Section 2.5 – Geology, Seismology, and Geotechnical Engineering

(Applies to RAIs 2.5-1 through 4)

> *NUREG-1537, Part 1, Section 2.5.2, "Site Geology," states, in part, "[t]he applicant should discuss in detail the structural geology at the facility site, including the relationship of site structure to regional tectonics, and should pay particular attention to specific structural units of significance to the site such as, folds, faults, synclines, anticlines, domes, and basins."*

RAI 2.5-1

SHINE PSAR, Section 2.5.1.4, "Structural Geology," provides a discussion of the major faults and folds and concludes that many of the faults are not capable based upon lack of evidence for Pleistocene or post-Pleistocene displacement. As noted in SHINE PSAR, Section 2.5.1, "Regional Geology," Appendix A of 10 CFR Part 100 defines a capable fault as a fault with "[m]ovement at or near the ground surface at least once within the past 35,000 years or movement of a recurring nature within the past 500,000 years."

Provide additional information explaining the basis for the determination that there are no capable faults, and provide additional information with respect to the recurring nature of the faults.

SHINE Response

Subsection 2.5.1.4 of the PSAR describes the geological structures mapped within approximately 200 miles of the SHINE site. The amount and quality of information on the precise fault locations are variable. Information on the history of structural development and the time since last displacement is also highly variable. Because most of the mapped faults are covered by glacial and glacial outwash sediments deposited during multiple continental ice sheet advances and retreats, fault locations and offsets have typically been evaluated from subsurface investigations (e.g., groundwater borehole logs, magnetic and gravity anomalies, seismic reflection/refraction surveys).

The current scientific consensus is that faults mapped within the basement and bedrock within 200 miles of the SHINE site are not capable faults. This consensus is based on:

- Published interpretations of the structural geologic development that indicates that most of the basement and bedrock faults formed and accumulated displacement during the Paleozoic Era;
- Regional and fault-specific studies for groundwater exploration that indicate that the larger faults (e.g., Waukesha fault) have no evidence for offset of the Quaternary glacial sediments;
- Paleoliquefaction features that appear limited to the Wabash Valley and New Madrid areas having possible sources located more than about 200 miles from the SHINE site; and
- Similar studies of faults and fault activity undertaken for two nuclear safety analyses in Wisconsin and Illinois completed in the last 10 years (References 9 and 10).

Most of the fault and fold structures in geologic maps appear to have been active during the early to middle Paleozoic Era, as judged by the varying vertical offsets of the Paleozoic bedrock units. A few of the mapped faults (e.g., Northern Wisconsin faults) appear to have been active in pre-Paleozoic time because they affect only the older basement rocks. In the absence of a Paleozoic sedimentary cover, however, these basement faults may also be similar in age to those that offset the Paleozoic sedimentary rocks farther south.

Because much of eastern Wisconsin and Illinois were ice-covered (glaciated) until late into the Wisconsin glaciation period, only those faults that have ruptured to the ground surface in the last 11,000 years have the potential to preserve surface traces. Similarly, in southeast Wisconsin and western Illinois, much of the land surface was ice-covered from Illinoian glaciation, so only those faults that have moved since the last glaciation period have the potential to preserve surface traces. Only those faults mapped within the driftless section of western Wisconsin, southeast Minnesota, and northeast Iowa that have not been glaciated in the Quaternary Period have the potential to preserve faults scarps showing surface evidence for repeated movement in the last 500,000 years.

Liquefaction features within the Wabash Valley suggest at least seven Holocene earthquakes and one late Pleistocene earthquake have occurred. Individual earthquakes are recognized from the timing of liquefaction features, the regional pattern of liquefaction effects, and geotechnical testing results. Although the fault or faults that that may have generated the Wabash Valley liquefaction features have not been identified, the liquefaction features appear to have originated from earthquakes centered in southern Indiana and Illinois, more than 200 miles from the SHINE site.

Accordingly, with the exception of unidentified possible faults beneath the Wabash Valley, the faults mapped within 200 miles of the SHINE site are not capable faults. The fault or fault sources of the multiple earthquakes that generated the Wabash Valley liquefaction features are yet to be identified. Once identified, however, these fault(s) would be considered as capable as defined in 10 CFR 100.

<u>RAI 2.5-2</u>

SHINE PSAR, Section 2.5.1.4.6, "Saint Charles Lineament (SCL)," states, in part, "[s]ince 1974, seven earthquakes of magnitude 2.5 or less have been recorded in regions surrounding the SCL." Information pertaining to these earthquakes is not provided in the summary tables.

Provide information regarding these earthquakes in Table 2.5-1, "Historic Earthquake Epicenters Located Within Approximately 200 Miles (322 km) of the SHINE Site," (page 2.5-26) or Table 2.5-3, "Recorded Earthquake Intensities (Modified Mercalli Intensity – MMI) (page 2.5-27), for Earthquakes Within Approximately 200 Miles (322 km) of the SHINE Site."

<u>SHINE Response</u>

The seven earthquakes referenced in Subsection 2.5.1.4.6 of the PSAR are shown in Figure 6 of Reference 11. These earthquakes were recorded and located as part of the New Madrid seismic network operated by Saint Louis University. As described in Reference 11, the epicenters of these earthquakes are along or near the Saint Charles Lineament (SCL). Four of the earthquakes have magnitudes less than body-wave magnitude (m_b) 2.0, and three are between m_b 2.0 and m_b 2.5.

Table 2.5-1 of the PSAR only provides data for those earthquake epicenters listed in the composite earthquake catalog developed for the Central and Eastern United States Seismic Source Characterization for Nuclear Facilities (CEUS-SSC) Project (Reference 12). The project was conducted from April 2008 to December 2011, and further updated in 2012. As part of this project, available intensity and instrumental earthquake records were evaluated, including those earthquakes recorded by Saint Louis University cited in Reference 11. The CEUS-SSC catalog lists only those earthquakes with data of sufficient quality to be used to establish earthquake activity rates for seismic hazard analysis. The minimum magnitude of earthquakes in the CEUS-SSC catalog and within about 200 miles of the SHINE site is about expected moment magnitude E(**M**) 2.3. None of the seven earthquakes shown in Figure 6 of Reference 11 as indicating seismic activity of the SCL are included in the CEUS-SSC catalog.

Since the seven earthquakes shown in Figure 6 of Reference 11 are not included in the CEUS-SSC catalog, SHINE considered them not of a large enough magnitude or well enough located to indicate neotectonic activity along the SCL. Based on a re-evaluation of the Reference 11 interpretations, the seven referenced earthquakes do not suggest ongoing activity on the SCL, and should not be listed in Table 2.5-1 of the PSAR. Additionally, because there is no evidence that any of these earthquakes were felt, SHINE did not include them in Table 2.5-3 of the PSAR.

RAI 2.5-4

SHINE PSAR, Section 2.5.3.1, "Historic Earthquakes," provides a list of databases and references that were used to identify historic earthquakes at the location of the SHINE facility. The most recent historic earthquake located within approximately 200 miles of the SHINE site was in 1985 (Table 2.5-1, page 2.5-26). Another database that includes six more recent earthquakes is compiled by the U.S. Geological Survey (USGS) at http://earthquake.usgs.gov/earthquakes.

Provide additional information justifying the exclusion of the earthquake information compiled by the USGS from analysis in the PSAR, or provide a reanalysis that takes this information into consideration in the PSAR.

SHINE Response

As described in the SHINE Response to RAI 2.5-2, earthquake epicenter data provided in Section 2.5 and Table 2.5-1 of the PSAR is from the CEUS-SSC composite catalog (Reference 12). The CEUS-SSC project included a robust and peer-reviewed process to develop a reliable and comprehensive earthquake catalog for the Central and Eastern United States. To develop the comprehensive earthquake catalog, the following regional catalogs were included in the compilation:

- Center for Earthquake Research and Information catalog
- Saint Louis University (Nuttli, microearthquake, and moment magnitude catalogs)
- Lamont-Doherty Cooperative Seismographic Network catalog
- Weston Observatory catalog
- Ohio Seismic Network catalog
- Department of Conservation and Natural Resources of Pennsylvania catalog
- Reinbold and Johnston (1987)
- Oklahoma Geological Survey catalog
- South Carolina Seismic Network catalog
- Southeastern United States catalog (Virginia Tech)

The above earthquake catalogs may individually show epicenters for additional events, some of which may be real, but unreliably recorded earthquakes, but some may also result from mine explosions, earthquakes triggered by deep fluid injection and/or hydraulic fracturing of near-surface rocks, or other non-tectonic processes. In the development of Section 2.5 of the PSAR, SHINE relied upon the analysis of earthquake records used to create the comprehensive earthquake catalog for the CEUS-SSC project. Therefore, while the U.S. Geological Survey (USGS)-hosted database includes six post-1985 earthquake epicenters, SHINE included only those earthquakes that have passed the robust screening process used to prepare the CEUS-SSC catalog in Table 2.5-1.

RAI 2.5-5

NUREG-1537, Part 1, Section 2.5.1, "Regional Geology," states, in part, "[t]he applicant should discuss all geologic and seismic hazards within the region that could affect the facility…."

SHINE PSAR, Section 2.5.2.4, "Non-Seismic Geological Hazards," states in part, "Rock County contains carbonate bedrock susceptible to dissolution or karst formation (WGNHS, 2009). The Rock County Hazard Mitigation Plan (Vierbicher, 2010) indicates that no significant sinkholes have been reported in Rock County in recent years. The plan indicates a potential for karst features to form in the county, particularly in the eastern third of the county that lies to the east of the SHINE site."

Provide additional information expanding the discussion of regional magnetic and gravity geophysical anomalies presented in SHINE PSAR, Section 2.5.1.5, "Regional Magnetic and Gravity Geophysical Anomalies," to include an evaluation of potential karst features at the SHINE site.

SHINE Response

Subsection 2.5.1.5 of the PSAR provides an evaluation of the gravity and magnetic anomaly data used to identify the geological structures in the continental basement rocks. The goal was to identify major crustal structures that may be capable faults and perhaps the source of future large earthquakes. These major basement structures interpreted from magnetic anomalies are provided in Figure 2.5-6 of the PSAR. The uninterpreted gravity anomaly map is shown in Figure 2.5-9 of the PSAR.

Details of the composite aeromagnetic and Bouguer gravity anomalies in southern Wisconsin are provided in Figure 2.5-5-1 and Figure 2.5-5-2, respectively, to expand the discussion of regional geophysical anomalies and to include an evaluation of potential karst features at the SHINE site.

The major structure observed from the geophysical anomalies provided in Figure 2.5-5-1 and Figure 2.5-5-2 is the northeast-striking Waukesha fault, identified from structural contours of the Precambrian basement rocks. Structural contours indicate up to 1500 ft of vertical separation across the Waukesha fault. Based on three-dimensional modeling of aeromagnetic and gravity anomalies, a total vertical separation of approximately 500 to 1100 meters at the Waukesha fault is inferred (Reference 13).

A review of the geophysical anomaly maps for southern Wisconsin indicates the following:

- Smaller faults and folds within the Paleozoic Era are not resolvable in the aeromagnetic anomaly map (Figure 2.5-5-1).
- The offset across the basement rocks at the Waukesha fault can reasonably be resolved in the Bouguer gravity anomaly map (Figure 2.5-5-2).
- Smaller faults and folds within both the basement and bedrock rocks are not readily apparent in the Bouguer gravity anomaly map (Figure 2.5-5-2).

Based on the above discussion, the available regional magnetic and Bouguer gravity anomalies in southern Wisconsin are suitable only for identifying the major regional fault structures with large vertical separations.

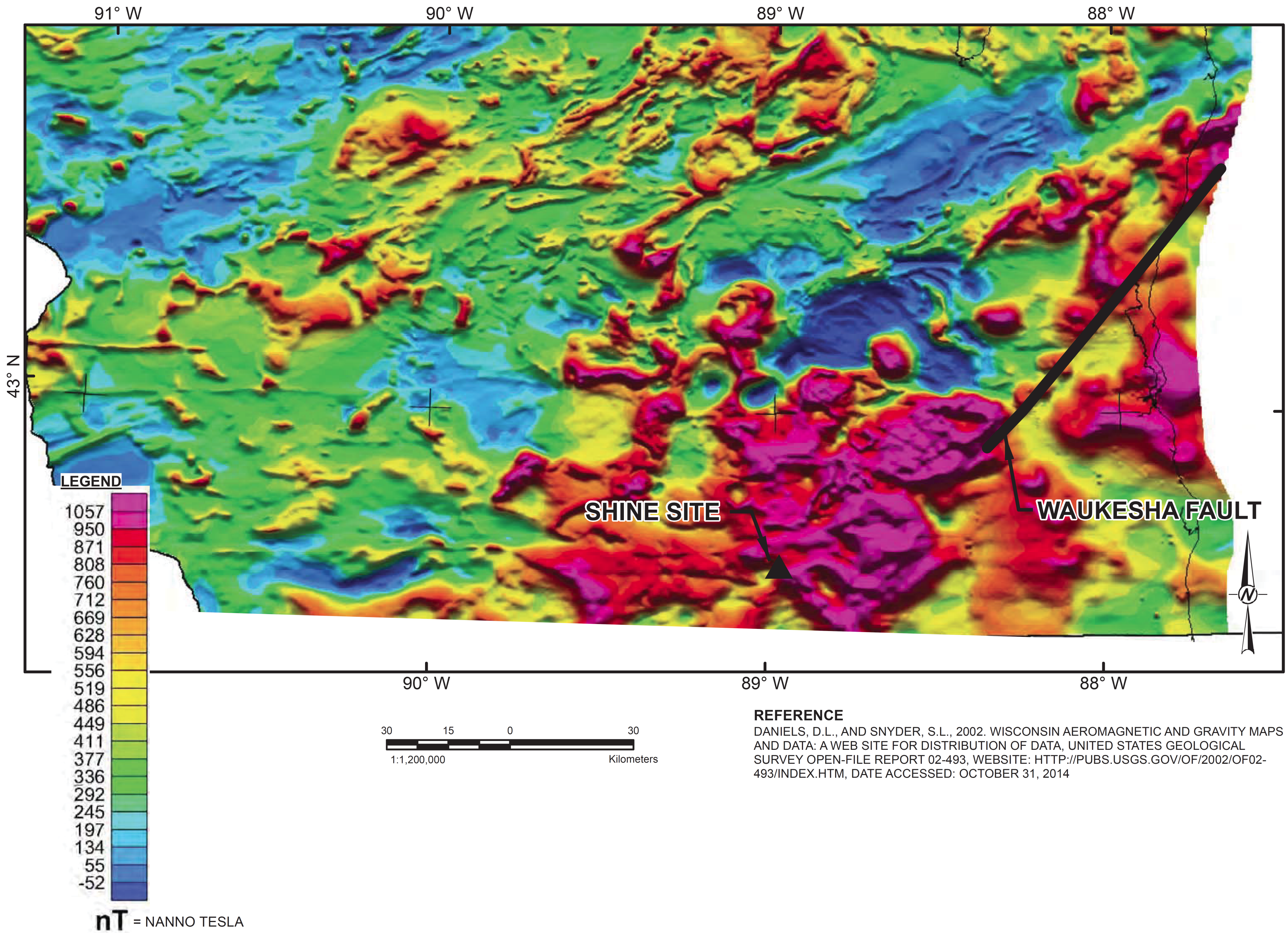
Karst features are a hazard to development because it not only presents a pathway for rapid movement of groundwater, but also it may cause surface subsidence as overlying soils collapse into open fractures. In addition to surface observations that indicate the presence of karst features, geophysical imaging techniques are used to detect the presence of existing subsurface voids with the potential for collapse. Electrical resistivity tomography has proven to be an effective method to detect past or incipient sinkholes.

The WGNHS do not have electrical resistivity tomography data or interpretations for the SHINE site. While the WGNHS have reports of small sinkholes (less than five ft in diameter and less than five ft in depth) in parts of Rock County, they are not aware of property damage or significant issues surrounding the presence of these sinkholes. WGNHS do not have any reports of sinkholes at the SHINE location. Because the site is in the Rock River Valley and has several hundred feet of sediment overlying the bedrock, it is very unlikely that a sinkhole will form near the SHINE site.

The SHINE site has little topographic relief and lacks any geomorphic evidence of differential subsidence that may indicate past or ongoing solution of any subsurface carbonate rocks and formation of karst features.

Based on the available evidence, there is a very low probability that karst features are present within the carbonate bedrock below the SHINE site.

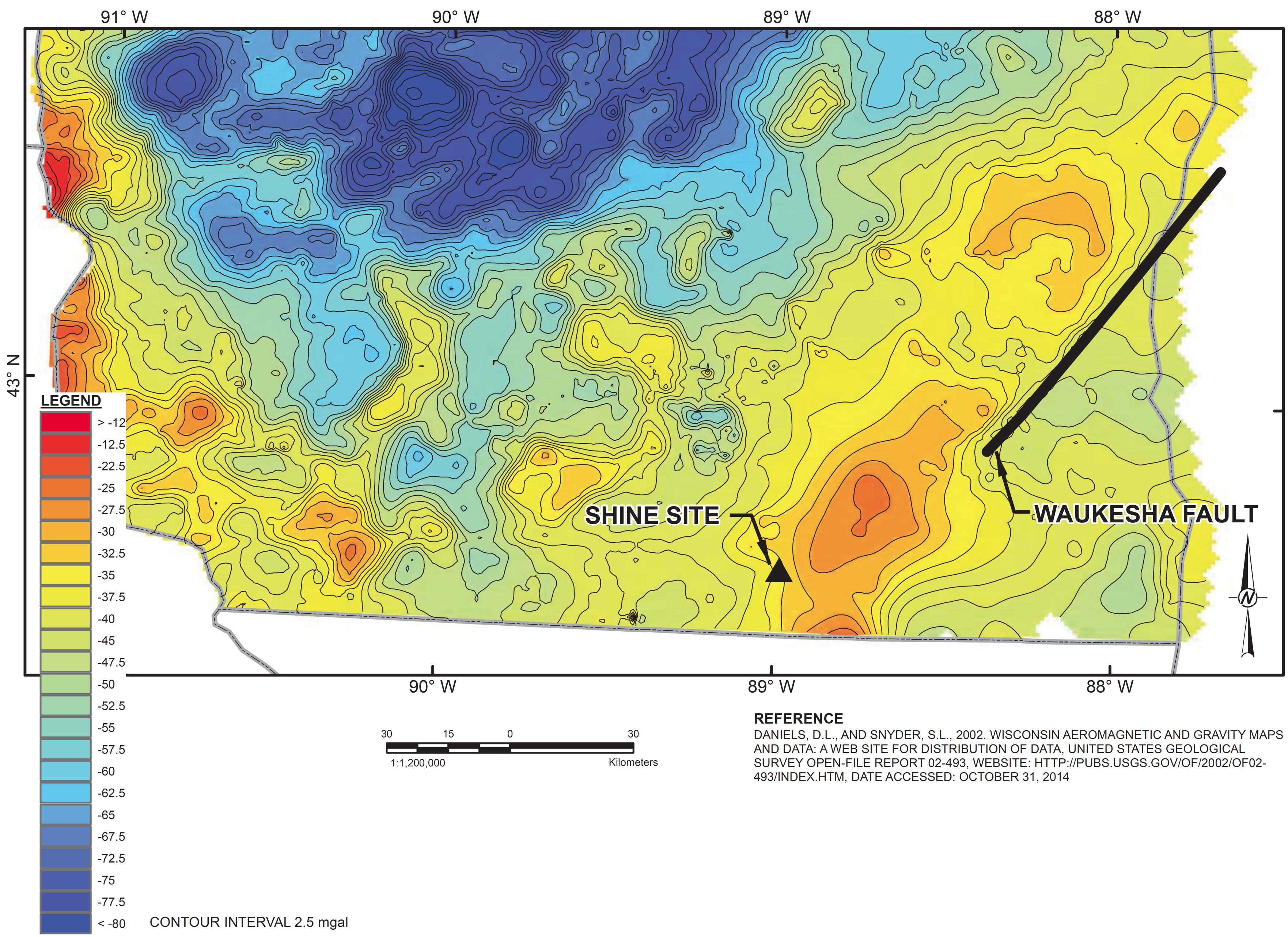
Figure 2.5-5-1: Composite Aeromagnetic Anomalies and Main Geological Structures, Southern Wisconsin



REFERENCE

DANIELS, D.L., AND SNYDER, S.L., 2002. WISCONSIN AEROMAGNETIC AND GRAVITY MAPS AND DATA: A WEB SITE FOR DISTRIBUTION OF DATA, UNITED STATES GEOLOGICAL SURVEY OPEN-FILE REPORT 02-493, WEBSITE: HTTP://PUBS.USGS.GOV/OF/2002/OF02-493/INDEX.HTM, DATE ACCESSED: OCTOBER 31, 2014

Figure 2.5-5-2: Bouguer Gravity Anomalies and Main Geological Structures, Southern Wisconsin



REFERENCE

DANIELS, D.L., AND SNYDER, S.L., 2002. WISCONSIN AEROMAGNETIC AND GRAVITY MAPS AND DATA: A WEB SITE FOR DISTRIBUTION OF DATA, UNITED STATES GEOLOGICAL SURVEY OPEN-FILE REPORT 02-493, WEBSITE: HTTP://PUBS.USGS.GOV/OF/2002/OF02-493/INDEX.HTM, DATE ACCESSED: OCTOBER 31, 2014

RAI 2.5-6

NUREG-1537, Part 1, Section 2.5.7, "Liquefaction Potential," states that the applicant should discuss soil structure. "If the foundation materials at the site adjacent to and under safety-related structures are saturated soils or soils that have a potential for becoming saturated, the applicant should prepare an appropriate state-of-the-art analysis of the potential for liquefaction at the site. The applicant should also determine the method of analysis on the basis of actual site conditions, the properties of the reactor facilities, and the earthquake, and seismic design requirements for the protection of the public."

NUREG-1537, Part 2, Section 2.5, "Geology, Seismology, and Geotechnical Engineering," instructs the reviewer to find that the information on the geologic features and geotechnical properties at the site has been provided in sufficient detail and in a form to be integrated acceptably into design bases for structures, systems, and operating characteristics of the reactor.

It is reported in SHINE PSAR, Section 2.5.7.1, "Site Soil Conditions," that geotechnical engineering field investigations were conducted that included standard penetrometer test (SPT) blow counts (N-values) measured in 14 boreholes. Details and an explanation were not given about how and whether these investigations were used to develop the soil parameters (engineering properties) listed in SHINE PSAR, Chapter 3 (Section 3.4.2.6.3.1).

Provide the report with details and results for the geotechnical investigations.

SHINE Response

The geotechnical engineering investigations described in Subsection 2.5.7.1 of the PSAR and used to develop the soil parameters provided in Subsection 3.4.2.6.3.1 of the PSAR are documented in the Preliminary Geotechnical Engineering Report for the SHINE site. This report was previously provided to the NRC as Attachment 26 to the SHINE Response to Environmental Requests for Additional Information (Reference 7).

Based on a review of the soil parameters provided in Subsection 3.4.2.6.3.1 and the Preliminary Geotechnical Engineering Report, SHINE will revise Subsection 3.4.2.6.3.1 in the FSAR as follows to more accurately reflect the results of the geotechnical engineering investigations documented in the Preliminary Geotechnical Engineering Report for the SHINE site.

Replace:

- Minimum static bearing capacity demand for 2-ft. (0.61-m) wide strip footings: 4000 pounds per foot square (psf) (191 kPa).
- Minimum static bearing capacity demand for 6-ft. (1.8-m) wide strip footings: 6000 psf (287.3 kPa).
- Minimum static bearing capacity demand for footings 22 ft. (6.7 m) below grade: 8000 psf (383.0 kPa).
- Minimum shear wave velocity: 459 ft/sec (140 m/s).
- Poisson's Ratio: 0.4.
- Unit Weight: 125 pounds per cubic foot (lb/ft^3) (2002 kilograms per cubic meters [kg/m3]).

With:

- Net allowable static bearing capacity for 2-ft. (0.61-m) wide strip footings: 4000 pounds per foot square (psf) (191 kPa).
- Net allowable static bearing capacity for 6-ft. (1.8-m) wide spread footings: 6000 psf (287.3 kPa).
- Net allowable static bearing capacity for footings 22 ft. (6.7 m) below grade: 8000 psf (383.0 kPa).
- Minimum shear wave velocity: 459 ft/sec (140 m/s).
- Poisson's Ratio: 0.4
- Unit Weight: 121 pounds per cubic foot (lb/ft^3) (1938 kilograms per cubic meters [kg/m3]).

Basis for the Change:

SHINE will revise the name of the bearing pressure soil parameter provided in Subsection 3.4.2.6.3.1 of the PSAR to "net allowable static bearing capacity" to facilitate consistency with Section 7.2.1 of the Preliminary Geotechnical Engineering Report for the SHINE site.

The minimum shear wave velocity soil parameter provided in Subsection 3.4.2.6.3.1 of the PSAR will remain unchanged. Shear wave velocity data is provided in Table A-1 of Appendix D of the Preliminary Geotechnical Engineering Report for the SHINE site.

The Poisson's ratio soil parameter provided in Subsection 3.4.2.6.3.1 of the PSAR will remain unchanged. The Poisson's ratio was calculated based on Vertical Seismic Profiling (VSP) measurements taken at the SHINE site, as described in Section 6.1 of the Preliminary Geotechnical Engineering Report for the SHINE site. Poisson's ratio data, based on VSP measurements within borehole VSP-1, is provided in Table A-1 of Appendix D of the Preliminary Geotechnical Engineering Report for the SHINE site. In order to provide a single, generalized value for the SHINE site, a Poisson's ratio value of 0.4 was provided in Subsection 3.4.2.6.3.1.

SHINE will revise the unit weight provided in Subsection 3.4.2.6.3.1 of the PSAR to 121 lb/ft^3 to represent the bulk (moist) unit weight. This bulk unit weight is equivalent to the minimum (dry) density values (118 lb/ft^3) provided in Figures C-12, C-13, and C-14 of the Preliminary Geotechnical Engineering Report for the SHINE site multiplied by the average moisture content (three percent) provided in Table C-1 of the Preliminary Geotechnical Engineering Report for the SHINE site.

An IMR has been initiated to track the revision to Subsection 3.4.2.6.3.1 in the FSAR.