbedded materials, the applicant successfully conducted pressuremeter testing and concluded that the test results should provide a conservative estimate of the in situ E. FSAR Table 2.5.4-219 contains the details of the test results.

The applicant backfilled the boreholes in the overburden or the Bass Islands Group with either bentonite chips within 0.3 to 0.6 m (1 to 2 ft) of the ground surface or cement/bentonite grout, and the top 0.3 to 0.6 m (1 to 2 ft) was backfilled with gravel.

Storage, Handling, and Transportation of Soil and Bedrock Samples

In FSAR Subsection 2.5.4.2.2.3, the applicant stated that the collected soil and bedrock samples were documented and stored in a way that will permit future retrieval for future examination and index testing. In addition, the applicant implemented American Society of Testing and Materials (ASTM) Standards D4220–95 and D5079–02; clearly labeled the samples; used a sample custody record form completed by a field engineer or geologist for storage and documentation; and delivered the samples to a temporary storage facility on a daily basis.

Laboratory Testing

FSAR Subsection 2.5.4.2.3 describes the goal of the laboratory testing program. The applicant stated that this program fully complies with the guidance of RG 1.138, and the testing was performed in accordance with standard test procedures. As part of the static laboratory testing, the applicant included different types of tests, such as the natural moisture content; specific gravity; Atterberg limits; mechanical sieve analysis; hydrometer analysis; percent finer than No. 200 sieve; consolidated-undrained triaxial compression test; unconsolidated-undrained triaxial compression test; unconfined compression test on soil and rock; one-dimensional consolidation test; direct shear test on soil and rock; hydraulic conductivity; and chemical analysis of soils. The applicant concluded that no dynamic testing was required for several bedrock units (the Bass Islands Group and Salina Group Units E, C, and B) because the V_s were equal to or greater than 2,042 m/s (6,700 fps). The applicant also concluded that no dynamic testing was required for Salina Group Unit F because the estimated shear strain levels were less than 0.03 percent, thus indicating a negligible modulus reduction for the Unit F bedrock. The applicant stated that because of poor core recovery and poor RQD for Salina Group F, the testable samples represent the more intact portion of the bedrock and testing under static or dynamic loading conditions will produce high values not representative of the overall unit. The applicant performed four resonant column torsional shear (RCTS) dynamic tests on samples of glacial till to obtain the modulus reduction and damping as a function of strain up to shear strain of approximately 0.3 percent. FSAR Section 2.5.4.7.3 presents the RCTS results.

2.5.4.2.3 Foundation Interfaces

FSAR Subsection 2.5.4.3 describes the geologic cross sections for Seismic Category I structures, including the detailed relationship of the foundations of structures to the subsurface materials. The applicant noted that the base of the RB/FB foundation lies in the Bass Islands Group, with an embedment depth of 20 m (65.6 ft) below the finished grade and a base elevation of 159.6 m (523.7 ft) NAVD 88. The base of the CB foundation also lies in the Bass Islands Group, with an embedment depth 14.9 m (48.9 ft) below the finished grade and an elevation of 164.7 m (540.4 ft) NAVD 88. For the FWSC, the applicant indicated an embedment depth of 2.35 m (7.7 ft) at an elevation of 177.3 m (581.6 ft) NAVD 88. The applicant will use fill concrete to backfill the gap between the RB/FB and CB and excavated bedrock up to 168.2 m (555 ft) NAVD 88. The applicant will remove and replace the glacial till underneath the TB with fill concrete to reduce the interaction between the TB and the RB as a result of the close proximity between the buildings. FSAR Appendix 2.5DD includes a list of the boring logs, monitoring well logs, piezometer logs, and test pit logs.

2.5.4.2.4 Geophysical Surveys

FSAR Subsection 2.5.4.4 refers to FSAR Subsection 2.5.4.2.2.2.4 for a list of the geophysical surveys performed. The details of the testing are discussed below in this section.

Geophysical Surveys for Dynamic Characteristics of Subsurface Materials

In FSAR Subsection 2.5.4.4.1, the applicant measured the dynamic characteristics of soils and bedrock using different types of testing that includes P-S suspension logging to obtain the V_s and V_p of the soil and bedrock; surface SASW to obtain the V_s in the soil; and downhole seismic testing to obtain the V_s and V_p in bedrocks. The applicant considered the P-S suspension logging method as the primary method for obtaining the V_s and V_p and used the downhole seismic method to validate the results.

P-S Suspension Logging and Downhole Seismic Testing in Bedrock Units

Initially the applicant experienced a repeated collapse of the boreholes at depths of 33.5 to 62.5 m (110 to 205 ft) in Salina Group Unit F that resulted in an oversized borehole and irregular borehole shapes. The applicant overcame the problem by using temporary steel casing and by conducting P-S suspension logging and downhole seismic testing below and above the Bass Islands Group and in the borehole collapsing zone.

The applicant obtained variable readings in Salina Group Unit F and in the Bass Islands Group between depths of 9.1 and 36.6 m (30 and 120 ft). The applicant compared the V_s and V_p measurements with the RQD, caliper, natural gamma, and optical televiewer (OTV) information to understand whether the measured velocities were representative of the actual subsurface conditions. FSAR Figure 2.5.4-213 and Figure 2.5.4-214 shows that the variability in the measured V_p and V_s correlates with the variability in the natural gamma logs, where the lower gamma indicates the presence of dolomite or limestone, the measured V_p and V_s increase. The applicant concluded that the variability in the measured V_p and V_s is caused by geologic features and that the measured V_p and V_s are representative of the actual ground conditions. The applicant stated that the measured V_p at Fermi 3 is in agreement with the V_p measured at Fermi 2 for the Bass Islands Group and for Salina Group Units F and E. But the V_p measured at Fermi 2 for Salina Group Units C and B have a difference of less than 15 percent lower than the V_p measured for Fermi 3. Figure 2.5.4-1 of this SER shows all of the V_p and V_s measurements at different borehole locations using both the P-S and downhole seismic methods. The applicant concluded that the results from P-S suspension logging are acceptable for all purpose of analysis.

P-S Suspension Logging and Spectral Analysis of Surface Wave in Soil Layers

FSAR Subsection 2.5.4.4.1.2 states that the results of the SASW method are acceptable because the soil shear wave velocities measured using the P-S suspension method agree with the SASW method. The applicant measured the seismic wave velocities in the overburden at boring RB-C6.

Natural Gamma, 3-Arm Caliper, Heat Pulse Flowmeter, and Optical Televiewer Logging

FSAR Subsection 2.5.4.4.2 describes the details of the various logging methods used. The applicant referenced the Black and Veatch report (Black and Veatch 2008) for the results of borehole loggings using the natural gamma, the 3-arm caliper, the heat pulse flowmeter, and the OTV. The applicant conducted all of the loggings in the same 18 boreholes except for the heat pulse flowmeter logging that was performed on borings RB-C8 and TB-C5.

Borehole Deviation Survey

In FSAR Subsection 2.5.4.4.3, the applicant conducted a borehole deviation survey in 22 steel-cased boreholes and recorded a maximum deviation of less than 1.5 degrees in the borings surveyed. The applicant utilized the EZ-Trac tool with the multi-shot function for most boreholes and the OTV probe for boring locations RB-C8 and TB-C5.

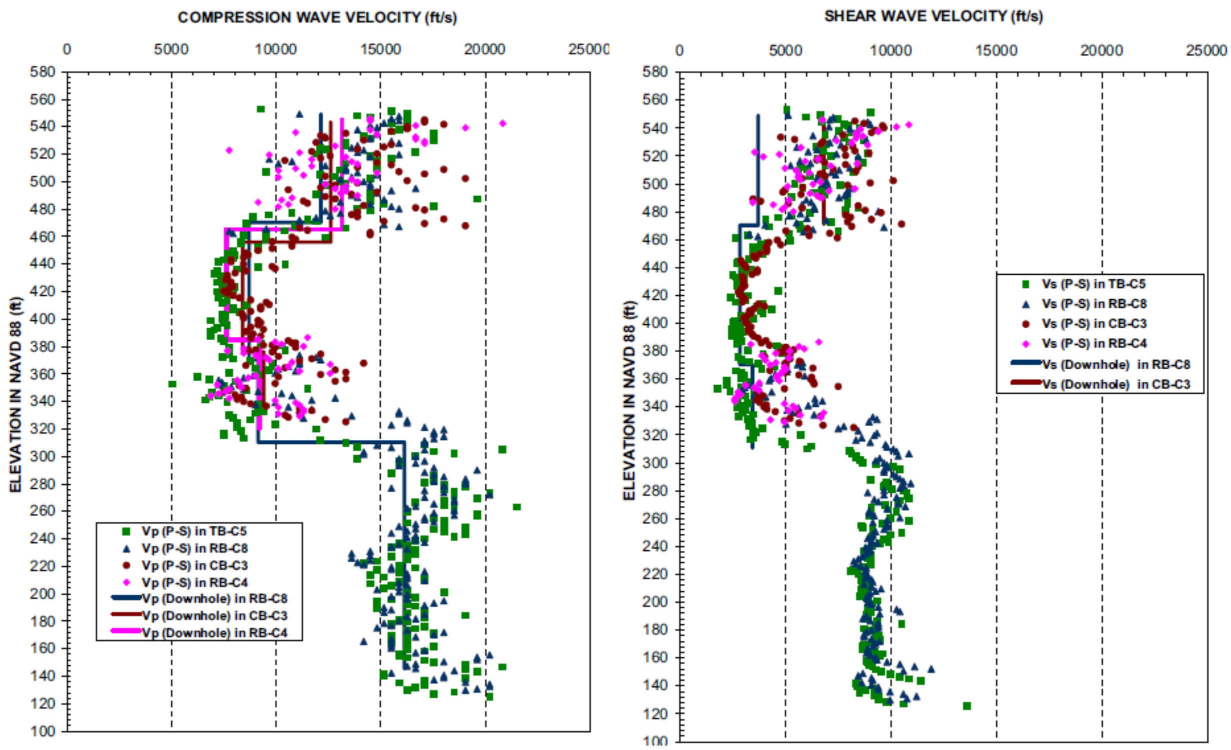


Figure 2.5.4-1 V_p and V_s measurements using P-S and Downhole Methods
(Reproduced from Fermi 3 COL FSAR Figure 2.5.4-215 and 2.5.4-216)

2.5.4.2.5 Excavation and Backfill

FSAR Subsection 2.5.4.5 describes source and quantities of backfill and borrow materials, excavation methods and stability. The applicant will commence all excavation activities for the power block structures from the existing ground surface elevation of approximately 177.1 m (581.0 ft) NAVD 88. FSAR Subsection 2.5.4.5.4.2 addresses the details of engineered granular backfill.

Source and Quantities of Backfill and Borrow Materials

In FSAR Subsection 2.5.4.5.1, the applicant indicated that the excavated material meeting gradation requirements will be used as engineered granular backfill. The applicant conducted laboratory and chemical testing and determined the static and dynamic properties to verify compliance with the design requirements of the proposed engineering granular backfill. The applicant indicated that the backfill surrounding Seismic Category I and II structures will be a well-graded engineered granular material and fill concrete. The applicant also stated that the backfill underneath the FWSC and the TB will be fill concrete. The applicant plans to complete the site excavation using vertical side wall excavation in soils and bedrocks. The total cut volume is estimated to be 313,000 cubic meters (m^3) (410,000 cubic yards [yd^3]) of which 256,000 m^3 (335,000 yd^3) are soil excavation and 57,000 m^3 (75,000 yd^3) are bedrock excavation. The total estimated backfill volume for full site development is 344,000 m^3 (450,000 yd^3), the volume of granular backfill from onsite excavation is approximately 180,000 m^3 (235,000 yd^3), and the amount of the engineered granular backfill within the perimeter of the reinforced concrete diaphragm wall is approximately 153,000 m^3 (200,000 yd^3). Since the potential total onsite source of granular material is greater than the quantity required to backfill within the perimeter of the reinforced concrete diaphragm wall, the applicant concluded that an onsite source will be used for backfill adjacent to the Seismic Category I structures. The applicant will apply the bulking and shrinkage factor during the final design.

Extent of Excavations, Fills, and Slopes

In FSAR Subsection 2.5.4.5.2, the applicant addressed the vertical cut-off as an excavation system possibility, which consists of a reinforced diaphragm wall system around the entire excavation. Figures 2.5.4-2 and 2.5.4-3 of this SER present the excavation site plan view and excavation cross-section D-D' for Fermi 3 using the vertical cut-off excavation system. The applicant stated that if the vertical cut-off excavation is used, this excavation system will be installed from the existing ground surface. The applicant assumed that the cut-off walls are 24.4 m (80 ft) deep with an embedment depth of 15.2 m (50 ft) into the bedrock, between elevations of 168.2 and 153.5 m (552.0 and 503.7 ft) NAVD 88. The applicant stated that the reinforced concrete diaphragm wall will act as a perimeter of the soil excavation and will provide vertical support for the portion of the excavation within the soil. FSAR Subsection 2.5.4.5.2 explains the considerations taken regarding the distance between the wall and the Seismic Category I structures. The applicant stated that the Seismic Category I structures are designed to resist all static and dynamic soil and bedrock loads and will not be adversely affected by the diaphragm wall. The applicant also stated that the concrete diaphragm wall will be designed to ensure that it will not adversely affect the seismic Category 1 structures.

Excavation Methods and Stability

Excavation in Soil

FSAR Subsection 2.5.4.5.3.1 states that the applicant may use conventional excavation methods to remove soil layers to the lines and grades shown on the excavation cross sections.

Excavation in Bedrock

FSAR Subsection 2.5.4.5.3.2 states that the applicant will use blasting, mechanical excavation, or a combination of both methods for the bedrock excavation. FSAR Figures 2.5.4-201 through 2.5.4-204 present lines and grades where the bedrock stratum will be excavated. The applicant indicated that all of the blasting will be designed by a qualified blasting professional in order to ensure the protection of all existing adjacent structures, including Fermi 2. The applicant stated that the mechanical excavation could include roadheaders, terrain levelers, rockwheels, and rock trenchers, among other excavation techniques.

Foundation Bedrock Grouting

In FSAR Subsection 2.5.4.5.3.3, the applicant indicated that a similar foundation bedrock grouting program used for Fermi 2 may be used for Fermi 3, as part of the excavation support and seepage control system. The applicant explained that for Fermi 2, the foundation bedrock grouting program was successful in reducing groundwater flow through the rock mass into the excavation during construction.

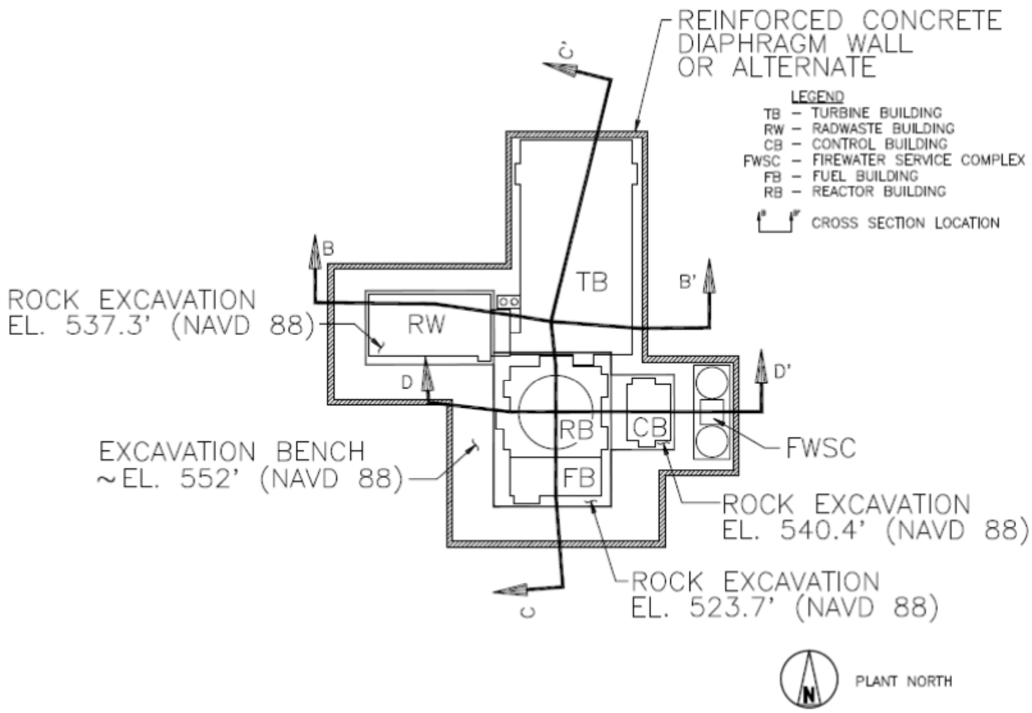


Figure 2.5.4-2 Excavation Site Plan
(Reproduced from Fermi 3 COL FSAR Figure 2.5.4-201)

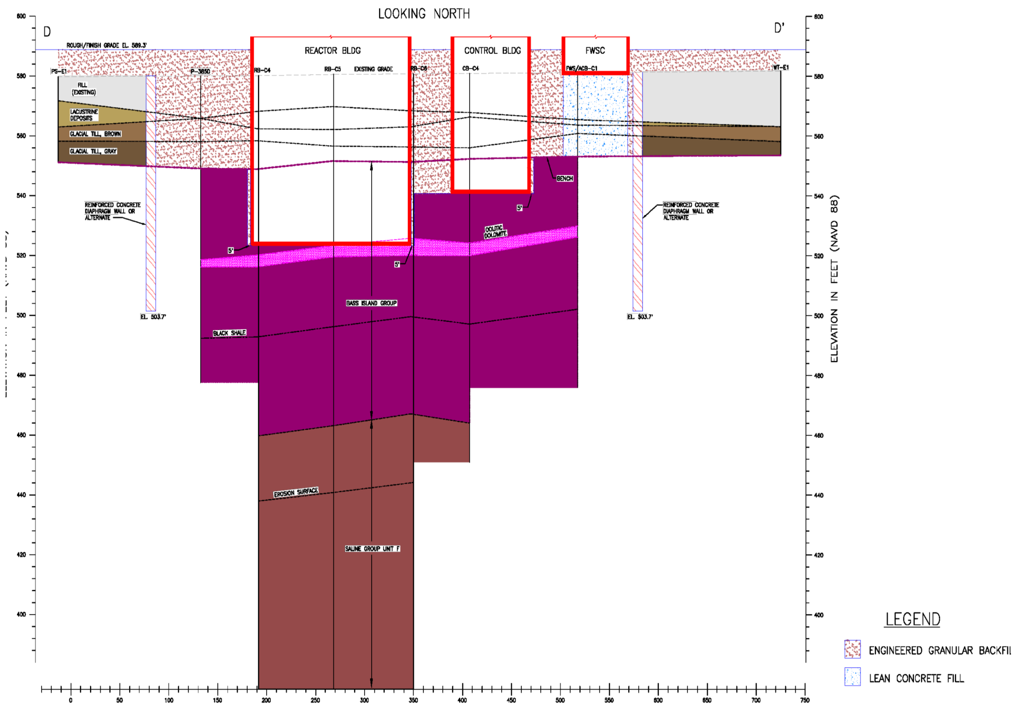


Figure 2.5.4-3 Excavation Cross Section D-D'
(Reproduced from Fermi 3 COL FSAR Figure 2.5.4-202)

Compaction Specifications and Quality Control

FSAR Subsection 2.5.4.5.4 describes the methods and procedures used for verification and quality control of foundation materials.

FSAR Subsection 2.5.4.5.4.1 describes methods used for quality control of foundation bedrock. FSAR states that the applicant plans to conduct a visual inspection of the final bedrock excavation surface to confirm that it conforms with the expected foundation materials based on borings loggings. In addition, the applicant will conduct visual inspections of the exposed bedrock subgrade to confirm the proper completion of the cleaning and surface preparations. The design specification includes details of quality control and quality assurance for the foundation bedrock.

FSAR Subsection 2.5.4.5.4.2 presents the consistency of the backfill materials and quality control for Fermi 3. The backfill will consist of fill concrete or a sound, well-graded granular backfill. FSAR Section 3.7.2 details the results of the site-specific SSI analyses for the RB/FB and CB, with fill concrete included as the backfill below the top of the Bass Islands Group bedrock and with and without the engineered granular backfill above the top of the bedrock. The applicant will place fill concrete as the supporting material below the FWSC, with a mean compressive strength of 31 MPa (4,500 psi). The applicant concluded that the FWSC sliding of not an issue when neglecting the engineered granular backfill surrounding the basemat, and the engineered granular backfill surrounding the basemat for the FWSC is not Seismic Category I backfill. In addition, the applicant specified that the engineered granular backfill surrounding the Seismic Category I structures will comply with the following criteria:

(a) Product of peak ground acceleration in g, α, Poisson's ratio, ν, and density, γ: α (0.95ν +0.65) γ: 1220 kg/m3 (76 pcf) maximum

(b) Angle of internal friction equal to or greater than 35 degrees when properly placed and compacted

(c) Soil density, γ, is 2,000 kg/m^3 (125 pcf) minimum

FSAR Figures 2.5.4-202 through 2.5.4-204 show the extent of the fill concrete and granular backfill. The applicant will use the concrete fill to backfill the gap between the bedrock and the foundation mats of the R/FB and the CB. The applicant will use the design specifications to address the concrete fill mix design. For quality control testing requirements for the bedrock, the applicant will use visual inspection and geologic mapping. In addition, the foundation bedrock and concrete fill will be tested against a bearing capacity failure. The applicant will conduct laboratory testing on the in-place engineered backfill adjacent to Seismic Category I structures during the detailed design phase in order to comply with the design requirements for the required density. The applicant will compact the engineered granular backfill surrounding the Seismic Category I structures above the top of the Bass Islands Group bedrock using a mean of 95 percent of the modified Proctor density or a mean of 75 percent of the maximum relative density. The applicant will compact the engineered granular backfill to achieve a minimum density of 35 degrees for the angle of friction (φ). FSAR Subsections 2.5.4.8 and 2.5.4.10 discuss liquefaction issues related to soil backfill materials and lateral pressures applied against foundation walls, respectively. In FSAR Part 10 Section 2.4.2, the applicant described a site-specific ITAAC for backfill surrounding Seismic Category I structures which states that the engineering properties of backfill material surrounding Seismic Category I structures will be equal to or exceed the FSAR Subsection 2.5.4.5.4.2 requirements.

The applicant will follow American Concrete Institute (ACI) 349 for concrete exposed to sulfate-containing solutions and will use fill concrete with a mean 28-day compressive strength greater than 31 MPa (4,500 psi) and with a mean V_s equal or greater than 2,175 m/s (7,140 ft/s) as fill under the FWSC, Seismic Category II structures, and surrounding the RB/FB and the CB. The applicant indicated that the mix design developed for the fill concrete will control erosion and leaching and will limit settlement to specified tolerances. The quality control program for fill concrete includes requirements for compressive strength testing, and the quality control program for engineered granular backfill includes requirements for in-place field density and index testing. The applicant will adhere to the ASTM standards for testing the aggregate of concrete for deleterious expansive alkali-silica reaction. The applicant will follow ACI 207.1R, 207.2R, and 207.4R to address thermal cracking control of the fill concrete adjacent to and underneath Seismic Category I and II structures. The applicant stated that the quality control program for fill concrete includes requirements for compressive strength testing. The applicant will perform verification to confirm that compressive strength testing results comply with mix design, minimum strengths, and placement requirements. The applicant will prepare design specifications as part of the detailed design phase of the project, including the details for the quality control and quality assurance programs for the fill concrete and engineered granular backfill. In FSAR Part 10 Section 2.4.1, the applicant described a site-specific ITAAC for fill concrete under Seismic Category I Structures, which states that the compactable backfill will not be placed under Fermi 3 Seismic Category I structures and that the fill concrete placed under

Seismic Category I structures to a thickness greater than 5 feet will be designed and tested as specified in FSAR Subsection 2.5.4.5.4.2.

Control of Groundwater during Excavation

FSAR Subsection 2.5.4.5.5 refers to Subsection 2.5.4.6.2 for the discussion of the control of groundwater and dewatering during excavation.

Geotechnical Instrumentation

FSAR Subsection 2.5.4.5.6 states that the instrumentation and monitoring program developed during the project's detailed design phase includes inclinometers, piezometers, seismograph survey points, and construction inspection documentation. The applicant expected a rebound or heave of less than 12.7 mm (0.5 inch) from the foundation excavation. The applicant predicted that the settlement would be within the ESBWR DCD design limits and would occur during the construction phases instead of post construction. The applicant based this prediction on the confirmation that the Seismic Category I structures are founded on bedrock that will compress elastically as the loads are applied. The applicant will confirm these settlement predictions by implementing a benchmark monitoring program.

2.5.4.2.6 Groundwater Condition

FSAR Subsection 2.5.4.6 presents information on the groundwater conditions at the site relative to foundation stability for the safety-related structures.

Groundwater Measurements

FSAR Subsection 2.5.4.6.1 refers to FSAR Subsection 2.5.4.2.2 for a discussion of the field investigation program for groundwater measurements and to FSAR Section 2.4.12, which presents the monitoring wells and piezometers data.

Construction Dewatering and Impact of Dewatering

FSAR Subsection 2.5.4.6.2 states that the applicant will use localized sump pumping systems and foundation bedrock grouting in order to control groundwater seepage through soils and bedrock during the excavation. For the sump pumping system, the applicant will place pumps at low points with water pumped to a location outside the excavation. The applicant will test the pumps and will use the results to evaluate the need for bedrock grouting before excavation. As needed, the applicant will perform foundation bedrock grouting to control groundwater inflow from zones of high permeability within the rock mass during excavation. The applicant will base the thickness of the grouted zone on the need to minimize inflow into the excavation and to resist any uplift pressures at the base of the excavations. The applicant will complete the design of the foundation grouting program during the detailed design phase of the project.

Seepage during Construction

FSAR Subsection 2.5.4.6.3 refers to FSAR Subsection 2.4.12.2.5 for a discussion of the impact of seepage into the excavation and groundwater control measures during construction. The applicant concluded that there is no potential for piping due to seepage in the bedrock, and the seepage will be minimized by excavation support and by a seepage control system. The applicant also confirmed that the potential for settlement on Fermi 3 associated with the dewatering operation is negligible, because it is associated with the Fermi 2 bedrock foundation. Before beginning the construction of Fermi 3, the applicant will develop a monitoring program during the Fermi 3 design stage (Commitment COM 2.5.4-001) to assess groundwater levels and settlement at existing Fermi 2 structures.

Permeability Testing

FSAR Subsection 2.5.4.6.4 refers to FSAR Section 2.4.12 for the results of the packer and slug testing and laboratory hydraulic conductivity testing performed to estimate the hydraulic conductivity of the bedrock and soil.

Impact of Groundwater Conditions on Foundation Stability

FSAR Subsection 2.5.4.6.5 states that the applicant will found the Seismic Category I structures on bedrock or concrete fill and will found other major structures in the power block area either on bedrock or structural fill. The applicant will design the foundations of all Fermi 3 structures to account for a short-term construction with a lowered groundwater level and a long-term operational in-service condition with a rebounded natural groundwater elevation.

2.5.4.2.7 Response of Soil and Rock to Dynamic Loadings

Effect of Past Earthquakes

FSAR Subsection 2.5.4.7.1 refers to FSAR Subsection 2.5.1.1.4.3 for the discussion of the historical earthquake events. The applicant stated that no reports or studies exist on liquefaction and paleoliquefaction in the 40-km (25-mi) radius of the site vicinity.

Seismic Wave Velocity Profiles

FSAR Subsection 2.5.4.7.2 refers to FSAR Subsection 2.5.4.4 for details on the geophysical surveys used for the dynamic characterizations of soils and bedrock. The applicant generated 60 randomized soil profiles for soil amplification analyses for the RB/FB, CB, and FWSC, in order to consider variations and uncertainties in the dynamic soil profiles. The applicant sorted the iterated V_s for each layer of the 60 randomized profiles into rank order (from the lowest to highest value) and determined the 16^{th}, 50^{th}, and 84^{th} percentile V_s profiles at the seismic strains. The applicant indicated that the 16^{th} percentiles of the randomized V_s at the seismic strains represent the mean minus one standard deviation, and the 16^{th} percentiles for the foundation materials below the RB/FB, CB, and FWSC are greater than 300 m/s (1,000 fps).

Dynamic Laboratory Testing

FSAR Subsection 2.5.4.7.3 discusses the RCTS tests performed on glacial till. The applicant conducted four RCTS tests on glacial till using undisturbed samples, after evaluating sample disturbance and quality by reviewing of X-ray radiography and performing a one-dimensional consolidation test. The applicant performed RCTS tests on samples with an acceptable specimen quality designation, which indicates relatively undisturbed samples.

Shear Modulus Reduction and Damping Curves for Rocks

FSAR Subsection 2.5.4.7.4 refers to FSAR Subsection 2.5.2.5 for a discussion of the shear modulus reduction and damping curves for bedrock.

Shear Modulus Reduction and Damping for Soils

FSAR Subsection 2.5.4.7.5 explains the shear modulus reduction and damping on soils even though Fermi 3 does not have a Seismic Category I structure founded on soil. The applicant performed RCTS testing for the glacial till to provide measured shear modulus reduction and damping data. FSAR Figure 2.5.4-226 provides the glacial till shear modulus reduction and damping data.

Shear Modulus Reduction and Damping Curves for Granular Backfill and Fill Concrete

FSAR Subsection 2.5.4.7.6 states that engineered granular backfill is not used to support any Seismic Category I structures. The applicant will use engineered granular backfill to surround the embedded walls of structures or to backfill beneath other structures with foundation levels above bedrock, except Seismic Category II structures, which will be founded on fill concrete. FSAR Subsection 3.7.1.1.4.1.1 discussed related information for fill concrete and engineered granular backfill, respectively.

Ground Motion and Response Spectra

FSAR Subsection 2.5.4.7.7 refers to FSAR Subsections 2.5.2.6 and 3.7.1 for a discussion of the GMRS and FIRS, respectively. The applicant's calculations of the GMRS and FIRS are based on the seismic velocity profiles in FSAR Figures 2.5.4-220 through 2.5.4-225 and on the modulus reduction and damping curve described in FSAR Subsection 2.5.2.6.

2.5.4.2.8 Liquefaction Potential

FSAR Subsection 2.5.4.8 states that the bedrock and concrete fill are not susceptible to liquefaction. The applicant did not consider the upper 4 m (13.1 ft) of the engineered granular backfill for a liquefaction potential, because the maximum historical groundwater level is approximately 4 m (13.1 ft) below the plant grade. The applicant conducted a liquefaction analysis based on a standard penetration test (SPT) that considered the engineered granular backfill. The applicant estimated N_{60} to be 30 blows per foot (bpf) at the ground surface that increased linearly to 60 bpf at a depth of 19.8 m (65 ft). The applicant used this distribution and a groundwater level at 0.61 m (2 ft) below the finished ground level grade to conclude that at all engineered granular backfill depths, N_{60} was greater than 30 bpf for the full depth of the deepest Seismic Category I structures. Therefore, the granular backfill adjacent to all Seismic Category I structures is not susceptible to liquefaction. The applicant stated that liquefaction analyses were not necessary for the existing fill, lacustrine deposits, and glacial till because they will be removed from under and adjacent to all Seismic Category I structures. The applicant will use glacial till and/or engineered backfill as the foundation support under non-Seismic Category I structures that could strike a Seismic Category I structure in case of a seismic event. The applicant stated that because the backfill below Seismic Category II structures from the base of the foundation to the top of bedrock is fill concrete, a liquefaction analysis for soil below Seismic Category II structures is not necessary. The applicant will use glacial till and/or engineered backfill as the foundation support under non-Seismic Category I and II structures that cannot strike a Seismic Category I structure in case of a seismic event. The applicant stated that glacial till is not susceptible to liquefaction because it is classified as lean clay with fine contents greater than 30 percent.

2.5.4.2.9 Earthquake Design Basis

FSAR Subsection 2.5.4.9 states that the top generic bedrock is 129 m (425 ft) below the existing ground surface where the V_s of the bedrock in Salina Group Unit B is greater than 2.8 km/s (9,200 fps). The applicant performed a site response analysis to develop the GMRS, and FSAR Subsection 2.5.2.6 describes the development of the GMRS.

2.5.4.2.10 Static Stability

FSAR Subsection 2.5.4.2.10 evaluates the static stability of safety-related structures. The applicant conducted analyses of the foundation-bearing capacity, settlement, excavation rebound, lateral earth pressures, and hydrostatic pressures.

Bearing Capacity

In FSAR Subsection 2.5.4.2.10.1, the applicant conducted a bearing capacity analysis for the Bass Islands Group and Salina Group Unit F. The two independent methods the applicant used to evaluate the bearing capacity are (1) ultimate bearing capacity using Terzaghi's approach in the UASCE EM 1110-2908 (USACE 1994); and (2) an allowable bearing pressure using the Uniform Building Code (Peck, Hanson, and Thornburn 1974). The applicant used Terzaghi's approach to compute the ultimate bearing capacity for the FWSC:

$$q_{ult} = cN_c + 0.5\gamma' B N_\gamma + \gamma' D N_q \qquad \text{(Equation 1)}$$

Where:

q_{ult} = the ultimate bearing capacity
γ' = effective unit weight
B = width of the foundation
D = depth of foundation below the ground surface
C = cohesion intercept for the bedrock mass

N_c, N_γ, and N_q are the bearing capacity factors dependent on the internal angle of friction, which the applicant assumed to be 52 degrees for the Bass Islands Group and 28 degrees for the Salina Group. For the ultimate bearing capacity of the RB/FB and the CB, the applicant indicated that because the bedrock contained fractures, cohesion was not relied upon to provide a resistance to failure. Thus, the applicant used Terzaghi's equation excluding the first term (cN_c) in Equation 1 above. The applicant used the Uniform Building Code as a second method to calculate the allowable bearing pressure on rock as 20 percent of q_u. In FSAR Table 2.5.4-227, the applicant reported 13,450 kPa (281 ksf) as the ultimate bearing capacity for the RB/FB using Terzaghi's approach and the allowable bearing capacity of 12,400 kPa (259 ksf) using the Uniform Building Code method. The applicant concluded that the allowable bearing capacities calculated using both methods were greater than the maximum static bearing demand required in the ESBWR DCD. The applicant also concluded that the allowable dynamic bearing demand based on Terzaghi's approach is greater than the maximum dynamic bearing demand required in the ESBWR DCD and in the site-specific SSI dynamic bearing demand. Table 2.5.4-3 of this SER provides a comparison of the results for both methods to those listed in the ESBWR DCD.

Table 2.5.4-3 Results of Bearing Capacity Analysis
(Reproduced from Fermi COL FSAR Table 2.5.4-227)

Structure	Terzaghi Approach			Uniform Building Code	Required Maximum Static and Dynamic Bearing Demand from DCD	
	Bearing Capacity					
	Ultimate	Allowable Under Static Loading	Allowable Under Dynamic Loading	Allowable Loading Condition	Static Loading Condition	Dynamic Loading Condition
Reactor Building/Fuel Building	13,450 (281)	4,500 (94)	5,985 (125)	12,400 (259)	699 (14.6)	1,101 (23)
Control Building	42,090 (879)	14,030 (293)	18,720 (391)	17,910 (374)	292 (6.1)	421 (8.8)
Firewater Service Complex	4,596 (96)	1,530 (32)	2,060 (43)	2,060 (43)	165 (3.45)	1,201 (25.1)
*All units are kPa (ksf); Ksf = kip per square-foot; kPa = kilopascal						

Rebound due to the Excavation and Settlement Analysis

FSAR Subsection 2.5.4.10.2 states that because all Seismic Category I structures are founded on bedrock or lean concrete overlying bedrock, the applicant only considered a linear elastic deformation for the settlement analysis in which the parameter of interest is E (elastic modulus). For the settlement analysis, the applicant selected the lower bound E based on the Hoek-Brown criterion (Hoek 2007) for each bedrock unit.

Because the arrangement and loading conditions of the Seismic Category I structures were not symmetrical, the applicant conducted a finite element analysis using the PLAXIS 3D Version 2.1 foundation computer program in order to estimate the settlements of Seismic Category I structures. The first stage of the analysis was used to define the initial states of stress in the ground. The second stage simulated the rebound associated with the load removal when the excavation was performed to foundation elevations or to the top of bedrock. The remaining stages were simulated to estimate settlement after applying the loadings. The applicant stated that there is no long-term or post-construction settlement anticipated at the Fermi 3 site.

FSAR Subsection 2.5.4.2.1.2 explains the E of bedrock selected for rebound and the settlement analysis. Table 2.5.4-4 of this SER presents the settlement analysis results for excavation rebound and the total foundation settlements.

Lateral Earth Pressures

FSAR Subsection 2.5.4.10.3 describes the static and seismic lateral earth pressures applied to the site's below-ground walls. The applicant concluded that the lateral at-rest pressure applied to the RB/FB and the CB does not cause yielding in the buildings. Therefore, the applicant conducted an analysis that assumed the engineered granular backfill was resting on the RB/FB and CB walls from the finish grade to the bottom of the foundations. For this assumption, the applicant used a 35-degree angle of internal friction and a saturated and unsaturated unit weight of 21.2 and 20.4 kilonewtons per cubic-meter (kN/m³) (135 and 130 pcf), respectively.

Table 2.5.4-4 Settlement Results for Excavation Rebound and Total Foundation Settlements

(Reproduced from Fermi COL FSAR Tables 2.5.4-230 and 2.5.4-231)

Building	Northwest Corner	Southwest Corner	Southeast Corner	Northeast Corner	Average of Four Corners	Center or close to Center
Rebound due to Excavation at Foundation Corners and Center, cm (in.)						
Reactor Building/Fuel Building	0.78 (0.31)	0.63 (0.25)	0.78 (0.31)	0.81 (0.32)	-	1.09 (0.43)
Control Building	0.84 (0.33)	0.89 (0.35)	0.74 (0.29)	0.71 (0.28)	-	0.86 (0.34)
Firewater Service Complex	0.66 (0.26)	0.66 (0.26)	0.53 (0.21)	0.53 (0.21)	-	0.61 (0.24)
Total Settlements due to Backfilling and Applied Loads, cm (in.)						
Reactor Building/Fuel Building	1.19 (0.47)	1.06 (0.42)	1.32 (0.52)	1.29 (0.51)	1.22 (0.48)	1.91 (0.75)
Control Building	1.29 (0.51)	1.42 (0.56)	1.04 (0.41)	0.99 (0.39)	1.19 (0.47)	1.19 (0.47)
Firewater Service Complex	0.41 (0.16)	0.46 (0.18)	0.30 (0.12)	0.29 (0.11)	0.35 (0.14)	0.38 (0.15)
cm= centimeter; in. = inch						

Static Lateral Earth Pressures

The applicant used the following equation to calculate the at-rest static lateral earth pressure:

$$\sigma_h = K_0\sigma'_0 + u \qquad \text{(Equation 2)}$$

Where:

K_0 = coefficient of at-rest earth pressure = 1-sin φ
φ = angle of internal friction
u = pore water pressure
σ'_0 = effective vertical subsurface stress

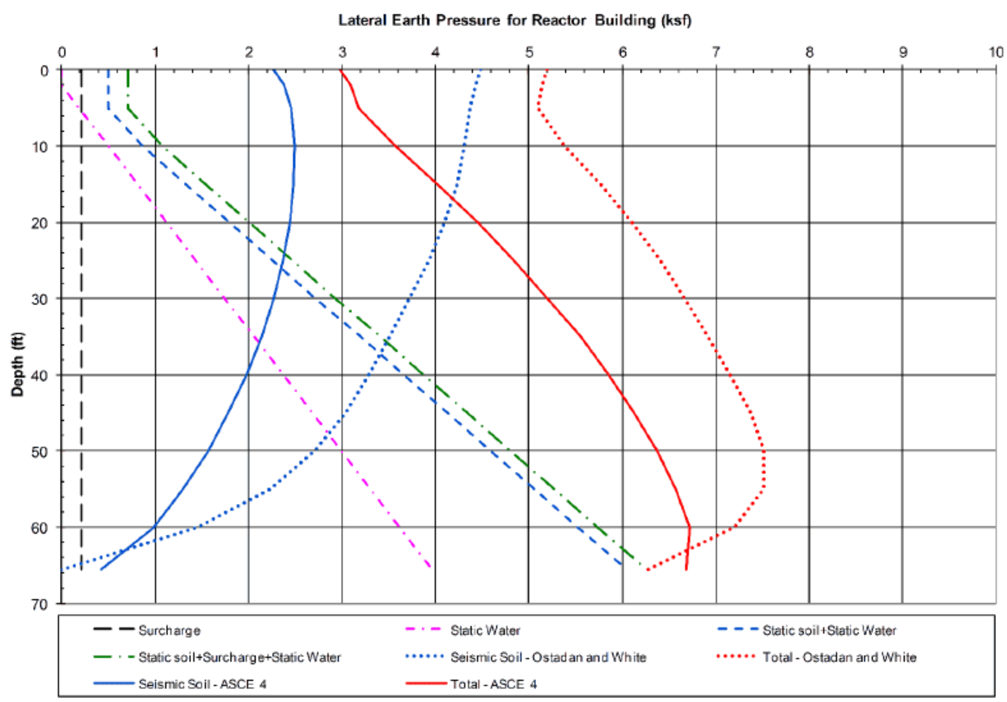
Dynamic Lateral Earth Pressures

The applicant used Ostadan and White, and ASCE 4 methodologies to compute seismic lateral earth pressure on RB/FB and CB embedded walls. For the Ostadan and White method the applicant used a peak response horizontal ground acceleration of approximately 0.41g for both the RB/FB and CB. For the ASCE 4 method, the applicant used a peak ground acceleration of 0.24g at the finished ground level grade to compute seismic lateral earth pressure on RB/FB and CB embedded walls.

The applicant stated that for both methods, the engineered granular backfill is considered to extend the full depth of the RB/FB and CB; and that below the top of the Bass Islands Group bedrock the excavations will be backfilled with fill concrete. The applicant stated that once cured, the fill concrete will not apply lateral pressure to the RB/FB or CB.

Results of Lateral Earth Pressures Analyses

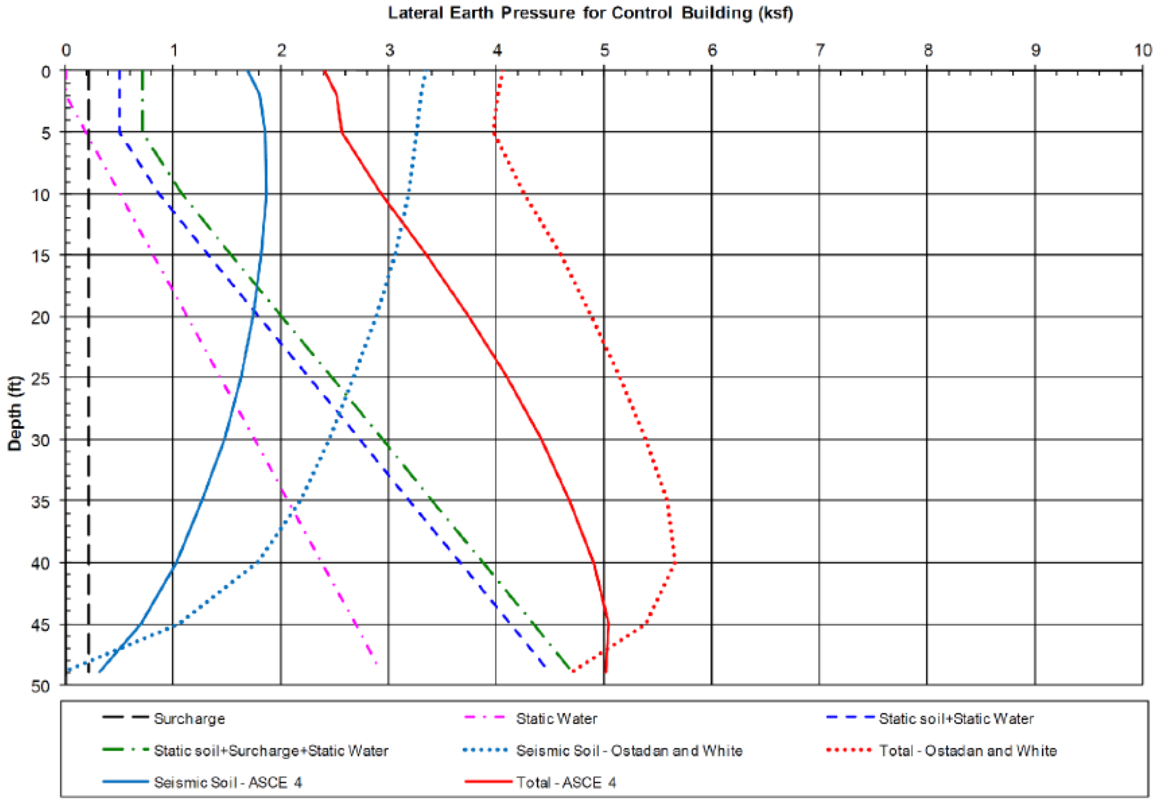
Figures 2.5.4-4 and 2.5.4-5 of this SER present the results of the static soil and seismic soil lateral earth pressures for the RB/FB and CB. The applicant stated that the results of the Ostadan and White method are generally greater than the ASCE 4-98 method, because a higher acceleration is used with the Ostadan and White method.



Notes:

1. Lateral load of 500 psf due to compaction is included in the static soil pressure.
2. Total = Static Soil + Static Water + Surcharge + Seismic Soil.

Figure 2.5.4-4 Lateral Earth Pressures on Reactor Building Walls
(Reproduced from Fermi 3 COL FSAR Figure 2.5.4-229)



Notes:

1. Lateral load of 500 psf due to compaction is included in the static soil pressure.
2. Total = Static Soil + Static Water + Surcharge + Seismic Soil.

SER Figure 2.5.4-5 Lateral Earth Pressures on Control Building Walls
(Reproduced from Fermi 3 COL FSAR Figure 2.5.4-230**)**

2.5.4.2.11 Design Criteria

FSAR Subsection 2.5.4.11 refers to ESBWR DCD Table 2.0-1 for a description of standard site parameters such as the allowable static and dynamic bearing capacities, liquefaction potential, angle of internal friction, maximum settlement values, and V_s. FSAR Subsection 2.5.4.10.1 addresses the criteria for minimum static and dynamic bearing capacities. The applicant concluded that the factor of safety (FS) for the static bearing capacity is at least 3, and it is at least 2.5 for the dynamic bearing capacity. FSAR Subsection 2.5.4.7.2 presents the minimum V_s of greater than 300 m/s (1,000 fps) for the supporting foundation material associated with seismic strains for lower bound soil properties at minus one sigma from the mean. The applicant indicated that the fill concrete surrounding the RB/FB and the CB embedded walls below the top of the bedrock and below the FSWC meets the DCD V_s requirements. The applicant stated that based on the SSI analysis, the DCD minimum V_s requirements are not required for the backfill above the top of the Bass Island Group bedrock surrounding Seismic Category I embedded walls. The applicant will place fill concrete as the supporting material below the FWSC, with deep shear keys extending into the fill concrete. The applicant's calculations neglected the engineered granular backfill surrounding the basemat and encountered no sliding issues for the FWSC. The applicant concluded that the DCD criteria for the engineered granular backfill surrounding the FWSC are not required.

FSAR Subsection 2.5.4.10 presents the design criteria for the static stability analyses. FSAR Subsection 2.5.4.8 discusses the liquefaction potential of soils. The applicant concluded that there are no liquefiable soils under and adjacent to all Seismic Category I structures. FSAR Subsection 2.5.4.10.2 discusses the design criteria for the foundation settlements. The applicant concluded that the calculated foundation settlements were less than the maximum specified in the ESBWR DCD.

2.5.4.2.12 Techniques to Improve Subsurface Conditions

Based on the stability analysis in FSAR Subsection 2.5.4.10, the applicant concluded that no subsurface improvement is needed. In FSAR Subsection 2.5.4.12, the applicant stated that the exposed foundation bedrock in the RB/FB and the CB will be examined by a qualified geologist to ensure that no excessive natural fracturing or blasting back-break exists and areas with open fractures will be filled with concrete backfill. The applicant will remove and replace all of the soils from below the foundation to the top of the bedrock with fill concrete for the FWSC and the Seismic Category II structures.

2.5.4.3 *Regulatory Basis*

The relevant requirements of the Commission regulations for the stability of subsurface materials and foundations, and the associated acceptance criteria, are in Section 2.5.4 of NUREG–0800. The applicable regulatory requirements are as follows:

- 10 CFR Part 50, Appendix A GDC 2, "Design bases for protection against natural phenomena," relates to a consideration of the most severe natural phenomena historically reported for the site and surrounding area with a sufficient margin for the limited accuracy, quantity, and period of time when the historical data were accumulated.

- 10 CFR Part 50 Appendix S, "Earthquake Engineering Criteria for Nuclear Power Plants," applies to the design of nuclear power plant structures, systems, and components important to safety to withstand the effects of earthquakes.

- 10 CFR 100.23 provides the nature of the investigations required to obtain the geologic and seismic data necessary to determine site suitability and to identify geologic and seismic factors required to be taken into account in the siting and design of nuclear power plants.

The related acceptance criteria from Section 2.5.4 of NUREG–0800 are as follows:

- Geologic Features: To meet the requirements of 10 CFR Parts 50 and 100, the section defining geologic features is acceptable if the discussions, maps, and profiles of the site stratigraphy, lithology, structural geology, geologic history, and engineering geology are complete and are supported by site investigations sufficiently detailed to obtain an unambiguous representation of the geology.

- Properties of Subsurface Materials: To meet the requirements of 10 CFR Parts 50 and 100, the description of properties of underlying materials is considered acceptable if state-of-the-art methods are used to determine the static and dynamic engineering properties of all foundation soils and rocks in the site area.

- Foundation Interfaces: To meet the requirements of 10 CFR Parts 50 and 100, the discussion of the relationship of foundations and underlying materials is acceptable if it includes (1) a plot plan or plans showing the locations of all site explorations such as borings, trenches, seismic lines, piezometers, geologic profiles, and excavations with the locations of the safety-related facilities superimposed thereon; (2) profiles illustrating the detailed relationship of the foundations of all Seismic Category I and other safety-related facilities to the subsurface materials; (3) logs of core borings and test pits; and (4) logs and maps of exploratory trenches in the COL application.

- Geophysical Surveys: To meet the requirements of 10 CFR 100.23, the presentation of the dynamic characteristics of soil or rock is acceptable if geophysical investigations are performed at the site and are presented in detail.

- Excavation and Backfill: To meet the requirements of 10 CFR Part 50, the presentation of the data concerning excavation, backfill, and earthwork analyses is acceptable if (1) they identify the sources and quantities of backfill and borrow and show that they were adequately investigated by borings, pits, and laboratory property and strength testing (dynamic and static) and the data are included, interpreted, and summarized; (2) they clearly show the extent (horizontally and vertically) of all Category I excavations, fills, and slopes on plot plans and profiles; (3) they justify compaction specifications and embankment and foundation designs by field and laboratory tests and analyses to ensure stability and reliable performance; (4) they incorporate the impact of compaction methods into the structural design of the plant facilities; (5) they discuss the quality control methods and describe and reference the quality assurance program; and (6) they describe and reference the control of groundwater during excavation to preclude the degradation of foundation materials and properties.

- Groundwater Conditions: To meet the requirements of 10 CFR Parts 50 and 100, the analysis of groundwater conditions is acceptable if the information in this subsection or cross-referenced to the appropriate subsections in SRP Section 2.4 of the SAR includes (1) a discussion of critical cases of groundwater conditions relative to the foundation settlement and stability of the safety-related facilities of the nuclear power plant; (2) plans for dewatering during construction and the impact of the dewatering on temporary and permanent structures; (3) an analysis and interpretation of seepage and potential piping conditions during construction; (4) records of field and laboratory permeability tests as well as dewatering-induced settlements; and (5) a history of groundwater fluctuations determined by the periodic monitoring of 16 local wells and piezometers.

- Response of Soil and Rock to Dynamic Loading: To meet the requirements of 10 CFR Parts 50 and 100, descriptions of the soil and rock responses to dynamic loading are acceptable if (1) an investigation is conducted and discussed to determine the effects of prior earthquakes on soils and rocks in the vicinity of the site; (2) there are field seismic surveys (surface refraction and reflection and in-hole and cross-hole seismic explorations) and the data are presented and interpreted to develop bounding P and S wave-velocity profiles; (3) dynamic tests are performed in the laboratory on undisturbed samples of the foundation soils and rocks and they are sufficient to develop strain-dependent modulus reductions and hysteretic damping properties of the soils and the results are included.

- Liquefaction Potential: To meet the requirements of 10 CFR Parts 50 and 100, the foundation materials at the site adjacent to and under Category I structures and facilities are saturated soils; the water table is above the bedrock; and a required analysis of the liquefaction potential at the site is conducted.

- Static Stability: To meet the requirements of 10 CFR Parts 50 and 100, the discussions of static analyses are acceptable if the stability of all safety-related facilities were analyzed from a static stability standpoint that included bearing capacity; rebound; settlement; differential settlements under dead loads of fills and plant facilities; and lateral loading conditions.

- Design Criteria: To meet the requirements of 10 CFR Part 50, the discussion of the criteria and the design methods is acceptable if the discussion describes the criteria used for the design; the design methods; and the factors of safety obtained in the design analyses and presents a list of references.

- Techniques to Improve Subsurface Conditions: To meet the requirements of 10 CFR Part 50, the discussion of techniques to improve subsurface conditions is acceptable if it describes plans; summaries of specifications; and methods of quality control for all techniques used to improve foundation conditions (such as grouting, vibroflotation, dental work, rock bolting, or anchors).

In addition, geologic characteristics should be consistent with the appropriate sections in RG 1.27 Revision 2, “Ultimate Heat Sink for Nuclear Power Plants”; RG 1.28 Revision 3, “Quality Assurance Program Requirements (Design and Construction)”; RG 1.132; RG 1.138; RG 1.198; and RG 1.206.

2.5.4.4 *Technical Evaluation*

NRC staff reviewed Section 2.5.4 of the Fermi 3 COL FSAR, Revision 5, related to the stability of subsurface materials and foundations. The staff reviewed Fermi 3 COL FSAR Section 2.5.4 to determine whether the applicant has complied with the applicable regulations and has conducted its investigations at an appropriate level of detail, in accordance with RG 1.132 as described below:

COL Item

- EF3 COL 2.0-29-A Stability of Subsurface Materials and Foundations

NRC staff reviewed COL Item EF3 COL 2.0-29-A included in Fermi 3 FSAR Section 2.5.4. This COL item addresses site-specific information that includes (1) localized liquefaction potential under other than Seismic Category I structures, and (2) settlement and differential settlements at the site. The NRC staff’s evaluation of COL Item EF3 COL 2.0-29-A is presented below.

2.5.4.4.1 Geologic Features

FSAR Subsection 2.5.4.1 refers to FSAR Section 2.5.1 for a complete description of the regional and site geology. Subsection 2.5.1.4 of this SER presents the staff's evaluation of the regional and site geology.

2.5.4.4.2 Properties of Subsurface Material

FSAR Subsection 2.5.4.2 describes the static and dynamic engineering properties of the soil and rock strata underlying the Fermi 3 site, as well as the methods the applicant used to determine the site engineering properties including field investigations and laboratory testing. The staff conducted a geology/seismology/geotechnical site audit from November 3, 2009, to November 5, 2009 (ML14112A212). During the audit, the geotechnical staff looked at core samples that included the units of the Bass Islands Group, Salina Group Unit F, and Salinas Group Unit E, as well as oolitic dolomite samples to confirm the FSAR's descriptions. The staff specifically checked full core samples from RB-C8 and some core samples from TB-C5, RB-C4, and CB-C2. The staff also discussed specific details on shear wave velocity determinations, settlement calculations, slope stability analyses, lean concrete backfill, and the process for excavation to reach the Bass Islands foundation layer. The staff reviewed sample calculations of complete settlement and earth pressure against embedded walls (static and dynamic) and the engineering properties used to perform settlement analysis and dynamic and static earth pressure analysis. The staff also reviewed shear wave velocity data from downhole and SASW investigations.

During these reviews, the staff issued several RAIs addressing specific technical issues related to the Fermi 3 site investigations. The staff's evaluations of the applicant's responses to these RAIs are discussed below. The staff also prepared a number of editorial RAIs and clarification RAIs that the staff does not discuss in the technical evaluation. Due to the applicant's FSAR revisions several RAIs are no longer applicable and are not discussed in further detail in this technical evaluation.

Engineering Properties of Subsurface Materials

FSAR Subsection 2.5.4.2.1 discusses the engineering properties of soils and rocks at the Fermi 3 site based on 68 borings that the applicant performed. FSAR Figures 2.5.1-235 and 2.5.1-236 show the locations of the borings drilled for the COL application. The boring logs are in FSAR Appendix 2.5DD. The applicant stated that fill, lacustrine deposits, and glacial till comprise the site overburden deposits, all of which the applicant will fully excavate beneath and adjacent to all Seismic Category I structures. If needed, the applicant can process the fill material to produce gradation suitable for use as engineered granular backfill surrounding Seismic Category I structures.

Engineering Properties of Soils

The staff reviewed FSAR Subsection 2.5.4.2.1.1 related to the engineering properties of soils at the Fermi 3 site. The staff issued RAIs 02.05.04-1, 02.05.04-14a, 02.05.04-17, and 02.05.04-28b related to the general gradation constraints needed for processing the fill that the applicant may reuse for engineered granular backfill. These RAIs also address the expected static and dynamic properties of the as-specified compacted borrow material including compaction ratio, density, shear strength, and V_s. The staff asked the applicant to justify whether the static and dynamic properties of the processed fill would affect the results of the safety analysis in FSAR Section 2.5.4.

In the responses to RAIs 02.05.04-1, 02.05.04-14a, and 02.05.04-17 dated January 11, 2010 (ML100130382); and RAI 02.05.04-28b dated February 15, 2010 (ML100540502); the applicant stated that it will follow the DCD requirements to performed test to verify the gravel backfill and will establish gradation constraints for the backfill. The applicant indicated that the rebound, settlement, and bearing capacity results in FSAR Subsection 2.5.4.10 are not affected by the engineered granular backfill material properties because the Fermi 3 Seismic Category I structures will be directly founded on the Bass Islands Group or on the fill concrete overlying the Bass Islands Group. The applicant stated that the change in the angle of internal friction for the engineered granular backfill affects the at-rest static lateral earth pressure. Also, the applicant mentioned that the change in the V_s affects the soil column frequency and the resulting horizontal ground acceleration. The applicant specified that the peak horizontal ground acceleration based on the FIRS for the RB/FB) and the CB is approximately 0.5 g.

The staff reviewed the responses to RAIs 02.05.04-1, 02.05.04-14a, 02.05.04-17, and 02.05.04-28b. The staff noted that the applicant plans to crush the excavated fill and bedrock to a well-graded, angular/sub-angular gravel backfill that will meet the requirements specified in ESBWR DCD Table 2.0-1. The staff also noted that within confined areas or close to the foundation walls, the applicant plans to use smaller compactors to prevent excessive lateral pressures against the walls due to the stress caused by heavy compactors. As a result of the RAIs, the applicant revised the seismic lateral earth pressure calculation by selecting the peak horizontal ground acceleration of 0.5 g based on the site-specific FIRS, in order to bound the maximum seismic pressures that can develop at the Fermi 3 site. The applicant selected the 0.5 g value instead of the values based on the calculated soil column frequencies, which are 0.31 g for the CB and 0.19 g for the RB/FB. The staff confirmed that this adjustment leads to conservative estimates of seismic lateral soil pressures, and Fermi 3 FSAR Revision 5 reflects the adjustment. In addition, the staff verified the applicant's seismic lateral earth pressure calculations. The staff concluded that the applicant's method and procedures used for the calculations are appropriate, because they are based on the current knowledge of computing dynamic lateral soil pressures. Finally, the staff compared the static and seismic lateral soil pressures that the applicant computed to the results in Appendix 3G to Chapter 3 of the ESBWR DCD, Tier 2. The staff concurred that both the static and seismic evaluations of soil pressures are less than the lateral earth pressures required in the ESBWR DCD. The applicant demonstrated that it can achieve the DCD requirements related to backfill and static and seismic lateral pressures by using the appropriate engineered granular backfill. RAI 02.05.04-1, RAI 02.05.04-14a, RAI 02.05.04-17, and RAI 02.05.04-28b are therefore resolved and closed.

Engineering Properties of Bedrock

FSAR Subsection 2.5.4.2.1.2 describes the two primary bedrock units beneath the Fermi 3 site: the Bass Islands Group and Salina Group Units F, E, C, and B. The applicant characterized the parameter values in terms of upper and lower bound values or minimum, maximum, standard deviation, mean, and median values. These parameters are specified in terms of a single number associated with the entire bedrock unit or for each borehole. In RAI 02.05.04-3a, the staff asked the applicant to explain why it is appropriate to provide a single value of each parameter for the entire bedrock group instead of providing an inferred spatial variation of these parameter values.

In the response to RAI 02.05.04-3a dated December 23, 2009 (ML100040548), the applicant stated that FSAR Figures 2.5.4-220 through 2.5.4-223 show that the V_s and V_p are relatively uniform within each bedrock unit. The staff reviewed the response to RAI 02.05.04-3a and FSAR Figures 2.5.4-220 through 2.5.4-223. The staff compared the measured V_s and V_p from P-S suspension logging and downhole seismic tests at different locations across the site. The staff noted that the relatively consistent V_s and V_p indicate the uniformity of each bedrock unit across the site. Based on this consistency, the staff concurred with the applicant's conclusion that it is appropriate to use a single value of each parameter for the entire bedrock group. Therefore, RAI 02.05.04-3a is resolved and closed.

The applicant estimated the strength and deformation characteristics of the bedrock units using the Hoek-Brown criterion (Hoek 2007). The applicant converted the Hoek-Brown criterion into the equivalent Mohr-Coulomb values. In RAI 02.05.04-3b, the staff asked the applicant to justify the use of the Hoek-Brown criterion and to describe each bedrock unit as applied to specify the Hoek-Brown parameters. The staff also asked the applicant to specify the relationship between the residual friction angle values associated with discontinuities in the Bass Islands Group and the parameters in the Hoek-Brown criterion for that material. In addition, the staff asked the applicant to explain how the effects of oolitic dolomite are reflected in the Hoek-Brown criterion for the Bass Islands Group. In RAI 02.05.04-3c, the staff asked the applicant to provide the effective confining pressure ranges and the rationale for the selected effective confining pressure range used to convert the Hoek-Brown criterion to the Mohr-Coulomb values.

In the response to RAI 02.05.04-3b dated December 23, 2009 (ML100040548), the applicant indicated that the Hoek-Brown criterion is based on an assessment of interlocking rock blocks and on the conditions of the surfaces between these blocks. The applicant mentioned that the shear strength along the discontinuities is not one of the input parameters used in the Hoek-Brown criterion methodology. The applicant presented the compressive strength and the elastic modulus of the oolitic dolomite and stated that these parameters are comparable with the average strength and elastic modulus of the remainder of the Bass Islands Group. The response to RAI 02.05.04-3c (ML100040548) included a table with the effective confining pressure ranges used to convert the Hoek-Brown criterion to the Mohr-Coulomb parameters. The applicant discussed the rationale for determining the upper limit of the confining stress (σ'_{3max}) for slopes with the selected range of effective confining pressures that adhered to the guidelines of the Hoek-Brown criterion.

The staff noted that the applicant's response to RAI 02.05.04-3 applies an equation of σ'_{3max}, and an equation developed for slopes to the evaluation of foundation behavior beneath key structures. In RAI 02.05.04-30, the staff asked the applicant to explain why the use of the σ'_{3max} equation provides an adequate representation of the Hoek-Brown criterion for evaluating the foundation behavior beneath key structures. The applicant's response to RAI 02.05.04-30 dated August 6, 2010 (ML102210351), is based on Hoek's (2007) two options for establishing $\sigma'_{3\mathrm{max}}$ that are a slope condition or a tunnel condition. The applicant stated that foundation of the Category I structures will be on exposed bedrock at the bottom of the excavation, thus providing a similar stress regime in the bedrock to that of the slopes exposed at the ground surface rather than a tunnel bored through the bedrock.

The staff reviewed the responses to RAIs 02.05.04-3b, 02.05.04-3c, and 02.05.04-30 and the related sections of Hoek (2007). The staff verified that the applicant has provided the appropriate information related to the Hoek-Brown criterion input parameters that were used to estimate rock mass strength for each bedrock unit. The staff verified that the applicant has based the input parameters for q_u and E on laboratory tests in accordance with ASTM D7012–

07, “Standard Test Methods for Compressive Strength and Elastic Moduli of Intact Rock Core Specimens under Varying States of Stress and Temperature.” The applicant obtained the input parameters of material index (m_i) and the geological strength index (GSI) based on bedrock descriptions and classifications from exploratory borings. The applicant conservatively selected the input parameter of the disturbance factor (D) based on the degree of disturbance from blast damage and stress relaxation. The staff determined that the applicant has appropriately selected these input parameters based on the laboratory tests and appropriate interpretations of the Hoek-Brown criterion.

As for the effects of oolitic dolomite reflected in the Hoek-Brown criterion for the Bass Islands Group, the staff noted that the compressive strength from the oolitic dolomite samples varies from 71 to 99 MPa (1,490 to 2,070 ksf), with an average of 82 MPa (1,707 ksf), and that the elastic modulus varies from 38,600 to 51,000 MPa (806,400 to 1,065,600 ksf) with an average of 46,660 MPa (974,400 ksf). Because the test results from the oolitic dolomite samples are analogous to the overall average compressive strength of 79 MPa (1,650 ksf) and to the overall elastic modulus of 40,330 MPa (842,400 ksf) for the Bass Islands Group, the staff found that the compressive strength and elastic modulus for the oolitic dolomite are integrated into the overall strength and modulus for the Bass Islands Group. The staff also noted that the physical descriptions of the oolitic dolomite are similar to the descriptions of the dolomite within the Bass Islands Group, as shown in the Fermi 3 boring logs. Based on the above discussion, the staff concluded that the effects of the oolitic dolomite were appropriately considered in the Hoek-Brown criterion for the Bass Islands Group.

Furthermore, the staff noted that because the geotechnical bearing capacity is calculated in terms of the Mohr-Coulomb failure criterion, it is necessary to determine equivalent angles of friction and cohesive strengths for each rock mass and stress range by fitting an average linear relationship to the curve generated by the Hoek-Brown criterion. The staff concluded that it is appropriate to follow the guidelines specified in Hoek (2007) to estimate the tensile strength of the rock mass σ_t and the upper limit of the confining stress σ'_{3max}. In addition, the staff agreed with the applicant’s determination that using σ'_{3max} based on the equation developed for slopes is appropriate, because the Category I structures are founded on exposed bedrock at the bottom of the excavation. Therefore, the stress in the bedrock is similar to that of slopes exposed at the ground surface rather than a tunnel bored through the bedrock. Based on the evaluation of the applicant’s responses RAIs 02.05.04-3b, 02.05.04-3c, and 02.05.04-30 are resolved and closed.

In FSAR Subsection 2.5.4.2.1.2.1, the applicant conducted 12 rock direct shear tests along sample discontinuities in the Bass Islands Group to obtain the residual friction angle along the discontinuities. The applicant’s test resulted in a friction angle that ranges from 33 to 74 degrees, with a mean of 52 degrees. In RAI 02.05.04-2, the staff asked the applicant to provide information on the prevalence of these discontinuities, and whether they involve any preferential directions. In addition, the staff asked the applicant to explain the extent to which these discontinuities, which are provided by the twelve rock direct shear tests, are representative of discontinuities observed within the Bass Islands Group.

In the response to RAI 02.05.04-2 dated December 23, 2009 (ML100040548), the applicant provided figures that show the 12 pairs of photos of the core/discontinuity before laboratory testing along with the OTV log corresponding to the sample log. The applicant indicated that the observed orientations of discontinuities in the Bass Islands Group vary from horizontal to vertical, with near horizontal and near vertical joints dominating. However, the applicant further stated that the orientation of the discontinuities tested was nearly horizontal, except for the orientation of samples CB-C4 at 17.3 m (57.0 ft) and RB-C3 at 14.3 m (46.9 ft), which were at inclined angles. Finally, the applicant concluded that the results for the discontinuities tested were representative of the discontinuities observed within the Bass Islands Group. In RAI 02.05.04-29, the staff asked the applicant to justify why the test results from mostly horizontal discontinuities (one dominant orientation) can be representative of vertical discontinuities (another dominant orientation) and to provide the basis for this conclusion. In the response to RAI 02.05.04-29 dated August 6, 2010 (ML102210351), the applicant explained that because of the higher potential for weaker material and the lower roughness of the horizontal fractures, the strength along the horizontal fractures will be lower. In addition, the applicant stated that the friction angle measured on core samples is in agreement with the friction angle estimated for the bedrock mass using the Hoek-Brown criterion. The applicant concluded that this agreement with the friction angle indicates that, for the bedrock mass, the testing was representative of fractures at all orientations.

The staff reviewed the responses to RAI 02.05.04-2 and RAI 02.05.04-29, as well as related figures and references. The staff noted that the Bass Islands Group dolomite is an undeformed sedimentary bedrock at the site. Therefore, horizontal to near horizontal fractures formed along depositional features in sedimentary bedrock are more likely than vertical fractures are to be present. Based on the fact that most direct shear tested samples had horizontal or near horizontal fractures, the staff concluded that the results of the applicant's tests represent strength values for the horizontal fractures. The staff also noted that horizontal fractures along depositional features tend to have a more consistent orientation and less roughness, while vertical fractures break across depositional features that which most likely result in a rougher fracture surface. The staff further concluded that the rougher surfaces or irregularities produce interlocks between discontinuity surfaces, which can contribute significantly to their shear strength (Patton 1966, Barton 1973). Therefore, the staff concluded that it is reasonable to deem that the test results from samples with horizontal or near horizontal fractures are representative of the lower bound strength for the vertical fractures, because the waviness and roughness on a natural joint surface increase the shear strength. The staff further concluded that the shear strength from mostly horizontal discontinuities can be conservatively representative of vertical discontinuities. Therefore, RAI 02.05.04-2 and RAI 02.05.04-29 are resolved and closed.

In FSAR Subsections 2.5.4.2.1.2.1 and 2.5.4.2.1.2.2, the applicant indicated that the RQD of the Bass Island Group and Salina Group Unit F are low with average RQD values of 54 percent and 13 percent, respectively, indicating that in situ rock masses in these layers are highly fractured. Furthermore, in these FSAR subsections, the applicant calculated Poisson's ratios based on the mean V_p and V_s varying from 0.33 to 0.34 for the Bass Islands Group and from 0.39 to 0.40 for Salina Group Unit F. Consequently, in RAI 02.05.04-41, the staff asked the applicant to justify whether these ranges of Poisson's ratio are appropriate for such highly fractured rocks.

In the response to RAI 02.05.04-41 dated March 29, 2012 (ML12093A004), the applicant discussed the approach of the Poisson's ratio calculation for the in situ shear and compression wave velocities. The applicant compared the calculated Poisson's ratios with similar materials from literature sources, demonstrating the calculated Poisson's ratios are in the range of values provided in literature sources for both the Bass Islands Group bedrock and the Salina Group Unit F bedrock. The applicant also performed a literature search to evaluate whether the fracturing of bedrock typically results in an increase or decrease in Poisson's ratio, indicating the lack of a direct relationship between the extent of bedrock fracturing and Poisson's ratio. The applicant concluded that the Poisson's ratios calculated on the basis of measured shear and compression wave velocities are considered the most appropriate for the Fermi 3 site.

The staff reviewed the responses to RAI 02.05.04-41 and the applicant's cited references. The applicant referred to Jaeger, J.C. and Cook, N. G. W., "Fundamentals of Rock Mechanics" (1979) to indicate that bedrock fracturing can either increase or decrease Poisson's ratio based on orientation and aperture of the fracturing. Because the in situ measurements of shear and compression wave velocities represent the more general condition of rock mass, the staff concluded that the Poisson's ratios calculated using the in situ measured shear and compression wave velocities are considered appropriate for the Bass Islands Group and Salina Group Unit F bedrock. Therefore, RAI 02.05.04-41 is resolved and closed.

NRC Staff's Conclusions Regarding the Engineering Properties of Subsurface Materials

Based on the staff's review of the information in FSAR Subsection 2.5.4.2.1 and the applicant's responses to RAIs associated with the engineering properties of subsurface materials discussed above, the staff concludes that the applicant has adequately characterized the static and dynamic engineering properties of the rock layers underlying the Fermi 3 site by appropriately following the guidance in RG 1.132 Revision 2, for satisfying the applicable requirements in 10 CFR Part 50 and 10 CFR Part 100. These layers include the Bass Islands Group and Salina Group Units F, E, C and B, which are the foundation-bearing layers for the nuclear island.

Field Investigations

The applicant employed a hydrogeological phase investigation and a geotechnical phase investigation to complete the field analyses. The hydrogeological investigation consisted of piezometers and monitoring wells installation, packer and slug testing, downhole geophysics, and sampling and groundwater testing. The applicant performed OTV logging to gather information on the bedrock where the rock core was not recovered. The applicant used the results from the downhole logging to correlate the bedrock geology across the site.

Hydrogeological Investigation Program

The staff reviewed FSAR Subsection 2.5.4.2.2.1 related to the hydrogeological investigation program at the Fermi 3 site. In RAI 02.05.04-4, the staff asked the applicant to clarify whether the results of the downhole logging provided additional information as to where the applicant did not obtain good core recovery.

In the response to RAI 02.05.04-4 dated January 11, 2010 (ML100130382), the applicant summarized how the results from the downhole logging were used to provide additional information in regions where there was not good core recovery. The applicant observed a poor recovery in some intervals of the Bass Islands Group, throughout most of the Salina Group Unit F, and in some intervals of the Salina Group Unit E. FSAR Figures 2.5.4-209 through 2.5.4-212 indicate that the poor RQD in the Bass Islands Group was from the fractured nature of the bedrock unit. The applicant also referenced these figures to point out a good correlation between the geologic feature and the variability of the measured compression and shear wave velocities. The applicant used the results of the OTV, the natural gamma, and the caliper logging to provide information regarding core loss; voids; cavities and tool drops that occurred in the Bass Islands Group and Salina Group Units F and E. The applicant also used the downhole logging to identify sediments in Salina Group Units E and F. The applicant confirmed the existence of joints and fractured zones using results from the OTV logging. Finally, the applicant indicated a correlation between the variability of the V_p and V_s with the natural gamma value in the selected borings within the Salina Group Unit F.

The staff reviewed the response to RAI 02.05.04-4. The staff also reviewed the OTV images shown on FSAR Figures 2.5.4-209 through 2.5.4-212, and the results from the OTV, natural gamma and caliper logging described in FSAR Section 2.5.1.2.3.1. The staffed agreed that the poor RQD was from the fractured nature; core loss was due to either soft weathered rock that washed away during drilling, or when harder layers became stuck in the core barrel and ground the softer or fractured rock; and cavities or voids were limited to a depth of 23.8 m (78 ft) below ground surface. The cavities or voids encountered were narrow, generally 3 cm (0.1 ft) along fractures. Based on the applicant's additional information related to the downhole logging, the staff concludes that the results from the OTV, the natural gamma, and the 3-arm caliper provide an acceptable alternative for understanding the bedrock geology where the applicant had not obtained good core recovery. Therefore, RAI 02.05.04-4 is resolved and closed.

FSAR Subsection 2.5.4.2.2.1.7 presents a list of the chemical tests for groundwater and surface water performed to establish baseline conditions at the site, but the subsection does not include the test results or discussions. Because the foundation and/or sub-foundation concrete may be exposed to the groundwater, the staff asked the applicant in RAI 02.05.04-5 to address whether or not the chemicals in groundwater are aggressive and to provide a discussion of these results.

In the response to RAI 02.05.04-5 dated December 23, 2009 (ML100040548), the applicant provided chemical test results for groundwater sulfate and chloride concentrations and indicated, based on ACI 349, that all sample results for sulfate concentrations from the monitoring wells fell into the categories of "moderate" and "severe" sulfate exposure for concrete. Therefore, in RAI 02.05.04-31, the staff asked the applicant to evaluate the potential aging effects on concrete fill resulting from groundwater conditions, to capture this evaluation in the FSAR, and to provide groundwater pH values because concrete is highly alkaline and strong acid degrades it. In addition, the staff requested the applicant to update the FSAR to ensure that the ACI 349 requirements will be followed—including cement type; the water-cement ratio; and the minimum compressive strength for concretes exposed to sulfate-containing solutions. In the response to RAI 02.05.04-31 dated August 6, 2010 (ML102210351), the applicant indicated that the pH of the groundwater was monitored during purging until the pH values stabilized, and the applicant had presented the last pH values measured during purging from the monitoring wells. The applicant concluded that the concrete will not be negatively impacted, because the overburden groundwater and the Bass Islands aquifer groundwater had a measured pH greater than 7.0, thus not acidic.

Regarding the potential aging effects, the applicant indicated that the only constituent of concern for concrete is the sulfate, and the concrete will not experience adverse aging effects from the high sulfates in the groundwater with the use of the correct cement—a well-designed concrete mix—and good construction control. The applicant stated that ACI 349 requirements for concrete exposed to solutions containing sulfate will be implemented during the detailed design phase.

The staff reviewed the responses to RAI 02.05.04-5 and RAI 02.05.04-31. The staff noted that based on the definition in ACI 349, all of the sampled results for sulfate concentrations from the monitoring wells fell into the categories of "moderate" and "severe" sulfate exposure for concrete. The staff also noted that the applicant will implement the ACI 349 requirements for concrete exposed to solutions containing sulfate by using a low water-to-cement ratio, an adequate cement content, a plasticizer or super plasticizer, a silica fume (fly ash), and an air entrainment. The staff found the applicant's response acceptable and verified that the applicant had revised the FSAR to reflect that the fill concrete will meet the ACI 349 requirements for concrete exposed to solutions containing sulfate. Therefore, RAIs 02.05.04-5 and 02.05.04-31 are resolved and closed.

In RAI 02.05.04-40, the staff asked the applicant to provide the inspections, tests, and analyses and acceptance criteria (ITAAC) to be used to ensure that the fill concrete placed underneath any Category I structure to a thickness greater than 1.5 m (5 ft) meets the design, construction, and testing of the applicable ACI standards.

In the response to RAI 02.05.04-40 dated February 16, 2012 (ML12052A031), the applicant added the associated ITAAC to indicate that the mean 28-day compressive strength of the fill concrete will be equal to or greater than 31 MPa (4,500psi).

The staff reviewed the response to RAI 02.05.04-40, as well as FSAR Subsection 2.5.4.5.4.2. The staff noted that FSAR Subsection 2.5.4.5.4.2 includes compressive strength, shear wave velocity, and associated design and testing requirements for the fill concrete under any Seismic Category I structure to a thickness greater than 1.5 m (5 ft). In addition, the applicant committed to use the concrete fill with 31 MPa (4.500 psi) compressive strength. The staff performed a confirmatory calculation based on the equations recommended by the ACI code. The staff found that the shear wave velocity for the fill concrete greatly exceeds the 300 m/s (1,000 ft/s) minimum shear wave velocity required in ESBWR DCD Revision 9 Table 2.0-1 for supporting foundation materials. The staff confirmed that the applicant had revised the Part 10 "ITAAC" of the application to include Section 2.4.1, "ITAAC for Fill Concrete under Seismic Category I Structures." The staff concludes that the strength degradation of the fill concrete will be well managed because the applicant will follow the ACI 349 requirements to address the staff's concern regarding concrete exposed to sulfate-containing solutions; and the applicant will follow the ACI 207.2R–07 requirements to address the staff's concern regarding thermal cracking control of the fill concrete. Based on the evaluations of the shear wave velocity and the durability of fill concrete, the staff concludes that the proposed ITAAC for the fill concrete under Seismic Category I structures is acceptable. RAI 02.05.04-40 is therefore resolved and closed.

Geotechnical Investigation Program

The staff reviewed FSAR Subsection 2.5.4.2.2.2 related to the geotechnical investigation program at the Fermi 3 site. Regarding site exploration plans for safety-related foundations, Appendix D of RG 1.132 suggests that borings should be performed beneath every safety-related structure—at least one boring per 900 m^2 (10,000 ft^2) (approximately 30 m (100 ft) spacing) for larger and/or heavier structures—in addition to a number of borings along the periphery at the corners and at other selected locations. In FSAR Figure 2.5.1-236, the staff noted that for the Seismic Category I CB and FSWC, the applicant had not followed the recommendation to drill borings along the periphery at the corners. Therefore, in RAI 02.05.04-7 the staff asked the applicant to justify the limited number of borings and whether that number is sufficient to adequately characterize the CB and FWSC foundations.

In the response to RAI 02.05.04-7 dated January 11, 2010 (ML100130382), the applicant indicated that the subsurface investigations for both the CB and the FWSC were considered sufficient and in conformance with the guidance of RG 1.132. The applicant indicated that the stratigraphy in the immediate area of Fermi 3 is uniform, the test results are consistent with the subsurface material properties, and the density of borings in the area of the CB and the FWSC is adequate. The applicant stated that two borings are sufficient to characterize the subsurface conditions below the CB because the total area of the CB is approximately 717 m^2 (7,722 ft^2), which is less than the 900 m^2 (10,000 ft^2) specified in RG 1.1.32. The applicant concluded that one boring is sufficient to adequately characterize the foundation of the FWSC based on the uniformity of the stratigraphy and the subsurface properties.

The staff reviewed the response to RAI 02.05.04-7 with respect to the recommendations in Appendix D of RG 1.132. The staff noted that although the FWSC is classified as a Seismic Category I structure, it is listed as a nonsafety-related structure in Table 3.2-1 of the ESBWR DCD. And though there are no corner borings within the footprints of the safety-related CB and the nonsafety-related FSWC, there are two borings beneath the CB and one boring beneath the FSWC. They are therefore within the threshold of one boring beneath every safety-related structure and one boring per 900 m^2 (10,000 ft^2) as suggested in RG 1.132. In addition, the staff noted the lateral continuity of the subsurface bedding at the site from the boring data and the consistency of the subsurface material properties from the laboratory and in situ test results. Based on the above information, the staff concluded that the existing boring grid is adequate to define the site subsurface conditions, including the subsurface beneath the CB and the FSWC. Therefore, RAI 02.05.04-7 is resolved and closed.

FSAR Subsection 2.5.4.2.2.2.5.2 discusses the results from pressuremeter testing. The applicant performed three unload/reload cycles. The applicant found it reasonable to select the unload-reload modulus E_{ur} value from the last cycle as an estimate of the in situ modulus, because the condition of the bedrock at the highest pressure level was probably closer to the in situ undisturbed bedrock than at the lower pressure levels and in the previous unload/reload cycles. Also, the applicant indicated that the material being tested was a very complex geological unit consisting of interbedded limestone/dolomite/claystone/siltstone/shale and breccias with varying degrees of induration. The staff was concerned that an applicable strain range and applied unload/reload cycle could affect the values of $E_{ur,}$ and the possible effects of the macro-features may not be present within the influence zone of the pressuremeter test. Therefore, in RAI 02.05.04-8, the staff asked the applicant to provide additional information regarding the appropriate selection of E_{ur} to represent the modulus of in situ undisturbed bedrock. In addition, the staff asked the applicant to describe the use of the results and to identify the calculations that used these pressuremeter test values.

In the response to RAI 02.05.04-8 dated December 23, 2009 (ML100040548), the applicant compared the typical pressure-displacement behavior in Salina Group Unit F with the ideal pressure-displacement curve for a pressuremeter test. In addition, the applicant compared the ideal pressuremeter test curves with several unload-reload loops. The applicant indicated that for the ideal pressuremeter test curves, the slopes of the unload-reload of the materials that are naturally or mechanically fractured during the drilling process increase with each successive unload-reload cycle performed at higher pressures. The applicant stated that the slopes of the three unload-reload loops for Salina Unit F become progressively steeper with the increasing strain, which is an indication of a fractured material. The applicant also indicated that in the ideal pressuremeter test, for a material that was mechanically fractured during the drilling process, the slope of the unload-reload loops continues to increase as the joints are closed. The applicant encountered this same scenario in tests performed for Salina Group Unit F. The applicant concluded that the E_{ur} from the last unload-reload cycle was an appropriate representation of the modulus of in situ undisturbed bedrock for Salina Group Unit F. The applicant compared the E obtained from the pressuremeter testing with the E based on the Hoek-Brown criterion. In order to provide a bounding estimate of settlement and rebound for Seismic Category I foundations, the applicant used the E obtained from the Hoek-Brown criterion because the E from the pressuremeter testing was higher.

The staff reviewed the response to RAI 02.05.04-8 and noted that in order to keep the material in the elastic range at any stage during the pressuremeter testing, the total pressure is controlled and maintained at less than 40 percent of the maximum pressure reached. The staff acknowledged that for homogeneous materials that contain no fractures, the successive unload-reload loops that performed at different pressure levels in the elastic range will be relatively parallel. The staff further noted that for materials that are fractured during the drilling process, the slope of the unload-reload loops increases until all of the joints have closed up. Beyond this point the slope of the unload-reload loops is presumably reached, but it does not exceed the slope for homogeneous materials. Based on the above rationale, the staff agreed with the applicant that the modulus based on the slope in the final unload-reload loop in the elastic range for material naturally or mechanically fractured during the drilling process will be a conservative estimate of the in situ modulus. In addition, the staff noted that the average E, based on the pressuremeter tests in Salina Group Unit F falls within the upper and lower bound E based on the Hoek-Brown criterion, which provides cross-references for the modulus between pressuremeter tests and the Hoek-Brown criterion. Finally, because the lower bound modulus from the Hoek-Brown criterion was used, the staff concluded that the calculated settlement and rebound of Seismic Category I foundations provides conservative estimates. The staff concluded that the E_{ur} obtained from the last unload-reload cycle is an appropriate representation of the in situ modulus for the Salina Group Unit F undisturbed bedrock, and the lower bound modulus from the Hoek-Brown criterion is appropriate to use. Therefore, RAI 02.05.04-8 is resolved and closed.

<u>NRC Staff's Conclusions Regarding Field Investigations</u>

The staff reviewed FSAR Subsection 2.5.4.2.2 and the applicant's response to RAIs associated with the Fermi 3 site field investigations discussed above. The staff concludes that the applicant has appropriately followed the guidance in RG 1.132 Revision 2. The applicant conducted an adequate boring exploration program based on the location and number of borings and the number and types of tests performed, in accordance with the appropriate ASTM standards.

<u>Laboratory Testing</u>

The staff reviewed FSAR Subsection 2.5.4.2.3 related to the laboratory testing program performed to identify, classify, and evaluate the physical and engineering properties of the soil and the bedrock. The applicant investigated the need to perform dynamic tests on Salina Group Unit F and concluded that no dynamic testing was required because the estimated shear strain for Salina Group Unit F was approximately 0.0252 percent, and the strain level for the till induced during the design earthquake would be less than 0.3 percent. The applicant also indicated that the testable samples would have been biased toward "the more intact portions of the bedrock and hence testing under static or dynamic loading conditions would possibly give high values not representative of the overall Unit F." The staff was concerned that the potential role of "weak" zones , which are the zones experiencing low recovery, within the Salina Group Unit F might have contributed to the overall characterization and performance of this group. FSAR Figure 2.5.4-208 shows P-S suspension logging results indicating missing V_s and V_p data in a significant portion of Salina Group Unit F. Consequently, in RAI 02.05.04-9 and RAI 02.05.04-13a, the staff asked the applicant to provide information on possible alternative means of sampling Salina Group Unit F; or if sampling was not feasible, to provide a non-laboratory testing alternative to obtain data regarding the potential effects of these conditions on the characterization of Salina Group Unit F. The staff also asked the applicant to explain how the induced seismic shear strains were conservatively estimated for the Salina Group Unit F and the till in order to be consistent with the postulated earthquake shaking conditions.

In the response to RAI 02.05.04-9 dated January 11, 2010 (ML100130382), and the response to RAI 02.05.04-13a dated February 11, 2010 (ML100570311), the applicant indicated that the data in the application are sufficient to characterize Salina Group Unit F and its weaker zones. The applicant stated that because of the poor recovery in the "weaker" zones of Salina Group Unit F, the collection of undisturbed bedrock core was considered unlikely in these zones and with a minimum V_s of 549 m/s (1,800 fps), the soil samples were not considered applicable. Regarding the induced shear strain estimates, the applicant indicated that the induced seismic shear strain estimates were performed for Salina Group Unit F using an assumed peak ground acceleration of 0.25g and a minimum V_s of 549 m/s (1,800 fps), which were measured at a depth of approximately 73.2 m (240 ft). The applicant estimated a shear strain of 0.0252 percent for the Salina Group Unit F, which indicates a G/G_{max} ratio of approximately 0.91. The applicant approximated the worst case based on sand between 36.6 and 76.2 m (120 and 250 ft) that resulted in a G/G_{max} ratio larger than that estimated before, thus indicating a negligible modulus reduction of bedrock. In FSAR Figures 2.5.2-280 and 2.5.2-281 the applicant showed that within the elevation range of Salina Group Unit F, the computed shear strains in the randomized site profiles are less than 0.03 percent, which confirms the previously estimated results. For the till, the applicant used an estimated average V_s of 305 m/s (1,000 fps) and indicated that this would induce strain levels during the design earthquake of less than 0.03 percent. The applicant further stated that the results of the RCTS testing provide the dynamic response of the till up to a shear strain of approximately 0.3 percent. FSAR Figures 2.5.2-280 and 2.5.2.281 show that within the elevation range of the glacial till, the computed shear strain in the randomized site profile is less than or equal to 0.1 percent. For that reason, the applicant indicated that the cyclic triaxial test and the cyclic direct test were not necessary for the till; and the RCTS testing provides the necessary data.

The staff reviewed the responses to RAI 02.05.04-9 and RAI 02.05.04-13a. The staff noted that the mean V_s and V_p of Salina Group Unit F that were obtained using the P-S suspension logging method agree with the mean V_s and V_p of Salina Group Unit F, which were obtained using the downhole seismic method. These in situ methods either directly tested weaker zones in Salina Group Unit F or tested across Salina Group Unit F and included weaker zones in the averaged measurements. Therefore the staff concludes that the applicant's data are sufficient to adequately characterize Salina Group Unit F, including the weaker zones. In addition, the staff reviewed the applicant's subsurface stability analyses and noted that these factors have been considered. Regarding the induced shear strain estimates, the staff reviewed the results of the effective shear strains computed in the site response analyses for the 10^{-4} and 10^{-5} input ground motions from FSAR Figures 2.5.2-280 and 2.5.2-281. These figures show that the computed shear strains in the randomized site profiles were all less than or equal to 0.03 percent within the elevation range of Salina Group Unit F, and were less than or equal to 0.1 percent within the elevation range of the glacial till. Because the computed Salina Group Unit F shear strain range is based on site response analyses with an assumed peak ground acceleration of 0.25 g and a minimum V_s of 549 m/s (1,800 fps), which confirmed the shear strain level of approximately 0.0252 percent, the staff concludes that the seismic shear strain for Salina Group Unit F is appropriate. Therefore, the shear modulus reduction based on this shear strain is acceptable.

The staff further noted that the RCTS test results provide the shear modulus reduction characteristic for the glacial till up to a shear strain of approximately 0.3 percent compared to the computed shear strains of less than or equal to 0.1 percent in the randomized site profiles and the calculated shear strain of 0.03 percent based on the V_s of 305 m/s (1,000 fps). Since the RCTS test results provided the modulus reduction characteristic of the glacial till up to a shear strain of approximately 0.3 percent, the staff found that the dynamic response of the till based on a shear strain of approximately 0.3 percent from the RCTS is appropriate and conservative. The staff confirmed that the applicant's revised FSAR Subsection 2.5.4.2.3 includes more detailed clarifications of how the induced seismic shear strains were estimated for Salina Group Unit F and for the till. Because the applicant provided reasonable justifications for the proper characterizations of Salina Group Unit F, including its weaker zones and the induced seismic shear strains for Salina Group Unit F and the till, RAI 02.05.04-9 and RAI 02.05.04-13a are resolved and closed.

FSAR Section 2.5.4.4.1.1 states that repeated collapse of boreholes was experienced in the 33.5 to 62.5 m (110 to 205 ft) depth range in Salina Group Unit F and resulted in oversized borehole and irregular borehole shapes. This section also states that the limited measurements were performed in Salina Group Unit F in any of the borings due to oversized holes and irregular hole shapes. The staff was concerned about any potential existence of cavities or other unstable subsurface conditions. In RAI 02.05.04-13b and RAI 02.05.04-13c, the staff asked the applicant to provide a detailed comparison of the elevations for the collapse of the boreholes under all Seismic Category I foundation bases; to discuss whether or not a repeated collapse of the boreholes might not be indicative of cavities below foundation levels; and to explain why systematic rock grouting should not be applied at this site.

In the response to RAI 02.05.04-13b and RAI 02.05.04-13c dated February 11, 2010 (ML100570311), the applicant provided caliper logs—a measure of the borehole diameter—for borings under and adjacent to Seismic Category I foundation bases with larger diameters that indicate the locations of borehole collapses. The applicant performed OTV logging for each of the borings with caliper logs in order to allow for a visual inspection of the borehole walls to see if voids or cavities are present at the Fermi 3 site. For boring RB-C8, the applicant compared the OTV log and the caliper log. The applicant did not identify any cavities where a borehole collapse had occurred; but the applicant did note that the larger diameter size was caused by material falling off the side of the borehole wall into the boring. FSAR Subsection 2.5.1.2.3.1 presents boring log analyses performed from the OTV logs; and natural gamma and caliper logging that the applicant used to provide information regarding core loss, voids, cavities, and tool drops that occurred in the Bass Islands Group and Salina Group Units F and E. The applicant concluded that the nature of the fracture of Salina Group Unit F resulted in the repeated collapse of boreholes as material fell off the borehole walls into the boring, rather than from the presence of cavities below foundation levels. The applicant did not propose systematic rock grouting to enhance the stability of subsurface materials because no void or cavities are present below the Fermi 3 site, and the strength and stiffness of the bedrock are sufficient to provide adequate bearing capacity and to control the settlement.

The staff reviewed the responses to RAI 02.05.04-13b and RAI 02.05.04-13c, the caliper logs for the borings under and adjacent to Seismic Category I structures, and the OTV logs. Because the applicant's analysis of boring logs regarding core loss, voids, cavities, and tool drops that occurred during the Fermi 3 subsurface investigation included the comparison of available boring logs; photos of the recovered core; caliper and gamma logs; and the downhole OTV logs to determine an explanation of the conditions that were encountered, the staff did not suspect that voids, cavities, or other unstable subsurface conditions are present beneath the Fermi 3 site. Based on the information from the applicant's analysis, observations during drilling, and a review of the OTV logs, the staff agreed with the applicant that the nature of the fracture of Salina Group Unit F resulted in repeated collapses of the boreholes as material fell off the borehole walls into the boring, rather than from the presence of cavities below the foundation levels. . Therefore, systematic rock grouting is not necessary, and RAI 02.05.04-13b and RAI 02.05.04-13c are resolved and closed.

The staff reviewed the information in FSAR Subsection 2.5.4.2.3 and the applicant's responses to the RAIs associated with laboratory testing described above. The staff concludes that the applicant's laboratory testing program was conducted in accordance with an approved quality assurance program that adhered to the guidance in RG 1.138, Revision 2. The staff also concludes that the applicant had conducted sufficient laboratory tests to adequately characterize the physical and engineering properties of the subsurface materials.

NRC Staff's Conclusions Regarding the Properties of Subsurface Materials

The staff found the applicant's description of the subsurface materials acceptable in that the applicant had followed the guidance in RG 1.132, Revision 2 and RG 1.138, Revision 2. The applicant investigated and tested the subsurface materials to determine the geotechnical engineering properties of the soil and rock at the planned Fermi 3 site. Furthermore, the staff concludes that the applicant had obtained sufficient undisturbed samples to allow for the adequate characterization of each of these soil/rock groups and had determined the extent, thickness, hardness, density, consistency, strength, and engineering and static design properties. Furthermore, the staff concludes that the applicant has provided sufficient information in the form of plots, plans, boring logs, and laboratory test results that enabled the staff to determine that the applicant had adequately characterized the subsurface soil and rock materials and adequately determined the engineering and design properties.

Therefore, the staff concludes that the applicant's description of the subsurface materials and properties at the proposed Fermi 3 site is acceptable and meets the requirements of 10 CFR 100.23.

2.5.4.4.3 Foundation Interfaces

The staff reviewed FSAR Figure 2.5.1-236, which is the site explorations locations including borings, monitoring wells, piezometers and the test pit, Figure 2.5.4-201, which is the plan view of the excavation for the RB/FB, CB, FWSC, TB and RW, and FSAR Figures 2.5.4-202 through 2.5.4-204, which are geologic cross sections illustrating the detailed relationship of the structural foundations to the subsurface materials. The staff also reviewed FSAR Table 2.5.4-224, which provides the foundation elevations of the major structures in the Power Block area.

The staff concluded that the applicant adequately investigated the subsurface materials beneath the nuclear island construction zone for the Fermi 3 site. The staff based its conclusions on: (1) its review of plot plans showing the locations of all site explorations, such as borings, seismic and non-seismic geophysical explorations, piezometers, geologic profiles, and the locations of the safety-related facilities; (2) its review of the profiles the applicant presented, illustrating the detailed relationship of the foundations of all Seismic Category I and other safety-related facilities to the subsurface materials; and (3) its review of core borings, SPT borings, V_s profiles and non-seismic geophysical logging results. Accordingly, the staff concluded that the foundation interfaces as described in FSAR Subsection 2.5.4.3 form an adequate basis for the characterization of the foundation interfaces at the Fermi 3 site and meets the requirements of 10 CFR Parts 50 and 100.

2.5.4.4.4 Geophysical Surveys

The staff reviewed FSAR Subsection 2.5.4.4 focusing on the applicant's description of the geophysical surveys performed to identify the dynamic characteristics of soils and rocks. The applicant measured the dynamic characteristics of soils and bedrock using downhole P-S suspension logging, downhole seismic testing, and SASW logging. As a result, the applicant concluded that the downhole V_s values generally agree with the values obtained using P-S suspensions logging; and the soil V_s measured using the P-S suspension method agrees with the soil V_s measured using the SASW method. In RAI 02.05.04-11, the staff asked the applicant to provide test data for V_s in addition to the average values and to discuss how these data may vary with the depth. The staff also asked the applicant whether the variability observed in downhole seismic testing and the SASW logging needs to be considered in the characterization of the soil and bedrock.

In the response to RAI 02.05.04-11 dated December 23, 2009 (ML100040548), the applicant provided detailed results of the V_p and V_s measurements in the Geovision report 7297-01 Revision 0 (March 12, 2008). The applicant indicated that for the Bass Islands Group, the measured V_s and V_p were constant throughout the depth at a given boring location. For Salina Group Unit F, the applicant performed limited V_p and V_s measurements between the depths of 33.5 and 62.5 m (110 and 205 ft) resulting from oversized holes and irregular shapes of holes. The applicant measured the arrival time of the shear and compression waves above and below the interval of the oversized zones and indicated that for the RB-C8 and CB-C3 locations, the measured V_s and V_p were constant over a given interval at a given boring location. The applicant measured the V_s in the overburden using the SASW and P-S suspension logging and discussed the variability in FSAR Subsection 2.5.4.4.1.2. The applicant employed the V_s measurement using the SASW logging to establish the V_s of only the glacial till and used the P-S suspension logging to establish the bedrock V_s and V_p values for analysis. The applicant used the downhole results to validate the P-S suspension logging results. The applicant indicated that the V_p and V_s measured using the downhole method fall with the variability of the V_p and V_s measured using P-S suspension logging method. The applicant concluded that the overall results obtained from the P-S Suspension logging are acceptable for all purposes of analysis. But the staff noted that the V_s obtained from the P-S suspension logging method are generally greater than those from the downhole and SASW methods. In RAI 02.05.04-12, the staff asked the applicant to justify the exclusive use of the P-S suspension logging results rather than using the downhole, SASW, and P-S suspension logging results.

In the response to RAI 02.05.04-12 dated December 23, 2009 (ML100040548), the applicant indicated that the clarity of the V_s wave form was better in the P-S suspension logging data than in the downhole seismic data and the variability of the P-S suspension logging data for the V_s and V_p could correlate well with the physical features observed in the bedrock. The applicant had more confidence in the ability to interpret the P-S suspension logging V_s data.

The staff reviewed the responses to RAIs 02.05.04-11 and 02.05.04-12 and noted that the applicant had applied the downhole seismic method to measure the V_p at boring locations RB-C8, CB-C3, and RB-C4 and the V_s at RB-C8 and CR-C3. The staff also noted that the V_p and V_s in the bedrock units were measured using the downhole seismic method and fall within the variability of the V_p and $V_{s,}$ which were measured using the P-S suspension logging method except for the lower V_s, which was measured in RB-C8 in the Bass Islands Group and the applicant attributed to poor quality shear wave forms. In addition, the staff noted that the applicant had compared the V_s and V_p measurements obtained with other subsurface information such as RQD, caliper, natural gamma, and OTV logs. The staff also reviewed FSAR Figures 2.5.4-205 through 2.5.4-208 to compare the measured P-S suspension logging V_s and V_p with the RQD in boring locations TB-C5, RB-C8, CB-C3, and RB-C4, respectively. The staff also reviewed FSAR Figures 2.5.4-209 through 2.5.4-212 to compare the OTV logs and the measured velocities in boring locations TB-C5, RB-C8, CB-C3, and RB-C4, respectively. Furthermore, the staff reviewed FSAR Figures 2.5.4-213 and 2.5.4-214 to compare the natural gamma logs and the measured velocities in boring locations TB-C5 and CB-C3. The staff concurred with the applicant that the variability in the measured V_p and V_s within the Bass Islands Group is mainly caused by geologic features such as fractures, bedding planes, brecciation, oolitic rock, and a pitting of the bedrock. Because the clarity of the V_s forms was better for the P-S suspension logging data than for the downhole seismic data, and the variability of the P-S suspension logging V_s and V_p data could correlate well with the physical features observed in the bedrock, the staff concluded that the P-S suspension logging V_s data are more reliable than the V_s downhole seismic data, while the downhole results were used to validate the P-S suspension logging results. The staff further concluded that the V_s measurements using the SASW logging were used to establish the V_s of only the glacial till that will be removed from beneath the Seismic Category I structures. Therefore, RAI 02.05.04-11 and RAI 02.05.04-12 are resolved and closed.

The staff reviewed the information in FSAR Subsection 2.5.4.4 and the applicant's responses to RAIs 02.05.04-11 and 02.05.04-12. The staff concluded that the applicant has appropriately followed the guidance in RG 1.132 Revision 2, and has provided sufficient geophysical surveys to characterize the dynamic characteristics of soils and rocks.

2.5.4.4.5 Excavation and Backfill

The staff reviewed FSAR Subsection 2.5.4.5 related to the engineering granular backfill requirements, the extent of excavation fills and slopes, excavation methods, and the stability at the Fermi 3 site. Initially, the applicant was planning to use lean concrete and engineered granular fill as the backfill beneath and surrounding Seismic Category I structures. As a result of the revisions to the referenced DCD for the required soil properties surrounding Category I structures, the applicant later proposed to use roller-compacted concrete or a similar product near the ground surface to maintain the 300 m/s (1,000 ft/s) shear wave velocity. The staff issued several RAIs regarding the applicant's fills properties, criteria, and extent of excavation and backfill. However, these RAIs are not discussed in further detail in this technical evaluation because the applicant later concluded—while developing responses to the RAIs—that the design for the backfill surrounding the Category I structures would not meet the DCD soil property requirements. Consequently, the response to RAI 02.05.04-38 dated June 17, 2011 (ML111711175), reflects the applicant's final decision to use granular backfill to surround the Category I structures and to perform a site-specific SSI analysis to demonstrate the adequacy of the site and the standard plant design. The applicant did not credit the engineered granular fill surrounding the Category I structures for performing any safety-related function and clarified that only onsite backfill sources will be used for engineered granular backfill surrounding the Category I structures. The applicant concluded that no ITAAC are necessary for compactable backfill surrounding the embedment walls of the RB/FB and CB. The applicant also concluded that the site parameter values are not required, including the shear wave velocity requirement referenced in the DCD for compactable backfill surrounding the foundation basemat of the FWSC. In addition, the applicant decided to use fill concrete instead of lean concrete to backfill the volume between the RB/FB, CB, and excavated bedrock and to support the FWSC and TB foundations from the top of the bedrock to address the staff's concern about the chemical composition requirements for sulfate exposure conditions. For the FWSC, the applicant indicated that it is a surface-founded structure that will have no embedment walls and will be supported by concrete fill founded on top of the Bass Island Group bedrock, with a mean shear wave velocity of at least 2,175 m/s (7,140 ft/s).

Source and Quantities of Backfill and Borrow Materials

The staff reviewed FSAR Subsection 2.5.4.5.1 related to the sources of backfill and borrow materials that follow the guidance in NUREG–0800. Based on the information in the applicant's response to RAI 02.05.04-38, the staff asked the applicant in RAI 02.05.04-39 to provide the technical basis for eliminating the ESBWR DCD site parameter requirement for the product of at-rest pressure coefficient and density ($K_0\gamma \geq 750$ Kg/m^3 [47 lb/ft^3]) for backfill material surrounding Seismic Category I structures in FSAR Table 2.0-201. The staff also asked the applicant to explain why Design Commitment Item 2 in Table 2.4.2-1 of the COL application Part 10 is not applicable—engineering properties of backfill material surrounding Seismic Category I structures. The staff also asked the applicant to explain the basis for eliminating Item 2 of the site-specific ITAAC corresponding to the backfill adjacent to Seismic Category I structures.

In the response to RAI 02.05.04-39 dated February 16, 2012 (ML120520154), the applicant eliminated $K_0\gamma$ as a required parameter for Seismic Category I structures. Because of the strength of the bedrock and the fill concrete, the applicant did not credit the frictional resistance along the portion of the foundation and the walls of the structure parallel to the direction of sliding motion. In addition, the applicant indicated that an ITAAC for the backfill surrounding Seismic Category I structures will be included to specify the applicable requirements for the DCD backfill soil parameters.

The staff reviewed the responses to part 1 of RAI 02.05.04-38 and RAI 02.05.04-39. The staff noted that the applicant had elected to perform site-specific SSI analyses in lieu of meeting the soil property requirement in the ESBWR DCD table to maintain the 300 m/s (1,000 ft/s) shear wave velocity for backfill surrounding Seismic Category I structures. The staff also noted that the applicant had properly revised its plot plans and profiles to present the horizontal and vertical extent of all Seismic Category I fills, including the engineered granular backfill and fill concrete. The staff further noted that ESBWR DCD also allows applicants to demonstrate the adequacy of the standard plant design by performing site-specific analyses. Therefore, the staff considered the applicant's alternative approach proper and acceptable. The staff's detailed evaluation of the site-specific SSI analyses is documented is in Sections 3.7.1, 3.7.2, and 3.8.5 of this SER. The staff noted that the site-specific SSI analyses for the RB/FB and the CB were performed by considering the partial embedment of the structures into the Bass Islands Group bedrock and by not taking credit for the engineered granular backfill located above the top of the Bass Islands Group bedrock. Because the applicant's site-specific SSI analyses demonstrated the adequacy of the standard plant design, the staff agreed that the shear wave velocity requirement referenced in the DCD for the backfill surrounding Seismic Category I structures may not be considered. Consequently, the staff concurred that an ITAAC on shear wave velocity for engineered granular fill surrounding Seismic Category I structures is not necessary.

The applicant's assumption that the engineered granular backfill surrounding Seismic Category I structures are not attributed to resisting sliding forces in the site-specific SSI analyses is conservative. Furthermore, the staff reviewed DCD Tier 2 Subsection 3.8.5.5 and GEH Letter MFN 09-772 to the NRC, "Revised Response to portion of NRC RAI Letter No. 386 Related to ESBWR Design Certification Application – DCD Tier 2 Section 3.8 – Seismic Category I Structures; RAI Number 3.8-96 S05 Revision 1," dated January 20, 2010 (ML100220503), in order to understand the ESBWR DCD requirement for $K_0\gamma$ and how to determine the FS against sliding. The staff also reviewed FSAR Revision 5 Subsection 3.8.5.5.1, "Foundation Stability," to confirm that the stability calculations against sliding are executed according to the procedure in Referenced DCD Subsection 3.8.5.5. Based on the above reviews, the staff found that the

DCD requirement for $K_0\gamma$ is related to at-rest soil forces that are normal to the basemat vertical surface, which develops skin friction resistance on the basement side parallel to the direction of the motion to resist sliding if necessary. The staff confirmed that the skin friction resistance force provided by the basemat side parallel to the direction of the motion is not taken into account in the applicant's analyses (i.e., $F_{us} = 0$). The staff agreed with the applicant that the great resistance force for sliding can be developed by the partial embedment of the structures into the bedrock. The staff noted that the calculated Fermi 3 site-specific FS against sliding for the Seismic Category I structures RB/FB, CB, and FWSC are 5.48, 3.09, and 15, respectively, which are greater than the minimum FS of 1.1 required by SRP Section 3.8.5. Therefore, the staff concluded that it is not necessary to take into account the DCD site parameter requirement $K_0\gamma \geq 750$ Kg/m^3 (47 lb/ft^3) for the Fermi 3 site. The staff further concluded that it is reasonable and acceptable to exclude an ITAAC item of $K_0\gamma \geq 750$ Kg/m^3 (47 lb/ft^3) from site-specific ITAAC for "Backfill Surrounding Seismic Category I Structures." Furthermore, the staff confirmed that the applicant has revised the ITAAC for "Backfill Surrounding Seismic Category I Structures" to reflect that (1) the DCD site parameter requirements of 300 m/s (1,000 ft/s) minimum shear wave velocity and $K_0\gamma \geq 750$ Kg/m^3 (47 lb/ft^3) for engineered granular fill surrounding Seismic Category I structures are no longer required design commitments; and (2) the other applicable DCD site parameter requirements for DCD backfill soil parameters are included in the ITAAC for "Backfill Surrounding Seismic Category I Structures" in Section 2.4.2 of COL application Part 10. Therefore, part 1 of RAI 02.05.04-38 and RAI 02.05.04-39 are resolved and closed.

In part 6 of RAI 02.05.04-38, the staff asked the applicant to specify the offsite backfill source(s) and to demonstrate the adequacy of the performed site and laboratory investigations.

In the response to part 6 of RAI 02.05.04-38 dated December 23, 2009 (ML100040548), the applicant indicated that only onsite backfill sources using materials excavated from Fermi 3 will be used for the engineered granular backfill surrounding Seismic Category I structures. This decision reflects investigations using borings and test pits, in addition to laboratory and field tests.

The staff reviewed the applicant's response to part 6 of RAI 02.05.04-38 and noted that the quantity of engineered granular backfill within the perimeter of the reinforced concrete diaphragm wall is approximately 153,000 m^3 (200,000 yd^3), and the volume of granular backfill from the onsite excavation (onsite source) of Fermi 3 is an estimated 180,000 m^3 (235,000 yd^3). The staff concluded that the quantity of material excavated from the Fermi 3 site is adequate for the engineered granular backfill surrounding the Fermi 3 Seismic Category I structures. The staff also noted that the source of the onsite backfill was investigated using borings, test pits, and laboratory and field tests; FSAR Subsection 2.5.4.2 discusses the properties of the onsite backfill materials. Based on this information, the staff found that the applicant has (1) identified the sources and quantities of the backfill; (2) adequately investigated them using borings, pits, and laboratory tests (dynamic and static); and (3) included, interpreted, and summarized the data in the FSAR. The staff concluded that the applicant has adhered to the SRP Section 2.5.4 acceptance criteria regarding backfill sources, quantities, and laboratory properties. Therefore, part 6 of RAI 02.05.04-38 is resolved and closed.

Extent of Excavation, Fills, and Slopes

The staff reviewed FSAR Subsection 2.5.4.5.2 that focuses on the extent of the excavation, fills, and slopes within the soil and bedrock. The applicant stated that vertical excavation faces within the soil and bedrock could be achieved by using an excavation system consisting of a reinforced concrete diaphragm wall system 24.4 m (80 ft) deep with an embedment depth of approximately 15.2 m (50 ft) into the bedrock around the entire excavation. The reinforced concrete diaphragm wall will act as the perimeter of the soil excavation and will provide vertical support for the portion of the excavation within the soil. Overburden soils will be excavated from the ground surface to the estimated top of the bedrock surface at elevation of 168.2 m (552 ft) NAVD 88. Bedrock will be excavated to reach the required foundation design elevations. FSAR Figure 2.5.4-201 depicts the plan view of the excavation for Fermi 3 using the vertical cut-off wall option in the soil and bedrock; Figures 2.5.4-202 through 2.5.4-204 show the cross sections of the excavation. Because the applicant is committed to a structural design of the concrete diaphragm wall that is in accordance with ACI 318, the wall will be aligned to prevent the deflected wall from encroaching on the limits of Seismic Category I structures plus any construction limitations. And because the wall will be aligned to allow sufficient space for the placement of backfill outside the Seismic Category I structures, the staff agreed with the applicant's conclusion that there are no impacts to the completed Seismic Category I structures from the presence of the concrete diaphragm wall.

The staff reviewed FSAR Subsection 2.5.4.5.2 and FSAR Figures 2.5.4-201 through 2.5.4-204. The staff concluded that the applicant has clearly illustrated the detailed relationships among the foundations of all Seismic Category I structures, backfill materials, and excavation boundaries created by the vertical cut-off reinforced concrete diaphragm wall. Therefore, the applicant's assessment of the extent of all Category I excavations, fills, and slopes is acceptable and meets the requirements of 10 CFR Part 50.

Excavation Methods and Stability

While reviewing FSAR Subsection 2.5.4.5.3, the staff noted that the applicant plans to use blasting, mechanical excavation, or a combination of both methods for the bedrock excavation. The applicant assured the staff that the blasting would be designed by a qualified and experienced blasting professional and controlled blasting techniques can be used to ensure the protection of all existing adjacent structures, including Fermi 2. The applicant indicated that during construction, excavated subgrades in the bedrock of safety-related structures will be mapped and photographed by a qualified and experienced geologist to evaluate any unforeseen geologic features. The staff asked the applicant in RAI 02.05.04-15 to provide the specific criteria to be used to evaluate whether the excavated faces would be acceptable as foundation material. Also, the staff asked for an explanation as to how the applicant will use a geologic evaluation of open faces to confirm the engineering properties of bedrock material and to provide specifics for any engineering property tests planned for the excavated bedrock material.

In the response to RAI 02.05.04-15 dated January 11, 2010 (ML100130382), the applicant indicated that the Seismic Category I structures at the Fermi 3 site are founded on bedrock or fill concrete over the bedrock. The applicant also indicated the intent to prepare during the development of the detailed design the specifications regarding the inspection and cleaning of the excavation that will ensure acceptable excavation faces. The applicant also committed to ensuring that a visual inspection of the final excavation surface will be performed to confirm that it is in general conformance with the expected foundation material based on boring logs. After fracturing from blasting, machine cleaning is followed by cleaning with hand tools and high-pressure water and air to remove unsuitable rock. The applicant pointed out that geologic mapping of the final exposed excavated bedrock surface will be performed before the placement of concrete fill and foundation concrete to determine the degree of fracturing in the excavated face after the surface has been cleaned. The applicant also stated that if the spacing between discontinuities is measured in feet, foundation treatment may be minimal or unnecessary. But if the spacing between fractures is measured in inches, removal or replacement with dental concrete or consolidation grouting may be required to improve the engineering properties of the bedrock at the excavated face. The applicant concluded by stating that the designer will identify specific engineering properties, tests, and the type and extent of the foundation treatment. The designer will thus confirm the condition of the excavation faces. The applicant added that there are no plans to test the excavated material.

The staff reviewed the response to RAI 02.05.04-15 and noted that the existing subsurface materials including fill, lacustrine, and glacial till will be removed to ensure that the Seismic Category I structures are founded on bedrock or concrete fill over bedrock. The staff also noted that the applicant will perform a visual inspection on the exposed bedrock foundation subgrade to confirm that cleaning and surface preparations were properly completed. In addition, the applicant will conduct the geologic mapping program after the surface is machine and hand cleaned and after there is a complete photographic documentation of the exposed surface to record significant geologic features. The applicant agreed to implement the foundation treatment where necessary, including removal and replacement with dental concrete or consolidation grouting to improve the engineering properties of the bedrock at the excavated face. The geologic mapping License Condition 2.5.3-1 is identified in the section 3.5.3.5 of this SER as the responsibility of the COL licensee. The NRC will be notified once excavations for Fermi 3 safety-related structures are open for examination by NRC staff. Therefore, the staff found the applicant's response acceptable, and RAI 02.05.04-15 is resolved and closed.

Compaction Specifications and Quality Control

The staff reviewed FSAR Subsection 2.5.4.5.4 that focuses on the methods and procedures used for verification and quality control of foundation materials. Based on the information in the applicant's response to part 2 of RAI 02.05.04-38 (ML100040548), the staff confirmed that the applicant has properly revised the plot plans and profiles to present the horizontal and vertical extent of all Category I fills—including the engineered granular backfill and fill concrete. The staff noted that the engineered granular backfill surrounding the Seismic Category I structures will be compacted to 95 percent of the modified Proctor density or 75 percent of the maximum relative density. The staff concurred that the engineered granular backfill is adequate to prevent liquefaction.

The applicant identified that the sulfate concentration of the site's groundwater is in the "moderate" to "severe" sulfate exposure category based on ACI 349. In part 3 of RAI 02.05.04-38, the staff asked the applicant how the backfill on the side of and underneath the Seismic Category I structures is designed to resist chemical attack, particularly if r*oller compacted concrete* (RCC) or c*ontrolled low-strength material* (CLSM) is selected. The staff also asked the applicant to discuss control of the thermal cracking of fill materials.

In the response to part 3 of RAI 02.05.04-38 (ML111711175), the applicant stated that the RCC will not be used to surround Seismic Category I structures and that no CLMS will be used as backfill material for Seismic Category I structures. The applicant will follow ACI 349 to address the chemical composition requirements for sulfate exposure conditions and ACI 207.2R to address the thermal cracking control of mass concrete. The applicant concluded that the mean compressive strength for the fill concrete will be 31 MPa (4,500 psi).

The staff reviewed the response to part 3 of RAI 02.05.04-38, and verified that the applicant will not use the RCC, CLSM, or lean concrete as backfill material for Seismic Category I structures. The staff also confirmed that the fill concrete will be used to backfill the volume between the RB/FB and CB and excavated bedrock, and to support the FWSC and TB foundations from the top of the bedrock. In addition, the staff noted the ITAAC, which ensure that the fill concrete placed underneath any Category I structure will be a thickness greater than 1.5 m (5 ft) to meet the design, construction, and testing of applicable ACI standards. The staff validated that ACI 349 Chapter 4 addresses the concrete durability requirements including concrete to be exposed to sulfate containing solutions or soils. The staff verified that for a severe sulfate exposure such as the Fermi 3 groundwater condition, concrete durability can be achieved following the guidance in Table 4.3.1 of ACI 349 by providing concrete containing Type V cement; controlling a 0.45 maximum water-cementitious-material ratio; and maintaining a 31 MPa (4,500 psi) minimum concrete compressive strength. The staff further noted that ACI 207.2R-07 addresses the thermal cracking control of mass concrete by providing guidance for the selection of concrete materials, mixture requirements, and construction procedures necessary to control the size and spacing of cracks. Because the concrete durability of the fill and thermal cracking can be controlled by committing to proper ACI codes, the staff considered part 3 of RAI 02.05.04-38 resolved and closed.

NRC Staff's Conclusions Regarding Excavation and Backfill

The staff concluded that the applicant has (1) provided detailed information on engineered granular backfill and fill concrete properties and requirements; (2) provided applicable methods and procedures used for the verification and quality control of engineered granular backfill and concrete fill; and (3) described concrete fill properties that will ensure that the proposed fill concrete meet the strength and stability requirements. In addition the applicant provided two site-specific ITAACs that will ensure that concrete fill placed under Seismic Category I structures and compacted backfill surrounding the embedded walls for Seismic Category I structures are designed and tested as specified in FSAR Subsection 2.5.4.5.4.2 and properties of backfill material are equal to or exceed the FSAR Subsection 2.5.4.5.4.2 requirements. Therefore, the proposed fills for this site are adequate for meeting design and engineering standards. Regarding the applicant's excavation plans, the staff concluded that the applicant's plans to use conventional excavation methods (e.g., backhoe, front end loader, and dump truck) to remove soil layers and to use blasting with controlled blasting techniques (cushion blasting, pre-splitting, and line drilling; mechanical excavation including the use of roadheaders, terrain levelers, rockwheels, rock trenchers, and other mechanical excavation; or a combination of blasting and mechanical excavation) to excavate bedrock are adequate and feasible. In SER Subsection 2.5.3.5, the staff identifies License Condition 2.5.3-1 as the responsibility of the COL applicant for a detailed geologic mapping of the excavation of Fermi 3 nuclear island structures and to examine and evaluate geologic features discovered in excavations for safety-related structures other than those for the Fermi 3 nuclear island. Furthermore, the staff concluded that the supporting foundation materials and/or qualified fill concrete will result in a solid foundation for the nuclear island that meets the requirements specified in ESBWR DCD Tier 1, Table 5.1-1 and 10 CFR Part 50.

2.5.4.4.6 Groundwater Conditions

FSAR Subsection 2.5.4.6 presents information on the groundwater conditions at the site relative to foundation stability for the safety-related structures. The applicant stated that a reinforced concrete diaphragm wall around the perimeter of the Fermi 3 excavation will control groundwater seepage through soils and bedrock, and localized sump pumping within the excavation may be used to supplement water control during excavation. The applicant also stated that foundation bedrock grouting may be performed at the base of the Fermi 3 excavation to aid in controlling groundwater seepage into the excavation. Regarding the impact of groundwater control measures during construction on the existing structures, the applicant stated that the potential for settlement associated with Fermi 3 dewatering operations is negligible because all Fermi 2 Seismic Category I structures are founded on bedrock. However, the applicant provided a regulatory commitment (COM 2.5.4-001) to develop a Contingency Plan for mitigating any settlement of existing Fermi 2 structures before the start of Fermi 3 construction.

The staff reviewed the groundwater information in the FSAR including the conditions before, during, and after excavation and the associated dewatering plan, as well as the proposed measures to minimize drawdown effects on the surrounding environment. The staff concluded that the applicant's assessment of groundwater conditions is acceptable and satisfies the requirements of 10 CFR Part 50 and 10 CFR 100.23.

2.5.4.4.7 Response of Soil and Rock Dynamic Loadings

FSAR Subsection 2.5.4.7 describes the response of soil and bedrock to dynamic loading and the effects of past earthquakes. In RAI 02.05.04-19, the staff asked the applicant to demonstrate that the ratio of the largest to the smallest V_s over the mat foundation does not exceed ESBWR DCD Criterion 1.7. In the response to this RAI dated February 11, 2010 (ML100570311), the applicant calculated the smallest and largest mean V_s for each bedrock unit (Bass Islands Group and Salina Group Units F, E, C and B) based on various boreholes. The applicant stated that the ratios obtained ranged from 1.01 to 1.44 and therefore concluded that for all bedrock units in question, ESBWR DCD Criterion 1.7 was achieved. The staff reviewed the response to RAI 02.05.04-19, including the calculated range of ratios. The applicant demonstrated that the ratio of the largest to the smallest mean V_s for full unit thickness based on various boreholes is less than 1.7. The staff concluded that the V_s ratio over the mat foundation width is enveloped by the requirement specified in the ESBWR DCD. Therefore, RAI 02.05.04-19 is resolved and closed.

Based on the above review, the staff concluded that the applicant has developed soil and rock dynamic properties for the Fermi 3 site based on field and laboratory tests that are in accordance with the guidance in RGs 1.132 and 1.138. In addition, the staff concluded that the applicant has conducted sufficient tests to determine soil and rock dynamic properties. The applicant's analyses considered variations of these properties and parameters. Therefore, the soil and rock dynamic property parameters used in the design are appropriate.

2.5.4.4.8 Liquefaction Potential

During the review of FSAR Subsection 2.5.4.8, the staff evaluated the applicant's description of the liquefaction potential at the Fermi 3 site. The staff focused on the applicant's conclusions and justifications that fill materials placed within excavated areas are not susceptible to liquefaction. In addition, the staff's review focused on the applicant's evaluation of localized liquefaction potential under other than Seismic Category I structures.

In RAI 02.05.04-20, the staff asked the applicant to demonstrate that the backfill adjacent to Seismic Category I structures is not susceptible to liquefaction per the requirements in 10 CFR Parts 50 and 100. In the response to RAI 02.05.04-20 dated February 11, 2010 (ML100570311), the applicant referenced various sources. FSAR Subsection 2.5.4.5.4.2 states that all engineered granular backfills, including the ones in question, will be placed in controlled lifts and compacted. The applicant stated that the engineered granular backfill will consist of well-graded and dense granular soils that will be compacted up to a dense or a very dense consistency, thus reducing the probability of liquefaction.

To further demonstrate this point, the applicant performed a liquefaction analysis based on the SPT method. The applicant postulated that the expected N_{60} value at the ground surface will be 30 bpf and will increase linearly to 60 bpf at a depth of 20 m (65 ft). Based on Youd et al. (2001), the applicant normalized the N_{60} value to a $(N1)_{60}$ value, which is a function of a normalized overburden pressure of 100 KPa (2.1 ksf) and the effective vertical stress. The applicant found that all normalized $(N1)_{60}$ values obtained from this method were greater than 30 bpf, which greatly reduces the possibility of liquefaction according to Youd et al. (2001). Therefore, the applicant concluded that the engineered granular backfill adjacent to the Seismic Category I structures is not susceptible to liquefaction. In RAI 02.05.04-34, the staff asked the applicant to capture this liquefaction evaluation in the FSAR and to provide details of and a commitment on how it will verify the assumed N_{60} values. Also, the staff asked the applicant to provide the expected field backfill compaction and to include this commitment in the FSAR.

In the response to RAI 02.05.04-34 dated August 6, 2010 (ML102210351), the applicant stated that laboratory testing will be implemented during the detailed design phase to establish the required density necessary to meet the design requirements of the engineered granular backfill adjacent to Seismic Category I structures. The applicant will implement a program for in-place testing of the engineered granular backfill to confirm that the density selected is based on laboratory test results and thus satisfies the design requirements.

The staff reviewed the responses to RAI 02.05.04-20 and RAI 02.05.04-34. The staff's review focused on the liquefaction potential to ensure that engineered granular backfill adjacent to all Seismic Category I structures is not susceptible to liquefaction. The staff noted that a well-graded granular backfill will be placed in controlled lifts with compaction, which will result in a dense to very dense consistency granular backfill. The staff also noted that the applicant's liquefaction analysis indicated that the backfill adjacent to Category I structures is not susceptible to liquefaction if it is compacted to a $(N_1)_{60}$ value equal to or greater than 30 bpf. Because the granular backfill has not yet been placed, the staff found that the applicant will implement (1) the laboratory testing during the detailed design phase to establish the required density to meet the design requirements of the engineered granular backfill adjacent to Seismic Category I structures; and (2) a program to test the in-place engineered granular backfill, which could consist of the construction of one or more test pads to further confirm the density selected based on laboratory test results that meet the design requirements. The staff thus concluded that the applicant had provided reasonable assurance that the engineered granular backfill adjacent to Seismic Category I structures will not be susceptible to liquefaction. The staff further noted that the applicant has revised the FSAR to provide more information on the liquefaction assessment demonstrating that there is no liquefaction potential for engineered granular backfill adjacent to Seismic Category I structures. Therefore, RAI 02.05.04-20 and RAI 02.05.04-34 are resolved and closed.

To comply with the DCD requirement of COL 2.0-29-A, the staff asked the applicant in RAI 02.05.04-35 to evaluate the localized liquefaction potential under other than Seismic Category I structures and to assess the potential safety implications, especially for those buildings that are adjacent to Seismic Category I structures. In the response to RAI 02.05.04-35 dated September 21, 2010 (ML102660141), the applicant indicated that all non-Seismic Category I SSCs—including the TB, RWB, service building, and ancillary diesel building—are all designed to meet the third criterion of ESBWR DCD Tier 2 Subsection 3.7.2.8, in order to prevent a failure under SSE ground motion conditions. The applicant also indicated that all site-specific, non-Seismic Category I structures meet the first DCD criterion. That means if they should collapse, the non-Seismic Category I SSCs will not strike any Seismic Category I SSCs. The applicant stated that non-Seismic Category I structures that do not satisfy the first criterion in DCD Subsection 3.7.2.8 should be evaluated for potential liquefaction events.

The applicant may use the glacial till removed from under Seismic Category I structures to support non-Seismic Category I structures. The applicant classified the glacial till as lean clay with an average fines content of 68 percent and a plasticity index of 14. The applicant verified that the glacial till satisfies the RG 1.198 guidance for liquefaction, in which cohesive soils with fines contents greater than 30 percent and fines that are classified as clays are either based on the Unified Soil Classification System or have a plasticity index of more than 30 percent and should generally not be considered susceptible for liquefaction. The applicant confirmed that if backfill is placed above the glacial till to the base of a foundation, it will be an engineered backfill with no potential for liquefaction and with quality control and testing.

The staff reviewed the response to RAI 02.05.04-35. The staff noted that non-Seismic Category I structures within the scope of the ESBWR DCD (also called Seismic Category II structures)—including the TB, RWB, service building, and ancillary diesel building—are analyzed and designed to prevent their failure under SSE ground motion conditions in a manner where the margin of safety of these structures is equivalent to that of Seismic Category I structures. The staff further noted that non-Seismic Category I structures outside the scope of the ESBWR DCD are located at least a distance equal to its above-grade height away from Seismic Category I structures. The staff thus concluded that the collapse of any site-specific, non-Seismic Category I SSC will not strike a Seismic Category I SSC. In addition, the staff noted that for the non-Seismic Category I structures that could strike a Seismic Category I structure if the non-Seismic Category I structure were to fail during a seismic event, the subsurface and/or backfill materials founded underneath are not susceptible to liquefaction. The staff also noted that the applicant has revised FSAR Subsection 2.5.4.8 to include the assessment of the potential safety implications from localized liquefaction potential under other than Seismic Category I structures. All non-Category I structures are designed to satisfy either the first criterion specified in Subsection 3.7.2.8 of the ESBWR DCD to provide a sufficient distance between the non-Category I structures and the Seismic Category I structures; or the third criterion to prevent a failure under SSE ground motion conditions. The staff concluded that the potential safety implications resulting from localized liquefaction under other than Seismic Category I structures are not likely to occur. Therefore, RAI 02.05.04-35 is resolved and closed.

Based on the bedrock or fill concrete under Seismic Category I structures and properties of the engineered granular backfill adjacent to Seismic Category I structures described in the above RAI responses, the applicant concluded that liquefaction is not a concern. The staff found the applicant's conclusion reasonable that the liquefaction potential for supporting materials of Seismic Category I structures will not be a concern at the site, because of the fact that the engineered granular backfill will be placed in controlled lifts and compacted to achieve a very dense consistency with relatively high blow counts and V_s value. Regarding the localized liquefaction potential under other than Seismic Category I structures, the staff concluded that the potential safety implications from localized liquefaction under other than Seismic Category I structures are not likely because all non-Seismic Category I structures are designed either to be a sufficient distance from the Seismic Category I structures or to avoid a failure under SSE ground motion conditions. The staff further concluded that the requirement of COL Item COL 2.0-29-A to evaluate the localized liquefaction potential under other than Seismic Category I structures is met. Therefore, the staff concluded that the assessment of the liquefaction potential at the planned Fermi 3 site is adequate and satisfies the requirements of 10 CFR Part 50, Appendix A; 10 CFR Part 50, Appendix S; GDC 2, and 10 CFR 100.23.

2.5.4.4.9 Earthquake Design Basis

The applicant conducted a field exploration using geophysical testing to determine the V_s of soils and bedrock and performed a site response analysis to develop the GMRS for the site. In FSAR Subsection 2.5.4.9, the applicant referred to FSAR Subsection 2.5.2.6 for a description of the methods used to develop the performance-based, site-specific GMRS developed for the Fermi 3 site. The applicant determined the GMRS is in accordance with the guidance in RG 1.208. Subsection 2.5.2.4 of this SER provides the staff's technical evaluation and a complete description of the performance–based GMRS for the Fermi 3 site.

2.5.4.4.10 Static Stability

The staff reviewed FSAR Subsection 2.5.4.10. The staff's review focused on the applicant's analyses performed to evaluate the stability of safety-related structures, including the foundation-bearing capacity and settlement analyses, excavation rebound lateral earth pressures, and hydrostatic pressures.

Bearing Capacity

In FSAR Subsection 2.5.4.10.1, the applicant used Terzaghi (USACE 1994) and the Uniform Building Code (Peck, Hanson, and Thornburn 1974) approaches when evaluating the bearing capacity. In RAI 02.05.04-23, the staff asked the applicant to explain the appropriateness of these two methods by considering the weaker Salina Group Unit F beneath the Bass Islands Group. In the response to RAI 02.05.04-23 dated December 23, 2009 (ML100040548), the applicant indicated that both approaches account for the influence of Salina Group Unit F. The applicant stated that the Terzaghi approach takes into consideration the effect of the weaker zones below the Bass Islands Group and is based on general bearing capacity failure behavior. The Uniform Building Code approach considers the allowable contact pressure on unweathered bedrock under a uniaxial loading condition to assure that the foundation bedrock has sufficient capacity against rupture. In the Uniform Building Code approach, the applicant used a weighted average of the unconfined compression strength of the Bass Islands Group and Salina Group Unit F. The staff asked the applicant in RAI 02.05.04-33 to provide an additional basis for selecting these two approaches for possible failure modes of the foundation rock unit at the site. The staff asked the applicant to take into consideration that the Terzaghi approach is based on a particular class of potential failure mode that involves a homogenous material, and the Uniform Building Code approach is based on information mainly for buildings.

In the response to RAI 02.05.04-33 dated August 6, 2010 (ML102210351), the applicant indicated that these two methods allow evaluations of two general potential bedrock failure modes. The applicant stated that the Terzaghi approach ignores the effects of cohesion and the interlocking of bedrock blocks, which makes it a conservative method for estimating the bearing capacity. The applicant further indicated that the Terzaghi approach addresses a general shear failure, and the Uniform Building Code approach addresses the potential against a rupture of intact bedrock resulting from the foundation loading. The applicant stated that both techniques were applied to account for the variations in bedrock properties.

The staff reviewed the responses to RAI 02.05.04-23 and RAI 02.05.04-33. The staff's review focused on the applied methods for evaluating the bearing capacity, in order to ensure that the approaches are appropriate and adequate to capture bearing capacities associated with possible failure modes for the Fermi 3 site. The staff noted that the bearing capacity evaluations accounted for variations in the depth of bedrock properties by using weighted average properties of the subsurface layers within the foundation zone of influence. Because the average fracture spacing in the bedrock is much smaller than the foundation width based on the RQD for the Fermi 3 site, the staff concurred with the applicant that a general shear failure is a possible failure mode. Therefore, the Terzaghi approach is reasonably applicable. And because the effects of cohesion and the interlocking of bedrock blocks were not taken into account for the evaluation of a general shear failure, the staff found that the result from the Terzaghi approach represents a conservative bearing capacity. As for the Uniform Building Code approach, the staff noted that it encompasses an empirical relationship by using 20 percent of the unconfined compressive strength to estimate the allowable pressure on the bedrock. Finally, after reviewing the Terzaghi and Uniform Building Code approaches and the information in Table 2.5.4-3 of this SER, the staff concluded that the bearing capacities evaluated with both approaches exceed the safety margins when compared to the bearing demands of the ESBWR DCD. Therefore, RAI 02.05.04-23 and RAI 02.05.04-33 are resolved and closed.

The staff asked the applicant in RAI 02.05.04-22 to justify the use of the upper bound Hoek-Brown effective angle of friction and cohesion for the Bass Islands Group bearing capacity but the lower bound values for the Salina Group Unit F bearing capacity. In the response to RAI 02.05.04-22 dated January 11, 2010 (ML100130382), the applicant compared the average elastic modulus based on pressuremeter testing to the elastic modulus using the Hoek-Brown criterion for Salina Group Unit F, and concluded that the measured elastic modulus was close to the lower elastic modulus based on the Hoek-Brown criterion. However, for the Bass Islands Group, the applicant indicated that the upper bound Hoek-Brown effective angle of friction of 53 degrees matches well with the mean residual friction angle of 52 degrees, which was measured from a direct rock shear test of discontinuities.

In RAI 02.05.04-32, the staff asked the applicant to discuss why a lower value of measured effective friction angle φ'—such as mean φ' minus one standard deviation— was not used to account for the variability of the test and to provide the basis for concluding that using the upper bound Hoek-Brown cohesion is appropriate for the Bass Islands Group in terms of matching well with the measured mean φ'. In the response to RAI 02.05.04-32 dated August 6, 2010 (ML102210351), the applicant calculated the mean residual friction angle of the Bass Islands Group using the test results for the fractures. The applicant considered the measured values from the direct testing of bedrock discontinuities to be representative of the lower values of strength along fractures. The applicant concluded that the calculated mean residual friction angle is appropriate for establishing the design shear strength parameter, because it represents the friction angle on a fracture after enough displacement has occurred to reach the steady-state resistance along the fracture, making it representative of the lower bound value for a fracture. In addition, the applicant indicated that the disturbance of the fractures during bedrock coring and preparation for testing resulted in reduced measured friction angles, and that further reduction in the measured residual friction angles by one standard deviation is not considered necessary. The applicant conducted the bearing capacity analyses of the RB/FB and CB without considering cohesion, and therefore removed the reference to the cohesion values for the Bass Islands Group and the Salina Group Unit F bedrock.

Furthermore, in RAI 02.05.04-21, the staff asked the applicant to provide information regarding the appropriateness of normal stress values used in the direct shear stress tests and applied to find the φ' for the Bass Islands Group. In the response to RAI 02.05.04-21 dated January 11, 2010 (ML100130382), the applicant indicated that the applied normal stresses selected for the direct shear test were the estimated in situ vertical stresses at the time of subsurface investigation. The applicant added that the normal stress used falls within the range of confining pressure used to estimate Mohr-Coulomb parameters using the Hoek-Brown criterion.

The staff reviewed the responses to RAI 02.05.04-21, RAI 02.05.04-22, and RAI 02.05.04-32 with the focus on confirming that the Hoek-Brown criterion is properly and conservatively applied to determine the Mohr-Coulomb parameters for bearing capacity evaluations. Based on the review of the responses to RAI 02.05.04-2 and its followup RAI 02.05.04-29, as described in Subsection 2.5.4.4.2 of this SER, the staff concluded that the direct shear test results from samples with horizontal or near horizontal fractures are representative of lower bound strength within the Bass Islands Group. Accordingly, the staff also concluded that the mean residual friction angle of the Bass Islands Group that was calculated from the test results of the fractures is also appropriate and conservative for establishing the friction angle φ' parameter. The staff also noted that the measured friction angle φ' values were not available for the Salina Group Unit F bedrock because samples of representative material could not be collected. The staff further noted that the average measured elastic modulus based on pressuremeter testing is close to the lower elastic modulus based on the Hoek-Brown criterion. Therefore, the staff concluded that it is reasonable to assume the lower bound friction angle φ' from the Hoek-Brown criterion for the Salina Group Unit F bedrock. Regarding the cohesion property, the staff noted that the cohesion is not taken into account for the bearing capacity analyses of the RB/FB and the CB. As a result of the RAIs, the applicant removed the reference to the cohesion values for the bearing capacity evaluation for the Bass Islands Group and Salina Group Unit F bedrock. The staff confirmed that this change was made in the revised FSAR. The staff also reviewed the normal stress values applied to the direct shear stress tests and noted that the applied normal stresses fall within the range of lower and upper bound confining pressures estimated using the Hoek-Brown criterion. Therefore, the staff concluded that the normal stresses used represent the in situ effective vertical stresses and the direct shear test results are dependable. Finally, the staff concluded that the calculated bearing capacities based on these conservatively assumed parameters still provide large safety margins against the bearing demands. RAI 02.05.04-21, RAI 02.05.04-22, and RAI 02.05.04-32 are therefore resolved and closed.

Rebound due to Excavation and Settlement Analyses

The staff reviewed Subsection 2.5.4.10.2 related to the methods and practices used by the applicant to evaluate the excavation rebound and the potential settlement of the foundations. For the settlement analysis, the applicant selected the lower bound E based on the Hoek-Brown criterion for each bedrock unit because the average E of the bedrock units will be greater than the lower bound E from the aforementioned criterion. Therefore, in RAI 02.05.04-24, the staff asked the applicant to provide information on how the modulus values were developed and to provide the basis for the assumption that the average E of the bedrock units will be greater than the lower bound E from the Hoek-Brown criterion. Also, the staff asked the applicant to explain any unconfined compression tests conducted under the safety-related foundations, and to provide additional information on the appropriateness of the selected modulus values in affecting the result of the differential settlement evaluation and total rebound.

In the response to RAI 02.05.04-24 dated January 11, 2010 (ML100130382), the applicant explained the rationale as to why the average E of the bedrock units is greater than the lower bound E from the Hoek-Brown criterion (1) by providing the ratio of E based on laboratory tests to the E based on the average V_s for the Bass Islands Group and Salina Group Units F, E, C and B; and (2) by comparing the ratios to the lower and upper bound of the Hoek- Brown criterion. The applicant concluded that for Salina Group Units F, E, and C and the Bass Islands

Group, the calculated E from average V_s and laboratory tests are both greater than the upper bound E based on the Hoek-Brown criterion. The applicant concluded that the calculated E based on the average V_s falls within the upper and lower bound E based on the Hoek-Brown criterion for Salina Group Unit B, which was also the same for Salina Group Unit F based on the pressuremeter test. FSAR Table 2.5.4-222 presents the unconfined compression test conducted close to or below the safety-related foundations. Table 2.5.4-5 of this SER summarizes the values of the average elastic modulus based on laboratory unconfined compression test results (E_{lab}) and the lower bound elastic modulus based on the Hoek-Brown criterion (E_{HBlow}). The applicant indicated that for bedrock with an RQD greater than 70 percent, E_{lab} is 1.4 to 1.9 times higher than E_{HBlow}. The applicant concluded that as the RQD decreases, the ratio E_{lab} / E_{HBlow} increases. The applicant also performed the settlement analysis using a 3D finite element program capable of calculating settlement caused by non-symmetrical loading induced by adjacent buildings in the power block area. The applicant reaffirmed the appropriateness and conservativeness of the selected modulus values, thus indicating that the site stratigraphy is relatively uniform; the subsurface material properties are consistent; and the obtained lower bound elastic modulus based on the Hoek-Brown criterion is significantly lower than the average elastic modulus obtained based on laboratory and in situ measurements.

Table 2.5.4-5 Average Elastic Modulus and Lower Bounds Elastic Modulus
(Reproduced from Table 1 in the response to RAI 02.05.04-24 dated January 11, 2010 [ML100130382])

Rock Unit		**Average RQD**	**Average Modulus of Elasticity based on Laboratory Tests (E_{lab})**	**Lower Bound Elastic Modulus based on Hoek-Brown Criterion ($E_{HB,low}$)**	**Ratio $E_{lab}/E_{HB,low}$**
		%	MPa (ksf)	MPa (ksf)	
Bass Island Group		54	43,025 (898,600)	2,870 (59,900)	15.0
Salina Group	Unit F	13	25,340 (529,200)	924 (19,300)	27.4
	Unit E	72	32,150 (671,500)	16,710 (349,000)	1.9
	Unit C	97	36,540 (763,200)	23,080 (482,100)	1.6
	Unit B	97	72,050 (1,504,800)	52,800 (1,102,700)	1.4
Ksf = kip per square-foot; MPa = megapascal					

The staff's review of the response to RAI 02.05.04-24 focused on the E values of the bedrock units to ensure that these values were realistically but conservatively estimated for settlement evaluation. The staff noted that the applicant had used four different methods to determine the E values of the bedrock units including the stress-strain curve from laboratory unconfined compression tests, the wave equation obtained by solving 3D equations of motion using mean V_s from P-S suspension, an empirical approach using the Hoek-Brown criterion, and the stress-strain curve from the results of in situ pressuremeter testing. Because these methods are commonly applied in evaluations of the rock mass E values, the staff concluded that the methods the applicant had employed to estimate E values are appropriate and adequate. The staff also found that the E values from different methods tend toward conformity as their RQD increases, which indicates that the applied methods are reliable. The staff further noted that among the four different methods, the lower bound E from the Hoek-Brown criterion provides the lowest value, as indicated in Table 2.5.4-6 of this SER. Accordingly, the staff concluded that it is conservative to estimate the settlements using the lower bound elastic modulus obtained based on the Hoek-Brown criterion. In addition, the staff noted that unconfined compression tests were conducted with bedrock samples from ten borings that are located close to or below the safety-related foundations based on the sample depths. Therefore, the staff also agreed with the applicant that the settlement estimates based on the lower bound elastic modulus obtained using the Hoek-Brown criterion represent the upper limit estimates, which meet the acceptance criteria required in the ESBWR DCD. Therefore, RAI 02.05.04-24 is resolved and closed.

The applicant based the settlement calculation on the referenced excavated level (rebounded position). Because the soil under the FWSC to the top of the bedrock will be removed, and noting that the referenced position is important to determine the FWSC settlements, the staff asked the applicant in RAI 02.05.04-25 to provide the rebound values at the excavated level and to clarify the referenced position of the settlement analysis for the FWSC. The staff also asked the applicant to describe the loading and construction procedures and to explain how the rebound at the excavation level is taken into account at the FWSC. In the response to RAI 02.05.04-25 dated January 11, 2010 (ML100130382), the applicant provided the rebound values for the excavation of the FWSC at the top of the Bass Islands Group and stated that the settlement of the FWSC was not calculated from the rebound position with the excavation level at the top of the bedrock. In a finite element analysis, the applicant simulated the FWSC construction sequence to estimate the settlement and stress changes. The first stage of the sequence was to simulate the excavation, the second stage to simulate the backfill placement, third stage to introduce loads of structures at the foundation level, and the fourth stage to introduce the engineered granular backfill around the FWSC and other structures. The applicant indicated that the settlement associated with the backfill should not be accounted for in the total settlement of the FWSC foundation because, it occurs as the backfill is placed before the construction of the FWSC.

Table 2.5.4-6 Summary of Modulus of Elasticity of Bedrock Units based Test Results, and Hoek-Brown Criterion

(Reproduced from Fermi COL FSAR Table 2.5.4-228)

Rock Unit		Average Modulus of Elasticity based on Laboratory Test	Elastic Modulus of Elasticity based on Average V_s	Elastic Modulus based on Hoek-Brown Criterion			Average Modulus of Elasticity based on Pressuremeter Test
				Upper Bound	Mean	Lower Bound	
Bass Island Group		43,025 (898,600)	26,630 (556,200)	5,240 (109,500)	3,860 (80,700)	2,870 (59,900)	Not measured
Salina Group	Unit F	25,340 (529,200)	6,350 (132,600)	1,520 (31,700)	1,160 (24,200)	924 (19,300)	995 (20,800)
	Unit E	32,150 (671,500)	36,190 (755,800)	23,560 (492,100)	20,310 (424,200)	16,710 (349,000)	Not measured
	Unit C	36,540 (763,200)	48,240 (1,007,600)	29,830 (623,000)	26,780 (559,300)	23,080 (482,100)	
	Unit B	72,050 (1,504,800)	55,390 (1,156,900)	63,430 (1,324,700)	58,820 (1,228,400)	52,800 (1,102,700)	
*All units are in MPa (ksf) Ksf = kip per square-foot; MPa= megapascal							

The staff reviewed the response to RAI 02.05.04-25, including the impact on rebound and settlement calculations for the FWSC from the excavation and the construction sequence. The staff noted that the applicant had applied an appropriate excavation and construction sequence for the FWSC to calculate the rebound at the top of the Bass Islands Group bedrock during the excavation. The staff also noted that the applicant had clarified that the presented total foundation settlement for the FWSC is referenced to the top of concrete backfill and not to the rebound position. Therefore, the staff agreed with the applicant that the settlement of the FWSC foundation is triggered by the loadings of the FWSC structure and the backfill above the foundation level; and the rebound position at the top of the bedrock under the FWSC is not used to estimate the FWSC settlements. Because the applicant had clarified the excavation and construction sequence for the FWSC, the staff concluded that the total settlement analysis of the FWSC is not influenced by the rebound position at the excavation level. Consequently, RAI 02.05.04-25 is resolved and closed.

Lateral Earth Pressures

The staff's review of FSAR Subsection 2.5.4.10.3 focused on the lateral earth pressures calculation. The applicant used a surcharge pressure of 24 kPa (500 psf) to represent the compaction of the backfill behind the rigid retaining wall. In RAI 02.05.04-26, the staff asked the applicant to provide information regarding the basis for adopting a surcharge pressure of 24 kPa (500 psf). In the response to RAI 02.05.04-26 dated January 11, 2010 (ML100130382), the applicant presented a figure to illustrate the configuration of the increase in the lateral earth pressure associated with compaction and the formula used to evaluate the lateral pressure on the wall due to backfill compaction. The applicant's calculation showed that the lateral earth pressure was approximately 23 kPa (484 psf), assuming a small size vibratory soil compactor.

Based on Black and Veatch (2007), the applicant stated that the 24 kPa (500 psf) compacted surcharge was appropriate for the additional compaction surcharges that are developed, thus indicating that the calculated lateral earth pressure of 23 kPa (484 psf) was less than those proposed. The applicant will apply at-rest lateral earth pressure at depths where the at-rest lateral earth pressures are greater than 24 kPa (500 psf).

The staff's review of the response to RAI 02.05.04-26 focused on the lateral earth pressure attributable to a surcharge pressure from compaction of backfill to ensure that the lateral earth pressure associated with compaction is adequately and appropriately taken into account. The staff reviewed the detailed calculation and found that the lateral earth pressure induced by small size compaction equipment was considered in the evaluation of the lateral earth pressure.

NRC Staff's Conclusion Regarding Static Stability

Based on the staff's review of the information in FSAR Subsection 2.5.4.10 and the applicant's responses to RAIs described in Subsection 2.5.4.4.10 of this SER, the staff concluded that the applicant has provided sufficient information in FSAR Subsection 2.5.4.10 which includes a static and dynamic bearing capacity evaluation; total and differential settlement evaluation; and a lateral earth pressure evaluation to meet the standard design values and to satisfy the applicable requirements of 10 CFR Part 50, Appendix S; 10 CFR Part 50, Appendix A GDC 2; and 10 CFR 100.23.

2.5.4.4.11 Design Criteria

FSAR Subsection 2.5.4.11 refers to ESBWR DCD Tier 2 Table 2.0-1 for a description of the standard site parameters, such as the allowable static and dynamic bearing capacity, liquefaction potential; angle of internal friction; and maximum settlement values and V_s. The ESBWR DCD latest revision changed significantly from the revision used by the applicant. Therefore, the staff asked the applicant in RAI 02.05.04-27 to demonstrate that the Fermi 3 site meets the revised ESBWR DCD requirements in terms of the friction angle; bearing capacity analysis; and minimum V_s. In the response to RAI 02.05.04-27 dated February 15, 2010 (ML100540502), the applicant demonstrated that the in situ material and backfill meet the requirement of the angle of internal friction of more than 35 degrees. The applicant indicated that the residual friction angle along the discontinuities had a mean of 52 degrees, and the estimated friction angle for the Bass Islands Group dolomite bedrock had a mean of 48 degrees. The applicant stated that the well-graded granular backfill will be placed in controlled lifts with compaction, and it will result in a dense to very dense engineered backfill with values for relative density in the range of 65 to 100 percent. Based on the Naval Facilities Engineering Command Soil Mechanics Design Manual 7.01 (NFEC 1986), the applicant indicated that for soils with a relative density greater than 65 percent, the angle of internal friction will be greater than 35 degrees.

In order to meet the criteria stipulated in Note 7 of the ESBWR DCD Tier 2 Table 2.0-1, the applicant performed the corresponding changes to the values of the dynamic loading conditions to provide the correct data for the comparison between the maximum dynamic bearing demand and the allowable bearing pressure.

To be in accordance with Note 8 of the ESBWR DCD Tier 2 Table 2.0-1, the applicant demonstrated that the V_s at minus one sigma from the mean were enveloped by the site-related minimum V_s parameter. The applicant performed soil amplification analyses for the RB/FB, CB, and FWSC soil profiles and obtained the response motions at the foundation level. The applicant sorted the iterated V_s into rank order and obtained the 16^{th}, 50^{th}, and 84^{th} percentiles V_s profile at the seismic strain. The applicant stated that the 16^{th} percentiles represent the mean minus one standard deviation and meet the criteria for the minimum V_s parameter as referenced in the ESBWR DCD.

The staff's review of the response to RAI 02.05.04-27 focused on foundation materials to ensure their properties meet the updated requirements from the ESBWR DCD updates to the site parameters. The staff concluded that the applicant had addressed all changes needed according to the latest revision of the ESBWR DCD. Based on the applicant's information, the staff also concluded that the site foundation material properties meet the updated requirements of the ESBWR DCD. As a result of this RAI, the applicant updated the FSAR. The staff confirmed that these updates are reflected in the revised FSAR. Based on the fact that the updated requirements of the ESBWR DCD have been met, RAI 02.05.04-27 is resolved and closed.

The staff reviewed the sections of the FSAR containing the geotechnical design criteria and determined that they contained sufficient details to meet the requirements of 10 CFR Part 50 and Part 100. Based on this review, the staff concluded that the applicant's design criteria for the Fermi 3 site are acceptable and meet the requirements of the applicable regulations.

2.5.4.4.12 Techniques to Improve Subsurface Conditions

In FSAR Subsection 2.5.4.12, the applicant stated that any area with open fractures in exposed foundation bedrock of the RB/FB and the CB will be filled with fill concrete. For the FWSC, the applicant stated that all soils will be removed below the foundation to the top of the bedrock and will be replaced with fill concrete to improve subsurface conditions. The staff reviewed this information and concluded that the plan for subsurface improvements will ensure the stability of the foundation and the structures to be built at this site. Therefore, the applicant's improvements satisfy the requirements of 10 CFR 100.23. The staff therefore concluded that the techniques presented to improve subsurface conditions of the Fermi 3 site are acceptable.

2.5.4.5 *Post Combined License Activities*

The applicant identifies the following commitment and ITAAC:

- Commitment (COM 2.5.4-001) – Develop a Contingency Plan for mitigation of any settlement before the start of the Fermi 3 construction.

- ITAAC Table 2.4.1-1 – Site-specific ITAAC for the fill concrete under Seismic Category I structures.

- ITAAC Table 2.4.2-1 – Site-specific ITAAC for the backfill surrounding Seismic Category I structures.

- License Condition 2.5.3-1- Geologic Mapping License Condition

2.5.4.6 *Conclusion*

NRC staff reviewed the application and confirmed that the applicant has addressed the required information, and no outstanding information is expected to be addressed in the Fermi 3 COL FSAR related to this section.

In addition, the staff compared the additional information in the COL application to the relevant NRC regulations, the guidance in Section 2.5.4 of NUREG–0800, and applicable NRC regulatory guides. The staff's review concludes that the applicant has provided sufficient information to satisfy the requirements of NRC regulations. The staff determined that the applicant has adequately addressed COL Item EF3 COL 2.0-29-A, as it relates to the stability of subsurface materials and foundations.

The staff's review concludes that the applicant has adequately determined the engineering properties of the soil and rock underlying the Fermi 3 site through field and laboratory investigations. The applicant used the latest field and laboratory methods in accordance with the guidance in RG 1.132, RG 1.138, and RG 1.198 to determine the required site-specific engineering properties for the Fermi 3 site and to ensure that those properties meet the design criteria outlined in the ESBWR DCD. Accordingly, the staff concludes that the applicant has performed sufficient field investigations and laboratory testing to determine the overall subsurface profile and the properties of the soil and rock underlying the Fermi 3 site. Specifically, the staff concludes that the applicant has adequately determined (1) the soil and rock dynamic properties through field investigations and laboratory tests; (2) the response of the soils and rocks to dynamic loading; and (3) the liquefaction potential of the soils.

As set forth above, the applicant presented and substantiated the necessary information to establish the geotechnical engineering characteristics of the Fermi 3 site. The staff reviewed the information and concludes that the applicant has performed sufficient investigations at the site to justify the soil and rock characteristics used in the ESBWR design, and the design analyses contain adequate margins of safety for the construction and operation of the nuclear power plant and meet the requirements of 10 CFR Part 50, 10 CFR Part 52, and 10 CFR 100.23.

2.5.5 Stability of Slopes

2.5.5.1 *Introduction*

This FSAR section addresses the stability of all earth and rock slopes, both natural and manmade (cuts, fill, embankments, dams, etc.) whose failure, under any of the conditions to which they could be exposed during the life of the plant, could adversely affect the safety of the plant. The topics that the staff evaluated based on the data provided by the applicant in the FSAR and information available from other sources are (1) slope characteristics; (2) design criteria and design analyses; (3) results of the investigations including borings, shafts, pits, trenches, and laboratory tests; (4) properties of borrow material, compaction, and excavation specifications; and (5) any additional information to meet requirements prescribed within the "Contents of Application" sections of the applicable subparts to 10 CFR Part 52.

2.5.5.2 *Summary of Application*

Section 2.5.5 of the Fermi 3 COL FSAR addresses the stability of all earth and rock slopes, both natural and manmade. In addition, in FSAR Section 2.5.5, the applicant provides the following:

COL Item

- EF3 COL 2.0-30-A Stability of Slopes in Accordance with SRP 2.5.5.

In FSAR Section 2.5.5, as summarized below, the applicant discusses the resolution of COL Item EF3 COL 2.0-30-A by providing site-specific information in accordance with SRP Section 2.5.5.

2.5.5.2.1 Slope Characteristics

FSAR Subsection 2.5.5.1 provides a general discussion of the slope characteristics including the slope materials, properties, groundwater, and seepage. The applicant indicated that in the Fermi 3 site area, there is no evidence of past instability or potentially unstable conditions. The applicant will place backfill in the water channels located west of the Fermi 3 site, and as a consequence, the applicant indicated that no natural or man-made slopes will be in the proximity of the site. The applicant established the grade for the power block area at an elevation of 179.6 m (589.3 ft) NAVD 88. The applicant used a slope of 12.5 horizontal to 1 vertical (12.5:1) and an 8 percent (4.5 degrees) slope angle away from the structures. The applicant concluded that slope stability in the fill will not impact Seismic Category I structures, because the foundations for all Seismic Category I structures are founded on bedrock or fill concrete that extends to the bedrock. The applicant's assumed groundwater level is at an elevation of 178.4 m (585.4 ft) NAV 88, which is equal to the flood level associated with the design basis Probable Maximum Flood (PMF). The applicant's estimated hydraulic conductivity is 76.5 to 541 m/day (251 to 1,776 ft/day). FSAR Subsection 2.5.5.1.2 refers to FSAR Subsection 2.5.4.2 and Section 2.4.12 for a detailed discussion of the subsurface material properties and the groundwater, respectively.

2.5.5.2.2 Design Criteria and Analyses

FSAR Subsection 2.5.5.2 states that the slope angle is 6.5 times less than the minimum required effective angle of internal friction for the engineered backfill or existing fill. The applicant concluded that the finished site grade has no impact on the site safety-related SSCs.

2.5.5.2.3 Boring Logs

FSAR Subsection 2.5.5.3 refers to FSAR Subsection 2.5.4.2 for a discussion of the exploration program and the drilling and sampling procedures. FSAR Appendix 2.5DD includes the soil and rock boring logs in the vicinity of the excavation.

2.5.5.2.4 Compacted Fill

The applicant will follow the backfilling and quality control requirements in the placement and compaction of the fill. The applicant indicated that the source of the fill material will be from the construction excavation or imported from local quarries.

2.5.5.3 *Regulatory Basis*

The relevant requirements of the Commission regulations for the stability of slopes, and the associated acceptance criteria, are in Section 2.5.5 of NUREG–0800. The applicable regulatory requirements are as follows:

- 10 CFR Part 50, Appendix A, GDC 2 as it relates to the consideration of the most severe natural phenomena historically reported for the site and surrounding area, with a sufficient margin for the limited accuracy, quantity, and period of time that the historical data were accumulated.

- 10 CFR Part 50, Appendix S, as it applies to the design of nuclear power plant structures, systems, and components important to safety to withstand the effects of earthquakes.

- 10 CFR 100.23 provides the nature of the investigations required to obtain the geologic and seismic data necessary to determine site suitability and to identify geologic and seismic factors required to be taken into account in the siting and design of nuclear power plants.

The related acceptance criteria from Section 2.5.5 of NUREG–0800 are as follows:

- <u>Slope Characteristics</u>: To meet the requirements of 10 CFR Part 50 and 10 CFR Part 100, the discussion of slope characteristics is acceptable if the subsection includes (1) cross sections and profiles of the slope in sufficient quantity and detail to represent the slope and foundation conditions; (2) a summary and description of static and dynamic properties of the soils and rocks comprised of seismic Category I embankment dams and their foundations, natural and cut slopes, and all soil or rock slopes whose stability would directly or indirectly affect safety-related and Category I facilities; and (3) a summary and description of groundwater, seepage, and high and low groundwater conditions.

- <u>Design Criteria and Analyses</u>: To meet the requirements of 10 CFR Part 50 and 10 CFR Part 100, the discussion of design criteria and analyses is acceptable if the criteria for the stability and design of all Seismic Category I slopes are described and valid static and dynamic analyses are presented to demonstrate that there is an adequate margin of safety.

- <u>Boring Logs</u>: To meet the requirements of 10 CFR Part 50 and 10 CFR Part 100, the applicant should describe the borings and soil tests carried out for slope stability studies and dam and dike analyses.

- <u>Compacted Fill</u>: To meet the requirements of 10 CFR Part 50, the applicant should describe the excavation, backfill, and borrow material planned for any dams, dikes, and embankment slopes.

In addition, the geologic characteristics should be consistent with appropriate sections in RG 1.27, RG 1.28, RG 1.132, RG 1.138, RG 1.198, and RG 1.206.

2.5.5.4 *Technical Evaluation*

NRC staff reviewed Section 2.5.5 of the Fermi 3 COL FSAR related to stability of slopes as follows:

COL Item

- EF3 COL 2.0-30-A Stability of Slopes

This COL item requires the applicant to provide site-specific information in accordance with SRP Section 2.5.5. The NRC staff's evaluation of COL Item EF3 COL 2.0-30-A is presented below.

2.5.5.4.1 Slope Characteristics

FSAR Subsection 2.5.5.1 provides the applicant's general discussion of the slope characteristics including the slope materials, properties, groundwater, and seepage. The applicant noted the existing water channels located west of the Fermi 3 site and plans to backfill them as part of the site development. The applicant therefore stated that there are no natural or manmade slopes, dams, embankments, or channels on or in the proximity of the Fermi 3 site. The applicant also stated that the finished grade for the Fermi 3 site will be relatively flat, with an 8 percent slope angle down from the periphery of the power block fill area without cut slopes. In addition, the applicant stated that slope stability in the fill will not impact Seismic Category I structures because the foundations for all Seismic Category I structures are founded on bedrock or concrete fill that extends to the bedrock. The applicant also discussed the groundwater and seepage conditions at the site.

The staff reviewed the site grade plan and foundation excavation sections as provided in FSAR Section 2.5.4. The staff also examined the site during the site audit (November 3–5, 2009, (ML14112A212). The staff also reviewed the site boring logs, the site subsurface soil profile, and the hydraulic conductivity properties of the soil to evaluate the seepage condition. The staff's analysis of these inputs is in Section 2.5.4 of this SER.

The staff's review determined that (1) all Seismic Category I structures will be founded on bedrock or fill concrete that extends to the bedrock, so a slope failure will not affect the safety of the structures; and (2) the existing water channels located west of the Fermi 3 site will be backfilled during construction; therefore, the water channels will not affect the safety of the structures. Based on these findings, the staff concluded that no slope failure at the site will adversely affect the safety of the nuclear power plant structures; and the applicant has provided sufficient information in FSAR Subsection 2.5.5.1 to satisfy the applicable criteria of 10 CFR Part 50 and Part 100.

2.5.5.4.2 Design Criteria and Analyses

In FSAR Subsection 2.5.5.2, the applicant concluded that the finished site grade has no impact on the site safety-related system structures or components. In RAI 02.05.05.1, the staff asked the applicant to provide information on seismically induced lateral spreading and to discuss the monitoring plans during and after construction to detect occurrences that could affect the facility.

In the response to this RAI dated February 11, 2010 (ML100570311), the applicant stated that according to Youd et al. (2001), if the site is nonliquefiable, then a lateral spread will not occur. Also, the applicant stated that a liquefiable layer with all SPT $(N_1)_{60}$ values greater than 15 is too dense and dilative for a lateral spread to occur. Therefore, the applicant concluded that because the engineered granular backfill used in the site is not susceptible to liquefaction, lateral spreading will not occur at the Fermi 3 site. The applicant indicated that heave monitoring is not needed, because the expected rebound heave from the foundation excavation is less than 12.7 mm (0.5 in.). The applicant predicted that the settlement will be within the

ESBWR DCD limits. To confirm the predictions, the applicant established benchmarks at the corners of selected Seismic Category I structures; at 1 m (3 ft) above the site grade; and connected to the sidewalls. The applicant indicated that the monitoring will continue until 90 percent of the expected settlement has occurred or until the rate of settlement has virtually stopped. The applicant stated that because there is no man-made earth or rock dams on the site and no anticipated seepage, no shallow sloping ground and no lateral spreading concern, the periodic examination of slopes, monitoring evidence for seepage and measurement of locals well and piezometer are not necessary after construction.

The staff's review of the response to RAI 02.05.05-1 focused on the potential for liquefaction-induced lateral spreading and its monitoring plans. The staff noted that all Seismic Category I structures are founded on either bedrock or fill concrete. The staff reviewed the applicant's response to RAI 02.05.04-20, which is documented in Subsection 2.5.4.4.6 of this SER. The staff concluded that the engineered granular backfill surrounding the Seismic Category I structures and used to develop the remainder of the site is not susceptible to liquefaction because of the $(N_1)_{60}$ values. Therefore, the staff concluded that seismically induced lateral spreading is not likely to occur. RAI 02.05.05-1 is therefore resolved and closed.

The staff considered the permanent slopes to be stable because the 8 percent (4.6 degrees) maximum permanent slope angle for the Fermi 3 site in the power block area or elsewhere is 7.6 times less than the minimum required effective angle of internal friction of 35 degrees for the engineered fill or existing fill. Based on this finding, the staff concluded that no slope failure at the site will adversely affect the safety of the nuclear power plant structures. Therefore, no slope stability analysis is necessary for the Fermi 3 site.

2.5.5.4.3 Boring Logs

The applicant provided boring logs in FSAR Appendix 2.5DD. The staff reviewed the applicant's exploration program, and the drilling and sampling procedures that are discussed in FSAR Subsection 2.5.4.2. The staff concluded that the applicant's information satisfies the requirements of 10 CFR Part 50 and Part 100.

2.5.5.4.4 Compacted Fill

In FSAR Subsection 2.5.5.4, the applicant indicated that the source of the fill material will be from onsite the construction excavation or imported from local quarries. The staff reviewed FSAR Subsection 2.5.4.5, which describes the specific property requirements, site preparation, fill placement, compaction requirements, and the proper verification and installation of the engineered granular fill. The staff concluded that this information is an acceptable consideration of compacted fill properties and it satisfies the requirements of 10 CFR Part 50.

2.5.5.5 *Post Combined License Activities*

There are no post COL activities related to this section.

2.5.5.6 *Conclusion*

NRC staff reviewed the application and confirmed that the applicant has addressed the required information, and no outstanding information is expected to be addressed in the COL FSAR related to this section.

In addition, the staff compared the additional information in the COL application to the relevant NRC regulations, the guidance in Section 2.5.5 of NUREG–0800, and applicable NRC regulatory guides. The staff's review concludes that the applicant has provided sufficient information to satisfy the requirements of NRC regulations. The staff determined that the applicant has adequately addressed COL Item EF3 COL 2.0-30-A, as it relates to the stability of slopes.

The staff's review concludes that the applicant has presented and substantiated information to assess the stability of all earth and rock slopes, both natural and man-made, at the Fermi 3 site. The staff reviewed the site investigations related to slope stability and concludes that (1) there are no natural or man-made slopes that could adversely affect the Fermi 3 Seismic Category I structures; (2) no safety-related retaining walls, bulkheads, or jetties are required for the site; and (3) no man-made earth or rock dams are on the site that could adversely affect the safety of the nuclear plant facilities. The staff further concludes that the applicant has provided sufficient information to meet the requirements of 10 CFR Part 50, Appendix A; GDC 2; 10 CFR Part 50, Appendix S; and 10 CFR 100.23.