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System Energy Resources, Inc.
1340 Echelon Parkway
Jackson, MS 39213

CNRO-2004-00077

December 10, 2004

U. S. Nuclear Regulatory Commission
Washington, DC 20555-0001
Attention: Document Control Desk

DOCKET: 52-009

SUBJECT: Response to Request for Additional Information Letter No. 5 – System Energy Resources, Inc., Early Site Permit Application for the Grand Gulf ESP Site (TAC NO. MC 1378)

REFERENCE:

1. System Energy Resources, Inc. (SERI) letter to USNRC – Early Site Permit Application (CNRO-2003-00054), dated October 16, 2003.
2. USNRC letter to SERI – Request for Additional Information Letter No. 5 – System Energy Resources, Inc., Early Site Permit Application for the Grand Gulf ESP Site (TAC No. MC1378) (CNRI-2004-00016), dated September 17, 2004.

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DOCUMENT COMPONENTS:

One (1) CD-ROM is included in this submission. The CD-ROM contains the following forty-six (46) files:

001_ESP-SSAR_draft_rev1_12-01-2004.pdf, 488 KB, publicly available
002_RAI_Table2.5.1-1-1.pdf, 156 KB, publicly available
003_SSAR_Fig_2.5-5draft_rev1_11-19-2004.pdf, 786 KB, publicly available
004_RAI_Fig_2.5.1-1-1.pdf, 555 KB, publicly available
005_RAI_Fig_2.5.1-1-2.pdf, 470 KB, publicly available
006_SSAR_Fig_2.5-97draft_rev0_11-19-2004.pdf, 257 KB, publicly available
007_SSAR_Fig_2.5-98draft_rev0_11-19-2004.pdf, 279 KB, publicly available
008_SSAR_Fig_2.5-99draft_rev0_11-19-2004.pdf, 283 KB, publicly available
009_SSAR_Fig_2.5-100draft_rev0_11-19-2004.pdf, 292 KB, publicly available
010_SSAR_Table2.5-5draft_rev1_11-19-2004.pdf, 62 KB, publicly available
011_SSAR_Table2.5-6draft_rev1_11-19-2004.pdf, 62 KB, publicly available
012_Cox2004_pers_comm_Golden_Morgan_data.pdf,11 KB, publicly available
013_Cox2003_pers_comm_radiocarbon_data.pdf, 15 KB, publicly available
014_RAI_Fig_2.5.1-4-1.pdf, 4750 KB, publicly available
015_RAI_Fig_2.5.1-4-2.pdf, 187 KB, publicly available
016_SSAR_Table2.5-13draft_rev1_11-19-2004.pdf, 32 KB, publicly available
017_SSAR_Fig_2.5-69draft_rev1_11-19-2004.pdf, 211 KB, publicly available
018_SSAR_Fig_2.5-75draft_rev1_11-19-2004.pdf, 155 KB, publicly available
019_SSAR_Fig_2.5-76draft_rev1_11-19-2004.pdf, 141 KB, publicly available
020_SSAR_Fig_2.5-77draft_rev1_11-19-2004.pdf, 324 KB, publicly available
021_RAI_Fig_2.5.4-4-1.pdf, 171 KB, publicly available
022_RAI_Fig_2.5.4-4-2.pdf, 210 KB, publicly available
023_RAI_Fig_2.5.4-4-3.pdf, 207 KB, publicly available
024_SSAR_Fig_2.5-87draft_rev1_11-19-2004.pdf, 23 KB, publicly available
025_SSAR_Fig_2.5-88draft_rev1_11-19-2004.pdf, 25 KB, publicly available
026_SSAR_Fig_2.5-89draft_rev1_11-19-2004.pdf, 24 KB, publicly available
027_SSAR_Fig_2.5-90draft_rev1_11-19-2004.pdf, 33 KB, publicly available
028_SSAR_Fig_2.5-91draft_rev1_11-19-2004.pdf, 36 KB, publicly available
029_SSAR_Fig_2.5-92draft_rev1_11-19-2004.pdf, 27 KB, publicly available
030_SSAR_Fig_2.5-93draft_rev1_11-19-2004.pdf, 33 KB, publicly available
031_SSAR_Fig_2.5-94draft_rev1_11-19-2004.pdf, 27 KB, publicly available
032_SSAR_Fig_2.5-95draft_rev0_11-19-2004.pdf, 23 KB, publicly available
033_SSAR_Fig_2.5-96draft_rev0_11-19-2004.pdf, 25 KB, publicly available
034_SSAR_Table_2.5-26draft_rev1_11-19-2004.pdf, 55 KB, publicly available
035_RAI_Fig_2.5.4-9-1.pdf, 2179 KB, publicly available
036_RAI_Fig_2.5.4-9-2.pdf, 12240 KB, publicly available
037_RAI_Fig_2.5.4-9-3.pdf, 1225 KB, publicly available
038_RAI_Table2.5.4-12-1a-d.pdf, 32 KB, publicly available
039_RAI_Table2.5.4-12-2a-c.pdf, 54 KB, publicly available
040_SSAR_Table2.5-7draft_rev1_11-19-2004.pdf, 82 KB, publicly available
041_RAI_Fig_2.5.5-1-1.pdf, 54 KB, publicly available
042_SSAR_Fig_2.5-59draft_rev1_11-19-2004.pdf, 160 KB, publicly available
043_SSAR_Table2.5-11draft_rev1_11-19-2004.pdf, 33 KB, publicly available
044_SSAR_Table2.5-12draft_rev1_11-19-2004.pdf, 33 KB, publicly available
045_SSAR_Table2.5-14draft_rev1_11-19-2004.pdf, 42 KB, publicly available
046_SSAR_Table2.5-20draft_rev1_11-19-2004.pdf, 47 KB, publicly available

In the referenced September 17, 2004, letter (Reference 2) the U.S. Nuclear Regulatory Commission requested additional information to support review of the SERI ESP Application. This letter transmits information as outlined in Attachment 1 to this letter. Additional information is also provided as discussed at the end of Attachment 1.

Should you have any questions, please contact me.

I declare under penalty of perjury that the foregoing is true and correct.
Executed on December 10, 2004.

Sincerely,

George A. Zinke
Project Manager
System Energy Resources Inc.

Enclosure: One CD-ROM
Attachment: Attachment 1

cc: Mr. R. K. Anand, USNRC/NRR/DRIP/RNRP
Ms. D. Curran, Harmon, Curran, Spielberg, & Eisenberg, L.L.P.
Mr. W. A. Eaton (ECH) (w/o enclosure)
Mr. B. S. Mallett, Administrator, USNRC/RIV
Mr. J. H. Wilson, USNRC/NRR/DRIP/RLEP

Resident Inspectors' Office: GGNS

ATTACHMENT 1

SSAR Section 2.5, Geology, Seismology, and Geotechnical Engineering

Request:

RAI 2.5.1-1

SSAR Figure 2.5-5 only shows seismicity down to Mb 3.3 and this low-magnitude cut off is cited several times in SSAR Sections 2.5.1 and 2.5.2. Please comment on whether this low-magnitude cutoff resulted in excluding seismicity along the Gulf Coast in Louisiana and an Mb 3.0 earthquake west of Jackson, Mississippi in 1927 as part of your seismic hazard characterization. Also, the 1927 Jackson, Mississippi earthquake, listed as Mb 3.4 in the U.S. Geological Survey (USGS) national seismic hazard map catalog, is not shown on SSAR Figure 2.5-5. Please provide an explanation for this omission.

Response:

SSAR Figure 2.5-5 shows seismicity in the Grand Gulf region using a composite catalog from the USGS, NCEER and the Center for Earthquake Research and Information, as stated on the Figure. These seismicity catalogs were selected in order to use current information on earthquake location and size, in terms of observing any changes in earthquake patterns or distribution in the time periods 1627-1984 (generally equivalent to the EPRI (1986) catalog) and 1985 to 2003 (i.e., post EPRI catalog). This catalog is included in RAI Table 2.5.1-1-1.

For the Grand Gulf seismic hazard analysis and assessment of activity rates, the EPRI (1986) catalog was used for events occurring between 1627 and 1984, and the ANSS-CNSS catalog was used for events occurring between 1985 and 2003. The analysis included all events of body wave magnitude (m_b) 3.3 or larger (same magnitude range as the original EPRI (1986) study).

In response to this RAI, SSAR Figure 2.5-5 will be replaced by the attached SSAR Figure 2.5-5, Draft Rev. 1. This figure shows a seismicity plot from the same catalog used in the hazard analysis (i.e., EPRI, 1986) catalog for events from 1627 to 1984 updated using the composite ANSS-CNSS catalog for events from 1985 to 2003. The distribution of seismicity is shown for all events of m_b 1.0 or larger in order to observe the full distribution of seismicity in the region.

Omission of the 1927 Jackson, Mississippi m_b 3.4 earthquake on Figure 2.5-5 resulted from a plotting error. However, because Figure 2.5-5 was not used in the hazard analysis, this omission did not affect the hazard results. SSAR Figure 2.5-5, Draft Rev. 1 accurately plots the seismic events near Vicksburg and Jackson, Mississippi, respectively.

RAI Figure 2.5.1-1-1 shows histograms of the number of earthquakes that occurred within the 200-mile site region for the periods 1627 to 1984 and 1985 to 2003. The pre-1984 earthquake catalog is the same catalog used in the EPRI SOG study (EPRI, 1986). The post-1984 catalog is provided to illustrate the events that occurred since completion of the EPRI SOG (1986) study and to provide a comparison between

events used by EPRI SOG and those that have occurred since the EPRI SOG study. These figures show that a higher number of earthquakes have been recorded post 1984 in the m_b 1.0 to 3.0 range relative to pre-1984 seismicity, primarily due to improved instrumentation in the Gulf Coast area. Fewer earthquakes of m_b 3.0 to 5.0 have occurred after 1984 relative to pre-1984 seismicity, primarily because of the shorter period of record. SSAR Table 2.5-14, Draft Rev. 1, provides a list of all earthquakes greater than m_b 3.0 that have occurred within 2000 miles of the site since 1984.

RAI Figure 2.5.1-1-2 shows a plot of events within a 100-mile radius for the pre-1984 period. As shown on this figure, only three earthquakes have occurred within a 100-mile radius of the site for the period 1627 to 1984, and no events have been recorded since 1984. As stated in the SSAR, the location and occurrence rates of earthquakes within the 200-mile radius Site Region for the pre-1984 and post-1984 periods are very similar.

SSAR Revisions:

Minor changes will be made to text in a number of places in the SSAR to correct dates and number of earthquakes cited. SSAR Figure 2.5-5 will be replaced with SSAR Figure 2.5-5, Draft Rev. 1. Replace SSAR Table 2.5-14 with SSAR Table 2.5-14, Draft Rev. 1.

See files:
001_ESP-SSAR_draft_rev1_12-01-2004.pdf
002_RAI_Table 2.5.1-1-1.pdf
003_SSAR_Fig_2.5-5draft_rev1_11-19-2004.pdf
004_RAI_Fig_2.5.1-1-1.pdf
005_RAI_Fig_2.5.1-1-2.pdf
045_SSAR_Table_2.5-14draft_rev1_11-19-2004.pdf

References:

Advanced National Seismic System (ANSS), 2004, Composite online catalog http://quake.geo.berkeley.edu/anss/

Electric Power Research Institute (EPRI), 1986, Seismic-hazard methodology for the central and eastern United States, Electric Power Research Institute Project P101-19 Final Report NP-4726, volumes 1-10, including seismicity catalog, no sequential page numbers.

Request:

RAI 2.5.1-2

SSAR section 2.5.1.1.6 on regional seismicity makes the statement, "This low rate of activity has characterized the seismicity of the Gulf Plain for over 150 years, and most likely throughout the Quaternary," at the end of the second paragraph. Please provide the scientific evidence for extending the last 150 years of seismicity to the whole Quaternary.

Response:

The statement referred to in RAI 2.5.1-2, "This low rate of activity has characterized the seismicity of the Gulf Plain for over 150 years, and most likely throughout the Quaternary" is a qualitative statement. As shown on the updated seismicity plot (SSAR Figure 2.5-5, Draft Rev. 1), seismicity rates in the region have been extremely low for the last 150 years. Only three earthquakes of magnitude (m_b) greater than 3.0 have occurred within the 100-mile-radius around site. Furthermore, as shown on SSAR Figures 2.5-6 and 2.5-12, the Gulf Coastal Plain has been characterized by extremely low rates of tectonic deformation with post-Cretaceous deposits on the limbs of the Gulf Coast Syncline dipping less than 0.5 degrees. Based on the low rates of tectonic deformation that have occurred over a period of tens of millions of years and the low rates of seismic activity over the last 150 years, we infer that these rates were "most likely" also characteristic of the Quaternary period. The statement was intended to highlight the facts that rates of both earthquake occurrence and tectonic deformation in the site region are extremely low. Although variability in earthquake occurrence rates may certainly occur over these periods of time, the minor amount of tectonic deformation in the region supports the qualitative assertion that seismicity rates have also been low for long periods of time.

The statement is regional and qualitative in nature and does not affect the assessment of seismic hazard at the Grand Gulf ESP site. No additional quantitative analysis is required for the assessment of seismic hazard.

SSAR Revisions:

See file: 003_SSAR_Fig_2.5-5draft_rev1_11-19-2004.pdf

Request:

RAI 2.5.1-3

SSAR 2.5.1.1.5.9 describes the Saline River source zone and the geologic and paleoliquefaction evidence for it, as summarized chiefly in Reference 152 (Cox, 2003) and in Cox (2004, published in the June issue of the Bull. Seism. Soc. Am., and cited in Reference 152 but not cited directly in the SSAR).

1. Please clarify whether the SSAR was based on Cox (2003), a preprint of Cox (2004), or both.

2. Reference 152 is a Final Contract Report by Cox to the USGS. However, there are two Final Contract Reports by Cox, and their references are identical except that one has a 2001 date and a 2001 contract number, whereas the other has 2003 date and contract number. SSAR 2.5.7 lists Reference 152 with the 2003 date but the 2001 contract number. Please confirm which Final Contract Report is referenced in SSAR 2.5.7.

3. Please explain the degree to which the latest findings of Cox (2004, BSSA) are consistent with the characterization of the Saline River source zone in SSAR 2.5.2.1.3 and Table 2.5-46.

4. Cox (2003, 2004) estimated the sizes of the prehistoric earthquakes that created the liquefaction features as approximately M 5.7-6.0. Cox measured the long diameters of two liquefaction fields and applied the Ambraseys relation between the most distant observed liquefaction and magnitude. SSAR 2.5.2.1.3.3 explains why the earthquakes were probably not much more than 0.5 M units larger than Cox's estimates. However, the sand that blows in Cox's trenches are thick and wide, much larger than one would expect of the most distant observed liquefaction. Additionally, the large sand blows exposed in all trenches published so far (Golden, Kelso, Morgan, Montrose, and Portland sites) are at or close to the edges of their liquefaction fields. Please explain, quantitatively if data allows, whether or not the large sizes of the sand blows are consistent with the moderate estimated magnitudes.

5. SSAR 2.5.1.1.5.9.3 and Tables 2.5-5 and 2.5-6 provide the characterization of the Saline River source zone. Regarding this SSAR Section and Tables: (1) please explain whether the minimum and maximum event dates are ±1 or 2 standard deviations; (2) distinguish between conclusions or values taken directly from Cox (2003) and inferences drawn from this source; (3) please explain the source of Table 2.5-5 as the heading of Table 2.5-5 states "Modified from Cox (2003)", whereas neither Reference 152, Cox (2004), nor any of Cox's three previous contract reports to the USGS contain anything like the table; (4) provide the reasoning or assumptions for the values listed in Table 2.5-5 and 2.5-6; and (5) provide a link between the events listed in SSAR 2.5.1.1.5.9.3 and in Table 2.5-5.

6. Reference 152 describes observations from new trenches at the Morgan and Golden sites, but these results could not be integrated into Cox (2003, 2004) or the SSAR because the event dates were not expected until July, 2004. Please explain whether the dates, and conclusions based on them, are yet available. Please also explain whether or not these new results alter any aspects of the characterization of the Saline River source zone.

Response:

Dr. Randy Cox and his coworkers have identified a number of liquefaction areas in Ashley and Desha Counties in southeastern Arkansas. Together with other geomorphic, seismologic and paleoseismic data, Cox and his coworkers have used the liquefaction data to interpret a possible local seismic source in the Saline River area. We concur with Cox and his coworkers that the information available indicates a seismic source may be present in southeastern Arkansas, and we call this seismic source the Saline River source zone in the Grand Gulf ESP SSAR (section 2.5.2.1.3). RAI 2.5.1-3 raises a number of issues related to the liquefaction data developed by Cox (2002) and Cox et al. (2004) and our use of this data to characterize the Saline River source zone.

The liquefaction data developed to date by Cox and his coworkers for the Saline River area successfully documents a number of liquefaction features in Ashley and Desha counties, in southeastern Arkansas. Cox et al. (2004) present the available liquefaction data, and a general interpretation of the number of possible events and possible size of earthquakes that may have produced the liquefaction features. However, the available data are not yet sufficiently precise to constrain the event

chronology or to document with certainty that the liquefaction features are produced by a near-field seismic source rather than a far-field (i.e., New Madrid) seismic source. Although interpretations by Cox (2002) and Cox et al. (2004) are consistent with the available data, these interpretations do not capture the full range of uncertainty in the data nor provide a full assessment of source parameters needed for characterization of the Saline River source zone as a seismic source for hazard analysis. Our analysis uses the available liquefaction data from Cox (2002), Cox et al. (2004), Cox and Larson (2004), and Cox (2004, personal communication) on the enclosed CD ROM, to estimate (1) probability of activity (i.e., that a local seismic source is present), (2) distribution of maximum earthquake magnitude that may have produced the observed liquefaction features, and (3) distribution of recurrence intervals based on the uncertainty in possible number and timing of liquefaction events. This information was used for input to the hazard analysis. The results of our analysis are based on and are consistent with the data presented in Cox's publications. Responses to the six RAI questions are provided in the following discussion.

1. Characterization of the Saline River source zone was based primarily on the work of Dr. Randy Cox and Dr. Roy Van Arsdale. Descriptions of regional geology, site conditions, and subsurface relationships were obtained in part from Cox's Final Technical Report (FTR) for his 2001 National Earthquake Hazard Reduction Program (NEHRP) research grant award, which was published in 2002. This citation in the SSAR was mistakenly labeled as Cox (2003). The correct citation for this publication is Cox (2002). The complete reference is included in the reference section that follows this response.

   We independently evaluated the stratigraphic relationships observed in the trenches as presented by Cox (2002). Our assessment of event ages was based on the radiocarbon and luminescence dates reported in Cox (2002) and later in Cox et al. (2004). These dates were provided directly to us by Dr. Cox in 2003 (personal communication) for our use in preparing the SSAR prior to their publication in Cox et al. (2004).

2. The FTR cited as reference number 152 in the SSAR was mistakenly shown to have a 2003 date. The correct citation for this publication is Cox (2002). The complete reference is included in the reference section that follows this response.

3. Development of the event history in the SSAR for the Saline River fault zone was based on independent analysis of observed stratigraphic relationships described in Cox (2002) and radiocarbon dates (Cox, 2003 personal communication) on the enclosed CD-ROM, which are now published in Cox et al. (2004). We developed our own interpretation of event history and earthquake recurrence because this information is not published. Cox et al. (2004) present a valid interpretation of the liquefaction features at the site, but do not present a detailed earthquake chronology that can be used to assess recurrence intervals. The interpretations of Cox et al. (2004) also do not consider the full range of uncertainty represented by the 2-sigma minimum and maximum limiting ages in assessing the possible timing of past liquefaction events. The interpretation presented in the SSAR was developed based on the data presented in the Cox publications, but considers the full range of uncertainty represented by the 2-sigma minimum and maximum limiting ages. The interpretation in the SSAR encompasses the range of possible liquefaction events (three events at Kelso, four events at Montrose, one to three

events at Portland) presented by Cox et al. (2004), as well as additional alternative event scenarios. Therefore, the results published in Cox et al. (2004) are consistent with the source characterization presented in Section 2.5.2.1.3 and no modifications to the logic tree or source characterization are necessary.

4. Several techniques are available to estimate earthquake magnitudes using paleoliquefaction and site geotechnical data. The techniques and required data types are summarized in RAI Table 2.5.1-3-1.

RAI Table 2.5.1-3-1
Techniques for Estimating Earthquake Magnitudes Using Paleoliquefaction Data

Method	Input Data Required	Output	Current data Availability	Reference	Comments
Magnitude-bound	Maximum distance from source to liquefaction field	Magnitude	Yes	Ambraseys, 1988; Obermeier, 2001; Pond, 1996	Compare distance to NMSZ and SRSZ
Cyclic Stress	Geotechnical borings (blow counts), ground motion attenuation models	Magnitude	No	Hwang et al., 1995; Obermeier, 1999; Seed et al., 1971, 1983; Whitman, 1971; Youd et al. 2001;	Most widely used method
Energy	Geotechnical data, Hypocenter data	Back calculated PGA for assumed magnitude	No	Berrill and Davis, 1985;	Attenuation relations do not apply
Ishihara	Thickness of cap, thickness of source sand	Back calculated PGA, also can predict thickness of fractured cap if PGA is known	No	Obermeier, 2001; Ishihara, 1985; Youd and Garris (1995)	Limited to one site
Energy Based Approach	Geotechnical borings (blow counts)	Energy and stress conditions at site	No	Dobry et al., 1982; Green, 2001; Law et al. 1990; Obermeier, 2001; Pond, 1996;	Similar to cyclic stress
Comparison to Modern Earthquakes	Modern earthquake analogs, size and spatial distribution, with known magnitudes	Magnitude	Yes	Tuttle, 2002	Data from NMSZ
Arias Intensity	Ground motion, field penetration tests	Magnitude, source distance	No	Tuttle, 2002; Arias, 1970; Kayen and Mitchell, 1997, Obermeier, 2001;	Does not account for effective confining pressure (e.g. depth of water table).

The available data on liquefaction features in the Saline River area include size of liquefaction fields, size of individual sand blows, thickness of vented sand, and possibly, thickness of impermeable capping layer. No data currently are available on the site stratigraphy at depths greater than trench depths and depth of push-sampler data, and no geotechnical data are available to characterize soil density, shear wave velocity, and grain size properties. Therefore, the available data do not allow application of the techniques requiring geotechnical data to estimate magnitude or PGA. The sizes of the liquefaction fields are consistent with the moderate earthquake magnitudes estimated for the Saline River source zone.
zone.

5. (1) Page 2.5-29 of the SSAR states that all ages are 2-sigma calibrated radiocarbon years before A.D. 1950.

   (2) The interpretation of earthquake chronology and recurrence presented in the SSAR is derived from our independent analysis of stratigraphic and age

relationships reported in Cox (2002) and radiocarbon and luminescence age data provided to us by Dr. Cox (personal communication, 2003) for our use in preparing the SSAR. These radiocarbon and luminescence data are now published in Cox et al. (2004).

For clarity of presentation, we have prepared several new figures and tables to illustrate our interpretation of the liquefaction data. The age data presented in Cox et al. (2004) are summarized in SSAR Table 2.5-5, Draft Rev. 1 and are illustrated in SSAR Figure 2.5-97, Draft Rev. 0. Our interpretations of the liquefaction event chronologies are shown on SSAR Figures 2.5-98 through 2.5-100, Draft Rev. 0.

Cox et al. (2004) describe stratigraphic features related to liquefaction and present age data that support interpretations of individual events at the investigation sites. However, interpretations of the event history and earthquake recurrence intervals for the liquefaction fields in the Saline River source zone are not provided. Furthermore, the interpretations of individual events in Cox et al. (2004) do not consider the full range of uncertainty represented by the 2-sigma minimum and maximum limiting ages in assessing the possible timing of past liquefaction events. The interpretation presented in the SSAR was developed based on the full range of uncertainty represented by the 2-sigma minimum and maximum limiting ages and captures a broader range of alternative interpretations than those presented in either Cox (2002) or Cox et al. (2004).

SSAR Figures 2.5-98, Draft Rev. 0 and 2.5-99, Draft Rev. 0 illustrate the alternative event scenarios inferred from the data presented in Cox (2002) and Cox et al. (2004) and used in our source characterization. We interpret four-event and five-event scenarios within the minimum and maximum allowable age ranges. These interpretations are not presented in either Cox paper and represent our interpretation of the stratigraphic and radiocarbon data for these sites.

(3) SSAR Table 2.5-5, Draft Rev. 1 is derived from our interpretation of the stratigraphic relationships described in Cox (2002) and radiocarbon ages provided to us by Cox (personal communication, 2003) now published in Cox et al. (2004). The rationale used in developing the event history presented in SSAR Table 2.5-5, Draft Rev. 1 is described in the SSAR, and is clarified in the following response to items (4) and (5), below.

SSAR Table 2.5-5 has been modified (Draft Rev. 1) to clarify the origin of the data.

(4) and (5) The interpreted event chronology presented in the SSAR is based on independent analyses of stratigraphic data reported in Cox (2002). The following discussion provides clarification and some modification to the discussion in the SSAR based on the information presented in Cox et al. (2004) and Cox and Larson (2004). The discussion refers to four new graphics (SSAR Figures 2.5-97, Draft Rev. 0 through 2.5-100, Draft Rev. 0) that illustrate the radiocarbon data and our interpretations of earthquake recurrence intervals. We also have included the new data from the Golden and Morgan sites (discussed in response (6), below).

The ages of deposits used to interpret the paleoliquefaction features at the Portland, Morgan, and Montrose sites (Ashley County), and Golden and Kelso sites (Desha County) are presented in SSAR Figure 2.5-97, Draft Rev. 0. This figure shows the minimum and maximum limiting ages and the interpreted age range for the liquefaction events; all radiocarbon ages are presented as 2-sigma calibrated radiocarbon years before present, where "present" refers to the year, A.D. 1950. When reporting calibrated radiocarbon ages we use the abbreviation cal. Yr B.P. to indicate calibrated years before A.D. 1950 (present). SSAR Figures 2.5-98, Draft Rev. 0 and 2.5-99, Draft Rev. 0 illustrate the alternative interpretations of the event history that were used to estimate earthquake recurrence intervals for the Saline River source zone. Due to large uncertainties in the luminescence data from these sites, we have excluded these data from our estimation of earthquake recurrence intervals.

One to three liquefaction events can be inferred from stratigraphic relationships at the Portland site in Ashley County (Cox, 2002; Cox et al., 2004). The data for these events are presented on SSAR Figure 2.5-97, Draft Rev. 0 and SSAR Table 2.5-5, Draft Rev. 1. The oldest event at this site (Portland Event 1) is identified as a series of "sand blow like features" within a silty clay unit. The limiting ages for this event are based on the age of the substrate (4840 to 5040 cal. yr B.P.) and the age of an overlying silty clay unit (910 to 990 cal. yr B.P.) The second event (Portland Event 2) is identified as a series of sand dikes that feed a sand layer. Sand dikes are cross-cut by a krotavina dated at 150 to 500 cal. yr B.P. (Cox et al., 2004), and therefore are older than the age of the krotavina. The krotavina provides the minimum limiting age for the Portland 2 event. Bioturbated charcoal from within the sand blow yielded ages of 0 to 430 cal. yr B.P. (Cox et al., 2004) and is also inferred to represent a minimum limiting age for the Portland 2 event (Cox et al., 2004). Charcoal from the silty clay unit yielded an age of 910 to 990 cal. yr B.P. (Cox et al., 2004), which provides the maximum limiting age for the Portland 2 event. The youngest event (Portland 3) is constrained by stratigraphic relationships where a sand vent cross-cuts the older sand blow (Cox, 2002; Cox et al., 2004) and is therefore younger than 0 to 500 cal. yr B.P. This younger event could be a separate liquefaction event, or could be related to the initial liquefaction event.

The Morgan I and II events are defined based on the presence of two sand layers separated by a reworked sand-blow/colluvial unit. The minimum age for both units is constrained by a weak soil with a radiocarbon age of 360 to 550 cal. yr B.P. The maximum age for both units is constrained by a luminescence age of 7500 to 6300 yr B.P. on the fluvial substrate. Cox (2004, personal communication) indicates there are large uncertainties in the luminescence ages.

Two to four liquefaction events can be inferred from stratigraphic relationships at the Montrose site in Ashley County. The radiocarbon ages constraining these events are shown on SSAR Figure 2.5-97, Draft Rev. 0 and SSAR Table 2.5-5, Draft Rev. 1. The oldest event (Montrose 1) is represented by a thin sand layer (<13 cm) within the fluvial deposits. The maximum limiting age for this event is based on the age of the substrate (5055 to 5320 cal. yr B.P.) and the age of a soil in an overlying sand layer (1300 to 1550 cal. yr B.P.). There is no date that directly provides a minimum age limit on this oldest sand layer.

This layer could alternatively be interpreted as a sill within the fluvial deposits and could be associated with any of the subsequent liquefaction events. In our calculation of recurrence we use this 5320 year age estimate as the maximum allowable age after which all observed events could have occurred.

The Montrose 2 event is defined by another thin (<10 cm) sand layer that overlies the fluvial substrate. The maximum limiting age of both the Montrose 1 and 2 events is constrained by the 5,055 to 5,320 cal. yr B.P. age (Cox et al., 2004) of the underlying substrate. There is no date that directly provides a minimum age limit on the Montrose 2 sand layer.

The Montrose 3 event is defined by the thickest sand layer and cross-cuts the Montrose 2 sand layer; no soil development is observed between the Montrose 2 and 3 sand layers (Cox, 2002). The minimum limiting age of the Montrose 3 sand layer is constrained by a 1,300 to 1,550 cal. yr B.P. date (Cox et al., 2004) from the organic soil developed within the layer; this date also represents the minimum limiting age for the Montrose 2 event. The maximum limiting age for the Montrose 3 event is constrained by the 5,055 to 5,320 cal. yr B.P. age (Cox et al., 2004) of the underlying substrate.

We infer that the minimum ages of liquefaction events Montrose 2 and 3 must be a minimum of several hundred years older than the age of the soil dated (1300 to 1550 cal. yr B.P.), as the soil horizon on the sand blow would require a period of time to develop. Thus, we infer a minimum age for Montrose 2 and 3 of about 1700 yr B.P.. The exact ages of these events are equivocal. Because there is an absence of soil development between these two sand layers, it is possible that the two sand layers may represent the same liquefaction event. In our calculation of recurrence we use this 1700 year age estimate as the minimum allowable age after which all observed events could have occurred.

The Montrose 4 event is defined based on the presence of a sand blow crater and sand dikes that cross cut the Montrose 3 sand layer. The maximum limiting age of the Montrose 4 sand layer is constrained by a 1,300 to 1,550 cal. yr B.P. date (Cox et al., 2004) from an organic soil developed within the Montrose 3 layer. The minimum limiting age of the Montrose 4 event is constrained by organic material in the sand blow crater dated 320 to 740 cal. yr B.P. (Cox et al., 2004).

A single event at the Golden site is defined based on the presence of a sand layer fed by sand dikes and brecciated clay clasts suspended in a fine-grained matrix. Sand dikes that feed sills within the fluvial unit also were observed. The minimum age for the sand layers is constrained by a fill within a crater dated 290 to 510 cal. yr B.P. The maximum age for the liquefaction features is constrained by a luminescence age of 8000 to 8500 yr B.P. on the fluvial substrate. Cox (personal communication, 2004) indicates there are large uncertainties in the luminescence ages.

Cox et al. (2004) interpret two or three events at the Kelso site. The radiocarbon ages constraining these events are shown on SSAR Figure 2.5-97, Draft Rev. 0. This interpretation is based on clustering of radiocarbon

dates from different sand blow craters. However, these sand blow craters feed the same sand layer and no stratigraphic features are reported that distinguish between the sand blow craters. The stratigraphy at this site also permits the interpretation of a single earthquake.

The oldest event (Kelso 1) and the middle event (Kelso 2) are recognized based on stratigraphic relationships observed in the trench where three sand vents feed a sand horizon (Cox, 2002). Charcoal from organic fill in these sand vents yield ages of 740 to 1,000, 1,030 to 1,040 cal. yr B.P.; 2,010 to 2,190, 2,230 to 2,310 cal. yr B.P.; and 960 to 1,310, cal. yr B.P. Cox et al. (2004) state that dates from 740 to 1,000, 1,030 to 1,040 cal. yr B.P. and 960 to 1,310, cal. yr B.P. are indistinguishable, and interpret these to represent a single event. The older set of dates represents an older event.

The Kelso 1 event is defined based on dates from sand blow craters that range from 2010 to 2310 cal. yr B.P. The dates represent the minimum limiting age for the Kelso 1 event. An alluvial horizon at the base of the trench was dated using infrared spectral luminescence (IRSL) at 5,200 to 6,200 yr B.P. (Cox and Larson, 2004) and represents the maximum limiting age for Kelso 1 event.

The Kelso 2 event is defined based on the younger dates from the sand blow craters that range from 740 to 1310 cal. yr B.P. (Cox et al., 2004). The dates represent the minimum limiting age for the Kelso 2 event. An alluvial horizon at the base of the trench was dated using infrared spectral luminescence (IRSL) at 5,200 to 6,200 yr B.P. (Cox and Larson, 2004) and represents the maximum limiting age for the Kelso 2 event.

The Kelso 3 event is based on an anecdotal report that describes ground cracking and bank failures, possibly associated with liquefaction during the 1812 New Madrid earthquakes at this location (Cox, 2002).

The observed liquefaction features can be interpreted in three ways. First, the liquefaction events record local moderate magnitude earthquakes that produced small liquefaction fields in Ashley and Desha Counties. These events may have been associated with earthquake activity within the Saline River source zone. Second, the observed liquefaction features may record ground shaking related to events in the New Madrid Seismic Zone. SSAR Figure 2.5-100, Draft Rev.0, illustrates that the available limiting dates and event age ranges for liquefaction features within the Saline River source zone allow correlation to the New Madrid composite event dates (Tuttle, 2002). This is supported by the historical observation of ground cracking and bank failures near the Kelso site during the 1811-1812 New Madrid earthquake sequence, although this also may be a local 1812 triggered aftershock within the Saline River source zone. Third, the observed liquefaction fields record a combination of these processes.

The data presented in Cox (2002), Cox et al. (2004), Cox and Larson (2004) and Cox (personal communication, 2004) were used to develop an earthquake recurrence model for the Saline River source zone. This earthquake recurrence model was developed independently because none of the publications on liquefaction in the Saline River source zone area (Cox, 2002,

Cox et al., 2004; Cox and Larson, 2004) present earthquake recurrence intervals. We use an approach that estimates the *average* recurrence intervals based on the estimated number of liquefaction events and the minimum and maximum allowable time in which these events could occur. Our recurrence model assumes that all of the liquefaction features could have occurred as a result of four or five earthquakes occurring in the Ashley County and Desha County areas. The minimum time in which these events could occur is between approximately A.D. 1800 (150 yr B.P., where yr B.P. stands for years before A.D 1950), when historical records became relatively complete, and 1700 yr B.P., the age of the soil formed on the Montrose 3 sand layer. For clarity, we use yr B.P. (omitting "cal.") when referring to a time or period that does not directly correspond to a calibrated radiocarbon age. The maximum time considered is between A.D. 1800 (150 yr B.P.) and 5320 cal. yr B.P., the maximum substrate age based on radiocarbon analysis. Due to the problems with luminescence dating described in Cox et al. (2004), Cox and Larson (2004), and Cox (personal communication, 2004) we choose not to use the older luminescence dates in our analysis.

The four event scenario for the period 150 to 5320 yr B.P. (SSAR Figure 2.5-98, Draft Rev. 0) involves:

Event IV	Portland 2 and 3, and Montrose 4
Event III	Portland 1, Morgan 2, Montrose 3, and Kelso 2
Event II	Montrose 2
Event I	Morgan 1, Montrose 1, Golden 1, and Kelso 1

The five event scenario for the period 150 to 1700 yr B.P. (SSAR Figure 2.5-99, Draft Rev. 0) involves:

Event V	Portland 3
Event IV	Portland 2 and Montrose 4
Event III	Kelso 2
Event II	Montrose 2 and 3 and Golden 1
Event I	Portland 1, Morgan 1, and Montrose 1

Recurrence times for the four and five event scenarios are estimated at 388 and 1725 years and represent the lower bound and middle values used in our hazard analysis. The shortest recurrence time of 388 years (rounded to 390 years) represents the average recurrence time for five events during the period 150 yr B.P. (A.D. 1800) to 1,700 yr B.P. The 1,700 year lower boundary was used because this represents the shortest, most conservative, time period in which the events could occur. The 1,725 year recurrence time represents the average recurrence time for four events occurring between 150 and 5,320 cal. yr B.P. (SSAR Table 2.5-6, Draft Rev. 1), the longest time period in which the events could occur. The 3,505 year recurrence time (rounded to 3500 years) represents the dated interval (5055 cal. yr B.P. minus 1550 cal. yr B.P.) between minimum and maximum limiting ages for liquefaction events at the

Montrose site in Ashley County. This recurrence was selected to approximate a longer possible recurrence time in addition to using the average recurrence interval calculation (above). The 3,500 year recurrence value is the upper bound value used in our hazard analysis.

6. The new data from the Golden and Morgan sites (Cox and Larson, 2004) were not available at the time of the SSAR development. This new information has been evaluated with respect to the event history presented in the SSAR for the Saline River fault zone. The data are presented on SSAR Figure 2.5-97, Draft Rev. 0, and event chronologies are presented on Draft SSAR Figures 2.5-98, Draft Rev. 0 through 2.5-100, Draft Rev. 0.

The precision of age dates for the Golden and Morgan sites is not sufficient to date specific liquefaction events; event correlations are based on the mid- Holocene dates from luminescence analysis, as well as field and stratigraphic observations made at each of the sites (Cox, personal communication, 2004). The interpreted age of paleoliquefaction features identified at the Golden and Morgan sites are consistent with the mid-Holocene events previously identified at Montrose and Kelso. Therefore, we correlate the event at the Morgan site with either the Montrose 1 or 2 events. Similarly, we correlate the event at the Golden site with either the Kelso 1 or 2 events.

The data presented in Cox and Larson (2004) are consistent with those used in the SSAR. No modifications to the analysis of recurrence intervals based on these data are required.

SSAR Revisions:

SSAR sections 2.5.1.1.5.9.3 and 2.5.2.1.3.5.1 will be revised based on this response. Tables 2.5-5 and 2.5-6 will be revised (Draft Rev. 1 versions). Four new figures will be included in the SSAR illustrating age data and interpreted event chronologies used in the recurrence analysis including, SSAR Figures 2.5-97 to 2.5-100, Draft Rev. 0.

See files:
001_ESP-SSAR_draft_rev1_12-01-2004.pdf
006_SSAR_Fig_2.5-97draft_rev0_11-19-2004.pdf
007_SSAR_Fig_2.5-98draft_rev0_11-19-2004.pdf
008_SSAR_Fig_2.5-99draft_rev0_11-19-2004.pdf
009_SSAR_Fig_2.5-100draft_rev0_11-19-2004.pdf
010_SSAR_Table2.5-5draft_rev1_11-19-2004.pdf
011_SSAR_Table2.5-6draft_rev1_11-19-2004.pdf
012_Cox2004_pers_comm_Golden-Morgan_data.pdf
013_Cox2003_pers_comm__radiocarbon_data.pdf

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Request:

RAI 2.5.1-4

Section 2.5.1.1.5.9 describes scenarios for the paleo-liquifaction features discovered in the Saline River Source Zone. One of the scenarios is to attribute these sandblows to the 1811-12 New Madrid earthquakes. Based on this scenario, the sandblow distribution of the 1811-1812 New Madrid earthquakes would extend farther south at least 175 km away from the previously recognized 1811-1812 sandblow distribution. Since the magnitudes of the 1811-1812 New Madrid earthquakes were estimated partially based on the areal distribution of the liquefaction sandblows, what is the impact of this areal expansion to the estimated magnitudes of the 1811-1812 earthquakes and the seismic hazard characterization of the ESP site?

Response:
The distribution of liquefaction features has been used as one means of estimating the magnitude of the 1811-1812 earthquake sequence associated with the New Madrid seismic zone (NMSZ). The estimation of magnitude from the liquefaction distribution is based on empirical relationships developed from a worldwide record of liquefaction occurrence (Ambraseys, 1988; Carter and Seed, 1988; Keefer, 1984; Papadopoulos and Lefkopoulos, 1993). RAI Figure 2.5.1-4-1 shows the distribution of liquefaction features associated with the NMSZ and Saline River source zone, the area of contemporary seismicity within the NMSZ, and the lineaments (inferred fault sources) that comprise the NMSZ and Saline River source zone.

The seismic source model developed for the ESP application provided maximum earthquake magnitude estimates for all three segments of the NMSZ. For the purpose of evaluating the potential occurrence of liquefaction in Desha and Ashley Counties, Arkansas from NMSZ events, the southern Blythville Arch segment is the most reasonable source because this fault is the closest NMSZ source to the liquefaction

fields in southeastern Arkansas. The earthquake magnitude distribution for the Blytheville Arch segment ranged from M_w 7.3 to 8.1. Using the empirical relationship of Ambraseys (1988), earthquakes of this magnitude range would produce liquefaction at distances of 180 to 350 km from the closest approach of the fault (RAI Figure 2.5.1-4-2). These estimated distances should be viewed as minimum estimates because the Ambraseys (1988) relationship is based on a worldwide dataset that includes a majority of plate boundary events with high attenuation rates, while the Central and Eastern US (CEUS) is characterized as a stable continental region with much lower attenuation rates (Olsen et al., 2004). RAI Figure 2.5.1-4-1 shows that the Ashley County and Desha County liquefaction fields are within the area estimated based on the worldwide data set, and therefore liquefaction could occur beyond these estimated limits.

The earthquake magnitude distribution developed for the NMSZ is consistent with the possibility that NMSZ earthquakes produced the liquefaction fields in the Saline River source zone. Therefore, there is no impact on the magnitude distribution estimated for the 1811-1812 earthquakes at the NMSZ or for the hazard characterization for the Grand Gulf ESP site.

SSAR Revisions:

None

See files: 014_RAI_Fig_2.5.1-4-1.pdf
015_RAI_Fig_2.5.1-4-2.pdf

References:

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Carter, D.P., and Seed, H.B., 1988, Liquefaction potential of sand deposits under low levels of excitation: Report No. UCB/EERC-88/11, Earthquake Engineering Research Center, Univ. of California, Berkeley, 119 p.

Keefer, D.K., 1984, Landslides caused by earthquakes, Geological Society of America Bull., v. 95, p. 406-421.

Olson, S.M., Green, R.A. and S.F. Obermeier, 2004, Geotechnical Analysis of Paleoseismic Shaking Using Liquefaction Features: Part I. Major Updating of Techniques for Analysis, U.S. Geological Survey Open-File Report 03-307 Version 1.1 - Revised January 30, 2004

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Request:

RAI 2.5.2-1

The SSAR at the end of section 2.5.2, refers to three engineering reports (ER-01, ER-02, and CP-01). One of the reports (CP-01) is not cited in the references at the end of

the entire SSAR Section 2.5. Please add a citation to this report to the reference list and provide a copy of the report so that the reviewers can better understand how the detailed site response calculations were done.

Response:

Two calculation packages were prepared in support of the SSAR. The citations for both of these calculation packages are:

William Lettis & Associates, Inc., 2004, Seismicity analysis for the Grand Gulf ESP Site, ENTO002-CP-01, Rev. 0.

William Lettis & Associates, Inc., 2004, Development of Safe Shutdown Earthquake (SSE) Ground Motions for the Grand Gulf ESP Site, ENTO002-CP-02, Rev. 1.

The reference in Section 2.5.2 of the SSAR mistakenly identified CP-01 as the document describing the site response analysis. Calculation Package CP-01 presents an analysis of the seismicity data for the Grand Gulf region. The detailed site response analysis and probabilistic seismic hazard analysis is provided in Calculation CP-02.

The Calculation Packages are available for NRC inspection in the project files.

SSAR Revisions:

The citations for these calculation packages will be added to the SSAR text and to the reference list.

See file: 001_ESP-SSAR_draft_rev1_12-01-2004.pdf

Request:

RAI 2.5.2-2

SSAR Section 2.5.2.1.2.4 discusses and applies a moment-rate constraint on New Madrid M7+ earthquakes from geodetic data. The use of moment-rate constraints in PSHA is common in California and near other plate boundary locations. However, in the Central and Eastern United States (CEUS) and the New Madrid seismic zone (NMSZ) in particular, the physical mechanism behind the occurrence of M7's at a rate much higher than strain accumulation is not scientifically understood. The paleoseismic evidence convincingly supports a 500-year mean recurrence interval for M7+ New Madrid events while the geodetic data, although somewhat equivocal, does not support such high moment rates. Viscous element models, such as Kenner and Segall, 2000 (Science, v 289, 2329-2332), have been proposed to allow high moment release in earthquakes over short geologic time intervals without high rates of stress accumulation.

1. In view of uncertainties of the physical mechanism behind CEUS M7 earthquakes, please provide a justification for applying a moment rate constraint for the modeling of these earthquakes.

2. A constant shear modulus of 3.5×10^{11} dyne cm^2 is used in the seismic moment rate calculations of this section. Please describe the impact of allowing for ruptures into the lower crust, where shear velocities and hence shear moduli are higher than the shallow crustal values of California.

3. The moment-rate constraint uses rupture-area estimates from the Reelfoot fault. Rupture area is the product of rupture length and down dip width. The length may be well constrained but the width of the Reelfoot and other NMSZ faults is not. Width is often taken to match the down dip extent of instrumental seismicity, which extends to a depth of 12-14 km on the Reelfoot fault. However, Johnston, 1996 (Geophys. J. Int., V 126, p 314-344) and the main shock rupture of the 2001 M 7.6 Bhuj intraplate earthquake suggests that major fault ruptures can occur down into the lower crust. Please explain and justify the assumptions and reasoning leading to an estimated rupture area of 1300 km^2 for a rupture of the Reelfoot fault (Table 2.5-13).

Response:

SSAR Section 2.5.2.1.2.4 presents a moment-rate analysis for the occurrence of large magnitude (M7+) earthquakes within the New Madrid seismic zone (NMSZ). This analysis was completed to provide information on the relationship between maximum earthquake magnitude and earthquake recurrence in the NMSZ. This information was not used directly to assign or calculate weights for maximum earthquake magnitude or earthquake recurrence in the hazard analysis. For example, the magnitude distribution developed for the NMSZ for the Grand Gulf ESP is the same as that developed for the Clinton ESP (EGC, 2003) which did not include a moment-rate analysis.

As indicated in the RAI, we recognize the uncertainties associated with understanding the physical mechanism that produces earthquakes in the NMSZ, as well as within Stable Continental Regions (SCRs), in general. The moment rate analysis was performed to explore one possible model of earthquake occurrence for magnitude M_w7.8 to 8.4 earthquakes (Johnston, 1996) in the NMSZ. Alternative models, such as that proposed by Kenner and Segall (2000), provide additional information on the possible association of maximum magnitude and earthquake recurrence. We also recognize the uncertainty associated with estimates of crustal rigidity (shear modulus) and down-dip geometry of faults within the NMSZ. Our analysis did not intend to understate these uncertainties, but only to provide one model (a moment-rate model) relating earthquake magnitude to earthquake recurrence using reasonable input parameters. We do feel strongly that the rate of strain accumulation (through tectonic or isostatic forces) ultimately must balance with the rate of strain release (through seismic or aseismic processes), and thus there is an important linkage within the physical process between earthquake magnitude and earthquake recurrence.

As stated above, our analysis of moment rate for the NMSZ was not directly used to develop our estimate of magnitude distribution or earthquake recurrence for the NMSZ. These parameters were developed through review of current published and unpublished literature, and were intended to capture the range of opinion in the informed technical community. An updated evaluation of maximum magnitude is provided in response to RAI 2.5.2-5. Because the moment-rate analysis was not directly used in the Grand Gulf ESP hazard analysis, SSAR Section 2.5.2.1.2.4 will be deleted from the SSAR.

SSAR Revisions:

SSAR Section 2.5.2.1.2.4 will be deleted
SSAR Tables 2.5-11 and 2.5-12 will be deleted

See file: 001_ESP-SSAR_draft_rev1_12-01-2004.pdf
043_SSAR_Table2.5-11draft_rev1_11-19-2004.pdf
044_SSAR_Table2.5-12draft_rev1_11-19-2004.pdf

References:

Exelon Generation Company (EGC), 2003, Early Site Permits – Exelon Generation Company Application for the Clinton ESP Site.

Kennar, S.J., and Segall, P., 2000, A Mechanical Model for Intraplate Earthquakes: Application to the New Madrid Seismic Zone: Science, v. 289, p. 2329-2332.

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Request:

RAI 2.5.2-3

SSAR section 2.5.2.2.2 provides a brief statement that the Electric Power Research Institute (EPRI) SOG's a- and b-values were converted from Mb to Mw for the hazard calculations. Please provide the details of the steps and equations employed in this conversion so that the staff can evaluate their validity. Also, provide the details of where in the hazard calculation this conversion is performed.

Response:

In the Grand Gulf PSHA calculation, the following steps were taken to convert m_b to M_w.

1. As input to the seismic hazard calculation, the user provides the following (with respect to converting from m_b to M_w):

   a. For each seismic source the user identifies whether seismicity parameters are defined in terms of m_b or M_w. This flag is to indicate whether the magnitude conversion is required during the hazard calculation.
   b. The parameters of the m_b-M_w relationships are input along with the probability weight assigned to each relationship.

2. For a given seismic source, the seismic hazard is computed by integrating over earthquake magnitude and distance. As part of the magnitude integration, the frequency of occurrence of earthquakes in a magnitude interval (defined by the integration step size) is computed. This calculation is performed for the magnitude scale (m_b or M_w) originally input for a seismic source.

3. For seismic sources whose seismicity is defined in terms of m_b, the conversion to M_w is performed prior to the call to the routine that computes ground motions. The conversion is made for the central m_b value in a magnitude interval.

   This step is skipped if the seismicity parameters for a seismic source are defined in terms of M_w.

4. At this point, ground motions are estimated for a given M_w and distance pair.

5. For seismic sources whose seismicity is defined in terms of m_b, Steps 3 and 4 are repeated for each m_b-M_w relationship input by the user.

In the Grand Gulf PSHA three relationships were used to convert m_b to M_w. The relationships, which were equally weighted, were EPRI (1993), Atkinson-Boore (1995) and Johnston (1996). The equations for these relationships are:

Authors	Equation
EPRI (1993)	$m_b = -10.23 + 6.105M_w - 0.7632M_w^2 + 0.03236M_w^3$
Atkinson and Boore (1995)	$M_w = -0.39 + 0.98m_b$ $m_b <= 5.5$ $M_w = 2.715 - 0.277m_b + 0.127\, m_b^2$ $m_b > 5.5$
Johnston (1996)	$M_w = 3.45 - 0.473\, m_b + 0.145\, m_b^2$

SSAR Revisions:

None

References:

Atkinson, G.M. and D.M. Boore (1995). Ground-Motion Relations for Eastern North America, Bulletin of the Seismological Society of America, v. 85, n. 1, 17-30.

Electric Power Research Institute (1993). Guidelines for Determining Design Basis Ground Motions. Volume 5: Quantification of Seismic Source Effects, EPRI Report TR-102293, November 1993.

Johnston, A.C., Seismic Moment Assessment of Earthquake in Stable Continental Regions – III. New Madrid 1811-1812, Charleston 1886 and Lisbon 1755, Geophysical Journal International, v. 126, p.314-344, 1996.

Request:

RAI 2.5.2-4

Figure 2.5-47 of the SSAR for Grand Gulf shows the estimated rate of earthquakes of magnitudes from 5 to 6 using the Electric Power Research Institute/Seismic Owners Group (EPRI/SOG) and updated catalogs. This figure's vertical axis is labeled frequency of exceedance per year. Does a point at magnitude 5 correspond to the

mean annual frequency of magnitude 5 and above, or magnitude 5.1 and above, or to some other rate of earthquakes? In addition, what b-value or range of b-values were used to generate the curves in this figure?

Response:

A point on the magnitude-frequency curve corresponds to the frequency of exceedance of the magnitude value one uses to enter the curve. So for example, the point at magnitude 5 corresponds to the annual frequency of events of magnitude 5 and above.

The magnitude-frequency curve that is provided in the figure corresponds to a single a- and b-value pair. Thus, the curve that is shown does not correspond to the mean of a set of alternative estimates of the seismicity parameters.

The b-value used to generate the magnitude-frequency curves is 0.91. This b-value corresponds to the value calculated using EPRI program EQPARAM assuming homogeneous seismicity. The b-value of 0.91 was computed for both the original EPRI-SOG catalog and the updated catalog.

SSAR Revisions:

None

Request:

RAI 2.5.2-5

In characterizing the seismic hazard of the New Madrid seismic source zone, (Draft SSAR 2.5.1.1.5.6, 2.5.2.1.2.2, and Draft Table 2.5-10) cite the preferred magnitudes of Bakun and Hopper (2003, in press) for the New Madrid main shocks of 1811-12 as Mw 7.2, 7.1, and 7.4. The work of Bakun and Hopper (2003, in press; Reference 115) has been withdrawn and revised with corrected magnitude estimates for the 1811-12 New Madrid main shocks as M 7.6, 7.5, and 7.8 (Bakun and Hopper, 2004, Bull. Seism. Soc. Am., v. 94, no. 1, p. 64-75).

1. Please explain what changes these revised magnitude estimates may require in the analysis and provide corrected copies of any affected tables and figures.

2. Please quantify the effect of the revised magnitude estimates on hazard at the site by providing a graph showing two long-period (ca. 1 Hz) hazard curves, one using the magnitudes of Bakun and Hopper (2003, in press) and the second using the magnitudes of Bakun and Hopper (2004). Other parameters should be held constant for both curves and the curves should extend to an annual probability at least as small as 10^{-5}.

Response:

As indicated in the RAI, the work of Bakun and Hopper (2003, in press) was used as one source of information to estimate the range in earthquake magnitudes for the New Madrid seismic zone (NMSZ). The NMSZ is divided into three distinct fault segments: the New Madrid South fault (NS), the Reelfoot fault (RF), and the New Madrid North

the New Madrid seismic source (NN, RF and NS faults). Their table and assumptions are given below:

RAI Table 2.5.2-5-2
Suggested Revision to the Magnitude Distributions for Characteristic New Madrid Earthquakes

Characteristic Earthquake Rupture Set	Characteristic Magnitude for Individual Faults (moment magnitude [M_w])			Weight
	New Madrid South	Reelfoot Thrust	New Madrid North	
1	7.8	7.7	7.5	0.1667
2	7.9	7.8	7.6	0.1667
3	7.6	7.8	7.5	0.25
4	7.2	7.4	7.2	0.083
5	7.2	7.4	7.0	0.1667
6	7.3	7.5	7.0	0.1667

Rupture sets 1 and 2 correspond to the revised Johnston (1996) preferred estimates, rupture sets 3 and 4 correspond to the revised Bakun and Hopper (2004) Model 3 and Model 1 estimates, respectively, and rupture sets 5 and 6 correspond to the Hough et al. (2000)/Mueller et al. (2004) preferred estimates. EGC (2004) gave equal weight to each author (1/3) and equally divided this weight for each rupture set, with the exception of Bakun and Hopper (2004) where more weight was given to their preferred Model 3 than to their alternative Model 1. Rather than duplicate the effort by EGC and to provide consistency in characterizing the New Madrid Seismic Source, we adopt the EGC (2004) summary of magnitude distribution and assigned weights given the information published in 2004 and ongoing work by Johnston (unpublished).

Given this revised maximum magnitude assessment, the weighted maximum magnitude for the NS fault is M_w 7.53. This compares to the weighted maximum magnitude of M_w 7.54 given in the Grand Gulf ESP SSAR section 2.5.2.1.2.2 (M_w 7.3 (0.4), M_w 7.7 (0.5), and M_w 8.1 (0.1)). Given the general range in magnitude distribution shown in RAI Table 2.5.2-5-2 from M_w 7.2 to 7.9 for the NS (Blythville Arch) fault and the nearly identical weighted maximum magnitude of 7.53 (versus 7.54 in the SSAR), we conclude that the magnitude distribution and weighting provided in the SSAR captures the range of uncertainty in the professional community.

EGC (2004) performed a sensitivity analysis to test the impact of the revised magnitude distribution and weighting on median and mean rock hazard for 1 Hz spectral acceleration at the EGC ESP site in Clinton, Illinois. Their results show an increase of approximately 3 to 4 percent at the median and mean hazard levels. Although we have not performed a similar quantitative analysis, given the distance to the GGNS ESP site from the New Madrid faults (>249 miles), lack of change in the overall weighted maximum magnitude for the NS fault, and reduction in the maximum considered magnitude from M_w 8.1 to 7.9 for the NS fault, we do not anticipate a significant change in hazard at the site at 1 Hz spectral acceleration.

In addition, the current hazard analysis provided in the GGNS ESP Application (SSAR Section 2.5.2.2) conservatively uses only attenuation relationships for the mid-

continent to estimate ground motion at the site from the NMSZ, even though the GGNS ESP site lies within the Mississippi Embayment. Attenuation relationships for the Mississippi Embayment show that ground motions attenuate more rapidly with distance than within the mid-continent. For these reasons, we conclude that the revision to magnitude distribution for the NMSZ published since submittal of the GGNS ESP Application will not significantly change the median 10^{-5} hazard at the site.

SSAR Revisions:

None

References:

Bakun and Hopper (2003, withdrawn). The 1811-1812 New Madrid, Missouri, and the 1886 Charleston, South Carolina, Earthquakes, Bulletin of the Seismological Society of America.

Bakun, W.H., and Hopper, M.G., 2004, Magnitudes and Locations of the 1811-1812 New Madrid, Missouri, and the 1886 Charleston, South Carolina, Earthquakes: Bulletin of the Seismological Society of America, v. 94, no. 1, p. 64-75.

EGC, 2004, Response to Request for Additional Information (RAI) Letter No. 7 – Exelon Early Site Permit (ESP) Application for the Clinton ESP Site (TAC No. MC1122), October 11, 2004.

Johnston, A.C., and Schweig, E.S., 1996, The enigma of the New Madrid earthquakes of 1811-1812, Ann. Rev. Earth Planet Sci., 24, p. 339-384.

Hough, S.E., Armbruster, J.G., Seeber, L., and Hough, J.F., 2000, On the Modified Mercalli intensities and magnitudes of the 1811-12 New Madrid earthquakes, Journal of Geophysical Research, v. 105, p. 23,839-23,864.

Mueller, K., Hough, S.E., and Bilham, R., 2004, Analysing the 1811-1812 New Madrid earthquakes with recent instrumentally recorded aftershocks: Nature, v. 429, p. 284-288.

Request:

RAI 2.5.2-6

SSAR 2.5.2.1.1 and Table 2.5-8 summarize maximum magnitudes (Mw(max)) and fractional weights developed by the six EPRI Earth Science Teams (ESTs) as part of the 1986 EPRI-SOG Project (Reference 9) for the seismic source zones surrounding the ESP site. In consideration of the 1994 EPRI study of Arch Johnston, "Seismotectonic Interpretation and Conclusion from the Stable Continental Region Seismicity Database," please provide a justification for not updating the EPRI EST seismic source characterizations to give more weight to larger magnitude earthquakes.

Response:

Based on the guidance provided in Regulatory Guide 1.165, which was used in the Grand Gulf ESP, an estimate for the seismic hazard which uses the EPRI SOG methodology and data (1986, 1989) must consider whether there is new Earth Sciences information that has become available since the original study was

conducted that would require an update of the parameters in the analysis. With this guidance, we reviewed existing literature and information published since completion of the 1986-1989 EPRI SOG study. This included updating the 1986 EPRI seismicity catalog, and reviewing the Johnston et al. (1994) EPRI study and the 2002 USGS National Seismic Hazard study (Frankel et al., 2002), as well as other studies. The updated seismicity catalog is described further in response to RAI 2.5.1-1. The updated seismicity catalog does not show a change in maximum magnitude seismicity distribution, or rate of occurrence since the 1986 EPRI SOG study, and thus does not require a change to the maximum magnitude estimate for background source zones in the Grand Gulf ESP Site Region.

The Johnston et al. (1994) and Frankel et al. (2002) studies provide additional information on maximum magnitude for the background source zone in the Gulf Coastal Plain. As described below, this information is encompassed within the uncertainty bounds of the EPRI SOG (1986, 1989) study and, thus, Regulatory Guide 1.165 does not require revision to the EPRI SOG source model. Appendix E of Regulation Guide 1.165, specifies that the EPRI study is an acceptable methodology for the evaluation of seismic hazard with the caveat "*If new information identified by the site-specific investigations would result in a significant increase in the hazard estimate for a site, and this new information is validated by a strong technical basis, the PSHA may have to be modified to incorporate the new technical information.*"

In 1994, EPRI published a five-volume study on "The Earthquakes of Stable Continental Regions" (Johnston et al., 1994). Volume 1 of the study, "Assessment of Large Earthquake Potential", presents results from a worldwide database of earthquakes within stable continental regions (SCRs) to access the relationship, if any, between maximum magnitude and specific tectonic environments. As stated in the introduction to this volume: "*Part of the focus of the early phase of this work was the evaluation of existing methods for assessing maximum earthquakes and preliminary development of new methods for use by the earth science teams in the EPRI-SOG seismic hazard analysis for the Central and Eastern United States (CEUS)*" (Johnston et al., 1994, page 1-1).

The Johnston et al. (1994) EPRI study was initiated in the mid 1980s to examine the assessment of maximum magnitudes in SCRs for specific use in the EPRI SOG seismic hazard analysis for the CEUS. The study makes the fundamental observation that the largest SCR earthquakes appear to be associated with tectonic domains of Mesozoic and younger extended crust. Initial results of the study (Coppersmith et al., 1987), "Methods for assessing maximum earthquakes in the central and eastern United States," were provided to the EPRI earth science teams (ESTs) for the EPRI SOG PSHA. Thus, the observation of the Johnston et al. (1994) worldwide database associating the largest SCR earthquakes with Mesozoic and younger extended crust was known to the ESTs at the time of the EPRI SOG study. However, given the preliminary nature of the database at the time, the ESTs generally used a variety of approaches (and philosophies) to estimate maximum magnitude, and incorporated a large degree of uncertainty in their estimates. Several of the EPRI earth science teams explicitly refer to the preliminary worldwide database in their estimate of maximum magnitudes for seismic sources in the central and eastern United States.

Based in part in the Johnston et al. (1994) study, the USGS National Hazard Map (2002) adopted a maximum magnitude of M_w 7.5 for background seismicity in the Gulf Coastal region and assigned a weight of 1.0 to this value, suggesting that the informed technical community of seismologists/geologists agrees in unanimity with the estimate of this parameter. We believe, rather, that a weight of 1.0 implies a higher level of certainty for the maximum magnitude in the Gulf Coastal plain then is warranted by the available information.

The six earth science teams that participated in the EPRI SOG seismic hazard project evaluated seismicity parameters and maximum magnitudes as part of an expert elicitation process in which epistemic uncertainties were explicitly evaluated. This elicitation process corresponded to a Senior Seismic Hazard Advisory Committee (SSHAC) Level 4 analysis. The ESTs were aware of the fundamental observation that the largest SCR earthquakes are associated with Mesozoic and younger extended crust and presumably considered this information in their deliberations and expert elicitation process.

For example, Johnston et al. (1994) state that, "The results of this study lend support to preliminary indications from this work (e.g. Coppersmith, 1991, Coppersmith et al., 1987) that were used in the assessments of maximum magnitude for seismic source zones in the EPRI SOG seismic hazard methodology." Thus, in a general sense, results from the Johnston et al. (1994) study were incorporated into the thought process and analysis of the initial EPRI EST source characterization. An estimate of M_w 7.5 (m_b 7.2) for the Gulf Coastal region is within the upper range of the Dames and Moore EST estimate of maximum magnitude. As such, the EPRI source model considered such an estimate to be credible, albeit with low weight.

The Gulf Coastal Plain of the southern United States lies within the Gulf Coast domain of Mesozoic and younger extended crust defined by Johnston et al. (1994). However, in the site vicinity there are no known Mesozoic or younger tectonic structures that may be reactivated, for example, similar to the faults within the New Madrid Seismic Zone (SSAR Figure 2.5-3). In addition, the site region is underlain by relatively undeformed Cretaceous and younger strata over 10,000 feet thick (SSAR Figure 2.5-6). The absence of faulting within these strata show that faults capable of providing M_w 7.5 earthquakes likely are not present in the Grand Gulf Site Region.

Given the extremely low rate of historic seismicity combined with the absence of observed late Cenozoic geologic or tectonic deformation in the Site Region, it is our opinion that we do not have a strong technical basis to alter the magnitude distribution and weights assigned by the ESTs during their SSHAC Level 4 elicitation process. In contrast, additional information for the Saline River Source Zone does provide a strong technical basis to alter the EPRI SOG source model, and this new source zone was added for the Grand Gulf ESP seismic hazard study.

In our opinion, therefore, the final results of the Johnston et al. (1994) and 2002 USGS (Frankel et al. 2002) studies do not provide new information that would significantly change the maximum magnitude estimates, probability of occurrence, recurrence models or source zone geometries of the 1989 EPRI SOG seismic source model.

SSAR Revision:

None

References:

Johnston, A.C., Coppersmith, K.J., Kanter, L.R., and Cornell, C.A., 1994, The Earthquakes of Stable Continental Regions: Volume 1 – Assessment of Large Earthquake Potential; Electric Power Research Institute TR- 102261-V1

Coppersmith, K.J., Johnston, A.C., Metzger, A.G., and Arabasz, W.J., 1987, Methods for assessing maximum earthquakes in the central and eastern United States; Electric Power Research Institute Research Project 2556-12

Electric Power Research Institute (EPRI), 1986, Seismic-hazard methodology for the central and eastern United States, Electric Power Research Institute Project P101-19 Final Report NP-4726, volumes 1-10, including seismicity catalog, no sequential page numbers.

Electric Power Research Institute (EPRI), 1989, EQHAZARD Primer, NP-6452-D, Research Project P101-46; Prepared by Risk Engineering, Inc.

Frankel, A., Petersen, M., Mueller, C., Haller, K., Wheeler, R., Leyendecker, E., Wesson, R., Harmsen, S., Cramer, C., Perkins, D., and Rukstales, K., 2002, Documentation for the 2002 update of the national seismic hazard maps, U.S. Geological Survey Open-File Report 02-420, available at geohazards.cr.usgs.gov/eq/

Request:

RAI 2.5.2-7

SSAR 2.5.2.1.3 characterizes the Saline River source zone, and Table 2.5-13 describes the calculation of recurrence intervals for characteristic earthquakes in the zone. Both parts of the SSAR list preferred slip rates of 0.01, 0.05, and 0.10 mm/yr, and the table assigns weights of 0.6 to the recurrence estimates calculated from slip rates of 0.05 mm/yr. The slip rates are vertical rates for which incision rates of uplifted terraces are taken as proxies (Fig. 2.5-23, SSAR 2.5.1.1.5.9.1). However, the incision rates are 0.05-0.09 mm/yr for a surface of age 800-1300 ka, 0.3-0.5 mm/yr for a younger surface 70-120 ka, and 0.8-1.7 mm/yr for the youngest surface 18-30 ka. SSAR 2.5.1.1.5.9.1 mentions no reason to prefer one of these incision rates over another. However, younger surfaces with offsets large enough to be the result of multiple earthquakes may be the better estimators of current and near-future slip rates. Please explain the evidence and reasoning that led to a choice of slip rates that are centered around the lowest of the measured incision rates (0.05 m/yr).

Response:

Fault slip rates estimated for the Saline River seismic zone were derived from both geomorphic analysis (SSAR Figure 2.5-23) and paleoseismic investigations conducted by Cox, et al. (2000). The rates obtained using incision as a proxy for uplift rate (SSAR Section 2.5.1.1.5.9.1) varies from 0.05 to 1.7 mm/yr, as indicated in the RAI. The rates obtained from paleoseismic studies using offset piercing points observed in trenches range from 0.008 mm/yr to 0.03 mm/yr (SSAR Section 2.5.1.1.5.9.4.3). The values and weights (in parentheses) selected for use in the recurrence model are 0.01 mm/yr (0.1), 0.05 mm/yr (0.3), and 0.1 mm/yr (0.6).

The minimum slip rate value of 0.01 mm/yr for the earthquake recurrence model was estimated from data obtained during paleoseismic investigations along the Saline River fault zone (Cox et al., 2000). The fault slip rate is estimated to be 0.008 to 0.03 mm/yr, based on the 30-meter offset of a secondary fault within Upland Complex deposits exposed in the trench and a 1- to 4-million year age range of the Upland Complex (Sites 3 and 4 of Cox et al., 2000). We have approximated this age range and assigned a slip rate value of 0.01 for the recurrence analysis. This value is considered a reasonable minimum slip rate value and is assigned a low weight of 0.1 in the hazard analysis.

The middle fault slip rate value of 0.05 mm/yr was estimated based on a combination of both the 0.03 mm/yr rate derived from the paleoseismic data, and the lower bound rate of 0.05 mm/yr rate derived from incision of the 800 to 1,300 Ka Intermediate Complex terrace (SSAR Figure 2.5-23). Because the value of 0.05 mm/yr is approximated by both the geomorphic data and paleoseismic data, we assign a significant weight of 0.3 for the hazard analysis.

The upper fault slip rate value of 0.1 mm/yr was estimated from the incision rate analysis (SSAR Figure 2.5-23). This value was estimated based on the upper bound rate of 0.09 mm/yr for incision of the 800 to 1,300 Ka Intermediate Complex terraces and the lower bound rate of 0.3 mm/yr for incision of the 70 to 120 Ka Prairie Complex (SSAR Figure 2.5-23). This upper fault slip rate of 0.1 is considered a reasonable

maximum slip rate value and was assigned the highest weight of 0.6 for the hazard analysis.

The higher fault slip rates approximated by incision of the 18 to 30 Ka Deweyville terraces (0.8 to 1.7 mm/yr) and the upper bound rate for the 70 to 120 Ka Prairie Terrace (0.5 mm/yr) were not included in the recurrence model. These rates are not considered to be reasonably consistent with other lines of evidence used to approximate the fault slip rates. Faults with high slip rate values, such as these, would be expected to produce clearer expression of active tectonic deformation due to repeated moderate to large magnitude earthquakes. We consider the estimated rates of incision for the Deweyville and Prairie terraces to have been affected by changes in hydrologic regime during the Wisconsin glacial periods (Saucier, 1994), and/or isostatic response to crustal unloading. In addition, field reconnaissance in the Saline River area identified discrepancies in the mapping of Deweyville terraces. The existing mapping is regional and preliminary in nature with large associated uncertainties. The mapping uncertainty may have resulted in misidentification of the Deweyville and Prairie Complex terraces leading to overestimation of incision rates. Therefore, we consider the incision rates associated with the Intermediate Complex terraces, and lower bound values associated with the Prairie Complex terraces, to be more representative of the inferred fault slip rates than the upper bound rates associated with the Prairie Complex, or the full range of rates associated with the Deweyville terraces.

The weights of slip rates selected for use in the hazard analysis are 0.01 mm/yr (0.1), 0.05 mm/yr (0.3), and 0.1 mm/yr (0.6) (SSAR Table 2.5-13, Draft Rev. 1). The values and weights were mistakenly reported in the SSAR as 0.01 mm/yr (0.1), 0.05 mm/yr (0.6), and 0.1 mm/yr (0.3). This error in description of the weighting will be corrected in the SSAR. The weighting used in the hazard analysis places the predominant weight on the highest slip rate value and therefore is a conservative assessment of the hazard. The analysis places a 90% weighting on the middle and upper estimates of slip rate used in the hazard assessment.

SSAR Revisions:

Section 2.5.2.1.3.5.2, entitled Slip Rate, will be modified. Table 2.5-13 will be revised to correct the weighting of slip rates and recurrence intervals.

See files: 001_ESP-SSAR_draft_rev1_12-01-2004.pdf
016_SSAR_Table2.5-13draft_rev1_11-19-2004.pdf

Reference:

Cox, R.T., Van Arsdale, R.B., Harris, J.B., Forman, S.L., Beard, W., and Galluzzi, J., 2000, Quaternary faulting in the southern Mississippi Embayment and implications for tectonics and seismicity in an intraplate setting, Geological Society of America Bulletin, v. 112, No. 11, p. 1724-1735, 8 figures, 2 tables.

Saucier, R.T., 1994, Geomorphology and Quaternary Geologic History of the Lower Mississippi Valley, U.S. Army Corps of Engineers, U.S. Army Engineer waterways Experiment Station, Vicksburg, Miss.

Request:

RAI 2.5.2-8

SSAR Figures 2.5-48 through 2.5-54 show hazard curves for 0.5 Hz, 1 Hz, 2.5 Hz, 5 Hz, 10 Hz, and 25 Hz Sa. In each figure, the mean curve is shown above or approximately coinciding with the 0.85 fractile curve for higher spectral accelerations. Please explain this asymmetry.

Response:

The results of a PSHA in which the epistemic uncertainty is modeled produces a probability distribution on the estimate of the annual frequency of exceedance of ground motions. Experience indicates this distribution is not symmetric (e.g., not Gaussian), and is typically skewed and approximately lognormal in shape (EPRI, 1989, Sobel, 1994). As a consequence the mean of this distribution is skewed (is higher) with respect to the median. The degree of skewness is a function of the epistemic uncertainty. As the epistemic uncertainty increases, the tendency is for the mean to correspond to higher fractile estimates of the frequency of exceedance.

In the Grand Gulf PSHA there are a number of factors that contribute to increased epistemic uncertainty as compared to the EPRI SOG calculation. These are the added uncertainty associated with the conversion from m_b to M_w and the uncertainty in the new EPRI 2003 ground motion model. The new EPRI 2003 ground motion model has somewhat higher epistemic uncertainty than the models used in the EPRI SOG calculations, particularly for higher frequency ground motions.

SSAR Revisions:

None

References:

Electric Power Research Institute, Probabilistic Seismic Hazard Evaluations at Nuclear Plant Sites in the Central and Eastern United States: Resolution of the Charleston Earthquake Issue, Report NP-6395-D, Palo Alto, CA, April 1989.

Sobel, P. Revised Livermore Seismic Hazard Estimates for Sixty-Nine Nuclear Power Plant Sites East of the Rocky Mountains, NUREG-1488, U.S. Nuclear Regulatory Commission, April 1994.

Request:

RAI 2.5.2-9

SSAR 2.5.2.2.5.1 and Figures 2.5-57 and 2.5-58 describe the deaggregation results. The Saline River source zone is 130-330 km distant from the site (Figure 2.5-19) and is presumed to have earthquakes as large as 6.0-7.0 (SSAR 2.5.2.1.3.3). However, those distance and magnitude bins make no contributions to the deaggregation graphs. Please explain this apparent discrepancy.

Response:

The purpose of the magnitude-distance deaggregation is to provide a measure of the relative contribution of events (of different magnitude-distance pairs) to the total hazard. The deaggregation graphs in the SSAR show the relative contribution of earthquakes to the 10^{-5} median. The fact that events associated with the Saline River source (and all sources in this distance range) do not contribute to the 10^{-5} median hazard for the Grand Gulf site is primarily due to the fact that the overall rate of earthquake occurrences ($M_w > 5$) at these distances is extremely low. Further, the rate of occurrence of earthquakes of magnitude 6.0-7.0 is thus much lower. The result is that the estimated ground motion hazard at the Grand Gulf site is extremely low and, in a relative sense, makes little or no contribution to the 10^{-5} median hazard.

SSAR Revisions:

None

Request:

RAI 2.5.2-10

SSAR 2.5.2.2.5.2 and Table 2.5-16 describe the computed controlling earthquakes for low and high frequencies (1-2.5 Hz and 5-10 Hz, respectively). The table lists the controlling earthquake for high frequencies to be M 6.3 at 82 km from the site. However, the high frequency deaggregation graph (Figure 2.5-58) shows no contribution from the magnitude-distance bin that contains the controlling earthquake. Please explain this discrepancy.

Response:

As described in Regulatory Guide 1.165, the controlling earthquake for a given frequency range is the mean magnitude and mean distance of the deaggregation distribution. In cases where the deaggregation distribution is multi-modal, or for the Grand Gulf case bimodal, the resulting mean may not correspond to the magnitude values that are actually defined in the distribution.

There are a number of factors that contribute to the bimodal nature of the magnitude-distance distribution. These are:

1. The seismicity (rate of earthquake occurrences) in proximity (in the distance range 0-50 km) to the Grand Gulf site is extremely low.

2. The maximum magnitudes in the vicinity of the site are low.

3. For seismic sources in the vicinity of the site, the EPRI 2003 Gulf Coast region attenuation models were used. These models have a high rate of attenuation, thus reducing the ground motions that may occur at the site.

4. The rate of occurrence of characteristic events associated with the three New Madrid seismic sources that were modeled in the Grand Gulf PSHA is high, relative to the seismicity in the vicinity of the site. In addition, the size of the characteristic events is very high. As a result, these events can produce ground

motions at the Grand Gulf site and we find that their relative contribution to the median 10^{-5} median hazard is high, in comparison to the smaller, nearby events ($M_w < 6$ and $R < 100$ km).

5. In the PSHA, ground motions generated by the New Madrid seismic zone are modeled using the Mid-continent ground motion parameters in the EPRI 2003 ground motion model. In comparison to the Gulf Coast parameters of the EPRI 2003 ground motion model which is used for seismic sources in proximity to the site, the rate of attenuation with distance of the Mid-continent models is less.

The first three factors listed contribute to low estimates of the seismic hazard at the site, on an absolute scale, for earthquakes that occur within 200 km. The final two factors result in high relative seismic hazard at the site as a result of New Madrid events (relative to the frequency of ground motions estimated for events that occur closer to the site) associated with the New Madrid seismic sources that were added to EPRI SOG model as part of the Grand Gulf ESP.

SSAR Revisions:

None

Request:

RAI 2.5.2-11

Section 2.5.2.3 indicates that Approach 2A was used to generate the soil uniform hazard spectrum (UHS) corresponding to the defined hardrock UHS, following the procedures of NUREG/CR-6728, "Technical Basis for Revision of Regulatory Guidance on Design Ground Motions: Hazard and Risk Consistent Ground Motions Spectra Guidelines." The procedure generally recommended in NUREG/CR-6728 for deep soil sites is Approach 2B and is the method that has been used to generate design spectra at the ground surface at a number of other soil sites. Please provide the basis for using Approach 2A as opposed to what is generally regarded as the more appropriate method 2B.

Response:

The use of Approach 2A, which employs the 1 to 2 Hz and 5-10 Hz scaled spectra to drive the soil column is considered appropriate because of the narrow range in earthquake magnitude contributions to the UHS at low- and at high-frequency. This range is only about 0.7 magnitude units. As a result, considering the range in magnitude at 1 to 2 Hz and at 5 to 10 Hz in site response (Approach 2B) is not warranted.

SSAR Revisions:

Section 2.5.2.3 of the SSAR will be revised to provide rationale for using Approach 2A for the Site Response analysis.

See file: 001_ESP-SSAR_draft_rev1_12-01-2004.pdf

Request:

RAI 2.5.2-12

Section 2.5.2.5 describes the resulting soil UHS developed from the site response calculations corresponding to the given rock UHS. This spectrum is shown in Figure 2.5-67 and is indicated to have a spectral acceleration at 100 Hz of about 0.2g. The corresponding vertical spectrum is developed for the ESP site by using the vertical-to-horizontal (V/H) ratios generated from the Regulatory Guide (RG) 1.60 criteria spectra. What is the basis for this selection and how does it compare with more recent recommendations for V/H ratios available in the literature?

Response:

V/H ratios are dependent on site conditions (rock verses soil), magnitude, and distance (Silva, 1997). Deep soil empirical V/H ratios increase with magnitude and decreasing source distance, within about 50 km. Beyond about 50 km, deep soil empirical V/H ratios at M 7.5 have a maximum of about 1 near 15 Hz and decrease to about 0.5 at 2 Hz and below. At high frequency (> 15 Hz) the ratios decrease to about 0.8. At larger distances (> 50km), the V/H ratios decrease somewhat at high-frequency with increasing distance and remain rather constant at about 0.5 at low-frequency. For source distances beyond 50 km, the Regulatory Guide (RG) 1.60 V/H criteria are considered to reflect an adequately conservative estimate of site-specific vertical motions.

SSAR Revisions:

None

Reference:

Silva, W.J., 1997, Characteristics of vertical strong ground motions for applications to engineering design, Proc. Of the FHWA/NCEER Workshop on the Nat'l Representation of Seismic Ground Motion for New and Existing Highway Facilities, I.M., Friedland, M.S Power and R. L. Mayes eds., Technical Report NCEER-97-0010.

Request:

RAI 2.5.4-1

Section 2.5.4.1.2 presents a general description of the soil profile at the site. Section 2.5.4.1.3.4 describes the Catahoula formation as hard clay and claystone. Section 2.5.4.1.2 and Sections 3.2 and 10.4 of Environmental Report (ER)-02 indicate that this material is Miocene in age, is often referred to as "bedrock," and is labeled as the primary load-bearing component for safety related facilities. The Miocene deposits are described in Section 2.5.1.1.4.2.3.2 of the SSAR as a succession of clays and sandy clays interspersed with lens of fine sands, sandstone and gravels that extend to great depths throughout the Gulf region.

Only three new borings were taken at the site since Borings 2 and 2A are essentially at the same location and no samples were taken in Boring 2A over the depth range

covered by Boring 2. Of the new borings, only one (Boring 2A) reached to the depth of the Catahoula and in this boring, no continuous core is indicated to have been taken in this material. This section goes on to indicate that the descriptions of the profile in the previous updated final safety analysis report (UFSAR) have been improperly categorized as members of the Catahoula formation. With only one boring available and no significant samples taken in this formation, what is the basis for categorizing this relatively shallow component of the deep profile as bedrock as opposed to dense sands and gravels? What is the impact of describing this formation as "bedrock" as opposed to dense sands and gravels in the various site evaluations?

Response:

Considerable effort was made to evaluate and develop an internally consistent interpretation of the site stratigraphy given the wide range of data sets available. A discussion of the borehole investigation program performed for the ESP and integration with earlier Grand Gulf UFSAR investigations is provided in response to RAI 2.5.4-3, and in SSAR Section 2.5.4.1.2 and Engineering Report ER-02 Sections 3.2 and 7.7. Descriptions from the UFSAR borings were compared to the ESP exploration classifications to define the site stratigraphy and to make unit correlations between borings. The nomenclature used in the ESP for the site geologic units is somewhat different than the convention used for the UFSAR, as explained in the SSAR and ER-02 sections listed above, and summarized in RAI Table 2.5.4-1-1, below.

Table RAI 2.5.4-1-1
Correlation Table Between ESP and UFSAR Stratigraphy

Formation	Age	ESP Unit	UFSAR Unit
Loess (Peoria, Roxanne, Loveland)	Pleistocene	Loess	Loess
Upland Complex	Pleistocene	Upland Complex Alluvium	Terrace Alluvium
Upland Complex	Plio-Pleistocene	Upland Complex Old Alluvium	Catahoula formation (upper part)
Catahoula Formation	Miocene	Catahoula formation	Catahoula formation (deeper part)

The stratigraphic nomenclature adopted for the UFSAR relied heavily on the regional geologic study of Fisk (1944; SSAR Reference 31). The ESP site nomenclature was updated and modified to be consistent with the more recent (post-UFSAR) regional geologic studies listed below:

- Saucier, 1994; SSAR Reference 17
- Autin et al., 1991; SSAR Reference 32
- Saucier and Snead, 1989; SSAR Reference 44

These recent studies provide a better understanding of the depositional history of Pliocene and Pleistocene sediments, and develop refined stratigraphic descriptions and correlations. For instance, the UFSAR generic classification of "Terrace Alluvium" now can be correlated to the Plio-Pleistocene Upland Complex alluvium. Careful examination of the deposits encountered in the lower parts of the ESP borings, that would have been

classified as Catahoula formation in the UFSAR, allowed us to define an older lower unit in the Upland Complex. This thinly interbedded sequence of dense sand, silt, and clay that we classified as Upland Complex Old Alluvium exhibits significantly lesser degrees of lithification and coarser, less-sorted texture than the underlying partly-lithified clay-claystone that we classify as Miocene Catahoula formation. The contact between the Upland Complex Alluvium and Old Alluvium is an irregular erosion surface, and a yellowish-brown slightly oxidized zone occurred at the contact in two of the ESP borings. The UFSAR states that a zone of oxidation was found at the contact between the Terrace Alluvium and UFSAR-defined top of Catahoula formation at, or slightly above, the elevation of the power plant foundations. This oxidized zone helped us make the correlation between the ESP SSAR Upland Complex Alluvium-Old Alluvium contact, and UFSAR Terrace Alluvium-Catahoula formation contact.

Even though the nomenclature is different between the ESP SSAR and UFSAR, the properties for the equivalent cross-correlated units are similar. For example, the general textural description and engineering properties of ESP unit Upland Complex Old Alluvium is essentially equivalent to the UFSAR designation of Catahoula formation into which the existing power plant foundations are embedded. Therefore, the nomenclature change from upper "Catahoula formation" bedrock used in the UFSAR to dense sand and in the gravel of the "Upland Complex Old Alluvium" used in the SSAR does not have any significant impact on the findings of the UFSAR and ESP SSAR.

As discussed in the ESP SSAR and UFSAR, the existing power plant foundations extend to elevations of between 78 and 86 feet and bear within gray to gray-green, silty to sandy clay and clayey silt with some locally indurated or cemented clay, sand, and silt seams. This foundation bearing strata is defined as the Catahoula formation in the UFSAR, and is correlative with the ESP SSAR Upland Complex old alluvium. As shown in SSAR Figure 2.5-78, the top of the Upland Complex Old Alluvium is irregular, and is in general about 30 to 80 feet higher in elevation at the power plant site than underneath the ESP site area. Therefore, foundations at the ESP site would require deeper excavations extending into the Upland Complex Old Alluvium to reach foundation conditions that are similar to the existing plant. The existing plant foundations do not extend to the ESP-defined Catahoula formation that consists of gray-green, hard clay to claystone that exhibits a slight degree of induration and somewhat brittle "rock-like" behavior. The descriptions for the ESP-defined Catahoula formation are similar to indurated and/or partly cemented clays and silts (with some cemented sand lenses) that are described in the deeper parts of the UFSAR borings below the bearing level of the plant foundation. We believe that these materials are a better correlation with the regional descriptions of the Catahoula formation (e.g., Bickner, 1996; SSAR reference 50) than the overlying less-indurated sediments that we classify as Upland Complex Old Alluvium.

We referred to the lithified Catahoula formation in the ESP SSAR as hard clay to claystone ("soft rock-like" brittle material) to denote the greater degree of lithification of this unit in comparison to the overlying deposits. The shear wave velocity range of about 1,500 to 2,830 feet per second fall within the ranges of "very dense soil and soft rock" (IBC, 2000) and "soft, fractured and/or weak rock" (Seed and others, 2002) in commonly-cited site response classification schemes. However, for site response analysis, the ESP-defined Catahoula formation (clay to claystone) is not intended to connote a hard bedrock strata, or basement rock that instead occurs at significantly greater depth under the ESP site. The Glendon Limestone member of the Vicksburg Group that unconformably underlies the Catahoula formation at a depth of about 435

feet (elevation -300 feet; SSAR Figure 2.5-15) is likely the shallowest, relatively thick and regionally extensive hard bedrock strata that underlies the site. Crystalline basement rock underlies the ESP site at a depth on the order of about 8 to 10 kilometers (SSAR Figure 2.5-16a). Refer to the response for RAI 2.5.4-3 for a description of the site velocity profile and extension of the profile below the depth of ESP exploration and Catahoula formation. There is no significant impact related to describing the Catahoula formation as "bedrock" of "soft rock-like" material as opposed to dense sands or gravels in descriptions of site materials.

In accordance with NRC Regulatory Guide RG 1.132 and Draft Regulatory Guide DG-1101, additional subsurface exploration should be performed during the COL phase to verify site stratigraphy. The COL phase exploratory borings should be located based on the final location of the new facility, the results from the ESP study, and consideration of the locations of the existing borings to obtain information in areas currently lacking data and to optimize further characterization of important subsurface relationships.

SSAR Revisions:

None

References:

Autin, W.J., Burns, S.F., Miller, B.J., Saucier, R.T., and Snead, J.I., 1991, Quaternary geology of the Lower Mississippi Valley, Quaternary nonglacial geology: Conterminous U.S., R.B. Morrison, ed., Geological Society of America, Boulder, CO, 547-582.

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Nuclear Regulatory Commission (U.S.) Washington D.C. "Site Investigations for Foundations of Nuclear Power Plants" (Reg. Guide 1.132), March, 1979

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Saucier, R.T., 1994, Geomorphology and Quaternary Geologic History of the Lower Mississippi Valley, U.S. Army Corps of Engineers, U.S. Army Engineer waterways Experiment Station, Vicksburg, Miss.

Saucier, R.T., and Snead, J.I., compilers, 1989, Quaternary geology of the Lower Mississippi Valley, 2 sheets, Louisiana Geological Survey, Baton Rouge.

Additional References:

IBC, 2000, International Building Code: International Code Council ISBN No. 1-892395-26-6, 756 p.

Seed, R.B., Cetin, K.O., Moss, R.E.S., Kammerer, A.M., Wu, J., Pestana, J.M., and Riemer, M.F.,2002, Recent advances in soil liquefaction engineering and seismic site response evaluation: Paper No. SPL-2, 45 p.

Request:

RAI 2.5.4-2

Section 2.5.4.1.2 indicates that the ESP area includes cut and fill sections. The fill is of variable thickness and was indicated to have been placed to fill the various swales that cross the site. What is known about the character of the fill material and what controls, if any, were placed at the time of their deposition?

Response:

Prior to development of the Grand Gulf site, a system of steep-walled, southwest-trending drainage swales crossed portions of the ESP site. The swales were filled during site grading to form the present upper (el. 155 feet) and lower (el. 134 feet) pads that are encompassed by the ESP site and Proposed Power Block Area. The localized swale fill at the ESP site is discussed in SSAR section 2.5.4.1.2, and an infilled swale is shown in SSAR Figure 2.5-76 (cross section B-B'). However, the extent of the infilled swales was not shown on the SSAR or Engineering Report ER-02 plan maps. Therefore, SSAR Figure 2.5-69 (a plan map of the ESP site area) will be modified to show the locations of the infilled swales, and is presented as Figure 2.5-69, Draft Rev. 1, on the enclosed CD-ROM. Additionally, SSAR Figures 2.5-75 to 2.5-77 will also be modified to more-accurately show the extent of the swale fills, and the modified figures are presented as Figures 2.5-75 to 2.5-77, Draft Rev. 1, on the enclosed CD-ROM. As shown on Figure 2.5-69, Draft Rev. 1, the bottoms of the swales were on the order of 30 to 50 feet below the present pad grades, and required filling with an equivalent thickness of soil to bring the ground surface up to the present pad grades.

The UFSAR discusses engineered structural fill placed under, and around, the power block of the existing plant (e.g., controlled compaction to 95% relative density by ASTM D1557), but does not discuss the placement or engineering controls for the swale infilling at the ESP site. Standard Penetration Test (SPT) blow counts in the fill from ESP boring WLA B-3, located in the center of one of the swale fill areas, ranged from 5 to 7. These blow counts are less than the underlying native loess soils (blow counts from 11 to 13), but are within the range of loess soils in other borings. The composition of the fill in boring WLA B-3 was a clayey silt very similar in texture to the native loess soils, and appears to have been derived from excavation of loess in cut areas of the site. No evidence of settlement of pavements or the filled ground surface was observed during the ESP field work, suggesting that the fill is not unusually compressible or prone to settlement under it's own weight, or light pavement and vehicular loading. Proposed foundations for the ESP reactor and safety-related facilities will be extended well below the maximum depth of the swale fills, and therefore the fill will have no effect on these facilities. Excavations to develop a uniform plant grade elevation of about 134 feet in the ESP area would remove much of the fill underlying the upper pad area, but a 10 to 30 foot thick section of fill may remain under the eastern parts of the yard area. Additional borings performed during the COL phase will evaluate the character of the fill, and determine if it (and underlying/adjacent loess soils) require subexcavation and replacement to minimize settlements of appurtenant non-safety facility foundations and pavements.

SSAR Revisions:

SSAR Figures 2.5-69, and 2.5-75 to 2.5-77 will be revised.

Text will be added to SSAR Section 2.5.4.1.3 to bolster the description of the swale infill and explain the revised figures.

See files: 001_ESP-SSAR_draft_rev1_12-01-2004.pdf
017_SSAR_Fig_2.5-69draft_rev1_11-19-2004.pdf
018_SSAR_Fig_2.5-75draft_rev1_11-19-2004.pdf
019_SSAR_Fig_2.5-76draft_rev1_11-19-2004.pdf
020_SSAR_Fig_2.5-77draft_rev1_11-19-2004.pdf

Request:

RAI 2.5.4-3

Section 2.5.4.1.1 indicates that four new borings and four cone penetrometers were installed to characterize the ESP area. It should be noted that actually only three borings are available for the site since borings 2 and 2A are essentially at the same location and no samples were recovered in 2A over the depth of Boring 2. The maximum depth investigated during this program is indicated to be about 240'. In the soil profiles developed for the site (Figs. 2.5-30 and 31), the descriptions developed from previously available site investigations were included. How many of the original borings were evaluated in characterizing the ESP site area and what was their maximum depth of investigation? Presuming that these borings are also relatively shallow, and that the site profile used in the site response analyses described in Section 2.5.2.3 extends down to thousands of feet above the relatively hard rock where the PSHA is defined, what additional information is available for the Grand Gulf Nuclear Station (GGNS) site to allow characterization to the deeper depths required for the site response?

Response:

ESP Site Investigation and Incorporation of Existing UFSAR Information

Descriptions of the ESP site geologic/geotechnical subsurface investigations and development of the site response soil profile are provided in SSAR Section 2.5.4.1.2 and Engineering Report (ER) ER-02 Sections 3.2 and 7.7. Site characterization for the ESP was performed by drilling two individual borings (WLA B-1 and B-3), one composite boring that consisted of two holes at the same location (WLA B-2/2A), and four Cone Penetrometer Test (CPT) soundings. The parameters for these borings and CPT soundings are listed on SSAR Table 2.5-20. The borings and CPT soundings were distributed throughout the ESP site as shown on SSAR Figure 2.5-69, Draft Rev. 1. The revised plan map shows a circular "Proposed Power Block Area" (PPBA) that supersedes the polygonal "Proposed Site Location Perimeter" that is shown on the SSAR and ER-02 report figures, and also to show the approximate locations of UFSAR borings within the ESP area. These changes do not affect the results from the ESP study, as the revised circular envelope largely fits within the polygonal perimeter area shown previously.

The depths of WLA borings within the ESP area ranged between 141.5 and 238.0 feet below ground surface (bgs); and the depths of CPT soundings ranged between 79.0 and 95.3 feet bgs. Drilling techniques performed in the ESP borings included mud rotary drilling with interval hammer and hydraulic push sampling (SPT, Modified California, and Shelby tube samplers), and limited continuous wireline core drilling. Borehole seismic velocity surveys were performed in three of the borings.

The ESP explorations were augmented with data from twenty previous borings performed for the UFSAR that fall within, or adjacent to, the Proposed Power Block Area (SSAR Figure 2.5-69, Draft Rev. 1). The UFSAR borings extended to depths of between 81.0 and 300.0 feet bgs, and were drilled with mud rotary equipment with interval hammer drive sampling (SPT) and continuous wireline core drilling. The combined coverage of the ESP and UFSAR borings provide sampling across the entire PPBA at 200 to 600 feet spacings, and down to a depth of 300 feet.

One of the ESP borings (WLA B-2A), and four to possibly six, UFSAR borings (B-9, B-22?, B-36?, B-42, B-105, and B-121) extend into dense, indurated clay to claystone that we define as the Miocene Catahoula formation. Two of these borings included interval wireline core sampling of the Catahoula formation:

- WLA B-2A, depth interval 233.0 to 237.5 feet
- B-42, depth interval 186.0 to 300 feet

In addition to the cored intervals, SPT testing in the ESP Site Area and UFSAR borings (typically at 5- to 20-foot intervals) provided numerous discrete samples of the Catahoula formation, and blow count profiles.

SSAR Figures 2.5-75 to 2.5-77, Draft Rev. 1, on the enclosed CD-ROM, are a series of three geologic cross sections that were revised to show the PPBA. These figures integrate the ESP and UFSAR explorations to characterize the subsurface stratigraphy. These cross sections have good control to a depth of about 250 feet below the existing ground surface. SSAR Figures 2.5-78 and 79 are structural contour maps that integrate the ESP and UFSAR borehole information to characterize the geometries of unconformable stratigraphic contacts below the PPBA. Cross sections and structure contour maps show generally subhorizontal geologic strata separated by eroded and irregular unconformable contacts.

The ESP site investigation program was specifically developed to obtain sufficient information to characterize site subsurface conditions and soil variability that may influence earthquake ground motion response and seismic hazards. The ESP site explorations, augmented by borehole data from the UFSAR, capture the three dimensional geometry of the strata, and variations in soil properties. The generally consistent, horizontal stratigraphy of the site provides a high level of confidence regarding characterization of the geologic and geotechnical conditions appropriate for the ESP study. The site stratigraphy would be verified by additional borings during the COL phase.

In addition to new and UFSAR subsurface information from the ESP site area, data from a series of cross-hole seismic surveys performed for the UFSAR in four borings at the existing power plant area was reviewed. The cross-hole velocities were

obtained to a depth of 300 feet, and recorded at 10-foot intervals to develop a site velocity profile. However, the cross-hole survey used explosives (poorly-controlled source) set off in a fifth borehole, and utilized old approaches and equipment that cannot be reliably correlated to the ESP site borehole seismic compressive and shear wave (P-S) surveys. Therefore, the UFSAR cross-hole velocity profiles were used only as a general comparison against the ESP site-specific data, and did not provide information useful to augment or extrapolate the ESP profiles to greater depth.

Site Profile Extension to Depth

The combined information from the ESP site borings and CPT and UFSAR studies were used to construct the site response velocity profile to a depth of about 300 feet. The velocity profile was extended below a depth of 300 feet using a generic deep profile that is developed from regional studies of the Mississippi embayment described in the response to RAI 2.5.4-4. These studies included extensive velocity measurements near the Memphis area and surrounding regions, and development of regional soil columns for the Mississippi lowlands and uplands. These generic profiles account for the depth to Paleozoic crystalline basement for long period response.

SSAR Revisions:

SSAR Figures 2.5-69, and 2.5-75 to 2.5-77 will be revised.

See files: 017_SSAR_Fig_2.5-69draft_rev1_11-19-2004.pdf
018_SSAR_Fig_2.5-75draft_rev1_11-19-2004.pdf
019_SSAR_Fig_2.5-76draft_rev1_11-19-2004.pdf
020_SSAR_Fig_2.5-77draft_rev1_11-19-2004.pdf

Request:

RAI 2.5.4-4

The site velocity profile used in the response calculations makes use of the site specific soil profile described in Section 2.5.4.1 developed from the site data extending down to a depth about 225 feet. The description provided in Section 2.5.2.3 indicates that this profile was then placed upon a generic shear wave model for the Mississippi embayment. Most other sites housing critical facilities and using the probabilistic method of NUREG/CR-6728 to generate soil surface ultimate heat sink (UHS) attempt to develop one or more base case site velocity models from site specific data available from other information (such as well logs, deep borings, etc). What is the basis for selecting this generic base case velocity model over any other model that may be generated from available information for the site and its environs?

Response:

Regarding shear-wave velocity information below the local site explorations, no measurements are known to exist within tens of kilometers of the site. Within the southern Mississippi embayment, old water well and oil exploration boreholes exist (some possibly with stratigraphy) but these are of little added value since the overall stratigraphy (geology) of the embayment is quite uniform laterally. The notable exceptions are Crowley's Ridge, located within the northeastern embayment and the

roughly north-south division between the lowlands and uplands. Based on rather extensive measurements near the Memphis area and surrounding regions, the differences in stratigraphy and velocities between the lowlands and uplands extends only to shallow depths (upper several hundred feet), is reasonably well characterized, and is generally considered uniform throughout the embayment. A number of surface wave analyses as well as low-frequency site amplification studies suggest generally uniform soil column properties throughout the embayment. As a result, ground motion hazard maps are computed with regional soil columns which differentiate lowlands and uplands and, for long periods, depth to paleozoic basement. The depth to Paleozoic basement is greatest along the axis of the Mississippi River near the center of the embayment, and diminishes to zero northward near Cairo, Illinois as well as in easterly and westerly directions from the river. The general lateral uniformity of the deeper velocities (deeper than several hundred feet) is consistent with other large basins (e.g., Los Angeles basin and Imperial Valley, California) and provides a basis for employing a generic deep profile beneath the local site profile. Since the profile is randomized, expected fluctuations are accommodated in the mean amplification, consistent with a probabilistic hazard analysis. Additionally, differences in a mean shear-wave velocity profile gradient, apart from the measurement-driven one that was used, would result in very little difference in mean motions. This arises because the low-strain damping in the deep profile (between about 200 and 3,000 feet deep) largely controls the response for frequencies above about 1 Hz. This is constrained by our use of a kappa value based on observations of motions recorded in the embayment. The empirical kappa value employed is considered conservative as a deeper sedimentary column (over 3 km at the site) over hard rock is expected to show larger kappa values (more cumulative damping) compared to shallower sedimentary columns.

This well known aspect of site response is clearly demonstrated in RAI Figure 2.5.4-4-1. RAI Figure 2.5.4-4-1 shows the base case shear-wave velocity profile to the analysis depth of 1 km along with two extreme cases for extrapolation to the hard rock shear-wave velocity of 2.8 km/sec. The "slow" profile reflects an assumption of extending the velocity just beneath the site uniformly to 1 km, with a jump to the hard rock value of 2.8 km/sec. As another extreme alternative, the "fast" profile assumes a linear (modeled as a stair-step) gradient with depth, reaching 2.8 km/sec at a depth of 1.0 km. Based on general experience with measured shear-wave velocity profiles in large sedimentary basins, the "slow" and "fast" profiles may be expected to reflect extreme (low likelihood) conditions, particularly with regard to the local and regional overall geology.

To compare median motions computed for the three profiles, the 1 to 2 Hz scaled 10^{-5} Annual Probability of Exceedence (APE) spectrum is used as control motions since it is quite similar to the UHS and sufficiently broad-band (large magnitude), compared to the UHS, to excite the column at low- as well as high-frequency. RAI Figures 2.5.4-4-2 and 2.5.4-4-3 show the resulting soil median motions in both logarithmic as well as linear spectral axis, respectively. As expected, there is little difference between the motions computed for the three profiles from 0.3 Hz to 100 Hz. At peak acceleration, the "fast" and "slow" profiles show about a five percent increase and decrease, respectively, in motions, compared to the base-case profile. The motions reflecting the "fast" profile generally exceed those from the base-case by about five percent. The largest exceedence is near a resonance at about 3 Hz where the "fast" profile motions exceed the base-case motions by about 10%. Based on regional geology as

well as experience with similar geology in deep basins, this "fast" profile is extremely unlikely and would receive very low weight in a hazard analysis. These site response analyses clearly illustrate the general insensitivity of the motions to the nature of velocity gradients likely to exist in the deep materials beneath the site.

SSAR Revisions:

Section 2.5.2.3 of the SSAR will be revised to provide additional rationale for selecting the generic base case velocity model for the Mississippi embayment.

See files: 001_ESP-SSAR_draft_rev1_12-01-2004.pdf
021_RAI_Fig_2.5.4-4-1.pdf
022_RAI_Fig_2.5.4-4-2.pdf
023_RAI_Fig_2.5.4-4-3.pdf

Request:

RAI 2.5.4-5

Section 2.5.4.1.3 and Sections 7.0 and 8.0 of ER-02 present descriptions of shear wave velocity properties for the various layers of the shallow profile. To perform the probabilistic site response calculations, the base case (best estimate, BE) velocity profile is used, together with upper and lower bound (UP and LB) shear wave velocity values over the entire soil profile. What were the values of the BE, UB and LB velocities selected for each primary component of the profile and what were the bases for their selection? Were these values used in the site response calculations described in Section 2.5.2.3?

Response:

The best estimate profile is shown in SSAR Figure 2.5-60 and is based on a visual average of the three P-S suspension log surveys obtained from the ESP site borings (borings WLA B-1, B-2A, B-3). The response to RAI 2.5.4-8 discusses the development of the best estimate profile. Upper bound and lower bound profiles were not developed, rather a profile randomization scheme was used to incorporate expected variabilities across the site (NUREG/CR-6728). This approach is intended to maintain the 10^{-5} APE hazard level of the rock outcrop UHS by developing statistically significant estimates of the mean amplification factors for the site.

SSAR Revisions:

None

References:

McGuire, R.K., W.J. Silva and C.J. Costantino, (2001). "Technical basis for revision of regulatory guidance on design ground motions: hazard- and risk-consistent ground motions spectra guidelines." Prepared for Division of Engineering Technology, Washington, D.C., *NUREG/CR-6728.*

Request:

RAI 2.5.4-6

Section 2.5.4.1.7 indicates that the shear modulus reduction and hysteretic damping models used in the site response calculations were the EPRI93 depth dependent curves. These are generally considered appropriate for normally consolidated cohesionless sands. As described in Sections 11.0 and 12.0 of ER-02, these curves may not be appropriate even for the near-surface layers of the profile for which laboratory data is available. They also may not be appropriate for any gravelly layers in the profile which tend to behave significantly more nonlinearly than indicated by the EPRI93 set. What is the basis for the selection of the EPRI93 curves as opposed to other models that may be more appropriate based on site specific information described in the geotechnical report?

Response:

RAI 2.5.4-6 requests a discussion of the basis for selection of the EPRI93 curves for shear modulus reduction and hysteretic damping that were used for the site response calculations. The statement in the RAI that the shear modulus reduction and hysteretic damping curves used in the site response calculations were the EPRI93 depth dependent curves is correct but not complete. SSAR Section 2.5.4.1.7 discusses the dynamic laboratory tests that were conducted, and issues involved in the interpretation of the laboratory test results. However, the SSAR description did not specify which of the EPRI curves were used for the various units in the site response analyses. Specification of which EPRI curves were assigned to the three principal units involved in the site response analyses (loess, alluvium, old alluvium) was included in SSAR Section 2.5.2.3. The EPRI curves corresponding to the depth ranges for these three soil units were not used; rather, EPRI curves that represent greater depths of normally consolidated soils were used to represent the aged and overconsolidated soils at the Grand Gulf site. Therefore, the EPRI curves for depths of 120 to 250 feet were used to represent the loess, the EPRI curves for depths of 250 to 500 feet were used to represent the alluvium, and the EPRI curves for depths of 500-1000 feet were used to represent the old alluvium and the underlying materials to a depth of 500 feet. Below a depth of 500 feet, the profile was assumed to exhibit essentially linear material properties as discussed in the response to RAI 2.5.4-4.

SSAR Section 2.5.4.1.7 references a set of figures (Figures 2.5-87 to 2.5-94) to present the results of the dynamic laboratory tests plotted on the families of EPRI modulus reduction and damping curves. These figures included separate plots for the loess samples, and combined plots for the Upland Complex Alluvium and Old Alluvium. However, these SSAR plots do not indicate which of the EPRI curves were selected for the site response analysis. We will revise these SSAR figures to delineate (in RED) the curves that were recommended for, and used in, the site response analyses as SSAR Figures 2.5-87 to 2.5-94, Draft Rev. 1. In addition, we have removed the plots for the Old Alluvium samples from Figures 2.5-93 and 2.5-94, and show these data separately on two new SSAR Figures 2.5-95 and 2.5-96, Draft Rev. 0.

SSAR Section 2.5.4.1.7 discusses the rationale for adopting the EPRI curves; namely that the shape of the curves defined by the site-specific laboratory tests are similar to the shape of the EPRI curves. As discussed previously, the selected EPRI curve for each soil layer actually corresponds to a greater depth than the actual depth of the samples. Two primary reasons justify the selection of the deeper curves. The first is that the raw laboratory data showed less modulus reduction and lower damping values than the EPRI curves for the same depths. Likely this occurs because the EPRI curves were developed for normally consolidated Holocene silty and clayey sands (EPRI, 1993; SSAR Reference 170) whereas the soils at the Grand Gulf ESP site are both older and overconsolidated. The second reason is to adjust the laboratory test results for the effects of stress relief sample disturbance (refer to response to RAI 2.5.4-13). As indicated in SSAR Table 2.5-26, Draft Rev. 1, the ratio of the shear wave velocities measured in the laboratory versus the field were generally less than unity. For example, the velocity ratio for the two samples of loess was less than 0.7 suggesting that the samples should have been reconsolidated with a higher value of K_o in order to compensate for the effects of stress release and sample disturbance. SSAR Figures 2.5-87 to 2.5-94, Draft Rev. 1, and new Figures 2.5-95 and 2.5-96,Draft Rev. 0, include results for test specimens of loess and alluvium consolidated to both the estimated in situ confining pressure and four times the estimated in situ confining pressure. As might be expected, the results for the specimens consolidated to four times the estimated in situ confining stress showed less modulus reduction and lower damping than the same specimens consolidated only to the in situ confining stress. As shown on SSAR Table 2.5-26, Draft Rev. 1, the ratio of the shear wave velocities measured in the laboratory for specimens consolidated to four times the estimated in situ stress versus the field-measured velocities are on the order of unity. This suggests that the additional sample consolidation produces results that better match the in situ field condition of these soils.

The RAI correctly points out that the EPRI depth dependent curves may not be appropriate for gravels and, indeed, the EPRI report (Reference 170) includes generic curves for pure gravels that are relatively more nonlinear than the family of depth dependent curves that are applicable for soils that range from gravelly sands to low plasticity silty or clayey sands. However, at the Grand Gulf site, there are no gravel layers as such. Rather, when gravelly materials are noted on the boring logs this simply indicates the presence of some gravel-size particles in a sandier matrix. Such gravelly materials are generally less than 5 feet thick and appear to be discontinuous. Therefore, use of EPRI gravel curves would not be appropriate for the site conditions.

SSAR Revisions:

Figures 2.5-87 to 2.5-94 will be replaced with Draft Rev. 1 versions
Table 2.5-26 will be replaced with Draft Rev. 1 version
Text Section 2.5.4.1.7 will be replaced
New Figures 2.5-95 and 2.5-96, Draft Rev. 0 will be added

See files: 001_ESP-SSAR_draft_rev1_12-01-2004.pdf
024_SSAR_Fig_2.5-87draft_rev1_11-19-2004.pdf
025_SSAR_Fig_2.5-88draft_rev1_11-19-2004.pdf
026_SSAR_Fig_2.5-89draft_rev1_11-19-2004.pdf
027_SSAR_Fig_2.5-90draft_rev1_11-19-2004.pdf

028_SSAR_Fig_2.5-91draft_rev1_11-19-2004.pdf
029_SSAR_Fig_2.5-92draft_rev1_11-19-2004.pdf
030_SSAR_Fig_2.5-93draft_rev1_11-19-2004.pdf
031_SSAR_Fig_2.5-94draft_rev1_11-19-2004.pdf
032_SSAR_Fig_2.5-95draft_rev0_11-19-2004.pdf
033_SSAR_Fig_2.5-96draft_rev0_11-19-2004.pdf
034_SSAR_Table 2.5-26draaft_rev1_11-19-2004.pdf

Request:

RAI 2.5.4-7

Sections 2.5.4.1.7 together with Section 11.0 and Appendix G of ER-02 present a detailed presentation of the laboratory dynamic test results. The shear modulus reduction and hysteretic damping curves generated from the laboratory testing are compared with the recommendations for cohesionless sands generated during the EPRI93 study. The shear modulus data presented in Appendix G for samples taken from a shallow depth are indicated to be reasonably comparable to the EPRI recommendations for deep depths of 500 feet to 1,000 feet. The laboratory results for hysteretic damping are also much lower than indicated from the EPRI study for comparable depths. Section 11.0 of ER-02 indicates that although the data are similar to the EPRI recommendations, they are much more linear and possess lower damping. Comparison of the low amplitude velocity test data with field measurements indicate that some sample disturbance may have occurred. Section 11.0 of ER-02 goes on to suggest a method to correct the measured data for use in the site response calculations. In addition, some parts of the soil profile are indicated in the boring logs of Appendix C of ER-02 to have significant gravel content. These materials would therefore normally be expected to be much more nonlinear than the EPRI93 recommendations. Section 2.5.2 of the SSAR indicates that the EPRI93 model was used for all layers of the deep profile. What is basis for not incorporating these effects in the site response calculations and what could be the potential impact of these modifications on the computed surface UHS?

Response:

Many of the issues raised in this RAI are common to those listed in RAI 2.5.4-6, and therefore, the response to RAI 2.5.4-6 also pertain to this RAI. As discussed in response to RAI 2.5.4-6, the effects of possible disturbance to the test specimens resulting from stress release during sampling, and possible movements during testing (discussed also in response to RAI 2.5.4-13) were fully accounted for in the analysis and selection of the appropriate EPRI93 curves for shear modulus reduction and hysteretic damping. The effects of sample relaxation were countered by examining the results from testing of the soils at both the estimated in situ confining stress, and four times the estimated in situ confining stress. These two data sets were plotted together on the EPRI93 base curves as shown on SSAR Figures 2.5.4-87 to 2.5-94, Draft Rev. 1 and new Figures 2.5-95 and 2.5-96, Draft Rev. 0, and weighted to select the most representative EPRI93 curve. The EPRI93 curves corresponding to the depth ranges for the three soil units were not used; rather, EPRI93 curves that represent greater depths of normally consolidated soils were used to represent the aged and overconsolidated soils at the Grand Gulf ESP site. Therefore, the EPRI curves for depths of 120 to 250 feet were used to represent the loess, the EPRI93 curves for depths of 250 to 500 feet were used to represent the alluvium, and the EPRI93 curves for depths of 500-1000 feet were used to represent the old alluvium

and underlying materials to a depth of 500 feet. The modulus reduction and damping curves adopted for use in the site response analysis represent the best fit to the dynamic soil test results that correct for the effects of soil disturbance and overconsolidation. Uncertainty and variability in these values were accounted for in the site response modeling by developing randomizing curves about the selected base case EPRI93 curves using an assumed log normal distribution. This randomization process is discussed further in the response to RAI 2.5.4-8 (for shear wave velocity input), and Calculation Package ENTO002-CP-02.

As discussed in response to RAI 2.5.4-6, no laterally-continuous, thick gravel layers were encountered in the ESP and UFSAR borings at the site. The RAI correctly points out that the EPRI curves may not be appropriate for gravels and, indeed, the EPRI report (Reference 170) includes generic curves for pure gravels that are relatively more nonlinear than the family of depth dependent curves that are stated to be applicable for soils that range from gravelly sands to low plasticity silty or clayey sands. However, at the Grand Gulf ESP site, there are no gravel layers as such. Rather, when gravelly materials are noted on the boring logs this simply indicates the presence of some gravel-size particles in a sandier matrix. Such gravelly materials are in any case generally less than 5 feet thick and appear to be discontinuous. Therefore, use of EPRI gravel curves would not be appropriate for the site conditions.

Because the EPRI93 curves selected as the base case for site response analysis are appropriate for the site soil conditions, and account for sample disturbance and overconsolidation, there is no impact on the computed surface UHS.

SSAR Revisions:

See files:
001_ESP-SSAR_draft_rev1_12-01-2004.pdf
024_SSAR_Fig_2.5-87draft_rev1_11-19-2004.pdf
025_SSAR_Fig_2.5-88draft_rev1_11-19-2004.pdf
026_SSAR_Fig_2.5-89draft_rev1_11-19-2004.pdf
027_SSAR_Fig_2.5-90draft_rev1_11-19-2004.pdf
028_SSAR_Fig_2.5-91draft_rev1_11-19-2004.pdf
029_SSAR_Fig_2.5-92draft_rev1_11-19-2004.pdf
030_SSAR_Fig_2.5-93draft_rev1_11-19-2004.pdf
031_SSAR_Fig_2.5-94draft_rev1_11-19-2004.pdf
032_SSAR_Fig_2.5-95draft_rev0_11-19-2004.pdf
033_SSAR_Fig_2.5-96draft_rev0_11-19-2004.pdf

Request:

RAI 2.5.4-8

Section 2.5.4.1.3 of the SSAR presents summary velocity properties for the various layers of the shallow soil profile. Section 7.7.1 of ER-02 indicates that the loess has a shear wave velocity that ranges from 800 to 900 feet per sec (fps). The borehole logger data of Appendix D shows values as low as 600 fps. Table ER-02-4 indicates values that range from about 600 fps to over 1400 fps. The best estimate (or mean value?) is indicated in Section 8.2 of ER-02 to be 770 fps. How do these values of shear wave velocity compare with the best estimate, upper bound and lower bound values used in the site response calculations? Why are the mean values of velocity for all the material layers not approximately centered on the ranges listed in Table 8.2?

Response:

The RAI notes apparent inconsistencies in the range of shear wave (S-wave) values presented for the various site stratigraphic units (loess, Upland Complex Alluvium, Upland Complex Old Alluvium, Catahoula formation) in the SSAR and Engineering Report ER-02 text, tables, and figures. These apparent inconsistencies are related to several items: (1) rounding of values for general descriptions of unit properties in the text; (2) presentation of localized extreme values on tables and figures (prior to data smoothing); and, (3) the use of different depth intervals over which averaged values are presented that sometimes cross over stratigraphic boundaries. Specific examples mentioned in the RAI are listed and explained below.

- ER-02 section 7.7.1-loess velocity range of 800 to 900 feet per second (fps). This reference is made as a general description of typical loess properties, and presents a typical average range for loess soils. This reported range was not used in the site soil response analysis.

- ER-02 Appendix D borehole data logger shows loess velocity values as low as 600 fps. The raw P-S velocity tables and plots actually show an extreme low value of 580 fps for loess. This low value is a localized extreme, and the average value for the loess layer at the site is considerably higher. The velocity profile used in the site response analysis is an averaged, smoothed profile that does not use the extreme localized values.

- Table ER-02-4 indicates loess velocity values that range from about 600 fps to over 1400 fps. The values reported in Table ER-02 for loess represent the S-wave velocity range measured in the loess soils, including localized extremes. This range was used for comparison against the reported UFSAR S-wave value for loess, and allowed us to evaluate how the UFSAR value fit within the range of velocities measured for loess at the ESP site. The Table ER-02 range of velocity for loess was not used in the site response analysis.

- ER-02 Section 8.2 discusses a best estimate (or mean) loess velocity value of 770 fps. The value of 770 fps reported for loess in ER-02 is a calculated interval average for the elevation range of between 103.5 and 153 feet (ER-02 Figure ER-02-13) that includes the composite measurements from the three separate P-S velocity profiles (ESP borings WLA B-1 to B-3). This interval brackets the loess and also incorporates velocities measured in the uppermost part of the Upland

Complex Alluvium. The elevation range for the interval average was selected based on visual inspection of the composite, elevation-corrected velocity profile from the three borings shown on SSAR Figure 2.5-80. The site response analysis did not use this same interval velocity, but rather binned the P-S data differently to break out two separate, smaller velocity intervals in this elevation range to discretely account for a lower velocity upper loess zone. This is discussed in ESP Calculation Package ENTO002-CP-02, and response to RAI 2.5.4-5.

As discussed in the response to RAI 2.5.4-5, the best estimate velocity profile adopted for the site soil response analysis is presented in SSAR Figure 2.5-60, and is based on a visual average of the composite, elevation-correlated P-S velocity profiles from the three ESP boreholes. It is not based on any of the values and ranges of values discussed above. It is an averaged, smoothed profile that does not use extreme values. The best estimate profile consists of five separate interval velocities that incorporate velocity data that was binned differently than the various general ranges and estimated velocity ranges described for different stratigraphic units as referenced above. The site soil response velocity profile best estimate interval velocities are not set at stratigraphic unit boundaries, but rather are assigned at visually-determined velocity breaks in the composite P-S profile. For this reason, the best estimate site soil response average velocities are not centered on the mean values listed for material layers in ER-02 Table 8.2.

SSAR Revisions:

None

Request:

RAI 2.5.4-9

Section 2.5.4.3 indicates that the site is stable and will not be prone to dynamically induced failures. Section 3.3 of ER-02 indicates that the site does not show any indications of dissolution cavities or sinkholes. The general descriptions of the site presented in the Section 2.5.1.2.3.1.2.3 of the SSAR indicate that calcareous clays, limestone and marl formations underlay the site profile and may even be exposed in the site vicinity. None of the borings shown in the section profiles (old or new) reach to these depths. Such materials are often susceptible to such problems. What is the basis for indicating that this site is not susceptible to such potential long-term problems?

Response:

Calcareous clay, limestone and marl underlie the Grand Gulf site at depths greater than 390 feet (SSAR Figures 2.5-6 and 2.5-11). These deposits are units within the Vicksburg Group, including the Glendon Limestone and the Bryam Marl. A structure contour map on the surface of the Glendon Limestone is shown on SSAR Figure 2.5-15. We interpret the surface of the Glendon Limestone to represent the shallowest significant occurrence of calcareous rocks under the ESP site. The Vicksburg Group calcareous units do not appear to be susceptible to karstic dissolution in the site area and evaluation of aerial photography, topographic maps and field reconnaissance show that there are no karstic features (e.g., sinkholes, circular depressions, caves, etc.) either in outcrop areas of this unit, or expressed within the overlying

unconsolidated Pliocene to Pleistocene deposits. In addition, foundations for the existing unit at Grand Gulf have performed satisfactorily and have not experienced any settlements related to potential dissolution of strata within the Vicksburg Group at depth.

Our response to this question involves three separate evaluations: (1) evaluate and document the presence or absence of karstic features in the Site Area (five-mile radius); (2) evaluate and document the presence or absence of karstic features in outcrop exposures of the Vicksburg Group in the Site Vicinity (twenty-five-mile radius) and Site Region (200 mile radius) (i.e., where the Vicksburg Group daylights at the ground surface); and (3) evaluate the zone of influence of any new proposed foundation on the Vicksburg Group strata.

1) Evaluate and document the presence or absence of karstic features in the Site Area.

   To evaluate the presence or absence of karstic features in the Site Area, we reviewed existing literature, examined topographic maps, aerial photography and orthophotographs, and performed field reconnaissance. These studies show that features indicative of karstic processes are not present in the Site Area. Karst topography is generally characterized by sink holes, circular and/or elongated closed depressions, caves and dissolution features (References 1, 2). None of these features have developed within the Pliocene to Pleistocene unconsolidated surficial deposits in the Site Area. SSAR Figure 2.5-10 shows a shaded relief map of the Site Area from a composite of 1:40,000 scale digital data (USGS 7.5 minute topographic quadrangles St. Joseph, Widows Creek, Willows, Port Gibson, and Grand Gulf). SSAR Figures 2.5-27 and 2.5-29 show topography and shaded relief maps for the Site Location. These maps show the absence of karstic features (e.g. sinkholes, caves, circular depressions, etc.) in the Site Area and Site Location.

   The geology of the Site Area is shown on SSAR Figure 2.5-10. The geologic map shows that no limestone, marl or calcareous units are exposed in the Site Area, and that the Vicksburg Group does not crop out in the Site Area. The geologic map was prepared from compilation of existing literature, interpretation of 1:20,000 scale black and white aerial photography (flown February 13, 1996, available from the Mississippi Department of Transportation), and field reconnaissance. During preparation of this geologic map, no evidence of karstic features were noted. Additionally, no discussion of karsitic features was found in the numerous geologic reports reviewed during our map compilation and site geologic evaluations.

   We conclude that karst-related geomorphic or topographic features are not present in the Site Area. The absence of karst features in the Pliocene and Pleistocene surficial deposits suggests that karst development has not occurred at or near the site for at least several hundreds of thousands to millions of years, and therefore is not an active geologic process. The topography of the site area was developed by fluvial erosion related to the Mississippi River and associated tributary drainages. These processes formed flat-bottomed stream valleys, rounded valley slopes, flat-topped ridgelines, and dendritic drainage patterns cut into Pleistocene terrace surfaces and the Pleistocene Upland Complex (Figure 2.5-10). There is no evidence of karstic morphology along river valleys despite the

presence of abundant ground water and extensive fluvial modification of the landscape.

Although the absence of karstic features at the ground surface does not preclude the potential for dissolution within the Vicksburg Group at depth, the absence of such features in the overlying Pliocene to Pleistocene unconsolidated sediments indicates that possible deep dissolution has not extended upward into the thick cover sediments. Based on our evaluation of existing information, we conclude that karstic processes have not influenced the ground surface or shallow subsurface in the Site Area in the late Pleistocene or Holocene, and that these processes, therefore, are not likely to influence the Site Area in the future.

2) Evaluate and document the presence or absence of karstic features in outcrop exposures of the Vicksburg Group in the Site Vicinity and Site Region

Limestone of the Vicksburg Group crops out in a narrow belt that extends in an east -west direction across the central part of the state of Mississippi (RAI Figure 2.5.4-9-1). Within the Vicksburg area, units of the Vicksburg Group, including the Glendon Limestone and Bryam Marl, crop out about 20 miles north of the Grand Gulf Site at its closest location (RAI Figure 2.5.4-9-1, an explanation of map units is provided in SSAR Figure 2.5-4b) (References 3, 4, 5). We evaluated the potential for karst development in the Vicksburg Group by reviewing topographic and geologic maps in the nearest outcropping areas of the formation, and contacting researchers familiar with the properties of the Vicksburg Group.

RAI Figure 2.5.4-9-2 is a regional geologic map showing the distribution of the Vicksburg Group outcrops on a shaded relief base map in the Vicksburg area. RAI Figure 2.5.4-9-3 shows a blow up of a portion of the regional geologic map superimposed on the Bovina USGS 7.5 minute topographic quadrangle. The available geologic and topographic maps of this area do not show any indication of karst-related topographic or geomorphic features (e.g. sinkholes, circular depressions, etc.) within the outcropping areas of Vicksburg Group carbonate rocks. The maps do define several concentric lakes within the Vicksburg Group outcrop areas that are up to about 100 m in diameter. However, these lakes also are developed in areas where the non-calcareous Catahoula Formation crops out (Reference 6, 7, 8), suggesting that the lakes are not associated with carbonate dissolution processes. None of the lakes have been reported to be associated with karst in the literature (Reference 11).

Although karst development has not been documented in the Vicksburg Group outcrops in the vicinity of Vicksburg and the Grand Gulf Site Vicinity, karst features are referenced as occurring within the Vicksburg Group in the area east of Jackson, approximately 50 miles northeast of the Grand Gulf ESP site (References 9, 10, 11). In this area, the Vicksburg Group contains the Marianna Limestone, which is more susceptible to dissolution and karstic development. Karst related features reported in the literature are associated primarily with the Marianna Limestone, although minor karst topography is reported associated with the Glendon Limestone near Waynesboro in eastern Mississippi approximately 175 miles east of the Grand Gulf ESP site (References 9, 10, 11). The lithology of the Vicksburg Group, in general, undergoes a lateral facies change west to east across the state. In western Mississippi (Vicksburg area), the Group includes a

greater percentage of terrigenous wackestones and sandstone, and the Marianna Limestone is not present as a thick clean limestone. East of Vicksburg, the Vicksburg Group grades into a more calcareous lithology, ultimately becoming a sequence of semi-indurated calcareous sand and silt and calcareous grainstone, and the Marianna Limestone becomes a prominent formation within the Vicksburg Group. Karst features develop only where the limestone is relatively homogeneous, "clean" and thickly bedded in the area east of Jackson. However, Coleman (1979) and Mylroie (oral communication) report that no true karst topography typical of the limestone terrain in Alabama, Florida and Kentucky exists along the Vicksburg Group outcrop belt in Mississippi. The prevailing topography is rather related to fluvial erosion, with a minor degree of karst development east of Jackson (Reference 10).

The only comprehensive cave survey of Mississippi State was published in the early 1970's by the National Speleological Society (Reference 12). This survey located approximately 40 caves, most of which occur in eastern Mississippi. However, this survey did not distinguish solution (karst) caves from artificially excavated or erosion-related caves (Mylroie, oral communication). Some instances of reported "caves" actually are artificial excavations. An example of a reported artificial cave is a recent news article reporting the death of three teens in "caves" along the Mississippi River (Reference 12). These failed "caves" turned out to be excavated caverns made by a local brewery to create earthen warehouses at the turn of the century (Reference 13), and are not related to carbonate dissolution (karst). Sixteen of the identified 40 caves in Mississippi, including all of the largest caves, are associated with outcrops of the Vicksburg Group (Reference 12). These caves include the Pitts Cave, Triple H Cave, Lamar Graham Cave, Graham Waterfall Cave, Eucutta Cave, Belding Cave, and Waddel Cave. All of these caves are located in eastern Mississippi over 100 miles northeast of the Grand Gulf ESP site where the Vicksburg Group is more calcareous. Other caves are distributed primarily across eastern Mississippi with no unique pattern of spatial association to the Vicksburg Group (although Reference 12 does not specify natural versus manmade caves).

Although no caves or evidence of karst development were found in the Grand Gulf Site Vicinity in our review of regional geologic maps and studies of the Vicksburg Group calcareous units, the U.S. Geological Survey classified the Vicksburg Group as having a potential for karstic development in a regional map compilation of the Appalachian region (Reference 14). The USGS classification is based on descriptions of regional lithology that include descriptions of calcareous units within the Vicksburg Group, and did not include field or other verification of karst development in these units. The statement regarding the potential for karst development was instead based on carbonate lithologies of regional units with a conservative bias towards inclusion of any potentially soluble units (Reference 14). As described above, the Vicksburg Group does not exhibit karstic features west of Jackson or within the general Site Vicinity, including the entire 25-mile radius around the ESP site.

We conclude that there is no documentation of karst development within the Vicksburg Group in the Site Vicinity or Site Region west of Jackson. In areas of outcrop exposure, the Vicksburg Group does not display characteristic morphology

of karst development or potential, and no evidence of karst features are reported in the literature.

3) Evaluate zone of influence of any new proposed foundation on the Vicksburg Group strata

At this time a reactor type and facility layout have not been selected for the ESP site (refer to response to RAI 2.5.4-10), and the geometry and depth of possible foundations is not defined. However, the greatest manufacturer-listed embedment depth for the six alternative reactors listed in the Plant Parameters Envelope (PPE) worksheet is 140 feet below grade (see RAI Table 2.5.4-10-1). This corresponds to an elevation of about -8 feet, assuming a final plant grade at elevation 132 feet. The estimated elevation of the top of the Glendale limestone beneath the ESP site is at about -300 feet. Therefore, ESP plant foundations would have a minimum separation distance of about 300 feet from the top of the limestone.

The maximum listed required static bearing pressures for the alternative ESP reactor foundations is 15 kips per square foot (ksf). At a depth of 140 feet, this pressure is about equivalent to the existing in situ stress level from the soil overburden. The soil overburden would be removed down to foundation level during construction, and the foundation load at the base of the excavation would be at least partly compensated by the stress reduction from the soil removal. As a result, the net increase in soil loads below the foundation would be relatively low, and likely would be largely supported by the soil in close vicinity to the foundation base. Because of this, the actual stress change in the soils below the reactor foundation may be only slightly above the in situ stresses that exist prior to foundation excavation. Therefore, reactor foundation surcharge loads on the soils are expected to be very minor, and limited to the immediate area below the foundation base. No significant loading increase would be transmitted to the elevation of the Glendon limestone that underlies the ESP site about 300 feet below the deepest considered foundation level for the ESP site.

Multi-point extensometer arrays were installed to a depth of 150 feet below the foundation base for the existing Grand Gulf power block foundations to measure soil rebound related to stress relief during deep excavations for the foundations (that were 65 to 80 feet deep). The stress relief measurements provide a general idea regarding the depth of influence in the soils related to foundation excavation, and also the likely depth of the foundation influence zone upon reloading from the power plant foundations. As discussed in UFSAR section 2.5.10, the rebound measurements decreased from about 1.6 to 1.9 inches at the base of the foundation excavation level, to 0.2 to 0.36 inches at a depth of 100 feet below the foundation level. Using these results as a guide, it is expected that the foundation influence zone extends about 100 to 200 feet below the base of the foundation. However, the percent load carried by the soil drops off significantly below a depth of about 100 feet beneath the foundation level (to less than about 10% to 20% of the total load) due to the partly-compensated load condition of the foundation, and overconsolidated nature of the site soils. We note that the foundation geometry, load, and soil conditions at the ESP site may differ somewhat from the conditions at the existing plant site, and therefore this comparative analysis provides only a rough estimate regarding the depth of foundation influence.

In accordance with Regulatory Guide 1.132 (and proposed revisions presented in Draft Regulatory Guide DG-1101), additional site investigations would be conducted during the COL phase of the project. These investigations should include deep borings in the planned foundation footprint and geotechnical analysis of the bearing pressure and load distribution in the foundation soils based on the specific geometry, embedment, and loading of the selected reactor. Should any calcareous clays, limestone or marl deposits be found within the incremental pressure bulb created by the planned construction (assumed at this time to extend about 200 feet below foundation level), further borings should be drilled at a sufficiently close spacing to confirm the absence of dissolution cavities within the foundation bearing zone.

SSAR Revision:

None

See files: 035_RAI_Fig_2.5.4-9-1.pdf
036_RAI_Fig_2.5.4-9-2.pdf
037_RAI_Fig_2.5.4-9-3.pdf

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Request:

RAI 2.5.4-10

Section 2.5.4.5.2 of the SSAR indicates that several inches of elastic rebound may be associated with the site excavations planned to relatively deep depths and that this rebound would be expected to be reversible, presuming the new structures are fully compensated designs. Presuming that the current GGNS power block structures are far enough from the ESP site, are any other facilities (piping, conduit, etc.) existing in the ESP area that may be influenced by such surface movements?

Response:

As discussed in the response to RAI 2.5.4-2, SSAR Figure 2.5-69, Draft Rev. 1 shows a revised circular "Proposed Power Block Area" (PPBA) that supersedes the former polygonal "Proposed Site Location Perimeter". This PPBA is considered to conservatively bracket any possible plant power block layout based on the range off different plant types considered for the ESP site. Table 2.5.4-10-1 summarizes the parameters for the alternative reactors used to estimate the range for foundation embedment.

RAI Table 2.5.4-10-1
Alternative Reactor Parameters

Reactor	Power Block Acreage	Vendor Foundation Embedment Depth Recommendation (feet)	Minimum Static Bearing Pressure (kips/ft^2)	Minimum Shear Wave Velocity (feet/sec.)
ABWR	2.5	66.25 (top of basemat)	15	1000
AP1000	25	39.5 (bottom of basemat)	8	1000
IRIS	9	49	8	1000
GT-MHR	2.5	140	15	1000
PBMR	2.6	32.75	10.2	1000
ACR-700	4.4	33	10	1000

Data extracted from Plant Parameters Envelope (PPE) Worksheet, Rev. 1, Enercon Services, Inc. (6/25/03). Note that this list is not inclusive for all possible reactors at the ESP Site, but to develop estimates of likely embedment depths for foundations.

As discussed in SSAR Section 2.5.4.5.1, it is anticipated that a new facility at the ESP site would maintain the existing plant grade of approximately elevation 132 to 134 feet.

The manufacturer-listed foundation embedment depth for the six example reactors range between about 33 and 140 feet, and minimum static bearing pressures range between 8 and 15 kips per square foot (ksf). For comparison, the existing Grand Gulf

power plant containment building is founded at a depth of about 65 to 80 feet below plant grade, and has a static bearing pressure of about 12 ksf (UFSAR section 2.5.4.10). As discussed in SSAR Section 2.5.4.5.1, suitable foundation and shear wave velocity conditions for reactor foundations at the ESP site would require embedment below the loess deposits into the Upland Complex Alluvium or Old Alluvium to an elevation where the average shear wave velocity is at least 1,000 feet per second (fps). This likely would require excavations to depths on the order of about 60 to 100 feet, or deeper (e.g., SSAR Figure 2.5-76, Draft Rev. 1). The in situ confining stresses at these embedment depths range between about 5 to 10 ksf. The in situ confining stress at the maximum manufacturer-listed depth of 140 feet is on the order of about 12 to 15 ksf. These estimated in situ pressures are in the range of, but somewhat lower than, the minimum static bearing pressure requirements for the various reactors, suggesting that the foundations will be partly compensated.

As discussed in SSAR Section 2.5.4.5.2, up to several inches of predominantly elastic rebound may occur as a result of reactor excavations. This value was estimated based on a review of the performance of the existing Grand Gulf containment and turbine buildings that were monitored during construction by multi-depth vertical extensometers that were anchored at a depth of 150 feet below the foundation levels. Measured rebound in the excavations ranged between 1.6 to 1.9 inches (UFSAR Section 2.5.4.10 and Figure 2.5-81). Total settlements of the completed plant structures were measured by repeated surveys (through 1991) of surface monuments placed in the same general vicinity as the extensometers (UFSAR Table 2.5-10, Rev. 6). Measured settlements of the containment and turbine buildings ranged between 0.5 and 1.3 inches, somewhat less than the magnitude of the rebound. However, we note that the settlement readings were not initiated until construction was in progress, and therefore some initial recovery of rebound likely was missed by the settlement surveys. Comparison of the measured rebound and settlement data for the existing Grand Gulf power plant shows that a significant percentage of the rebound was recovered by settlement.

The extensometer and survey network at the existing power plant does not extend around the power plant area at a sufficient density to evaluate the lateral extent of rebound or settlement around the foundations. However, structures adjacent to the deep plant foundations do not appear to be affected by unusual or damaging settlements. For the purposes of our evaluation, we have assumed that the influence zone around the proposed ESP plant foundations includes the area within a 1:1 (horizontal to vertical) projection extending upward from the base of the foundation to the ground surface. To conservatively capture any possible structures within this assumed influence zone, we overprinted such an influence zone around the perimeter of the PPBA shown on SSAR Figure 2.5-69, Draft Rev. 1. This influence zone was constructed by projecting the circular intercept location of a 1:1 truncated cone extending upward from the deepest manufacturer-listed foundation embedment depth of 140 feet below the PPBA, to the proposed plant surface grade between elevation 132 and 134 feet (SSAR Figures 2.5-69, Draft Rev. 1, and 2.5-76, Draft Rev. 1). The resulting influence zone is formed by the area between the PPBA and projected 1:1 intercept line, and is 140 feet wide. The 1:1 projection is believed to be conservative, considering the overconsolidated state of the site soils, and likely deep bearing elevations for future power plant foundations that together would minimize ground deformations from the foundation loading.

No existing safety-related Class I facilities fall within, or adjacent to, the estimated ESP influence zone. Based on this evaluation, construction and foundation loads from a new plant at the ESP site will not impact the existing power plant structures, operation, or safety. Additionally, during construction, deep excavations would likely be supported by tied-back sheet piles or other bracing systems, in a similar manner to the excavations for the existing power plant. These support systems, if requiried, would be designed to minimize soil deformations during construction, and confine possible excavation-related ground deformations to the immediate areas adjacent to the excavations.

In accordance with Regulatory Guide 1.132 (and proposed revisions in Draft Regulatory Guide DG-1101) additional site exploration, laboratory testing, and geotechnical analyses will be performed during the COL phase of the project after a plant design has been selected to verify site conditions for foundation design geotechnical analyses and determination of embedment criteria. These borings and additional engineering analysis should include evaluation of deformation moduli for the subsurface materials for refined estimates of the influence zone related to the selected reactor and foundation configurations. Consolidation and triaxial shear testing will be performed on undisturbed samples from the foundation bearing level of the selected reactor to evaluate foundation bearing pressures and settlement potential. The COL investigations also should consider development of an instrumentation and monitoring program to measure actual construction-related soil movements.

SSAR Revisions:

A statement will be added that the estimated foundation influence zone is shown on Figure 2.5-69, Draft Rev. 1

See files: 001_ESP-SSAR_draft_rev1_12-01-2004.pdf
017_SSAR_Fig_2.5-69draft_rev1_11-19-2004.pdf
018_SSAR_Fig_2.5-76darft_rev1_11-19-2004.pdf

Request:

RAI 2.5.4-11

Section 3.3 of ER-02 indicates that all safety related facilities located at the ESP site would be located on alluvium or old alluvium that has an average shear wave velocity of "at least 1,000 fps". The suspension logging data provided in Appendix D indicates measured shear wave velocities as low as 500 fps at depths of up to 120 feet (see results for Boring B-1, for example). This depth is well below the planned depth of foundations indicated in the SSAR. Since measured shear wave velocities are based on the results from only three borings, and considering the normal variability anticipated in shear wave velocity, what would the impact of such a velocity cutoff have on the minimum depth for future siting, especially since some of the advanced reactor designs may be qualified for velocities of at least 1,000 fps?

Response:

As shown in SSAR Figure 2.5-71 and in Engineering Report ER-02 Appendix D tables and graphs, individual measurements of shear wave velocity obtained using the P-S Suspension Logger are as low as 530 feet per second (fps). However, these are

localized zones in a single boring (do not occur at the same elevations between borings), and generally occur within the loess or Upland Complex Alluvium (although they also occur less commonly in the Old Alluvium). The lower-velocity zones typically are less than 10 to 20 feet thick, represent a relatively small percentage of the strata within each stratigraphic unit, and are bounded by zones exhibiting greater velocities. The deepest occurrence of a lower-velocity zone is at a depth of about 154 feet, and the minimum elevation at the base of a lower-velocity zone is at an elevation of about -7.4 feet. The lower-velocity zones have zone-specific average velocities in the range of between about 760 and 970 fps. It is uncertain whether the low values are the result of softer lenses in the deposit, or rather are the result of local variations in the P-S suspension logger measurements that can result from varying hole diameters. In some cases, the lower-velocity zones correlate to clay lenses or clayier zones within the sand sediments: some of these zones also are denoted by a locally lower Standard Penetration Test (SPT) blowcount.

The minimum required shear wave velocities at the foundation level for all example reactor types considered is 1,000 fps. As stated in Section 3.3 of ER-02, safety related facilities at the ESP site would be founded on Upland Complex Alluvium or Old Alluvium that exhibit an average shear wave velocity of at least 1000 fps. Data from the existing three deep borings at the ESP site, as shown in SSAR Figures 2.5-60 and 2.5-80, suggest that this criterion is marginally met in the Upland Complex Alluvium and is easily met in the Upland Complex Old Alluvium. In accordance with Regulatory Guide 1.132 (and proposed revisions in Draft Regulatory Guide DG-1101) confirmatory borings should be drilled at the site during the COL phase site investigations. These borings should include additional borehole velocity surveys to verify the velocity profile under the foundation footprint and to confirm the depth of the target foundation bearing strata that satisfy the selected plant's shear wave velocity design criteria. Based on the existing UFSAR and ESP data, we believe that the depth range to deposits exhibiting a shear wave velocity of 1,000 fps will not vary significantly from the results presented in the SSAR.

SSAR Revision:

None

Request:

RAI 2.5.4-12

Section 2.5.4.1.3 of the SSAR and Section 7.5 of ER-02 indicate that the difference in blow counts for the standard penetration test (SPT) between previous field programs and the current program performed for the ESP may be due to a difference in hammer equipment used for the samples. Since only three borings were taken for the ESP program and since conclusions for this evaluation rely heavily on the previous site investigations, was any simple program performed to quantify this difference (such as taking a new boring adjacent to an old boring using the new equipment)?

Response:

The response to RAI 2.5.4-3 provides a background discussion pertaining to correlation between the ESP and UFSAR borings that is also relevant to this RAI. The ESP explorations were augmented with data from twenty previous borings performed

for the UFSAR that fall within, or adjacent to, the Proposed Power Block Area (PPBA) area (SSAR Figure 2.5-69, Draft Rev. 1). The UFSAR borings extended to depths of between 81.0 and 300.0 feet below ground surface (bgs), and were drilled with mud rotary equipment with interval Standard Penetration Test (SPT) drive sampling. The combined coverage of the ESP and UFSAR borings provide sampling across the entire proposed power block location at spacings of between about 200 and 600 feet, and to a depth of 300 feet.

As described in Engineering Report ER-02 Section 12.3, the locations of UFSAR borings that are shown on SSAR Figure 2.5-69, Draft Rev. 1 were estimated by enlarging UFSAR boring location maps (e.g., UFSAR Figure 2.5-39) to a common scale as the ESP site map, superimposing several index structures that are common to each map to obtain a best fit match (e.g., containment building outline), and transferring the boring locations by hand. The resulting UFSAR boring locations are believed to have an estimated positional error of about 50 feet. The UFSAR borings were made prior to extensive grading during construction of the existing Grand Gulf power plant site that included deep cuts and localized filling across the ESP site area. This grading removed any evidence of the locations of the UFSAR borings, and therefore their locations could not be verified in the field. The margin of error related to location of the UFSAR borings did not allow us to make confident side-by-side comparisons between ESP and UFSAR borings to directly compare SPT and other techniques in adjacent boreholes. The closest distance between an ESP boring and estimated location of an UFSAR boring within the PPBA is about 185 feet (borings ESP WLA B-1 and UFSAR B-16)

SSAR Figures 2.5-75 to 2.5-77, Draft Rev. 1 (cross sections A-A', B-B', and C-C', respectively) show SPT data from the ESP borings, and estimated locations of the nearest UFSAR borings. The UFSAR borings surround the ESP borings, and the stratigraphic units were correlated between the two boring sets. Therefore, the UFSAR and ESP borings sampled the same general soil volume, making comparisons between the data reasonable.

RAI Tables 2.5.4-12-1 and 2.5.4-12-2 list 38 SPT tests made in the ESP borings and 1,069 SPT tests from the UFSAR borings, respectively. These SPT data are segregated into the various ESP stratigraphic units from which the samples were obtained. Comparison of the tabulated data shows that the UFSAR blow counts upper and lower bound ranges are about 110% to 250% higher than in the ESP borings for loess, 150% to 300% higher for Upland Complex Alluvium, and 110% to 120% higher for Upland Complex Old Alluvium.

The SPT blow counts for the ESP boreholes were delivered by an automatic trip hammer that is a very consistent, highly efficient delivery system. The delivery system for SPT sampling in the UFSAR boreholes is not documented on the boring logs or UFSAR. However, based on the vintage of the exploration program ((1971 to 1972), it is not likely that the UFSAR sampling was performed with automatic trip hammer equipment that came into standard usage about the mid-1980's. Rather, these samples probably were driven by a less-efficient and consistent cathead or wireline delivery system. Based on standardized hammer efficiency correction factors such as presented by Youd and Idriss (2001), the ESP automatic hammer system has an estimated efficiency factor of about 90%, compared to the probable lower efficiency for the UFSAR SPT testing with an assumed cathead or wireline delivery system of about

60%. The assumed differences in SPT hammer sampling delivery systems could largely account for the markedly lower SPT blow count ranges obtained in the ESP borings for the same stratigraphic units as sampled in the UFSAR borings.

SPT test data for the ESP were used in a qualitative and relative sense to perform an initial characterization and evaluation of the site subsurface conditions rather than for engineering design or quantitative geotechnical analysis. In this sense, the ESP SPT data are believed to provide a conservative general assessment of the material properties, as an adjustment of the ESP blow counts to correspond with the UFSAR blow counts (using a less-efficient hammer delivery system) would result in higher blow counts.

In accordance with Regulatory Guide 1.132 (and proposed revisions in Draft Regulatory Guide DG-1101), COL phase investigations would include additional borings and SPT testing throughout the selected power plant footprint area to increase the SPT data base for design of the plant. It is expected that selected COL borings would be performed with energy calibration equipment to allow accurate measurement and adjustment of the hammer blows for design-level geotechnical analysis (e.g., liquefaction analysis) and development of foundation and excavation design parameters. The COL borings should also include index borings at the ESP boring locations to allow calibration between these boring sets. The ESP borings are marked with steel stakes set in cement grout at the borehole locations, and also were surveyed for future reference purposes.

SSAR Revisions:

See files: 018_SSAR_Fig_2.5-75draft_rev1_11-19-2004.pdf
019_SSAR_Fig_2.5-76draft_rev1_11-19-2004.pdf
020_SSAR_Fig_2.5-77draft_rev1_11-19-2004.pdf
038_RAI_Tables_2.5.4-12-1a-d.pdf
039_RAI_Tables_2.5.4-12-2a-c.pdf

References:

Youd, T.L., and Idriss, I.M., 2001, Liquefaction resistance of soils: summary report from the 1996 NCEER and 1998 NCEER/NSF workshops on evaluation of liquefaction resistance of soils: American Society of Civil Engineers Journal of Geotechnical and Geoenvironmental Engineering, p. 297-313.

Request:

RAI 2.5.4-13

Section 2.5.4.1.6 indicates that samples were shipped to the University of Texas by automobile and to Eustis by Federal Express. The UTEXAS description included in Appendix G of ER-02 indicates that all samples examined for dynamic testing had the appearance of competent, intact materials. Section 11.0 of ER-02 indicates that samples were carefully extracted from the borehole and presumably carefully shipped to UTEXAS. Yet, the report indicates that the results of the dynamic testing indicate some effect of sample disturbance. What measures were taken, if any, aside from these qualitative statements, to ascertain whether any significant disturbance occurred during the sampling, transportation or laboratory extrusion process? Since the static

testing program included consolidated undrained (CU) triaxial tests, was any concern expressed about disturbance to these samples as well?

Response:

Undisturbed hydraulically-pushed, thin-wall Shelby tube samples were obtained from the ESP borings for the UTEXAS dynamic testing. Partly-disturbed, driven Modified California sampler brass tube samples were collected from the borings for index and UC triaxial shear testing by the Eustis laboratory. Both the Shelby and Modified California samples were carefully extracted from the borings, inspected, capped with plastic lids and electrical tape, and sealed with paraffin according to the Project Instruction PI-05. The Shelby tube samples were placed in foam padded wood crates, and driven to the UTEXAS laboratory in a passenger van to minimize disturbance during transportation. They also were kept upright at all times. The Modified California tube samples were placed in cardboard boxes, padded, and shipped to the Eustis testing laboratory.

Upon receipt at the laboratories, the samples were inspected by laboratory personnel. The transporting field geologist noted that the UTEXAS samples remained undisturbed during transportation. The UTEXAS laboratory report included as Appendix G in ER-02 states that the six samples selected for testing were carefully extruded, trimmed, and had the appearance of competent, intact materials after the extrusion and trimming process was completed. This indicates that the UTEXAS dynamic samples were not disturbed during transportation or extrusion. In their discussion of results, UTEXAS reported that the sample behavior suggests that some disturbance likely occurred, and also comments that some samples underwent tilting during the testing. The Eustis laboratory report included in Appendix F of ER-02 does not discuss the condition of the samples upon arrival at the laboratory, but does comment that one of the triaxial test specimens was disturbed by the presence of shells or gravel.

Based on our review of the laboratory reports and test results, we believe that some disturbance occurred to the samples that was caused by stress relief during borehole extraction, movement of shells or gravel-size clasts in the samples during sampling, or movements (e.g., tilting) during laboratory testing. These effects do not appear to be the result of handling or transportation of the samples, as the documentation of the transportation and initial laboratory inspection upon receipt do not indicate disturbance of the samples.

As discussed in the response to RAI 2.5.4-6, the ratios of the shear wave velocities measured in the laboratory and those measured in the field at the same depth for the UTEXAS samples were taken as an indication of possible extraction-related sample disturbance and were accounted for in our interpretation of the results of the dynamic tests and selection of appropriate shear modulus reduction and damping curves. No corrections were made to the static triaxial test results because it is generally assumed that sample disturbance will have less effect on strengths that are measured at large strains induced by triaxial testing as opposed to the small to medium strains employed in the dynamic tests. Additionally, the triaxial tests performed for the ESP were used only as index tests to generally compare relative properties between different stratigraphic units, and also to compare against triaxial tests performed for the UFSAR. The triaxial test results were not used as input parameters to calculate

foundation or design criteria, which instead would be developed in the COL phase after a specific reactor is selected, in accordance with Regulatory Guide 1.138 (and proposed revisions in Draft Regulatory Guide DG-1109).

SSAR Revision:

None

Request:

RAI 2.5.4-14

Appendix D of ER-02 presents the results of the P-S Borehole Logging that was conducted by GeoVision in the three boreholes. From this data, P-wave and S-wave profiles were generated to depths of from about 180 feet to 225 feet.

Page 7 of this Appendix presents the assessment that the "shear wave data was of excellent quality in the three boreholes". What is the basis for this judgment? Does the fact that the statement only refers to the quality of the S-wave data imply that the P-wave profiles are of lower quality?

The plots of P-wave velocity with depth show the relatively rapid increase one would normally expect near the ground water table. The results from Borings 1 and 3 show this characteristic velocity increase. However, the results for Boring B-2A show the characteristic rise followed by a significant reduction at a depth of approximately 70 feet. What is the cause of this anomaly?

Response:

Page 7 of Appendix D of ER-02 states that "the shear wave data was of excellent quality in the three boreholes." This statement is included in a contractor's report by GeoVision and reflects their confidence in the quality of the borehole P-S data based on their examination of the records and internal QA/QC procedures. As discussed in their report, the GeoVision QA/QC procedures included comparison between the independently-acquired source-to-receiver velocities and receiver-to-receiver velocities, and independent review by a second geophysicist. GeoVision's report discusses the good agreement between the source-to-receiver and receiver-to-receiver interval velocities for both shear wave (S-wave) and compressive wave (P-wave) velocities in each borehole, providing verification of the general good data quality. Therefore, the good data quality refers to both the S-wave and P-wave data, and no implication is made regarding a lower quality with respect to the P-wave data.

We independently reviewed the GeoVision P-S survey data, and found the correlation between source-to-receiver and receiver-to-receiver data to be very good in all boreholes. Additionally, our geologists observed the GeoVision P-S survey field setup, calibration, and logging for each borehole. Based on the field review, the surveys were performed carefully and according to the approved ESP Project Instruction PI-05.

The initial rise in the P-wave velocities in boring WLA B-2A occurs near the contact between the loess and Upland Complex Alluvium. We believe that this initial rise results from a perched water table within the base of the loess soils, above the

alluvium. The permanent ground water table is delineated by a P-wave rise within the Alluvium about 15 feet deeper in the boring that does not drop back down, and correlates well with the P-wave rise that marks the top of the groundwater table in borings WLA B-1 and B-2.

SSAR Revision:

None

Request:

RAI-2.5.4-15

Appendix F of ER-02 presents the results of standard geotechnical identification tests as well as some results from consolidated undrained (CU) triaxial strength tests.

The sample descriptors provided with the grain size distribution curves present descriptions such as "FINE SAND w/Silt" (see, for example, B1-S22 as well as others) for cases where the sample contains less than 10% fines. Can such descriptors mislead evaluations based on verbal descriptions?

The tables also include unified soil classification (USC) descriptors such as lean clay or silt (CL or ML) for samples for which no Atterberg Limits were determined. For these cases, what was the basis for developing such classifications?

For some samples, only one CU test was performed from which estimates of strength parameters (cohesion and friction angle) are listed. What was the basis of such judgments?

Response:

Classification of ESP Site soil samples obtained from the exploratory borings were based on an initial field "Visual-Manual" descriptions according to ASTM 2488 as specified in ESP Project Instruction PI-05. Field descriptions were performed by geologists and aided by the following qualitative techniques: (1) manipulation of the samples by hand to detect gravel and sand-size grains; (2) simple settlement tests using water-filled jars and a stopwatch to measure the settlement time and observe different grain size layers of settled soil; (3) finger manipulation and rolling out of threads of cohesive soil to evaluate soil plasticity and toughness; (4) observation of dilative behavior of moist soil pats; (5) observation of soil samples under a handlens; (6) measurements of soil compressive strength or shear strength with a pocket penetrometer and torvane, respectively; and (7) testing of dried crushing strength of soil cubes dried in the sun. These field descriptions were modified, if necessary, for the final soil classification based on the results from laboratory index testing performed by Eustis Laboratory (Engineering Report ER-02 Appendix F), and according to the ASTM 2487 "Unified Soil Classification System" (USCS). The laboratory testing program was specifically configured to confirm or refine the field descriptions, and was especially targeted toward field samples that had uncertain descriptions or soils that fell on the border between two different possible classifications.

The final soil classifications are presented on SSAR Table 2.5.-7, Draft Rev. 1. Differences between field and laboratory classifications were evaluated, and the geologists made a decision as to which classification to adopt for the final soil description.

SSAR Table 2.5.-7, Draft Rev. 1 shows both the laboratory and field classifications when these are not in agreement. In some cases, the field classification was kept, or slightly modified, rather than adopting the laboratory classification. The decision to keep field classifications was based on the perceived quality and quantity of the laboratory data, and also level of confidence in the field description.

As is true with any geotechnical exploration program, the number of samples submitted for laboratory testing was limited by the number and quality of samples that could be extracted from the borings, budget, and schedule. Therefore, the results from the laboratory testing were extrapolated by indexing tested samples to the field descriptions, and then developing correlations for other samples that were not tested in the laboratory.

Responses to the specific RAI subquestions are listed below.

1. Samples include the descriptor "with silt" for cases where the sample contains less than 10 percent fines. Is this misleading?

   The referenced sample, B-1-22, was classified as a fine sand with silt (SP-SM), and contains 9.5% silt and 2.2% clay (total fines content of 11.7%). This sample was correctly classified by the descriptor "with silt" according to the USCS (ASTM D2487) that specifies the use of this descriptor when a sand contains between 5% and 12% silt. We adhered to the USCS because this is a universally-applied standard soil classification scheme for geotechnical and engineering applications, and therefore should not be misleading. In response to the RAI, we performed another round of review for all of the ESP soil classifications, and found that some sand samples were not correctly classified with regard to the grading (poorly graded versus well graded (SP/SW-SM)). Also some fine-grain soil classifications require changing from lean clay to silt (CL/ML), or visa versa. Modified classifications are presented on SSAR Tables 2.5.-7, Draft Rev. 1. The soil classification modifications do not change the findings from the investigation or require changes to analysis input, as the overall descriptions for the general properties of the major stratigraphic units do not change, and most of the changes pertain to soils that were borderline between classifications. Additionally, the actual soil testing results are presented on SSAR Table 2.5.-7, Draft Rev. 1 and are also included in ER-02 Appendix F, to facilitate incorporation of these data for evaluation purposes that should not be solely based on verbal descriptions.

2. Soil classifications of lean clay or silt were made without specific Atterberg Indices tests on these samples. What was the basis for these classifications?

   Soil classifications made for clay or silt samples that did not have Atterberg Limits were based on the soil behavior observed by field Visual-Manual description methods, or extrapolated from similar samples that were subjected to Atterberg Limits testing. Eighteen Atterberg Limits tests were performed on selected fine-grained ESP samples, and include multiple tests from each of the site stratigraphic units (loess, Upland Complex Alluvium, Upland Complex Old Alluvium) and one sample of Catahoula formation claystone. With the exception of the Catahoula formation sample that classifies as a fat clay (CH), all of the other samples fall within the classification zones for lean clay or silt (CL or ML). These samples also exhibited similar Visual-Manual properties. On this basis, it is reasonable to extend the classification of lean clay and silt to the samples that had similar field behavior, but were not submitted for Atterberg Indices testing.

3. Only one CU test was performed for some samples from which estimates of strength parameters are listed. What is the basis of such judgments?

   Although eighteen samples were submitted to the Eustis Laboratory for CU triaxial shear testing, only ten of these samples were determined to be suitable for triaxial testing, or remained intact while they were placed in the testing load cell. Only one 3-point CU test series, and two 2-point CU test series, were possible on stratigraphically-adjacent intact samples. The remaining 3 samples were obtained from non-adjacent stratigraphic units, and were tested as single-point CU tests.

   The triaxial test results were plotted on p-q and Mohr Circle plots to estimate the cohesion and friction angle components for the shear strength failure envelopes. For tests with a single point, the failure envelope was defined by a line extending from the graphical origin (zero cohesion), and constrained by a single tangential contact point on the Mohr circle. For multi-point tests, a best fit between tangential points on the multiple Mohr circles was use to estimate these parameters.

   The single-point test results plot consistently when transferred to the multi-point test plots. Additionally, the one-point and multi-point stress-strain curves for the loess samples have generally similar shapes, as do the single and multi-point sand stress-strain curves. The strength values estimated by Eustis personnel were reviewed and appear to be reasonable based on our experience performing multi-point triaxial tests on similar materials. They also fit within the range for soils with similar classifications reported in the literature (e.g., Kulwahy and Mayne, 1990). As described in the response to RAI 2.5.4-13, the ESP triaxial test results were used only as index tests to generally compare relative properties between different stratigraphic units, and also to compare against triaxial tests performed for the UFSAR. The triaxial test results were not used as input parameters to calculate foundation or design criteria. Therefore, extrapolation of the single-point test results to estimate shear strength parameters is deemed to be valid for the purposes of the ESP study.

SSAR Revisions:

See file: 040_SSAR_Table2.5-7draft_rev1_11-19-2004.pdf

References:

Kulwahy, F.H., and Mayne, P.W., 1990, Manual on estimating soil properties for foundation design: Electric Power Research Institute Report No. EL-6800, Research Project 1493-6, 243 pp.

Request:

RAI 2.5.4-16

Appendix G of ER-02 presents the results of dynamic laboratory testing conducted by the University of Texas on six intact samples obtained from borings B-1, B-2 and B-3 taken at the ESP site. The purpose of the tests was to evaluate the linear and nonlinear shear modulus and material damping characteristics of the samples. The dynamic laboratory tests included both Resonant Column (RC) and Torsional Shear

(TS) conducted at different confining pressures and maximum strain levels. The samples tested were all fine-grained soil samples, four having low plasticity indices (PIs) (less than 5%) and two having more plasticity (PI = 12-13 percent). Table 3 of Appendix G (as well as Table ER-02-6) of the body of the report indicates that three of the samples were confined at pressures based on an assumed value of K_o of 0.5 and three were tested at an assumed value of 1.0. What was the basis of these selections and how did the resulting pressures compare with current estimated in situ stress levels?

Response:

Six samples from borings WLA B-1, B-2, and B-3 were submitted to the University of Texas for dynamic laboratory testing. In all six cases the test specimens were reconsolidated to an isotropic stress equal to the mean estimated in situ stress based on an estimate of K_o, the coefficient of lateral earth pressure. The two loess specimens were reconsolidated assuming a K_o value of 0.5 while the other four test specimens (two each of Upland Complex Alluvium and Old Alluvium) were reconsolidated assuming a K_o value of 1.0. We note that the RAI incorrectly states that three samples were assigned a K_o value of 0.5, and three samples utilized a K_o value of 1.0.

A K_o value of 0.5 was selected for the loess because this material is younger (less consolidated) than the Upper Complex Alluvium and Old Alluvium. As discussed in the response to RAI 2.5.4-6, in retrospect, it appears that a better match would have been obtained between the loess field and laboratory-measured shear wave velocities using the higher K_o value of 1.0 for the laboratory samples. This is reflected by the improved agreement between the field and laboratory velocities for the loess samples that were tested at a confining pressure of four times the estimated in situ stress, as shown on SSAR Table 2.5-26, Draft Rev. 1. The K_o value of 0.5 for the loess therefore did not sufficiently account for the significantly overconsolidated nature of these deposits. As discussed in our response to RAI 2.5.4-6, the results from the loess samples tested at four times the estimated in situ confining stress were given a greater weight during our evaluation and selection of the appropriate EPRI 1993 shear modulus reduction and hysteretic damping curves for the site response analysis.

SSAR Revisions:

See file: 034_SSAR_Table_2.5-26draft_rev1_11-19-2004.pdf

Request:

RAI 2.5.5-1

Section 2.5.5 of the SSAR and Sections 3.3 and 12.5.2 of ER-02 indicate that the west-side of the proposed ESP site is bounded by a 60-foot to 70 foot escarpment that may be subjected to surficial slumps and potential creep of the loess soils. They go on to indicate that since future safety related facilities would be founded on alluvium or old alluvium encountered below the loess, future movements of the slope should not have any significant impact on these foundations. However, if such facilities would be founded close to the scarp, such slump or creep effects could have an impact on lateral loads applied to such deeply founded facilities. Was any evaluation performed to indicate the expected behavior of the loess escarpment or the extent to which such

movements could occur? Should the potential site area therefore contain some exclusionary zone along the west-side boundary that would not be susceptible to such potential future slump?

Response:

SSAR Figure 2.5-69, Draft Rev. 1 shows the spatial relationships between the Proposed Power Block Area (PPBA), Mississippi River floodplain bluff (in loess soil), and the postulated shallow slump in the bluff near the west boundary of the ESP site. The subsurface geologic conditions are shown on vertically-exaggerated cross section B-B' from SSAR Figure 2.5-76, Draft Rev. 1. The potential hazard to the ESP site from slope failure and creep in the loess bluff was evaluated by examination of geologic cross sections, evaluation of embedment depths and positioning of ESP building foundations, and qualitative assessment of the bluff slope stability in relation to relative strengths of subsurface materials. No numerical slope stability analyses were performed, and are deferred to the COL phase when a final reactor design and layout are selected.

A simplified cross section, RAI Figure 2.5.5-1-1 (attached), was developed for this RAI at a true 1:1 scale (vertical to horizontal) to show the geometric relationships between the loess bluff and ESP site that were used for the stability assessment. As apparent in this schematic section, the PPBA is setback over 100 feet from the closest approach of the bluff and top of the postulated slump. The maximum foundation influence zone envelope (discussed in response to RAI 2.5.4-11), extends to just within the headscarp of the slump area (SSAR Figure 2.5-69, Draft Rev. 1). However, the likely depth range of ESP reactor foundations required to satisfy minimum embedment and shear wave velocity criteria place the foundation level about 10 to 80 feet below the elevation of the toe of the bluff slope (the Mississippi River floodplain).

It is unlikely that a failure plane could develop that extends from the toe of the bluff, or head scarp of the postulated slump, back to the PPBA. Such a failure plane would have a very gentle inclination of about 8 degrees (<8:1, horizontal to vertical) to reach the proposed plant grade along the closest approach of the PPBA (RAI Figure 2.5.5.1-1). Such an intercept location also would not affect the stability or lateral confinement of the power plant foundation that will be embedded well below the plant yard. In order to significantly affect the lateral confinement of ESP building foundations, a failure plane would need to intercept the perimeter of the PPBA at least 5 to 10 feet below the plant grade, requiring a failure plane that would be even flatter than 8 degrees. Such low angle failure planes are believed to be very unlikely based on the estimated in situ effective friction angle of 33 to 34 degrees measured by triaxial UC testing of loess samples during the ESP study (SSAR Section 2.5.4.1.6.1). Based on examination of the cross section shown in RAI Figure 2.5.5-1-1, no kinematically feasible bluff failures could extend back to, or negatively impact, the stability and lateral confinement of ESP power plant foundations within the PPBA.

Based on our qualitative stability assessment, the hazard to the ESP site from possible future movements in the loess bluff is very low to nil, and does not require additional analysis for this ESP stage. An exclusionary zone between the top of the bluff and ESP PPBA therefore is not necessary.

The design of the cut slope between the ESP PPBA and top of the loess bluff would be developed during the COL phase based on additional exploratory borings in the cut area and specific slope stability analysis.

SSAR Revisions:

See file: 017_SSAR_Fig_2.5-69draft_rev1_11-19-2004.pdf
019_SSAR_Fig_2.5-76draft_rev1_11-19-2004.pdf
041_RAI_Fig_2.5.5-1-1.pdf

ADDITIONAL INFORMATION:

During review of the SSAR, we noted an error in Table 2.5-20 and Figure 2.5-59. This table and figure will be revised.

See file: 046_SSAR_Table_2.5-20draft_rev1_11-19-2004.pdf
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2.5 Geology, Seismology, and Geotechnical Engineering

This section of the SAR presents information on the geological, seismological, and geophysical characteristics of the Site Region (200-mile radius), Site Vicinity (25-mile radius), Site Area (5-mile radius), and Site Location (0.6-mile radius) (Figure 2.5-1). This information was used to evaluate geologic and seismic hazards at the location of the proposed new unit at the Grand Gulf Nuclear Station and to develop the Safe Shutdown Earthquake (SSE) and Operating Basis Earthquake (OBE) ground motions. These analyses were performed in accordance with the applicable federal regulations and regulatory guidelines described in Section 1.3 of this report, and which are summarized below.

- Federal regulation 10CFR52 - "Early Site Permits, Standard Design Certifications, and Combined Licenses for Nuclear Power Plants" requires that the ESP application contain a description and safety assessment of the site on which the facility is to be located, including seismic, hydrologic, and geologic characteristics (Reference 1).
- 10CFR52 references Appendix S of 10CFR50 - "Earthquake Engineering Criteria for Nuclear Power Plants", which provides requirements for development of the Safe Shutdown Earthquake ground motions (Reference 2).
- 10CFR100 "Reactor Site Criteria", Part 23 - "Geologic and Seismic Siting Factors", sets forth the principal geologic and seismic considerations required to demonstrate the suitability of a proposed site and adequacy of the design basis in consideration of the geologic and seismic characteristics of the proposed site for the new facility (Reference 3).

The ground motion analysis was performed in compliance with Regulatory Guide (RG) 1.165 – "Identification and Characterization of Seismic Sources and Determination of Safe Shutdown Earthquake Ground Motion" (Reference 4). This guide provides detailed methodology and guidance to satisfy the requirements of 10CFR52, Appendix S of 10CFR50, and 10CFR100 Part 23 for the assessment of ground motions at the site.

Detailed site investigations and laboratory analyses completed to evaluate site conditions in accordance with RG-1.165 were performed following the methodology provided in:

- Regulatory Guide 1.132 (and proposed revision Draft Regulatory Guide, DG-1101), Site Investigations for Foundations of Nuclear Power Plants (Reference 5, 212); and,
- Regulatory Guide 1.138 (and proposed revision Draft Regulatory Guide, DG-1109), Laboratory Investigations of Soils and Rocks for Engineering Analysis and Design of Nuclear Power Plants (Reference 6, 213).

These investigations and analyses were performed to support evaluation of ground motion site response and to provide a preliminary assessment of geotechnical parameters (i.e. modulus reduction) at the site. A detailed geotechnical evaluation of the site as required for full compliance of DG-1101 (RG-1.132) will be performed following selection of the final site design and footprint of the facility.

Ground motion site response was evaluated following the methodology provided in NUREG/CR-6728 (Reference 7).

Regulatory Guide 1.165 recommends that a probabilistic seismic hazard assessment (PSHA) be performed to define the median rock ground motion at the site that has an annual probability of exceedance of not greater than 10^{-5}, and for soil sites, that a site response analysis be

performed to develop the SSE ground motion. RG-1.165 further recommends that the applicant may use either the Lawrence Livermore National Laboratory (LLNL) or Electric Power Research Institute (EPRI) PSHA methodology to develop the median 10^{-5} rock ground motion at the site. Either of these methodologies may be used provided that a thorough review of geological, seismological, and geophysical data and information published since the LLNL 1993 (Reference 10) or EPRI 1986 (Reference 9) studies does not show significant change in either the seismic source model or ground motion model. If changes have occurred then an updated LLNL or EPRI model should be used to perform the PSHA.

For this ESP application, the EPRI methodology (Reference 11) was adopted for developing the 10^{-5} median rock ground motion at the site. Because most of the seismic source characterization for the EPRI study occurred in 1985, data and information published since 1985 was compiled and reviewed to evaluate the current status of scientific knowledge regarding seismic sources in the Grand Gulf Site Region (including the New Madrid Seismic Zone). This review is documented in Engineering Report ER-01 "Seismic Source Characterization for updated EPRI PSHA" (Reference 12), and is presented below in Section 2.5.1. An updated seismicity analysis was performed as described in Calculation Package CP-01 "Seismicity Analysis for the Grand Gulf ESP Site" (Reference 206).

Review of data published since 1985 show that the EPRI seismic source model should be updated to include an improved understanding of the New Madrid source zone and a recently identified potential seismic source, the Saline River source zone, within the Site Region. These sources are described in Section 2.5.1 and the updated EPRI PSHA is summarized in Section 2.5.2.

In parallel with this review of the seismic source model, EPRI (Reference 13) performed a review of the 1986 EPRI SOG ground motion attenuation model. This review showed a significant change in the ground motion model for the central and eastern United States, including the Gulf Coast region. This updated model was used for the PSHA for the Grand Gulf site (Reference 14). Based on the PSHA, a site response analysis was performed to develop the SSE ground motion at the site and in Calculation Package CP-02 "Development of Safe Shutdown Earthquake (SSE) Ground Motions for the Grand Gulf ESP Site" (Reference 207) as described in section 2.5.2.

As recommended by RG-1.165, a site geotechnical investigation was performed to develop information on soil properties to support the ground motion Site Response analysis. These geotechnical investigations were performed following the methodologies provided in RG-1.132 and 1.138, although a full geotechnical evaluation of the site in compliance with these guides will be deferred until selection of the final plant design and footprint of the facility during the Construction and Operating License (COL) phase of the project. Results of the site geotechnical investigations are provided in Engineering Report ER-02 "Geologic, Geotechnical, and Geophysical Field Exploration and Laboratory Testing, Grand Gulf ESP" (Reference 15), and are presented in Sections 2.5.1.2.5, 2.5.4, and 2.5.5.

Other geological hazards, including surface faulting, stability of subsurface materials, liquefaction, stability of slopes, and safety of embankments and dams are described in Sections 2.5.3 through 2.5.6, respectively. References of literature and data sources used in this assessment are presented in Section 2.5.7.

2.5.1 Basic Data

This section provides basic data and information on the geology, seismology, geophysics and tectonic setting of the Site Region. A detailed description of the existing site and Site Region is provided in the updated Final Safety Evaluation Report (UFSAR) for the Grand Gulf Nuclear Station (Reference 16). This information has been reviewed and approved by the NRC staff, and forms the basis for understanding the site geology.

Information contained in the UFSAR has been updated based on review of data and information published since the 1986 EPRI study (Reference 9) and discussions with current researchers familiar with the regional geology. References reviewed are listed in Section 2.7. In addition, new geologic maps showing the distribution of surficial deposits in the Site Vicinity, Site Area, and Site Location have been prepared, and new geologic cross-sections and subsurface contour maps have been prepared incorporating data from the geotechnical exploration program.

The proposed location of the new facility at the Grand Gulf Nuclear Station (Grand Gulf Site) is in west-central Mississippi adjacent to the Mississippi River floodplain (Figure 2.5-1). The Site Region is divided into both physiographic and geologic provinces and subprovinces, which are shown on Figures 2.5-2 and 2.5-3 respectively, and are summarized in Table 2.5-1.

2.5.1.1 Regional Geology

The Gulf Coastal Plain consists of two primary geological provinces, the Gulf Coast Basin and Mississippi Embayment (Figure 2.5-3). These geologic provinces encompass a variety of geologic features including localized uplifts, zones of salt migration, growth faults, pre-Quaternary tectonic faults, and basins. These provinces and geologic features are described in Section 2.5.1.1.2 and 2.5.1.1.5.

The Gulf Coastal Plain has been dominated by marine and fluvial processes along the Gulf of Mexico continental margin for several hundred million years (Reference 17). Thick sedimentary sequences deposited by the Mississippi River within the Gulf Coastal Plain played an important role in the geologic processes of the region since post-Miocene time. The distribution of major geologic features and sedimentary units in the Gulf Coastal Plain and Site Region is shown on Figures 2.5-3 and 2.5-4.

The Gulf Coast Basin contains marine sediments deposited during episodic sea-level transgressions and regressions, and terrestrial sediments deposited on river floodplains and deltas along the continental margin. The sediments are composed of sand, silt, gravel, clay, marl, limestone, salt, and chalk that range in age from Jurassic to Holocene, and form a seaward thickening wedge greater than 50,000-feet-thick near the present Gulf of Mexico coastline. Development of the thick sedimentary wedge resulted in depression of the crust within the Gulf Coast Basin to depths of up to 7 miles (Reference 18).

Global climatic changes and tectonic events played important roles in the geologic history of the Gulf Coastal Plain. Tectonic and climatic events from the eastern coast of North America to as far west as the Rocky Mountains influenced the formation of sedimentary rocks, emplacement of igneous bodies, and deformation of the crust and overlying sedimentary section in the Site Region. The principal tectonic events include: the Taconic, Acadian, and Allegheny orogenies that formed the Appalachian Mountains and the Ouachita Orogenic Belt; continental rifting that formed the Gulf of Mexico; and changes in regional stress that deformed the crust along the Reelfoot Rift and formed the Mississippi Embayment. Secondary processes such as igneous

intrusion, basin settlement, and salt diapirism also played important roles in the geological development of the Site Region.

The Site Region is characterized by extremely low rates of earthquake activity (Figure 2.5-5). Previous seismic hazard investigations, such as the original licensing studies for the Grand Gulf Nuclear Station (Reference 16), the 1986 EPRI study (Reference 9), and the 2002 USGS National Seismic Hazard maps (Reference 19) all indicate that the rate of earthquake activity in the Gulf Coastal Plain is among the lowest in the United States. The geologic setting and modern tectonic framework suggest that the earthquake hazard for the Site Region will remain low for the foreseeable future. A detailed discussion of the seismological setting is presented in Section 2.5.1.1.6.

2.5.1.1.1 Regional Physiography

The Grand Gulf Site is located within the Gulf Coastal Plain physiographic province (Figure 2.5-2). The Site Region also includes the Ouachita Mountains province and a buried continuation of the Southern Appalachian province (Figure 2.5.2). The Gulf Coastal Plain province is divided into subprovinces including the Mississippi Alluvial Valley, Chenier/Delta Plain, Loess Hills, Prairie Coastwise Terrace, Southern Hills, Eastern Hills, and Western Hills.

2.5.1.1.1.1 Loess Hills Subprovince

The Grand Gulf Site straddles the margin of the Loess Hills subprovince and the Mississippi Alluvial Valley subprovince (described below; Figure 2.5-2). The Loess Hills subprovince extends along the eastern bank of the Mississippi River from Kentucky to southwestern Mississippi (Figure 2.5-2). The Loess Hills consists of an eastward thinning loess (silt) deposit that is zero to 100-feet-thick and extends 10- to 30-miles east of the Mississippi River (References 17, 21).

The topography of the Loess Hills is characterized by flat-topped ridgelines and fluvial terraces separated by deeply incised dendritic drainage systems. In the Site Vicinity, the Loess Hills vary in elevation from 100- to 300-feet above mean sea level (amsl). Erosion along the eastern edge of the Mississippi River flood plain has formed a steep escarpment along the western edge of the Loess Hills. At the Grand Gulf Nuclear Station the bluff is approximately 65- to 80-feet high.

The Loess Hills were formed through deposition of successive sheets of silt during late Quaternary time. Up to five distinct periods of loess deposition are documented. Each of these deposits are separated by leached buried soils that represent significant periods of landscape stability (Reference 20; 21). Loess deposits up to 82-feet-thick are present in the Site Vicinity. These deposits are described in Section 2.5.1.2, below.

2.5.1.1.1.2 Mississippi Alluvial Valley Subprovince

The Mississippi Alluvial Valley subprovince extends up to 80 miles west and 200 miles north and south of the proposed new facility at the Grand Gulf Nuclear Station (Figure 2.5-2). In the Site Region, the Mississippi Alluvial Valley subprovince also includes a number of interdistributary lowlands, basins and ridges. Elevations generally range from 50 to 250 feet. Higher elevations occur in tributary valleys with highs of 300 feet in the Ouachita River valley and 500 feet in the upper Red River valley near the Ouachita Mountains. The topographic highs along the Mississippi River are remnants of older alluvial deposits that mostly were eroded and removed from the valley. The valley topography is relatively flat with a gentle southward gradient and is characterized by fluvial geomorphic features typical of a braided stream and meandering river system (e.g. valley train, oxbow lakes, meander belts, and floodplains).

Deposits in the Mississippi Alluvial Valley consist primarily of Pleistocene to Holocene sediments derived from the Mississippi River and its tributaries.

2.5.1.1.1.3 Eastern Hills Subprovince

The Eastern Hills subprovince lies north of the Southern Hills and east of the Loess Hills (Figure 2.5-2). The subprovince covers the area from central Mississippi and central Alabama to western Tennessee, and extends to the eastern margin of the Gulf Coastal Plain. The topography is characterized by gently rolling hills that range in elevation from 100 to 600 feet (amsl) and which gradually decrease in elevation southward. The Eastern Hills are underlain by Miocene to Paleocene sedimentary rocks and drained by tributaries of the Mississippi River.

2.5.1.1.1.4 Western Hills Subprovince

The Western Hills subprovince lies north of the Southern Hills and west of the Mississippi Alluvial Valley (Figure 2.5-2). The subprovince covers the area from central Louisiana to central Arkansas, and extends westward into eastern Texas. The topography is characterized by gently rolling hills that range in elevation from 200 to 700 feet (amsl) and gradually decrease in elevation southward. The Western Hills are underlain by Miocene to Paleocene sedimentary rocks and drained by the Arkansas River and Red River, two major tributaries of the Mississippi River.

2.5.1.1.1.5 Southern Hills Subprovince

The Southern Hills subprovince occupies the area between the Prairie Coastwise Terrace (described below) and the Eastern and Western Hills subprovinces (Figure 2.5-2). The Southern Hills cover portions of southern Mississippi, southern Louisiana, and southeastern Texas. The topography of this subprovince is characterized by gently rolling hills and flat-topped ridges that range in elevation from 50 to 500 feet, and generally decrease toward the Gulf Coast. The Southern Hills are underlain by the Miocene Catahoula Formation, and the Pliocene and Pleistocene Upland Complex.

2.5.1.1.1.6 Prairie Coastwise Terrace Subprovince

The Prairie Coastwise Terrace subprovince occupies the area south of the Southern Hills, and north of the Chenier and Delta Plain subprovinces (described below) along the Gulf Coast (Figure 2.5-2). The subprovince extends across southern Mississippi, southern Louisiana and southeastern Texas. The topography of the Prairie Coastwise Terrace is characterized by gently rolling hills and remnants of dissected terrace surfaces that range in elevation from 25 to 150 feet and gradually decrease in elevation coastward. This subprovince is underlain by terrace deposits of the late Pleistocene Prairie Complex.

2.5.1.1.1.7 Chenier Plain Subprovince

The Chenier Plain subprovince occupies the area between the Prairie Coastwise Terrace and the Gulf of Mexico (Figure 2.5-2). The subprovince extends along the Louisiana and eastern Texas coastline. "Cheniers" are abandoned beaches of the Gulf of Mexico, with large expanses of Holocene marshes that developed on prograding mudflats (Reference 17). A typical chenier ridge is less than 10-feet high, but may extend for miles or tens of miles. The topography of the Chenier Plain is characterized by low lying coastal ridges and marshes. The most prominent features are abandoned beach ridges at elevations of between sea level and 25-feet amsl. Subtle variations in elevations, on the order of inches, have a pronounced effect on vegetation and habitat in the Chenier Plain (Reference 17). The only preserved pre-Holocene features are

remnants of the Prairie Coastwise Terrace and emergent landforms developed above salt dome piercement structures (Reference 17).

2.5.1.1.1.8 Delta Plain Subprovince

The Delta Plain subprovince occurs in southeastern Louisiana where the Mississippi River meets the Gulf of Mexico (Figure 2.5-2). The topography of the Delta Plain is characterized by abandoned distributary channels, distributary levee ridges, and coalescing delta complexes near the mouth of the Mississippi River. The distributary levee ridges form the most prominent topographic features, but do not exceed 10 feet elevation. Distributary channels radiate in a fan shape and form apices of delta complexes (Reference 17). The morphologic expression of the channel and distributary features become markedly less pronounced with increasing age, and eventually become buried due to coastal subsidence

2.5.1.1.2 Regional Geological Provinces

The Gulf Coastal Plain province is divided into two primary geological provinces, the Gulf Coast Basin and the Mississippi Embayment (Figure 2.5-3). Both the Gulf Coast Basin and Mississippi Embayment have distinct geological histories.

2.5.1.1.2.1 Mississippi Embayment

The Mississippi Embayment extends from the buried Ouachita Orogenic belt to the northern margin of the Gulf Coastal Plain and lies between the Appalachian Mountains in west-central Alabama and the Ouachita Mountains in southern Arkansas (Figure 2.5-3). The Mississippi Embayment formed in response to crustal downwarping associated with extension of the Reelfoot Rift (described in Section 2.5.1.1.5.4) within the North American craton during the Late Cretaceous. The Mississippi Embayment is underlain by Paleozoic strata, and igneous and metamorphic basement rocks. The structure of the embayment is characterized by a south-southwest plunging syncline that continues southward across the Gulf Coast Basin (Figure 2.5-3). The top of the Paleozoic section in the Mississippi Embayment defines a slightly asymmetric syncline: the western limb dips 0.59 degrees and the eastern limb dips 0.34 degrees. The southern portion of the Mississippi Embayment and the seismically active Reelfoot Rift lie within the northern part of the Site Region.

2.5.1.1.2.2 Gulf Coast Basin

The Gulf Coast Basin extends from the Gulf of Mexico to the buried Ouachita Orogenic Belt (Figure 2.5-3; described in Section 2.5.1.1.4.2). The Gulf Coast Basin formed during initial rifting of the Gulf of Mexico in the Triassic. As a result of continental rifting and formation of new oceanic crust, the properties of basement materials within the Gulf Coast Basin are transitional between continental and oceanic materials. In the northern part of the basin, the basement is defined as thick transitional crust reflecting continental affinity. In areas closer to the Gulf of Mexico oceanic plate the crust is defined as thin transitional crust reflecting oceanic affinity (Reference 18). The basin has been affected by a long series of tectonic, volcanic, depositional, isostatic and climatic processes, which are described in greater detail below.

The southward plunging syncline that characterizes the Mississippi Embayment projects across the Gulf Coast Basin and forms a structural downwarp that affects the depth to basement and thickness of the overlying sedimentary column. The limbs of the syncline in the Gulf Coast Basin typically dip less than 1-degree towards the synclinal axis (Figure 2.5-6).

2.5.1.1.3 Regional Geologic History

Crystalline basement of the North American craton in the central United States is wholly Precambrian in age, with the possible exception of basement rocks underlying the Gulf Coast Basin (Reference 18, 22, 23). The central United States basement complex is divided into eight major cratonic elements (Figure 2.5-7). These are the products of major Precambrian orogenic events, ranging in age from Archean (3.8 billion years) to middle Proterozoic (750 million years [Ma]; Reference 22). The North American craton is inferred to have progressively enlarged to the south and east due to lateral accretion during successively younger Precambrian orogenies (Reference 23).

Primary tectonic elements within the south-central part of the North American craton include the Reelfoot Rift complex, Paleozoic Ouachita Orogenic belt, and Appalachian Mountains (Figure 2.5-3). The Reelfoot Rift, and possibly other rift systems within the North American craton, were reactivated and experienced additional extension and intrusion during early Mesozoic time (Reference 24; 25). The similarity in ages of rift systems within the craton suggests that they initially formed as failed arms of triple junctions during an episode of late Precambrian continental fragmentation that predated the Paleozoic Ouachita and Appalachian orogenies (Reference 26). The sequence of major geological events is summarized on Figure 2.5-8.

Cratonic rocks of south-central North America extend to the southern margin of the Ouachita Orogenic Belt (Figure 2.5-7). The exact nature of the basement materials beneath the Paleozoic sediments south of the Ouachita Orogenic Belt is equivocal. However, the basement materials likely are related to formation of oceanic crust during rifting and evolution of the Gulf of Mexico (Reference 27). The Gulf of Mexico began forming in Triassic time by tensional rifting of the supercontinent Pangea and the divergent motion of the North American and Afro-South American plates (Reference 28).

As separation of Pangea continued through mid-Jurassic time, the Gulf Coastal Plain began to develop north of the Gulf of Mexico by the slow deposition of sediment on top of the Paleozoic sedimentary rocks. During the Triassic, sediments accumulated in grabens formed during rifting and block faulting, and by the mid-Jurassic, the region became a restricted seaway with evaporitic condition that accumulated more than 9,900 feet of salt deposits (Reference 28). By the late Jurassic, conditions changed to an open marine environment and resulted in the first major marine transgression into the Gulf Coast Basin and Mississippi Embayment (Reference 29). During the Cretaceous, a series of transgressive and regressive episodes, and coincident crustal subsidence caused widespread deposition of carbonates over the Jurassic sediments and salt deposits throughout the Gulf Coast basin (Reference 30).

In the Mississippi Embayment, crustal subsidence continued into the Early Cretaceous allowing marine deposition to extend further north and west towards the Ouachita Mountains (Reference 17; 32). During the mid-Cretaceous, the area was uplifted and partially eroded, although minor deposition locally occurred. During the Late Cretaceous, marine sediments lapped onto Early Cretaceous and older coastal plain sediments in response to the advance of the Gulfian Sea (Reference 17). The weight of these sediments accelerated subsidence of the Mississippi Embayment in the early part of the Upper Cretaceous. Minor transgressions and regressions of the Cretaceous Gulfian Sea caused deposition of alternating shallow and moderately deep water lithologies that are separated by unconformities. Near the end of the Cretaceous, volcanic activity and igneous intrusion formed the Sabine and Monroe Uplifts, and the Jackson Dome (Figures 2.5-3 and 2.5-4; Reference 34). These features continued to uplift into the Oligocene (Reference 34). Formation of these volcanogenic structural highs, oriented across the axis of

the Mississippi Embayment, isolated the northern part of the embayment from the Gulf Coast Basin to the south (Reference 17).

During the latest Cretaceous and early Tertiary, the Laramide orogeny in western North America supplied voluminous quantities of terrigenous siliciclastic sediment to the Mississippi Embayment and Gulf Coastal Basin (Reference 35). Paleocene marine sediments of the Midway group were deposited unconformably on top of the Cretaceous sediments in the northernmost Mississippi Embayment (Reference 36). Subsidence of the Mississippi Embayment ceased in the Eocene due to a tectonic change from crustal extension to crustal shortening with development of folds and faults along the Reelfoot Rift. In Oligocene time, the locus of deposition shifted southward in response to progradation of sediments within the Mississippi Embayment. In the southern part of the basin, where the Cretaceous deposits are thickest, the weight of overlying sediments initiated the intermittent upward diapiric movement of salt plugs and folds, which eventually formed salt domes during the Tertiary (References 30; 37). Localized tensional faults are associated with the salt domes. Growth of salt domes in the Mississippi and Northern Louisiana salt basins ceased in the Oligocene (Reference 30). South of the Mississippi Embayment, in the Gulf Coast Basin, minor sea level fluctuations resulted in partial erosion of sediments.

During the Cenozoic, the rate of deposition into the Gulf Coast Basin exceeded the rate of regional subsidence, resulting in gulfward progradation of the Gulf Coastal Plain by as much as 250 miles. The rates of sedimentation, basin subsidence, and eustatic changes were not synchronous, so that transgressive and regressive cyclic deposits characterize the late Tertiary stratigraphic section. The basin depocenter, located along successive shelf edges, migrated across the Gulf Coast Basin throughout Tertiary time reflecting changing sediment sources and volumes (Reference 17; 29; 38).

Sea level retreat in the late Tertiary (Reference 39) allowed deposition of the littoral and non-marine Catahoula Formation (Miocene) and the alluvial Citronelle Formation (Pliocene) on the exposed Gulf Coastal Plain (Reference 17). The Catahoula Formation, which underlies the Site Vicinity, was deeply eroded in the Late Miocene and Pliocene (Reference 16).

During the Pleistocene, massive volumes of sediment were transported to the Gulf Coast Basin by the Mississippi River, partly in response to advances and retreats of continental glaciers (References 17; 31; 32; 40). The thickest accumulations of Pleistocene deposits occur along the present Louisiana shelf edge (Reference 41). The entire sedimentary wedge in the vicinity of the Louisiana shelf edge is on the order of 50,000-feet thick (Reference 17). Late Wisconsin sea level rise submerged the late Pleistocene continental shelf and reached its present position approximately 3,000 to 4,000 years ago, defining the current configuration of the Gulf Coast margin (Reference 17). Throughout the Quaternary, alluvial material was deposited in the Mississippi Alluvial Valley and extensive blankets of loess mantled the former ground surface (Reference 32; 21).

The prograding clastic wedge of the Mississippi delta has been affected by gravity-failure structures, such as the syndepositional growth faults observed in southern Louisiana and eastern Texas (Figures 2.5-3 and 2.5-5). The growth faults typically are oriented parallel or subparallel to the depositional strike (east-west orientation), and are characterized by (1) down-to-the-south displacement; (2) notable thickening of displaced strata on the downthrown side; (3) an increase in stratigraphic throw with depth; and (4) lack of significant seismic activity. Post-depositional gravity failures, or growth faults, also are common intra-basin structures. No

surficial growth faults have been mapped at the surface closer than about 90 miles from the Grand Gulf site.

The Site Region is characterized by very low rates of historical seismicity (Figure 2.5-5). Only two earthquakes of m_b 3.3 to 3.9 have been recorded within 100 miles of the site since 1627 and only 39 earthquakes >m_b 3.3 have been recorded in the entire 200 mile radius of the site since 1627. Most earthquakes in the Site Region occur in areas underlain by crystalline basement rock of the North American Craton.

2.5.1.1.4 Regional Stratigraphy

Regional stratigraphic units within the Gulf Coastal Basin are described from youngest to oldest in the following sections. Geologic maps of the Site Region (200 miles), Site Vicinity (25 miles), and Site Area (5 miles) are shown on Figures 2.5-4, 2.5-9 and 2.5-10, respectively. Cross-sections through the Site Region and Site Vicinity are shown on Figures 2.5-6, 2.5-11, and 2.5-12. The major stratigraphic units are summarized on Figure 2.5-13. A detailed description of the Site Location stratigraphy is presented in Section 2.5.1.2.

2.5.1.1.4.1 Cenozoic Era

2.5.1.1.4.2 Quaternary System

Quaternary deposits within the Site Region occur along the Mississippi Alluvial Valley and its tributaries, the Southern Hills subprovince of the Gulf Coastal Plain, and the Loess Hills subprovince (Figure 2.5-4). Quaternary deposits predominantly include alluvial sediments related to the Mississippi River, lacustrine sediments, and eolian silt derived from sediment sources in the Mississippi Alluvial Valley (Reference 17; 32). The composition, texture and morphology of Quaternary sediments in the Site Region are strongly influenced by climatic changes and glacial cycles. The response of regional marine, alluvial, and terrestrial systems to these changes is summarized in Table 2.5-2.

In the Pleistocene, episodes of continental glaciation produced massive volumes of sediment that were transported through the Mississippi Alluvial Valley to the Gulf of Mexico (References 17; 31; 32). These sediments were deposited at various elevations due to climatic changes, local depositional environments (e.g. lakes formed behind glacial outwash deposits) and the isostatic effects of continental glaciations, sea level fluctuations, and regional epirogenic uplift. The major Holocene and Pleistocene units are described below.

2.5.1.1.4.2.1 Holocene Series

Within the Site Region, Holocene deposits include alluvium and loess that occur within the Mississippi River valley and its tributary valleys, and deltaic and beach facies within the Chenier Plain and Delta Plain (Reference 17). Holocene sediments within the Site Vicinity and Site Area include alluvium (Hal), backswamp (Hb), and a series of Mississippi meander belt (Hmm_1 to Hmm_3) deposits (Figures 2.5-9 and 2.5-10).

Holocene alluvial and deltaic deposits thicken from a few tens of feet in the northern portion of the Site Region to greater than 600 feet in the southern portion of the Site Region (Reference 16). In the Site Vicinity, the thickness of Holocene deposits in the Mississippi Alluvial Valley is on the order of 0 to 400 feet thick (Reference 17). Holocene sediments in the two main tributary valleys within the Site Vicinity, Bayou Pierre and Big Black River (Figure 2.5-9), range in thickness from 70 to 100 feet (Reference 16).

The composition of Holocene alluvial deposits varies depending on the specific type of depositional environment. The meander belt deposits commonly form an upward fining sequence that grades from a basal gravel and coarse sand into a sand facies capped by silt and clay facies (Reference 17). Backswamp deposits consist of overbank sediments (silt and fine sand) along with a large component of organic material. Lacustrine deposits are also fine grained with significant organic materials. The Chenier Plain consists of Mississippi deltaic sediments that were deposited episodically in beach environments by longshore transport (Reference 17). The thickness and areal distribution of Holocene alluvial deposits are variable and occur as interfingering lenses of sand, silt, and clay.

2.5.1.1.4.2.2 Pleistocene Series

2.5.1.1.4.2.2.1 Loess Deposits

Regionally extensive sheets of Pleistocene loess occur along the eastern edge of the Mississippi Alluvial Valley and the surrounding areas (Figure 2.5-2). The deposits also occur within the Site Vicinity and Site Area (Figures 2.5-9 and 2.5-10). Erosion along the eastern side of the Mississippi flood plain forms a prominent erosional escarpment in the loess.

Loess deposits mantle the former landscape and consist predominantly of silt with minor sand and clay fractions (Reference 44). The loess has internal stratigraphy with distinct silty layers separated by buried soils. In the Site Region, loess deposits occur in a belt up to 30 miles wide on the east side of the Mississippi River (Figure 2.5-2). These deposits unconformably overlie Pleistocene to Pliocene alluvial deposits, and Tertiary deposits in the Site Vicinity and Site Area (Figures 2.5-8 and 2.5-9).

During near-maximum to early-waning stages of glaciation, strong seasonally prevailing, north-to-northwest winds carried large quantities of silt from unvegetated areas of glacial outwash in the central United States for tens to hundreds of miles throughout the Site Region (Table 2.5-2; Reference 17). In the Vicksburg area, depositional rates for the Peoria loess (late Wisconsin age) exceeded 2 mm/yr between about 15,500 and 17,000 years ago (Reference 42). Individual loess sheets are well-sorted, massive to subtly banded, unconsolidated, tan to brown silt. The maximum thickness (75 feet) and most prominent outcrops of the loess occur east of the Mississippi Alluvial Valley in a 10 to 30 -mile-wide zone across the Site Region (Reference 17). Loess deposits thin considerably eastward and form only localized deposits outside of the Loess Hills subprovince. Four discrete loess deposits are identified in the region, including from youngest to oldest, the Peoria, Ferndale, Roxana, and Loveland loess sheets (Reference 21, 32; 43). In the Site Vicinity, only the Peoria, Roxanne and Loveland loess sheets are present.

2.5.1.1.4.2.2.2 Terrace Deposits

Pleistocene terrace deposits occur along most of the Mississippi Alluvial Valley and extend across the Site Region (Reference 17). The terraces are assigned different names in different parts of the Site Region (Figure 2.5-13). Terrace deposits that occur in eastern Texas and southwestern Louisiana include the Beaumont and Lissie terraces. Terrace deposits in southern Louisiana include the Prairie, Montgomery, Bentley, and Williana terraces. Terrace deposits in southern Arkansas, Northern Louisiana, and west-central Mississippi include valley trains, Deweyville Complex, Prairie Complex, and Intermediate Complex. In the Site Vicinity, these include undifferentiated terraces in Bayou Pierre (probable Prairie Complex) and the Pliocene to Pleistocene Upland Complex.

Investigations of the Quaternary geology of the Mississippi Alluvial Valley (Reference 17; 32; 44) resulted in major updates and refinements of the seminal work of Fisk (Reference 31).

Figure 2.5-14 and Table 2.5-3 present comparisons of the proposed terrace relationships (References 31; 32). The model of Fisk (Reference 31) was revised because the sequence of continental glaciations leading to terrace formation along the Mississippi River is far more complex than thought in 1944, and the processes leading to terrace formation are better understood. Fisk's postulated model (Reference 31) involves progressive narrowing and downcutting of the Mississippi Alluvial Valley (Figure 2.5-14). However, during the Pleistocene the Mississippi Alluvial Valley progressively widened during downcutting, rather than narrowing (Reference 32). This observation indicates that the Pleistocene terraces of Fisk are now interpreted to be Pliocene to early Pleistocene age (i.e. Upland Complex). Saucier also observed that Quaternary erosional surfaces, or "strath" terraces are present in the Site Region and likely formed in response to base-level changes (Reference 17).

Early to Late Wisconsin valley train terraces occur in the northern portion of the Site Region, but not within the Site Vicinity. Five distinct levels of Early Wisconsin terraces and two distinct levels of Late Wisconsin terraces are mapped (Reference 44). The deposits consist of thin, 5- to 10-feet thick, very silty and sandy clays, silts, and silty sands that overlie much thicker coarse grained sediments (Reference 17). The fine-grained surface and near surface deposits are slightly organic, horizontally bedded, slack-water accumulations of clays, silts, sands, loess, and local lacustrine deposits. These sediments directly overlie massive, clean sands that may be 75 to 100 feet in thickness and are indicative of high energy fluvial channel deposition. The clean sands locally overlie coarse sand and gravel, forming an upward-fining sequence.

Terrace deposits of the Deweyville Complex occur in the northwestern portion of the Site Region (Figure 2.5-4) along the Ouachita and Saline Rivers, but are not present in the Site Vicinity. The Deweyville Complex is similar in age to the Wisconsin valley train deposits, and is characterized by unique meander scars that are considerably larger than observed along the present river courses (Reference 45). There is little direct information regarding this complex (Reference 17). Based on analogy with other terrace complexes, the Deweyville Complex most likely includes multiple fluvial environments, such as point bar, backswamp, and abandoned channel. The deposits consist of a fining upward sequence approximately 100-feet thick. The coarser grained deposits of the Deweyville Complex, relative to other terrace complexes, may reflect higher stream discharges and energy levels than along the current fluvial system (Reference 32).

Terrace deposits of the Prairie Complex occur within the Site Region along the Gulf Coast from Texas to Alabama (included in unit Qp on Figure 2.5-4). The Prairie Complex includes a wide range of sediments including fluvial terrace deposits, colluvium, estuarine, deltaic and marine deposits. The Prairie Complex deposits range in age from pre-Wisconsin to late-Wisconsin. Undifferentiated terrace deposits in the Site Vicinity occur along tributary stream valleys (shown as Ptu on Figures 2.5-9 and Pt1 to Pt3 on 2.5-10), including Big Black River and Bayou Pierre, and may be related to the Prairie Complex (Reference 44). In the Site Area, terrace deposits equivalent to the Prairie Complex occur between elevations of 140 +/- 10 feet and 180 +/- 20 feet.

Terrace deposits of the Intermediate Complex occur in the western and southern portions of the Site Region, but are not mapped in the Site Vicinity. The deposits occur in tributary valleys west of the Mississippi River and in a 10- to 20-mile-wide, coast-parallel belt that extends from Texas to Alabama. Very little information is available regarding the Intermediate Complex, but the available data suggest that much of the complex consists of sediments deposited as a broad alluvial apron by small streams draining the adjacent higher terraces and uplands (Reference

17). The Intermediate Complex represents a transitional unit between the younger Prairie Complex and the Pliocene-Pleistocene Upland Complex described below.

Deposits of the Upland Complex occur extensively along the Mississippi Alluvial Valley and Gulf Coast margin in the Site Region, Site Vicinity, Site Area, and Site Location (Figures 2.5-9, 2.5-10, and 2.5-27). The deposits range in age from Pliocene to Pleistocene (approximately 1 to 4 million years) reflecting uncertainty in the time of deposition; we describe the Upland Complex in greater detail in the Pliocene-Pleistocene discussion, below. In general, the Upland Complex includes the Lafayette and Citronelle gravels and consists of sandy gravels, clayey sandy gravels, silty sands, and clayey gravelly sands (Reference 46). The deposits may be more than 100 feet thick and individual beds typically are lenticular and laterally discontinuous. Beds of clay and silt are rare.

Pleistocene terraces extend continuously along the length of the Mississippi Valley (Reference 44). The continuity and absence of vertical deformation of the terraces serves to demonstrate the tectonic stability of the Gulf Coastal Plain through the Pliocene and Pleistocene.

2.5.1.1.4.2.3 Tertiary System

Tertiary deposits are more than 6,000-feet thick in the Site Vicinity (Figure 2.5-9). These deposits thicken from north to south across the region with a maximum thickness greater than 50,000 feet in the Gulf of Mexico. The Tertiary deposits consist of terrigenous sediment eroded from the interior of North America and marine sediment deposited during marine transgressions and regressions. These deposits are divided into a number of formations in the Site Region and Site Vicinity and are described below (Figure 2.5-13).

2.5.1.1.4.2.3.1 Pliocene-Pleistocene Series

Pliocene deposits occur in the southern part of the Site Region, but are not present in the Site Vicinity (Figure 2.5-4). South of the Site Vicinity, the Pliocene section consists of interbedded marginal marine sediments that reach a maximum thickness of about 6,000 feet offshore. These deposits are overlain unconformably by the Upland Complex deposits (Figure 2.5-13).

The Pliocene-Pleistocene Upland Complex, also referred to as the Citronelle and Lafayette formations, is one of the most regionally extensive deposits in the Gulf Coastal Plain (Reference 32). Remnants of Upland Complex are identified in a 10- to 50-mile wide band east of the Mississippi River and extend from the head of the Mississippi Embayment to the Gulf of Mexico (Reference 17). This formation covers the majority of southern Mississippi, south of Jackson, and also crops out west of the Mississippi Alluvial Valley in south-central and southwestern Louisiana (Reference 17). The Upland Complex represents a widespread sand and gravel sheet deposited prior to regional stream entrenchment (Reference 44). Other Pliocene units in the Site Region include the Willis formation in southeastern Texas, and Graham Ferry in southeastern Mississippi, eastern Alabama, and offshore (Figure 2.5-13)

Deposits of the Upland Complex generally consist of a basal gravel and coarse sand facies, overlain by a finer sand facies that grades into an upper silt-and-clay facies. Gravels are predominantly chert and quartz and are reddish in color, while the silt-and-clay facies vary in color from reddish to light gray and tan (Reference 47). Silicified wood is common near the base of higher terraces. Individual terraces range in thickness from tens to hundreds of feet and commonly are buried by loess. The basal contact of the terrace deposits, as identified in test wells, ranges from 85 feet to over 300 feet below ground surface (Reference 47).

The Upland Complex is considered to be a combination of glacial outwash and non-glacial fluvial deposits of both central United States and Appalachian Mountains provenance (References 17; 48). However, the age and origin of the deposits are controversial. Fluvial gravels were inferred to have been deposited in the Mississippi Valley during the Pliocene to Early Pleistocene (Reference 49). The source of the Upland Complex terrace material was attributed to glacial outwash along the Mississippi River (Reference 31), and to erosion of the eastern Appalachian Mountains (References 46; 48). The deposits most likely formed from a combination of both sources (Reference 17).

A prolonged period of low sea level in the early Pleistocene led to entrenchment of upland areas, and erosion and partial redistribution of Pliocene glacial outwash and alluvial fan deposits (Reference 17). Inset terraces formed due to reworking of Upland Complex deposits and grading of streams to sequentially lower base levels during the Early Pleistocene. These reworked terrace deposits occur at progressively lower elevations and are generally finer grained than the source materials. These Early Pleistocene terraces commonly are described as being a part of the Upland Complex. At some localities, the deposits clearly originated from glacial outwash processes (Reference 17). Thus, the younger terrace deposits may represent a combination of alluvial fan and glacial outwash deposits that merged or interfingered at the mouth of tributary valleys.

Deposits of the Upland Complex are present in the Site Location, and are described in greater detail in Section 2.5.1.2, Site Geology

2.5.1.1.4.2.3.2 Miocene Series

Miocene Series deposits (Tm) occur in the Site Region and Site Vicinity (Figures 2.5-4 and 2.5-9. Miocene Series formations include the Catahoula, Pascagoula, Hattiesburg, Amphist shale, and Flemming formations (Figure 2.5-12). The locus of deposition for the Catahoula formation shifted through time as a result of eustatic sea level fluctuations. In the eastern and southern part of the Site Region, the Catahoula Formation was deposited in the upper Oligocene and lower Miocene. In the Site Vicinity, the Catahoula formations is of Miocene age.

Miocene deposits occur beneath the Grand Gulf Nuclear Station at depths of between approximately 140 and 260 feet (Figure 2.5-11). The Miocene deposits reflect a regressional sequence of nonmarine clays, sandy clays, and sands that grade upward to deltaic and occasional lignitic non-marine sand and clay (Reference 16). The Miocene deposits consist of hard, gray, green or blue, freshwater to brackish-water clay and sandy clay interbedded with irregular fine sand, cemented sandstone, and lenses of black chert gravel (Reference 17). The thickness of Miocene deposits ranges from 750 feet to more than 44,000 feet from north to south across the Gulf Coastal Plain and offshore northern Gulf of Mexico (References 17; 16; 50; 51).

In the Site Vicinity, the Miocene Series has an unconformable lower contact with Oligocene and Upper Eocene marine deposits and an unconformable upper contact with the Pliocene-Pleistocene Upland Complex (Reference 16). The unconformable lower contact projects to the surface in the northern portion of the Site Vicinity near Vicksburg, and the unconformable upper contact with the Upland Complex occurs in the southeastern portion of the Site Vicinity (Figure 2.5-9). In the Site Vicinity, the Miocene deposits are covered by loess, Upland Complex deposits, alluvium, and colluvium (Figure 2.5-9).

The Miocene Series deposits dip gently southward across the Site Region. There are no surficial faults or structures that deform these deposits in the Site Vicinity (References 52; 53).

The Miocene Catahoula Formation is one of the most prominent and widespread deposits in the Site Vicinity (Figure 2.5-9). The formation underlies the Site Area and is identified as the load-bearing stratum for the existing Grand Gulf Nuclear Station. These deposits are described in greater detail in Section 2.5.1.2, Site Geology.

2.5.1.1.4.2.3.3 Oligocene Series

The Oligocene Series is exposed in the Site Vicinity and consists of the Vicksburg Group, including the Bucatunna, Byram, Mint Springs, Forest Hill, Red Bluff formations, and the Glendon, Bump Nose, and Marianna limestone formations (Figures 2.5-9 and 2.5-13). Other Oligocene formations in the Site Region include the Paynes Hammock, Chickasawhay, Hackberry, Frio, Anahuac, and Catahoula formations (Figure 2.5-13). As shown on Figure 2.5-4, Oligocene Series deposits are exposed in the banks of the Mississippi River bluffs for approximately 20 miles in the vicinity of Vicksburg (Reference 17). Additionally, Oligocene deposits crop out in the uplands northwest of Sicily Island and the uplands of southwestern Mississippi (Reference 17). Oligocene Series deposits increase in thickness southward and dip into the subsurface south of Vicksburg.

Deposits of the Vicksburg Group consist of estuarine to marine, limestone and marl with lesser amounts of bentonite, clay, and sand (Reference 52). These deposits unconformably overlie freshwater, interbedded, clayey, lignitic silts and fine cross-bedded sands of the Forest Hill Formation. The Forest Hill Formation is in unconformable contact with the underlying Eocene Jackson Group (described below). Oligocene deposits range in thickness from about 300 feet in the Site Vicinity (Figure 2.5-10) to a maximum thickness of approximately 12,000 feet in the southern portion of the Site Region (Reference 17; 54). The Oligocene Series deposits occur at a depth of about 350 feet beneath the Grand Gulf Site (Figure 2.5-11), and are described in greater detail in Section 2.5.1.2, Site Geology.

A structure contour map of the top of the Glendon Limestone Formation of the Vicksburg Group shows no evidence for faults or structures that deform these deposits in the Site Vicinity (Figure 2.5-15). The structure contours project smoothly through the Site Area documenting the absence of faulting or other forms of tectonic or non-tectonic (i.e. salt piercement structures) deformation in the Site Area. As shown by the structure contour map, salt diapirs have formed domes in the Oligocene deposits approximately 8-miles to the northeast and southwest, respectively. However, the salt diapirs have not pierced the Oligocene horizon at these locations.

2.5.1.1.4.2.3.4 Eocene Series

The Eocene Series is exposed in the Site Region (Figure 2.5-4) and includes the Jackson (Te3), Claiborne (Te2), and the Wilcox (Te1) Groups (Figure 2.5-13). As shown on Figure 2.5-6, these stratigraphic groups occur beneath the Site Area at depths of between approximately 1,000 to 7,000 feet. Deposits of the Eocene Series in the Site Region range in thickness from 2,900 to 6,900 feet (Reference 17; 33). The Eocene Series deposits are composed of carbonaceous and calcareous shales, sandy clays, marls, sands, silts, and beds of lignite (Reference 52).The Eocene Series is interpreted to have an unconformable upper contact with the Oligocene deposits and a transitional or conformable contact with underlying Paleocene deposits (Reference 50). The lower contact with the Paleocene was later reinterpreted to be locally unconformable (Reference 52).

Deposits of the upper Eocene Jackson Group are exposed in a continuous 50- to 75-mile-wide band that extends from the uplands of southeastern Arkansas northeastward into the uplands of

western Tennessee and southwestern Kentucky (Reference 17; Figure 2.5-4). The deposits also are exposed in the bluffs west of the Ouachita River in central Louisiana and in the bluffs east of the Yazoo Basin in western Mississippi. The maximum thickness of the Jackson Group is 540 feet (Reference 17). In the Site Region, the Jackson Group includes the Whitsett, Manning, Wellborn, Cadell, Yazoo Clay and Moodys Branch Formations (Figure 2.5-13). In the Site Vicinity, the Yazoo Clay Formation consists of dark gray to brown, massive fossiliferous clay with irregular zones of fine sand and silty clay. The Yazoo Clay overlies the Moodys Branch Formation, which consists of fossiliferous, sandy and clayey marls with occasional limestone nodules.

Deposits of the Claiborne Group are exposed in the Site Region (Figure 2.5-4). Subdivisions are shown on Figure 2.5-13 and vary by region. The Claiborne Group has a total thickness of up to 1,450 feet (Reference 56). In the Site Vicinity, the formations include thinly interbedded gray to gray-brown clays, silt and silty sands, thick brown clays, massive fine to medium grained sands, and fossiliferous, calcareous, clays, marls, and sands. Faults deform Claiborne Group deposits in the eastern portion of the Site Region, approximately 135 miles east of the site (Figure 2.5-4)

Deposits of the lower Eocene-upper Paleocene Wilcox Group occur beneath the site at depths between approximately 3,500 feet and 7,000 feet (Figure 2.5-6), but are not exposed at the surface within the Site Region (Figure 2.5-4). Subdivisions of the Wilcox Group are shown on Figure 2.5-13. In the Site Region, the Wilcox Group ranges in thickness from 100 to 3,500 feet and consists of fine- to medium-grained sands and sandy clays interbedded with massive coarse grained and gravelly sands (References 17, 56). The Wilcox Group has unconformable contacts with both the overlying Claiborne Group and the underlying Paleocene Midway Group.

2.5.1.1.4.2.3.5 Paleocene Series

The Paleocene Series (Tx, Figure 2.5-4) includes the Porters Creek Clay, Clayton, Wills Point, Kincaid, and Naheola formations of the Midway Group (Figure 2.5-13). These deposits are exposed in the eastern and northern portions of the Site Region (Figure 2.5-4), but are not exposed within the Site Vicinity (References 17; 44). The Porters Creek Clay Formation consists of massive, dark gray to black fissile shales, clay shales, and clays with sandy clay beds. The underlying Clayton Formation consists of gray, calcareous, glauconitic, fossiliferous, shales with lenses of white limestone. Deposits of the Midway Group occur beneath the Grand Gulf site at depths of 5,000 to 6,000 feet (Reference 16), and unconformably overlie Upper Cretaceous rocks (Figure 2.5-12). The maximum thickness of Paleocene deposits in the Site Region ranges from 730 to 1,200 feet (References 17, 33, 56).

2.5.1.1.4.3 Mesozoic Era

Mesozoic deposits in the Site Region consist of buried Triassic and Jurassic rocks, and locally exposed Cretaceous marine and terrestrial sediments that accumulated in response to active rifting and marine transgressions and regressions (Figures 2.5-4, 2.5-8). Non-marine, Triassic and Jurassic deposits in the Site Region were originally termed the Eagle Mills Formation or "Red Beds" (References 57, 58). Later, the "Red Bed" sequence was further subdivided into the Late Triassic Eagle Mills Formation and the Middle Jurassic Werner, Luann, and Norphlet Formations (Figure 2.5-13). Accumulation of sediment accelerated crustal subsidence and formation of the Mississippi Embayment in the northern Gulf Coast Plain. Each of the major stratigraphic systems of the Mesozoic Era is described below.

2.5.1.1.4.3.1 Cretaceous System

Deposits of the Cretaceous System are exposed in the eastern and northern portions of the Site Region (Figure 2.5-4). The subdivisions of the Cretaceous System are shown on Figure 2.5-13. In the Site Vicinity, deposits of the Cretaceous System occur at depths of between 3,000 and 10,000 feet (Figure 2.5-12). The Cretaceous System is also referred to as the Gulfian Series, which is subdivided into the Arkadelphia Marl and Nacatoch Sand formations (Figure 2.5-13; Reference 17). Previous mapping of Cretaceous System deposits includes a greater number of subdivisions including the Tuscaloosa Formation, Eutaw Formation, and Selma Group (Reference 52). Current stratigraphic nomenclature is summarized on Figure 2.5-13 (Reference 56).

Deposits of the Cretaceous Selma Group (Arkadelphia Marl Formation of Reference 17), include chalk and calcareous clay, glauconitic sand and sandy limestone and marl (Reference 52). Deposits of the underlying Eutaw Formation consist of massive, cross bedded, glaucanitic, fine sand, and deposits of the Tuscaloosa Formation consist of irregularly bedded sand, clay and gravel (Reference 52). Each of the above formations is separated by erosional unconformities. The Cretaceous System deposits have a maximum combined thickness of more than 5,000 feet beneath the site (Reference 16).

2.5.1.1.4.3.2 Jurassic System

Deposits of the Jurassic System in the Site Region include the Cotton Valley Group (Upper Jurassic), the Louark Group (Upper Jurassic), Louann Salt Group (Middle Jurassic), and unnamed Lower Jurassic deposits of anhydrite, sandstone, and conglomerate (Figure 2.5-13; Reference 56). These deposits are not exposed, but occur in the subsurface in the Site Region and Site Vicinity. The Cotton Valley Group includes the Knowles Limestone, Schuler, and Bossier formations and consist of marine and terrestrial sandstone, shale, and limestone. The Louark Group includes the Haynesville, Buckner, Smackover, and Norphlet formations and consist of basal red clay overlain by oolitic limestone, shale, and sandstone. The Louann Salt consists of thick evaporite deposits. Plastic flow of the Louann Salt related to sediment loading effects caused widespread diapirism and associated folding and faulting in the Interior Salt Basin and Coastal Salt Basin (Figure 2.5-3). The Louann Salt overlies the Werner Formation, which is also part of the evaporite sequence. Cumulatively, the Jurassic deposits in the southern portion of the Site Region have a thickness of nearly 10,000 feet (References 33, 59).

2.5.1.1.4.3.3 Triassic Deposits

The Eagle Mills Formation is the only Late Triassic deposit identified in the Site Region. This depositional sequence is not exposed at the surface, but has been penetrated by wells in southern Arkansas, eastern Texas, west-central Mississippi, northern Louisiana, south-eastern Mississippi, and southern Alabama at depths ranging from 984 feet to 9,840 feet (Reference 60). Deposits of the Eagle Mills Formation consist of non-marine, clastic, varicolored (red, purplish, greenish-gray, or mottled) shales, mudstones, and siltstones with less abundant fine- to very fine-grained sandstone (Reference 60). Basal units of the Eagle Mills Formation contain pebbles and cobbles of Paleozoic limestone. The Eagle Mills Formation represents the deposits that filled grabens, half grabens, and rift basins in prograding alluvial fan, fluvial, deltaic plain, and freshwater lake environments. The lower contact of the Eagle Mills formation is unconformable with Paleozoic rocks and the upper contact is unconformable with the Jurassic Werner Formation. The Eagle Mills Formation changes thickness over short distances from less than 10 feet to over 7,200 feet due to contemporaneous deposition in an active rift system (Reference 60).

2.5.1.1.4.4 Paleozoic Era

Paleozoic rocks are exposed in the northwestern portion of the Site Region, but do not occur in the Site Vicinity Figure 2.5-4. In the subsurface, deposits of the Paleozoic Era consist of seven major stratigraphic series and 19 individual formations (References 17, 56). The maximum combined thickness of Paleozoic deposits in the northwestern portion of the Site Region is in excess of 5,600 feet (Reference 17) and the maximum thickness south of the site is unknown. South of the Ouachita and Appalachian Mountains, Paleozoic and older deposits are not exposed. The depth to these deposits in the subsurface beneath the Site Vicinity is greater than 13,000 feet (Figure 2.5-6). Deposits of the Mississippian and Pennsylvanian Systems consist of interbedded shale, fine-grained sandstone, and minor limestone. Deposits of the Ordovician System consist of dolomite interbedded with thin beds of limestone, shale, and sandstone. Paleozoic rocks have an unconformable contact with the overlying Mesozoic rocks. The nature of the lower contact is unknown, but most likely is a nonconformity separating the Paleozoic deposits from crystalline basement rocks.

2.5.1.1.4.5 Precambrian

Precambrian basement rocks are not exposed in the Site Region (Figures 2.5-4 and 2.5-16a). The depth to basement in the Site Vicinity is estimated to be between 6 and 8 miles (Figure 2.5-16b; Reference 18).

Samples obtained from deep oil and gas exploration wells in the Site Region indicate the presence of Precambrian age North American continental crust beneath the Paleozoic stratigraphic section along the buried Ouachita Orogenic Belt (Reference 61). The basement rocks consist of sialic hornblende syenite dated approximately 785 +/- 34 Ma. The location of this subcrop, association with other samples collected from deep exploration borings, and similarity in age and composition to samples from the Blue Ridge Terrane of the southern Appalachian Mountains (described below) suggests that the Precambrian rocks encountered in the Site Region are related to the North American craton.

South of the buried Ouachita Orogenic Belt, Precambrian crystalline basement consists of highly attenuated continental crust or transitional crust related to formation of the Gulf of Mexico (Figure 2.5-5; Reference 18). Due to the depth of the crust in the Gulf Coast Basin actual rock samples have not been obtained. However, based on seismic velocity surveys the crust is thought to be transitional between continental and oceanic materials (Reference 18).

2.5.1.1.5 Regional Tectonic Setting

In 1986, EPRI developed a seismic source model for the Central and Eastern United States (CEUS) including the Site Region (Reference 9). The seismic source model included the independent interpretations of six earth science teams and reflected the general state of knowledge of the geoscience community as of 1986. The seismic source models developed by each of the six teams for the EPRI model were based on the tectonic setting and the occurrence, rates, and distribution of historical seismicity.

Since 1986, additional geological, seismological, and geophysical research has been completed in the Site Region. This more recent research has identified a potentially active seismic source, the Saline River source zone within the Site Region that includes the trends of the Arkansas, Saline, and Ouachita river lineaments in southeastern Arkansas (Figure 2.5-5). Recent research also has improved the characterization of seismic source parameters associated with the New Madrid seismic zone, the source of the 1811-1812 earthquake sequence.

In the following sections, we describe each of the major tectonic features in the Site Region, and the tectonic basis for their identification. The original seismic sources identified by EPRI (Reference 9) are thoroughly described in the EPRI report. The discussion below provides a summary of each tectonic feature modeled by EPRI in the Site Region and focuses on new information acquired since 1986 that is relevant to the assessment of seismic parameters for each source zone. A description of the Saline River source zone and new information on the New Madrid seismic zone is provided.

The EPRI Earth Science teams independently defined the geometry and source parameters of seismic sources in the CEUS. This independent assessment led to a range of interpretations that captured the variability and uncertainty in each seismic source. Each team modeled the major tectonic elements of the CEUS to develop their seismic source models. Figure 2.5-5 illustrates the distribution of tectonic features and historical seismicity in the Site Region from which the six EPRI team source models are based. The tectonic features shown on Figure 2.5-5 reflect the cumulative deformation of tectonic events throughout the Paleozoic, Mesozoic, and Cenozoic Eras. A chronology of events that influenced the development and distribution of tectonic features in the Site Region is described below and presented in Figure 2.5-8.

The south central United States is a passive continental margin with no relative differential motion between the Gulf of Mexico oceanic plate and the North American continental plate (Reference 63). The region is one of low earthquake activity and low stress, and is cited as an example of a stable continental region (References 62; 64, 65, 66, 67). The orientation of the maximum horizontal stress is northeast to east-northeast within the craton. The orientation of maximum extension is south-southeast near the Gulf Coast (Figure 2.5-5; Reference 68; 69). The southward oriented extension along the Gulf Coast reflects crustal loading and deformation within the Mississippi River deltaic complex in the Gulf of Mexico and may be distinct from the regional east-northeastward directed regional compressive stress in the underlying basement.

The primary tectonic elements of the region are fossil rift systems such as the Reelfoot Rift, or former collision zones such as the Paleozoic Ouachita Orogenic Belt and Appalachian Mountains (Figures 2.5-5). Each of these structures are regional in scale, and geologically and geophysically recognizable. Quaternary active structures, if present, appear to be entirely related to reactivation of these older bedrock rift or collisional structures. Nearly all earthquakes with well-located hypocenters occur within the Precambrian basement complex, and a majority of events >M4.5 appear related to regional scale structures such as the Reelfoot Rift, or Ouachita Orogenic Belt (Figure 2.5-5; Reference 70).

2.5.1.1.5.1 Tectonic Stress in the Mid-Continent Region

Expert teams that participated in the 1986 EPRI evaluation of intra-plate stress found that tectonic stress in the CEUS primarily is characterized by NE-SW-directed horizontal compression. In general, the expert teams concluded that the most likely source of tectonic stress in the mid-continent region was ridge-push force associated with the Mid-Atlantic ridge, transmitted to the interior of the North American plate by the elastic strength of the lithosphere. Other potential forces acting on the North American plate were judged to be less significant in contributing to the magnitude and orientation of the maximum compressive principal stress ($\sigma 1$). Some of the expert teams noted that deviations from the regional NE-SW trend of $\sigma 1$ may be present along the east coast and in the New Madrid region. They assessed the quality of stress indicator data, and discussed various hypotheses to account for what were interpreted as variations in the regional stress trajectories.

Since 1986, an international effort to collate and evaluate stress indicator data resulted in publication of a new World Stress Map (References 68; 71). Data for the map were ranked in terms of quality, and plate-scale trends in the orientations of principal stresses were assessed qualitatively (Reference 72). Subsequent statistical analyses of stress indicators confirmed that the trajectory of the maximum compressive principal stress ($\sigma 1$) is uniform across broad continental regions at a high level of statistical confidence (Reference 73). In particular, the NE-SW orientation of $\sigma 1$in the central and eastern United States inferred by the EPRI experts is statistically robust, and is consistent with the theoretical trend of compressive forces acting on the North American plate from the mid-Atlantic ridge (Reference 73).

The more recent assessments of lithospheric stress have not confirmed inferences of some EPRI expert teams that the orientation of $\sigma 1$ may be locally perturbed in the New England area, along the east coast of the United States, or in the New Madrid region. Zoback and Zoback summarized a variety of data, including well-bore breakouts, results of hydraulic fracturing studies, and newly calculated focal mechanisms, which indicate that the New England and eastern seaboard regions of the U.S. are characterized by horizontal NE-SW to E-W compression (Reference 68). Similar trends are present in the expanded set of stress indicators for the New Madrid region. All of these regions, were grouped with a large area of eastern Canada, and the central and eastern U.S. in an expanded "Mid-Plate" stress province (Reference 68).

In addition to better documenting the orientation of stress, research conducted since 1986 has addressed quantitatively the relative contributions of various forces that may be acting on the North American plate to the total stress within the plate. Richardson and Reding (Reference 74) performed numerical modeling of stress in the continental U.S. interior, and considered the contribution to total tectonic stress from three classes of forces:

1) Horizontal stresses arising from gravitational body forces acting on lateral variations in lithospheric density. These forces are commonly called "buoyancy forces". Richardson and Reding emphasize that what is commonly called "ridge-push force" is an example of this class of force (Reference 74). Rather than a "line-force" that acts outwardly from the axis of a spreading ridge, "ridge push" arises from the pressure exerted by positively buoyant, young oceanic lithosphere near the ridge against older, cooler, denser and less buoyant lithosphere in the deeper ocean basins (Reference 75). The force is an integrated effect over oceanic lithosphere ranging in age from about 0 to 100 million years (Reference 76). The "ridge push" force is transmitted as stress to the interior of continents by the elastic strength of the lithosphere.
2) Shear and compressive stresses transmitted across major plate boundaries (i.e., strike-slip faults and subduction zones).
3) Shear tractions acting on the base of the lithosphere from relative flow of the underlying asthenospheric mantle.

The observed NE-SW trend of σ_1 in the central and eastern United States dominantly reflects "ridge-push" body forces (Reference 74). They estimated the magnitude of these forces to be about 2 to 3 x 10^{12} N/m (i.e., the total vertically integrated force acting on a column of lithosphere 1 meter wide), which corresponds to average equivalent stresses of about 40 to 60 MPa distributed across a 50-km-thick elastic plate. The fit of the model stress trajectories to data is improved by addition of modest compressive stress (about 5 to 10 MPa) acting on the San Andreas fault and Caribbean plate boundary structures (Reference 74). The fit of the model

stresses to data further indicated that shear stresses acting on these plate boundary structures must also be in the range of 5 to 10 MPa.

The general NE-SW orientation of σ_1 in the central and eastern United States also can be reproduced by numerical models that assume a shear stress, or "drag", is acting on base on the North American plate (Reference 74). This model is not favored (Reference 74; 68) as a significant contributor to total stress in the mid-continent region, however, because it predicts or requires that the horizontal compressive stress in the lithosphere increase by an order of magnitude moving from east to west across the central United States. The state of stress in the southern Great Plains is characterized by north-south extension, which is contrary to this prediction (Reference 68). They further observed that seismic activity generally increases from west to east across the central and eastern U.S., which is not consistent with the prediction of the basal drag model that compressive stresses (and presumably rates of seismic activity) should be higher in the west central U.S. than in the eastern U.S.

2.5.1.1.5.2 Appalachian Mountains

The Appalachian Mountains extend from Newfoundland, Canada to central Alabama. The Appalachian Mountains consists of a southwest-trending complex of folded, thrusted, and metamorphosed terranes that evolved over a period of approximately 800 million year.

The Appalachian Mountains are up to 400 miles wide and 2,000 miles long and include the Valley and Ridge, Piedmont, and Blue Ridge terranes. Each terrane is bounded by a zone of major thrust faults. These terranes include Proterozoic and younger age rocks of both oceanic and continental affinity that were accreted to the North American craton during three episodes (or orogenies) of plate collision and northwest-directed crustal shortening. The episodes of plate collision include the Allegheny orogeny (270 to 350 Ma), Acadian orogeny (350 to 400 Ma), and Taconic orogeny (400 to 500 Ma; Reference 77). The Taconic orogeny produced the Blue Ridge terrane which consists of highly metamorphosed, folded and thrust faulted Proterozoic and Cambrian crystalline rocks. The Acadian orogeny produced the Piedmont terrane and deformed the eastern Blue Ridge. The Piedmont terrane consists of metamorphosed Precambrian and Paleozoic sediments and volcanic rocks that were intruded by granitic plutons. The Allegheny orogeny produced the Valley and Ridge terrane and deformed the Blue Ridge and Piedmont terranes. The Valley and Ridge terrane consists of a thick sequence of folded and thrust faulted Paleozoic sediments (Reference 77). Each subsequent orogeny deformed the pre-existing rocks from earlier orogenies resulting in a complex sequence of poly-deformed and metamorphosed rocks.

The surface expression of the Appalachian Mountains terminates outside of the 200-mile Study Region. However, the northeast-trending geological structures associated with the Appalachian Mountains extend in the subsurface into the northeastern portion of the Site Region where they merge with the northwest-trending Ouachita Mountains in southeastern Mississippi and southwestern Alabama (Figure 2.5-4). The southern end of the Appalachian Mountains structures approximately coincides with the Pickens-Gilberttown fault zone (Figure 2.5-5). The Appalachian and Ouachita Mountains define the eastern and southeastern edges, respectively, of the current North American craton (Reference 78).

Many Paleozoic thrust faults of regional extent are mapped within the Appalachian Mountains. However, in the Site Region none of these faults have geological or seismological evidence of Quaternary activity and only the southernmost portion of the Appalachian Mountains extends in the subsurface into the Site Region. There are no distinct faults identified as individual seismic sources within the Appalachian Mountains in the Site Region. Historical seismicity generally

aligns along the northeastern trend of the Appalachian Mountains, but within the Site Region, only six earthquakes m_b>3.3 (lower bound threshold used by Reference 9) were recorded between 1627 and 1984. Since 1984 study, only three earthquakes (m_b<3.3) occurred within the subsurface extent of the Appalachian Mountains in the Site Region (Reference 11; Figure 2.5-5). The seismicity that occurs at the southern end of the buried Appalachian Mountains also coincides with the location of the Pickens-Gilberttown fault zone. Some of these earthquakes are spatially related to an area of high petroleum withdrawal and may be triggered events caused by fluid recovery.

The April 2003 M_w 4.9 Alabama earthquake occurred within the Appalachian Mountains province, outside of the Site Region (Figure 2.5-17). This event is within the normal range of earthquake magnitudes expected for this region. The event occurred at a depth of about 3 miles (5 km) and had a strike-slip focal mechanism. The event was not felt at the Grand Gulf Nuclear Station and did not trigger any monitoring instruments at the site.

The six EPRI teams developed estimates of maximum earthquake magnitudes for the Appalachian Mountains province that range from m_b 5.4 to 7.2 (M_w 5.1 to 7.6). Since the EPRI study, the USGS developed a new seismic source model that estimates a maximum earthquake magnitude of M_w 7.5 for the Appalachian Mountains in the Site Region. No new information was identified during our data review that provides estimates of the maximum earthquake magnitudes for the Appalachian Mountains that are outside of the range of values developed by the six EPRI teams (Reference 9).

2.5.1.1.5.3 Ouachita Orogenic Belt

The Ouachita Orogenic Belt is the eroded core of a mountain belt that formed during continental collision and formation of the supercontinent Pangea, in the Paleozoic (Figure 2.5-8; Reference 79). The Ouachita Orogenic Belt extends from western Alabama through northern Mississippi, central Arkansas, southeastern Oklahoma, and eastern Texas (Figure 2.5-5). The Ouachita Orogenic Belt consists of an arcuate salient of complexly folded, thrust-faulted, and metamorphosed rocks that, like the Appalachian Mountains, includes accreted oceanic crust of Proterozoic age (Reference 79).

The Ouachita Orogenic Belt is up to 50 miles wide and 1,260 miles long, although about 80 percent of its length is buried beneath Mesozoic and Tertiary sediments of the Gulf Coast Basin. The Ouachita Orogenic Belt defines the northern edge of the Gulf Coastal Basin, the southern margin of the Mississippi Embayment, and the southern edge of the North American craton (Figures 2.5-3 and 2.5-7). The belt includes three regional subdivisions including the Southeastern Ouachitas, the Ouachita Mountains, and the Subsurface Ouachitas of Texas.

The topography of the Ouachita Orogenic Belt is expressed by a low relief erosional surface that was buried by Jurassic sediments in the Gulf Coastal Plain. Across the Gulf Coastal Plain from Alabama to southern Texas this erosional unconformity dips toward the Gulf of Mexico at an angle of less than 1 degree (References 79; 80).

Repeated episodes of deformation formed asymmetrical folds, and low- and high-angle thrust faults that involve Middle to Upper Paleozoic rocks along the edge of the North American craton (Reference 81). Middle to Upper Paleozoic rocks are unconformably overlain by late Paleozoic rocks that were not involved in the Ouachita orogeny. Thus, deformation along the Ouachita Orogenic Belt ceased in late Paleozoic time.

Throughout the entire length of the Ouachita Orogenic Belt, the base of the orogen is defined by a major decollement, along which allochthonous marine sedimentary rocks are thrust northward

over North American cratonic rocks. The northern side the Ouachita Orogenic Belt overlies 21- to 24-miles of North American continental crust (Reference 82). On the southern, or Gulf Coast side, the Ouachita Orogenic Belt overlies transitional continental crust (Reference 18; 82).

Two major stratigraphic units collectively known as the Ouachita facies compose the majority of rocks in the Ouachita Orogenic Belt. The lower stratigraphic unit, referred to as the pre-orogenic off-shelf facies, ranges from Late Cambrian to Early Mississippian in age, and is approximately 9,500 to 11,000 feet thick. This lower stratigraphic unit consists of shale, sandstone and micrite that grade upward to chert, siliceous shale, and novaculite.

The upper stratigraphic unit is referred to as the synorogenic facies. This unit ranges from Late Mississippian (Meramecian) to Early Permian (Wolfcampian) in age, and represents over 50,000 feet of shelf-delta clastic deposits that originated in foreland basins, and outboard deep water clastic wedge deposits. The shelf-delta deposits of the foreland basin were deformed by folding and faulting during the Ouachita orogeny (Reference 79).

The Southeastern Ouachitas, in the Site Region, lie entirely in the subsurface of northern Mississippi and southwestern Alabama (Reference 81), within the Gulf Coastal Plain (Figure 2.5-2). On the northern side of the Ouachita Orogenic Belt, Carboniferous age shelf-delta deposits (upper stratigraphic unit) occur in the subsurface foreland basin and extend southward into the frontal thrusts in Mississippi. Southwest of the Orogenic Belt undifferentiated pre-orogenic and synorogenic rocks are present.

In Mississippi, the decollement beneath the Southeastern Ouachitas ramps downward into the shelf strata of the Appalachian Mountains and interleaves with the decollement beneath the southern part of the Appalachian Mountains (Reference 79). The intersection of the Ouachita Orogenic Belt and the thrust faults of the Appalachian Mountains leads to a cross-cutting fault pattern (Figure 2.5-5).

Although many large Paleozoic thrust faults of regional extent are mapped through the Ouachita Orogenic Belt, none display geological evidence of Quaternary activity. As shown on Figure 2.5-5, historical seismicity occurs along the trend of the Ouachita Orogenic Belt, but within the Site Region, only 10 earthquakes of m_b>3.3 to 3.9 (lower threshold used by EPRI (Reference 9) were recorded between 1627 and 1984. Since the EPRI study, only one earthquake of m_b> 3.3 occurred during the period 1985 and 2003, within the Ouachita Orogenic Belt in the Site Region (Figure 2.5-5; Reference 83). This cluster of seismicity includes events within the Saline River source zone, described in Section 2.5.1.1.5.9. Only one earthquake of m_b>3.3 occurred within the part of the Ouachita Orogenic Belt that lies within the 200-mile radius Site Area and outside of the Saline River source zone for the period 1627 to 2003.

The six EPRI teams developed estimates of maximum earthquake magnitudes for the area encompassing the Ouachita Orogenic Belt that range from m_b 5.5 to 7.2 (M_w 5.1 to 7.5). Since the EPRI study, the USGS developed a new seismic source model that estimates a maximum earthquake magnitude of M_w 7.5 for the Ouachita Orogenic Belt in the Site Region (Reference 84). This new information is within the range of estimates of maximum earthquake magnitude for the Ouachita Orogenic Belt provided by the EPRI teams (Reference 9). The USGS estimate of M_w 7.5 is defined for an areal source zone that includes the entire area of the Gulf and East Coasts that extends from the edge of the North American cratonic rocks to the coastline (Reference 84).

Several potential Quaternary active fault zones within the Ouachita Orogenic Belt have been identified primarily by geomorphic evidence of basin asymmetry, and localized evidence of

faulting in road-cuts and trenches, weak clustering of earthquake epicenters, and liquefaction features (Reference 85). The potential faults are identified along the Arkansas River, Saline River, and Ouachita rivers in northern Louisiana and Arkansas. Detailed descriptions of these features are provided in Section 2.5.1.1.5.7.

2.5.1.1.5.4 Arkoma Basin and Black Warrior Basins

The Arkoma and Black Warrior basins are located directly north of the Ouachita Orogenic Belt (Figure 2.5-3). Both basins straddle the margin of the Site Region. The Arkoma and Black Warrior basins are foreland basins containing synorogenic sedimentary deposits associated with the Ouachita Orogenic Belt. The sedimentary deposits overlie North American cratonic rocks. The major period of deposition and basin deformation ceased in Late Paleozoic to early Mesozoic time (Figure 2.5-8). There are no active tectonic features identified within the Arkoma Basin and Black Warrior basins (Reference 86, 90).

Paleozoic thrust faults in the Arkoma and Black Warrior basins show no evidence of Quaternary activity. Historical seismicity within the parts of the Arkoma and Black Warrior basins that are within the Site Region is sparse Figure 2.5-5. Only two earthquakes of m_b 3.3 to 3.9 (lower threshold used by Reference 9) were recorded between 1627 and 1984. Since the EPRI study, no additional earthquakes greater than m_b 3.3 have been recorded (Figure 2.5-5) in this part of the Site Region. A swarm of small magnitude earthquakes m_b<4.5 occurred in central Arkansas, within the Arkoma Basin, outside of the Site Region. This event, referred to as the Enola earthquake swarm, occurred within a small volume of crust (approximately 25 km^3; Reference 159). The earthquake swarm is interpreted to be associated with a short, 2.6-km long, west-northwest-trending fault segment, that is related to a basement listric fault within a Paleozoic graben (Reference 160). This fault may have a favorable orientation with respect to the east-northeast maximum compressive stress (Reference 69) to produce left-lateral strike slip deformation (Reference 159). Based on the cross-cutting fault patterns within this area (Reference 160) larger earthquakes are not expected to occur in the Enola, Arkansas area.

The six EPRI teams developed estimates of maximum earthquake magnitudes for the area encompassing the Arkoma and Black Warrior basins that range from m_b 5.4 to 7.2 (M_w 5.1 to 7.5). Since the EPRI study, the USGS developed a new seismic source model that estimates a maximum earthquake magnitude of Mw 7.5 for the area encompassing the Arkoma and Black Warrior Basins. The estimate of maximum earthquake magnitude for the area encompassing the Arkoma and Black Warrior basins is within the range of values developed by the six EPRI teams (Reference 9).

2.5.1.1.5.5 Reelfoot Rift

The Reelfoot Rift represents a northeast-trending fault system that originated in Precambrian or Early Cambrian time during extension of the North American continent (Figure 2.5-8; References 81; 87). The Reelfoot Rift extends from southern Illinois at the northern end of the Mississippi Embayment, to east-central Arkansas and northern Mississippi beneath the Ouachita Orogenic Belt (Reference 27). As shown on Figures 2.5-3 and 2.5-5, the closest approach of faults within the Reelfoot Rift to the site is approximately 175-miles. The Reelfoot Rift now accommodates crustal shortening due to northeast-southwest directed regional compressive stress (References 68, 69).

The Reelfoot Rift is approximately 45 miles wide and 180 miles long with as much as 25,000 feet of structural relief (Reference 88). An alignment of magnetic intrusive rocks defines the rift boundaries (References 24, 87; 91). Within the Reelfoot Rift, Upper Paleozoic through Middle

Cretaceous strata are absent and a major unconformity exists between Late Cretaceous and Early Paleozoic strata (Reference 92). The Reelfoot Rift comprises a number of distinct structural features, including the Commerce Geophysical Lineament, Western Margin of Reelfoot Rift, Crowleys Ridge, Sikeston Ridge, New Madrid Seismic Zone, and Eastern Margin of Reelfoot Rift (Reference 93). The New Madrid Seismic Zone is the primary seismically active tectonic feature within the Reelfoot Rift, and is described in Section 2.5.1.1.5.6, below.

The geologic history of the Reelfoot Rift includes numerous episodes of uplift, subsidence, intrusion, and sedimentation (Figure 2.5-8). During Precambrian to Cambrian time, the Reelfoot Rift formed as a result of continental rifting and crustal extension of the North American continent (Reference 27). In Late Cambrian time, rifting ceased and the Reelfoot Rift was filled with Paleozoic marine clastic and carbonate rocks (Reference 92). During Middle Cretaceous time, the Reelfoot Rift was reactivated forming an arch that resulted in erosion and removal of Late Paleozoic to Middle Cretaceous rocks of the Late Cambrian Reelfoot Rift (Reference 27; 85).

Reactivation of the Reelfoot Rift in Middle Cretaceous time was accompanied by emplacement of igneous rocks along the rift margins (Reference 85; 94). The emplacement of plutons and crustal arching in the Middle Cretaceous may have been related to the North American continent passing over the Bermuda Hot Spot (Reference 85). Cox and Van Arsdale (Reference 85) also suggest that reactivation of the Reelfoot Rift occurred in Middle Cretaceous time rather than Jurassic time, and therefore could not have been related to opening of the Gulf of Mexico (Reference 92). Reactivation of rift structures in the Late Cretaceous to Eocene caused crustal subsidence and formation of the Mississippi Embayment subprovince of the Gulf Coastal Plain, and initial deposition of alluvial sediment from the Mississippi River over Jurassic age carbonates in the northern Gulf of Mexico.

Regional stress again changed from extension to compression in Late Eocene time causing minor folding and faulting (e.g. Crittenden County fault) within the Reelfoot Rift (References 92; 95). Oligocene and Miocene strata are absent in the Mississippi Embayment and deposits in the Gulf Coast Basin indicate that the embayment was subaerially exposed and subjected to erosional processes during this time. Pliocene to Pleistocene glacial outwash deposits of the Upland Complex unconformably overlie Eocene deposits in the Mississippi Embayment (as well as Miocene deposits in the Site Vicinity). The Mississippi Embayment was entrenched during the Pleistocene and Holocene resulting in progressive flights of terraces incised into Upland Complex deposits along the Mississippi River and its tributaries (Reference 17).

Potentially active faults within the Mississippi Embayment may be associated with the Precambrian, Middle Cretaceous, Late Cretaceous, or Early Tertiary faults of the Reelfoot Rift (Reference 87). The potentially active faults may have been reactivated in Late Eocene time when the regional stress field changed from extension to NE-SW compression. Extensive geophysical investigations of the Reelfoot Rift have been completed for a variety of purposes including deep crustal dynamics, oil exploration, active tectonics, and geotechnical projects (Reference 92). These geophysical investigations indicate that many faults in the Reelfoot Rift do not offset post-Cretaceous deposits (Reference 88). However, Tertiary and Quaternary age faults are identified beneath the margins of Crowley's Ridge (References 97; 98), Sikeston Ridge (References 99, 100), Blytheville Arch (References 89, 101, 102, 104), Benton Hills (Reference 103), Reelfoot fault (Reference 105, 106, 108, 109), Bootheel Lineament (Reference 100, 107), Crittenden County fault (Reference 95; 96), Commerce Geophysical Lineament (Reference 110) and one of the west-bounding faults of the Reelfoot Rift (Reference 98).

With the exception of seismicity associated with the New Madrid seismic zone (described below), seismicity within the Reelfoot Rift is diffuse (Figure 2.5-5). A visual assessment of seismicity patterns indicates that pre-1985 and post-1985 earthquake occurrence has been relatively constant.

The six EPRI teams developed estimates of maximum earthquake magnitudes for the area encompassing the Reelfoot Rift (exclusive of the New Madrid Seismic Zone) that range from m_b 5.4 to 7.2 (Mw 5.0 to 7.5). Since the EPRI study, the USGS developed a new seismic source model that estimates a maximum earthquake magnitude of Mw 7.5 for the Reelfoot Rift (Reference 84). The USGS estimate of maximum earthquake magnitude for the area encompassing the Reelfoot Rift is within the range of values developed by the six EPRI teams (Reference 9). The USGS estimate of Mw 7.5 is defined for an areal source zone that includes the entire area along the southern and eastern edge of the North American craton to the Gulf and Atlantic coasts.

2.5.1.1.5.6 New Madrid Seismic Zone

The New Madrid Seismic Zone (NMSZ) lies within the Reelfoot Rift and is defined by post-Eocene to Quaternary faulting, and historical seismicity. The NMSZ extends from southeastern Missouri to northeastern Arkansas and northwestern Tennessee (Figure 2.5-18). The NMSZ lies outside of the Site Region, but remains a significant contributor to the seismic hazard at the site of the proposed new facility at GGNS.

EPRI (Reference 9) defined the NMSZ as an aerial source zone that is approximately 124-miles long and 25-miles wide. Additional information published since 1986 shows that a distinct fault system is embedded within this source zone. The fault system consists of three distinct segments (Figure 2.5-18). These three segments include a southern northeast-trending dextral slip fault referred to as the Cottonwood Grove fault and Blytheville Arch, a middle northwest-trending reverse fault referred to as the Reelfoot fault, and a northern northeast-trending dextral strike-slip fault referred to as the East Prairie fault (References 92; 102; 111; 112; 113). In the current east-northeast to west-southwest directed regional stress field, Precambrian and Late Cretaceous age extensional structures of the Reelfoot Rift have been reactivated as right-lateral strike-slip and reverse faults (Reference 114).

The NMSZ produced three large magnitude earthquakes (estimates range from M_w 7.1 to 8.4) between December, 1811 and February, 1812 (Reference 115; 116; 117; 114; 118; 119; 120). The actual size of these pre-instrumental events is not known with certainty and is based primarily on various estimates of damage intensity and amount and pattern of liquefaction. Magnitude estimates using these approaches range from Mw 7.1 to 8.4.

The December 16, 1811 earthquake is inferred to be associated with strike-slip displacement along the southern portion of the NMSZ, either on the Blytheville Arch-Cottonwood Grove fault, or Blytheville Arch-Bootheel Lineament (Figure 2.5-18; References 118; 114). The southern portion of the NMSZ extends for approximately 70 miles from northeastern Arkansas through the eastern corner of the Missouri "Bootheel" (References 92; 113). This southwestern part of the NMSZ follows the pre-middle Ordovician subsurface Blytheville Arch and coincides with the axis of the Reelfoot Rift. Johnston estimated the December event to have a magnitude of M_w 8.1$\pm$0.31 (Reference 118). Hough, later re-evaluated the intensity data for the region and concluded that the event had a magnitude of M_w 7.2 to 7.3 (Reference 117). Bakun and Hopper also re-evaluated the intensity data and derive a magnitude of M_w 7.2 for the December,1811 event (Reference 115).

The February 7, 1812 New Madrid earthquake is associated with reverse displacement along the middle part of the NMSZ (Figure 2.5-18; Reference 108; 109; 114; 115; 118). This earthquake most likely occurred along the northwest-trending Reelfoot fault that extends approximately 43 miles from northwestern Tennessee to southeastern Missouri (Reference 121; 122). The Reelfoot fault is a northwest-trending southwest-vergent reverse fault (Reference 109; 123). The Reelfoot fault forms a topographic scarp developed as a result of fault-propagation (References 109; 122; 124). Kelson et al. (Reference 109) investigated near-surface deformation along the trace of the scarp and found evidence for three events within the past 2,400 years. The most recent event was associated with the 1811-1812 earthquake sequence. The penultimate event is estimated to have occurred between A.D. 1260 and 1650. The pre-penultimate event occurred prior to about A.D. 780-1000 (Reference 108). A range of recurrence intervals for the Reelfoot fault are estimated between 150 to 900 years, with a preferred range of about 400 to 500 years (Reference 109). The geometry and reverse sense of motion of the Reelfoot fault implies that the fault serves as a step-over segment between the southern and northern portions of the fault (Reference 92; 113). Johnston estimated a magnitude of M_w 8.0 $\pm$ 0.33 for the February, 1812 event (Reference 118). Hough (Reference 117) later re-evaluated the intensity data for the region and concluded that the February event had a magnitude of M_w 7.4 to 7.5. Bakun and Hopper (Reference 115) also re-evaluated the intensity data from 1811-1812 sequence and derive a magnitude of Mw 7.2 to 7.6 for the event.

The January 23, 1812 earthquake is inferred to be associated with strike-slip displacement on the East Prairie fault along the northern portion of the NMSZ (Figure 2.5-30; Reference 114). The northern portion of the NMSZ extends 45 miles in a northeast direction through southeastern Missouri, and approximately coincides with the northwestern boundary of the Reelfoot Rift (Reference 114). The interpretation that the January, 1812 earthquake occurred along the East Prairie fault of the NMSZ is based on fault mechanics and limited historical data, and is more poorly constrained than interpretations of the December 16, 1811 and February 7, 1812 earthquakes. Baldwin et al. conducted paleoseismic investigations along this segment of the fault (Reference 99). Although they have identified liquefaction evidence for the 1811/1812 earthquake sequence, their data do not support the presence of a major throughgoing fault with repeated late Holocene events.

Johnston estimated a magnitude of Mw 7.8$\pm$0.33 for the January, 1812 event (Reference 118). Hough et al. later re-evaluated the intensity data for the region and concluded that the January event had a magnitude of Mw 7.1 (Reference 117). Bakun and Hopper also re-evaluated the intensity data from 1811-1812 sequence and derive a magnitude of M_w7.1 for the January 23, 1812 event (Reference 115).

2.5.1.1.5.6.1 Earthquake Recurrence

Because there is very little surface expression of faults within the NMSZ, earthquake recurrence estimates are based largely on dates of paleo-liquefaction and offset geological features (References 125; 126;109). These data suggest that strong earthquakes occurred around A.D. 900 +/- 100, A.D. 1450 +/- 150, and A.D. 1810 +/- 130 (References 125; 127; 128; 129). Kelson dated the penultimate event that deformed the scarp of the Reelfoot fault between A.D. 1260 and 1650, and an older event between A.D. 780 and 1000 (References 109).

Conclusions from paleoseismic investigations suggest that the recurrence interval for surface deforming earthquakes in the NMSZ is about 200 to 800 years (Reference 125; 130; 131; 132; 133; 109; 127; 129). The 200 to 800 year recurrence estimate, with a preferred estimate of 500

years is significantly shorter than the 5,000 year earthquake recurrence interval used in the 1986 EPRI study based on extrapolation of historical seismicity (Reference 9).

2.5.1.1.5.6.2 Slip Rate

A wide range of slip rates are reported for the NMSZ. Slip rate estimates include data from geodetic measurements that range from 5 to 7 mm/yr (Reference 134) to no detectable deformation (Reference 135), and geologic rates that range from 1.8 to 6.2 mm/yr for the Holocene, and 0.0003 to 0.002 mm/yr for the late Cretaceous to late Eocene (References 122; 136). Mueller and Pujol (Reference 123) report a slip rate along the northern and southern portions of the NMSZ of 1.8-2.0 mm/yr based on the geometric relationships (fault strike and slip vectors) with the Reelfoot fault.

2.5.1.1.5.6.3 Maximum Earthquake Magnitude

The six EPRI teams developed estimates of maximum earthquake magnitudes for the NMSZ that range from m_b 7.1 to 7.9 (Mw 7.3 to 8.7). Since the EPRI study, several independent estimates of maximum earthquake magnitudes for the NMSZ have been developed (Reference 84; 118; 117; 115). The estimates of maximum earthquake magnitude of Frankel et al. (Reference 84) and Johnston (Reference 118) are within the range of values developed by the six EPRI teams (Reference 9). The estimates presented by Hough et al. (Reference 117), Bakun and Hopper (Reference 115), and Mueller and Pujol (Reference 123) are lower than the EPRI range of maximum magnitudes for the NMSZ.

2.5.1.1.5.7 Gulf Coast Basin

The Grand Gulf Nuclear Station is located in the Gulf Coast Basin (Figure 2.5-3), a broad, low relief geomorphic province extending from eastern Texas to western Alabama and Florida, and from southern Arkansas to the Gulf Coast. The Gulf Coast Basin is a north-south trending syncline approximately 280 miles long and 400 miles wide. The basin is structurally bounded by the buried Ouachita Orogenic Belt on the north, and southern Appalachian Mountains on the east. These structures define the boundaries of a deep crustal depression that contains more than 50,000 feet of Mesozoic and Cenozoic sediment (Reference 17). Sediments within the Gulf Coast Basin accumulated since post-Jurassic continental rifting and formation of the Gulf of Mexico (Reference 27). The amount of sediment transported to the Gulf Coast Basin exceeded the volume that could be accommodated through basin subsidence and infilling, and as a result, fluvial depocenters have migrated through time, and the sedimentary complex has prograded gulfward over 250 miles. Each shift in the depocenter was marked by development of a series of growth faults (e.g. Pickens-Gilberttown, Southern Arkansas, Gulf Margin Normal faults) that defined the margins of unstable shelves. The growth faults are interpreted as aseismic gravitational collapse features that slip basinward under sedimentary load. Currently active growth faults are located along the Cretaceous shelf edge in the vicinity of the modern Gulf Coast, 90 miles south of the site (Figure 2.5-5; Reference 29).

2.5.1.1.5.8 Pickens-Gilberttown and Southern Arkansas Fault Zones

The Pickens-Gilberttown and Southern Arkansas fault zones are a system of faults that extend from southwestern Alabama through west-central Mississippi (Figure 2.5-5, Reference 137) to southern Arkansas and eastern Texas. The Pickens-Gilberttown and Southern Arkansas fault zones consist of a series of grabens developed in Paleozoic to Middle Tertiary deposits, on the gulfward side of the Ouachita Orogenic Belt (Reference 16).

The Pickens-Gilberttown and Southern Arkansas fault zones together are more than 500 miles long in a zone typically less than 25-miles wide (Figures 2.5-3 and 2.5-5). The Pickens-Gilberttown and Southern Arkansas fault zones offset Mesozoic and Cenozoic deposits. Mesozoic and Cenozoic deposits thicken gulfward across the fault zones indicating syndepositional down-to-the-south movement. Movement along the Pickens-Gilberttown and Southern Arkansas fault zones displaces Miocene age sediments as much as 200 feet, but Pliocene and Pleistocene age deposits are not offset. Pre-Miocene deposits are offset up to 1,000 feet at depth, and similar age deposits on opposite sides of the fault zones are as much as 10-fold thicker on the down-dropped, gulfward side of the structure (Reference 16). The Pickens-Gilberttown and Southern Arkansas fault zones formed by gravitational collapse related to large sedimentary loads in the Tertiary age Gulf Coastal Plain, or continental shelf. The Pickens-Gilberttown and Southern Arkansas fault zones are Tertiary age analogues to the currently active Gulf Margin Normal faults.

Unfaulted Pliocene and Pleistocene Upland Complex terrace deposits overlie the Pickens-Gilberttown fault zone in the vicinity of the Alabama River (Reference 138). The continuity of Pliocene and Pleistocene deposits across the fault zone indicates that the Pickens-Gilberttown fault zone is not active. Seismic data and continuity of stratigraphy documented from deep exploration wells also indicate that the Southern Arkansas fault zone has not been active since Miocene time (Reference 139).

Very little historical seismicity has occurred along the Pickens-Gilberttown and Southern Arkansas fault zones (Figure 2.5-5). Six earthquakes of m_b 3.3 to 3.9 occurred along the southeastern portion of the Pickens-Gilberttown fault zone near the Mississippi-Alabama border within the Site Region, and three additional earthquakes (m_b<4.4) occurred along the trend of the fault zone in southern Alabama, outside of the Site Region. These earthquakes occurred at the 1.8- to 3.6-mile depth of fluid recovery in active well fields, suggesting that they are most likely triggered earthquakes related to hydrocarbon recovery (Reference 140). No earthquakes > m_b 3.3, the lower threshold used by EPRI (Reference 9), have been recorded along the Southern Arkansas fault zone in the Site Region.

EPRI defined a- and b-values to characterize earthquake occurrence for major tectonic features within the Site Region (Reference 9). However, because the geologic data indicate that these fault zones have been inactive since post-Miocene time, none of the six EPRI Teams specifically characterized the Pickens-Gilberttown or Southern Arkansas fault zones in their seismic source models. The Pickens-Gilberttown and Southern Arkansas fault zones were incorporated within background seismic source zones across the Gulf Coastal Plain gulfward of the Ouachita Orogenic Belt. Therefore, no specific seismicity parameters were developed for the Pickens-Gilberttown or Southern Arkansas fault zones for the EPRI study. Since the EPRI study, only one new earthquake of m_b 3.3 to 3.9 has occurred along the entire 500 mile long Pickens-Gilberttown Southern Arkansas fault zone. The addition of this one earthquake does not significantly modify the earthquake rate parameters within the Site Region used by the six EPRI Teams in their seismic source model for the southern portion of the Gulf Coastal Plain.

The six EPRI teams developed estimates of maximum earthquake magnitudes for the area encompassing the Pickens-Gilberttown and Southern Arkansas fault zones (Gulf Coastal Plain south of Ouachita Orogenic Belt) that range from m_b 4.6 to 7.2 (Mw 4.2 to 7.5). Since the EPRI study, maximum earthquake magnitudes for this area have been estimated to be Mw 7.5 (Reference 19) and m_b 5.0 (Reference 70). These estimates of maximum earthquake magnitude are within the range of values developed by the six EPRI teams (Reference 9).

2.5.1.1.5.9 Saline River Source Zone

The Saline River source zone lies within the Ouachita Orogenic Belt and structurally overlies the southwestward subsurface extension of the Proterozoic Reelfoot Rift. The Saline River source zone is located primarily in southeastern Arkansas and northwestern Mississippi, with a minor extension into northern Louisiana (Figure 2.5-19). The source zone was not identified by any EPRI earth science team, and is defined based on more recent geomorphic, geologic and seismologic data that is suggestive of Holocene and late Pleistocene deformation and paleoseismicity (Reference 150; 151; 152; 153). Although suggestive of late-Pleistocene deformation, the evidence is not conclusive and may alternatively be explained by activity along the Reelfoot Rift and/or through non-tectonic processes such as isostatic adjustments from glacial loading to the north, or sediment loading within the Mississippi Embayment and/or Mississippi delta fan complex.

2.5.1.1.5.9.1 Geomorphic Evidence

Basin analysis techniques were used to assess possible tectonic influences on the location and orientation of the Ouachita, Saline, and Arkansas Rivers (Reference 150). Based on the distribution and ages of river terraces, the progressive southwestward migration of each river channel producing drainage basins with distinct asymmetries was documented. The southwestward river migration and drainage basin asymmetry was interpreted to reflect southwestward tilting of a series of northwest-trending structural blocks (Reference 154). These northwest-trending, tilted structural blocks are bordered by assumed northwest-trending normal or oblique slip faults and are interpreted to control the patterns, position, and orientation of these major drainages.

Quaternary geological mapping (References 44; 154) identified a sequence of Quaternary fluvial terraces within the Mississippi River and tributary valleys. In the vicinity of the Arkansas, Saline, and Ouachita rivers these terraces include from oldest to youngest the Intermediate Complex, Prairie Complex and Deweyville Complex (Figures 2.5-20, 2.5-21 and 2.5-22). Each of these individual terrace complexes contains several discrete terrace treads.

The amount of stream incision into terraces of known age can be used as a proxy to estimate the total amount and rate of block uplift and thus, the amount and rate of vertical separation on the assumed bordering faults (Reference 161). This approach was used to evaluate the possible rate of deformation within the Saline River source zone. Cross-sections used to estimate slip rates on the Saline River source zone are shown on Figure 2.5-23. The incision rates provide an order of magnitude estimate of long-term incision and slip rate. Figure 2.5-23 provides estimates of incision rates, used as a proxy for vertical slip-rates, for various terrace surfaces. The rates range from 0.05 to 1.7 mm/yr.

The location and vertical position of terraces within the Arkansas, Saline, and Ouachita rivers indicate basin asymmetry. The oldest and highest terraces (e.g. Intermediate Complex) typically are preserved on the northeast side of the basin. The lowest and youngest terraces (Deweyville Complex), as well as the active stream channels, are located on the southwest sides of the basins (Figures 2.5-29, 10 and 11). Although there is a general pattern of basin asymmetry, the positions of Holocene to recent stream patterns do not always follow this pattern as streams have migrated locally due to channel avulsion (Reference 17). Furthermore, geomorphic mapping (References 17; 154;150) is preliminary and regional in nature, and therefore the mapped locations and correlations of some terraces are uncertain.

2.5.1.1.5.9.2 Geological Evidence – Surface faulting

Geological field investigations in the vicinity of Saline River were conducted to evaluate faults initially identified in road-cuts (Reference 151). Trenches were excavated at several of the road-cuts to evaluate the recency of fault activity. The locations of the field investigation areas are shown on Figure 2.5-20. Investigations have not yet been conducted along the Arkansas or Ouachita Rivers. Observations made in the trench and road-cut exposures indicate post-Eocene faulting and are suggestive of Quaternary faulting, but are not conclusive.

Surface expression of the Saline River source zone includes topographic lineaments and linear drainage patterns. Six small-displacement fault splays have been identified in trenches and road-cuts near Monticello, Arkansas (References 85; 151). Two of these faults trend in a northwest direction parallel to the Saline River. Four subsidiary faults strike east-northeast. The chronology of deformation for each of the sites is summarized in Table 2.5-4.

Five trench and road-cut locations expose faults with Eocene or younger deformation (Reference 151). All faults deform Eocene Jackson Group deposits (Figure 2.5-24). Three trenches exposed faults that deform Pliocene to Pleistocene Upland Complex (Lafayette Gravel). One fault may displace the late Pleistocene Peoria Loess. Holocene silt deposits may be deformed in two trenches, although these relationships are equivocal and could be explained by erosional processes (Reference 151). Relationships observed in the fault exposures indicate strike-slip, normal and reverse senses of displacement. One fault splay underlies a gentle anticline that deforms alluvium with an age of 640 cal. yr B.P. (Figure 2.5-25; note: all ages are reported as 2-sigma calibrated radiocarbon years before A.D. 1950 (present)). This fold is interpreted to be a fault-propagation fold related to Holocene activity along the Saline River fault zone (Figure 2.5-25; Reference 155).

2.5.1.1.5.9.3 Geological Evidence – Liquefaction

Liquefaction-related features have been identified locally within the Saline River source zone in Ashley County and Desha County, Arkansas (Reference 152). The liquefaction features are recognized on the surface as sand blows (Figure 2.5-26). These surficial sand blows were trenched (Reference 152) at five locations to document their stratigraphic relationships and provide estimates of event ages. The three liquefaction sites include Portland, Morgan and Montrose in Ashley County, and Golden and Kelso in Desha County. The liquefaction data from the three sites are summarized in Tables 2.5-5, Rev.1.

The ages of deposits used to interpret the paleoliquefaction features at the Portland, Morgan, and Montrose sites (Ashley County), and Golden and Kelso sites (Desha County) are presented in Figure 2.5-97. This figure shows the minimum and maximum limiting ages and the interpreted age range for the liquefaction events; all radiocarbon ages are presented as 2-sigma calibrated radiocarbon years before present, where "present" refers to the year, A.D. 1950. When reporting calibrated radiocarbon ages we use the abbreviation cal. yr B.P. to indicate calibrated years before A.D. 1950 (present).

One to three liquefaction events are inferred from stratigraphic relationships at the Portland site in Ashley County (References 152, 210). The data for these events are presented on Figure 2.5-97 and Table 2.5-5. The oldest event at this site (Portland Event 1) is identified as a series of "sand blow like features" within a silty clay unit. The limiting ages for this event are based on the age of the substrate (4840 to 5040 cal. yr B.P.) and the age of an overlying silty clay unit (910 to 990 cal. yr B.P.). The second event (Portland Event 2) is identified as a series of sand dikes that feed a sand layer. Sand dikes are cross-cut by a krotavina dated at 150 to 500 cal. yr

B.P. (Reference 210), and therefore are older than the age of the krotavina. The krotavina provides the minimum limiting age for the Portland 2 event. Bioturbated charcoal from within the sand blow yielded ages of 0 to 430 cal. yr B.P. (Reference 210) and is also inferred to represent a minimum limiting age for the Portland 2 event (Reference 210). Charcoal from the silty clay unit yielded an age of 910 to 990 cal. yr B.P. (Reference 210), which provides the maximum limiting age for the Portland 2 event. The youngest event (Portland 3) is constrained by stratigraphic relationships where a sand vent cross-cuts the older sand blow (Reference 152, 210) and is therefore younger than 0 to 500 cal. yr B.P. This younger event could be a separate liquefaction event, or could be related to the initial liquefaction event.

The Morgan I and II events are defined based on the presence of two sand layers separated by a reworked sand-blow/colluvial unit. The minimum age for both units is constrained by a weak soil with a radiocarbon age of 360 to 550 cal. yr B.P. The maximum age for both units is constrained by a luminescence age of 7500 to 6300 years ago on the fluvial substrate. Cox (Reference 211) indicates there are large uncertainties in the luminescence ages.

Two to four liquefaction events can be inferred from stratigraphic relationships at the Montrose site in Ashley County. The radiocarbon ages constraining these events are shown on Figure 2.5-97 and Table 2.5-5. The oldest event (Montrose 1) is represented by a thin sand layer (<13 cm) within the fluvial deposits. The maximum limiting age for this event is based on the age of the substrate (5055 to 5320 cal. yr B.P.) and the age of a soil in an overlying sand layer (1300 to 1550 cal. yr B.P.). There is no date that directly provides a minimum age limit on this oldest sand layer. This layer could alternatively be interpreted as a sill within the fluvial deposits and could be associated with any of the subsequent liquefaction events. In our calculation of recurrence we use this 5320 year age estimate as the maximum allowable age after which all observed events could have occurred.

The Montrose 2 event is defined by another thin (<10 cm) sand layer that overlies the fluvial substrate. The maximum limiting age of both the Montrose 1 and 2 events is constrained by the 5,055 to 5,320 cal. yr B.P. age (Reference 210) of the underlying substrate. There is no date that directly provides a minimum age limit on the Montrose 2 sand layer.

The Montrose 3 event is defined by the thickest sand layer and cross-cuts the Montrose 2 sand layer; no soil development is observed between the Montrose 2 and 3 sand layers (Reference 152). The minimum limiting age of the Montrose 3 sand layer is constrained by a 1,300 to 1,550 cal. yr B.P. date (Reference 210) from the organic soil developed within the layer; this date also represents the minimum limiting age for the Montrose 2 event. The maximum limiting age for the Montrose 3 event is constrained by the 5,055 to 5,320 cal. yr B.P. age (Reference 210) of the underlying substrate.

We infer that the minimum ages of liquefaction events Montrose 2 and 3 must be a minimum of several hundred years older than the age of the soil dated (1300 to 1550 cal. yr B.P.), as the soil horizon on the sand blow would require a period of time to develop. Thus, we infer a minimum age for Montrose 2 and 3 of about 1700 years ago. The exact ages of these events are equivocal. Because there is an absence of soil development between these two sand layers, it is possible that the two sand layers may represent the same liquefaction event. In our calculation of recurrence we use this 1700 year age estimate as the minimum allowable age after which all observed events could have occurred.

The Montrose 4 event is defined based on the presence of a sand blow crater and sand dikes that cross cut the Montrose 3 sand layer. The maximum limiting age of the Montrose 4 sand layer is constrained by a 1,300 to 1,550 cal. yr B.P. date (Reference 210) from an organic soil

developed within the Montrose 3 layer. The minimum limiting age of the Montrose 4 event is constrained by organic material in the sand blow crater dated 320 to 740 cal. yr B.P. (Reference 210).

A single event at the Golden site is defined based on the presence of a sand layer fed by sand dikes and brecciated clay clasts suspended in a fine-grained matrix. Sand dikes that feed sills within the fluvial unit also were observed. The minimum age for the sand layers is constrained by a fill within a crater dated 290 to 510 cal. yr B.P. The maximum age for the liquefaction features is constrained by a luminescence age of 8000 to 8500 years ago on the fluvial substrate. Cox (Reference 211) indicates there are large uncertainties in the luminescence ages.

Cox et al. (Reference 210) interpret two or three events at the Kelso site. The radiocarbon ages constraining these events are shown on Figure 2.5-97. This interpretation is based on clustering of radiocarbon dates from different sand blow craters. However, these sand blow craters feed the same sand layer and no stratigraphic features are reported that distinguish between the sand blow craters. The stratigraphy at this site also permits the interpretation of a single earthquake.

The oldest event (Kelso 1) and the middle event (Kelso 2) are recognized based on stratigraphic relationships observed in the trench where three sand vents feed a sand horizon (Reference 152). Charcoal from organic fill in these sand vents yield ages of 740 to 1,000, 1,030 to 1,040 cal. yr B.P.; 2,010 to 2,190, 2,230 to 2,310 cal. yr B.P.; and 960 to 1,310, cal. yr B.P. Cox et al. (Reference 210) state that dates from 740 to 1,000, 1,030 to 1,040 cal. yr B.P. and 960 to 1,310, cal. yr B.P. are indistinguishable, and interpret these to represent a single event. The older set of dates represents an older event.

The Kelso 1 event is defined based on dates from sand blow craters that range from 2010 to 2310 cal. yr B.P. The dates represent the minimum limiting age for the Kelso 1 event. An alluvial horizon at the base of the trench was dated using infrared spectral luminescence (IRSL) at 5,200 to 6,200 years ago (Reference 209) and represents the maximum limiting age for Kelso 1 event.

The Kelso 2 event is defined based on the younger dates from the sand blow craters that range from 740 to 1310 cal. yr B.P. (Reference 210). The dates represent the minimum limiting age for the Kelso 2 event. An alluvial horizon at the base of the trench was dated using infrared spectral luminescence (IRSL) at 5,200 to 6,200 years ago (Reference 209) and represents the maximum limiting age for the Kelso 2 event.

The Kelso 3 event is based on an anecdotal report that describes ground cracking and bank failures, possibly associated with liquefaction during the 1812 New Madrid earthquakes at this location (Reference 152).

The observed liquefaction features can be interpreted in three ways. First, the liquefaction events record local moderate magnitude earthquakes that produced small liquefaction fields in Ashley County and Desha counties. These events may have been associated with earthquake activity within the Saline River source zone. Second, the observed liquefaction features may record ground shaking related to events in the New Madrid Seismic Zone. Figure 2.5-100 illustrates that the available limiting dates and event age ranges for liquefaction features within the Saline River source zone allow correlation to the New Madrid composite event dates (Tuttle, 2002). This is supported by the historical observation of ground cracking and bank failures near the Kelso site during the 1811-1812 New Madrid earthquake sequence, although this also may

be a local 1812 triggered aftershock within the Saline River source zone. Third, the observed liquefaction fields record a combination of these processes.

2.5.1.1.5.9.4 Seismological Evidence

Very little historical seismicity has occurred within the Saline River seismic zone (Figures 2.5-5 and 2.5-20). Eight earthquakes of m_b 3.3 (lower bound used by EPRI, 1985) to 4.9 occurred within the source zone during the period 1627 to 1984. These events were not temporally or spatially sufficient for the EPRI earth science teams to identify a unique source zone in the Saline River area. One additional earthquake of m_b 3.3 to 3.9 occurred in the source zone during the period 1985 to 2003. Based on the locations of events smaller than m_b 3.3, Cox et al. (Reference 151) suggest that these earthquakes form a weak alignment in a northwest-southeast direction along the trends of the Ouachita, Saline and Arkansas rivers (Figure 2.5-20).

2.5.1.1.5.9.4.1 Earthquake Recurrence Interval

The data presented in Cox's publications (References 152, 209, 210) were used to develop an earthquake recurrence model for the Saline River source zone. Figures 2.5-98 and 2.5-99 illustrate the alternative interpretations of the event history that were used to estimate earthquake recurrence intervals for the Saline River source zone. This earthquake recurrence model was developed independently because none of the publications on liquefaction in the Saline River source zone area (References 152, 209, 210) present earthquake recurrence intervals. We use an approach that estimates the *average* recurrence intervals based on the estimated number of liquefaction events and the minimum and maximum allowable time in which these events could occur. Our recurrence model assumes that all of the liquefaction features could have occurred as a result of four or five earthquakes occurring in the Ashley County and Desha County areas. The minimum time in which these events could occur is between approximately A.D. 1800 (150 yr B.P., where yr B.P. stands for years before A.D. 1950), when historical records became relatively complete, and 1700 yr B.P., the age of the soil formed on the Montrose 3 sand layer. For clarity, we use yr B.P. (omitting "cal.") when referring to a time or period that does not directly correspond to a calibrated radiocarbon age. The maximum time considered is between A.D. 1800 (150 yr B.P.) and 5320 cal. yr B.P., the maximum substrate age based on radiocarbon analysis. Due to the problems with luminescence dating described in References (209, 210, and 211) we choose not to use the older luminescence dates in our analysis.

The four event scenario for the period 150 to 5320 yr B.P. (Figure 2.5-98) involves:

Event IV	Portland 2 and 3, and Montrose 4
Event III	Portland 1, Morgan 1, Montrose 3, and Kelso 2
Event II	Montrose 2
Event I	Morgan 1, Montrose 1, Golden 1, and Kelso 1

The five event scenario for the period 150 to 1700 yr B.P. (Figure 2.5-99) involves:

Event V	Portland 3
Event IV	Portland 2 and Montrose 4
Event III	Kelso 2
Event II	Montrose 2 and 3 and Golden 1
Event I	Portland 1, Morgan 1, and Montrose 1

Recurrence times for the four and five event scenarios are estimated at 388 and 1725 years and represent the lower bound and middle values used in our hazard analysis (Table 2.5-6). The shortest recurrence time of 388 years (rounded to 390 years) represents the average recurrence time for five events during the period 150 yr B.P. (A.D. 1800) to 1,700 yr B.P. The 1,700 year lower boundary was used because this represents the shortest, most conservative, time period in which the events could occur. The 1,725 year recurrence time represents the average recurrence time for four events occurring between 150 and 5,320 cal. yr B.P. (Table 2.5-6), the longest time period in which the events could occur. The 3,505 year recurrence time (rounded to 3500 years) represents the dated interval (5055 cal. yr B.P. minus 1550 cal. yr B.P.) between minimum and maximum limiting ages for liquefaction events at the Montrose site in Ashley County. This recurrence was selected to approximate a longer possible recurrence time in addition to using the average recurrence interval calculation (above). The 3500 year recurrence value is the upper bound value used in our hazard analysis.

2.5.1.1.5.9.4.2 Slip Rate

The amount of stream incision into terraces of known age can be used as a proxy to estimate the total amount and rate of block uplift and thus, the amount and rate of vertical separation on the assumed bordering faults (Reference 157). This approach was used to evaluate the possible rate of deformation within the Saline River source zone. Cross-sections used to estimate slip rates on the Saline River source zone are shown on Figure 2.5-23. Although not as precise as displacement data from paleoseismic trenches, the incision rates provide an order of magnitude estimate of long-term incision and slip rate. Figure 2.5-23 provides estimates of incision rates, used as a proxy for vertical slip-rates, for various terrace surfaces. The rates range from 0.05 to 1.7 mm/yr.

We use the geologic relationships in trenches near Monticello (Sites 3 and 4 of Reference 151) to estimate fault slip-rate. As shown on the enlargement on Figure 2.5-20, a subsidiary northeast-trending fault is offset approximately 30 meters by a northwest-trending fault that possibly deforms Upland Complex deposits. The base of the Upland Complex is offset by the northwest trending fault; this fault terminates within the Upland Complex. Based on the 30-meter offset of the secondary fault and a 1 to 4 million year age range of the Upland Complex, the fault slip rate is estimated to be 0.008 to 0.03 mm/yr. Because this fault is likely a subsidiary fault within a larger fault zone, we infer that this slip-rate is a minimum bounding estimate for the rate of deformation within the Saline River source zone.

2.5.1.1.5.9.4.3 Maximum Earthquake Magnitude

Potential magnitudes of M 5.5 to 6.0 for the events that produced the liquefaction fields in Ashley and Desha counties have been estimated (Reference 152). If the events reflect localized seismicity, this magnitude range is a reasonable lower bound estimate for the maximum magnitude within the Saline River source zone. However, if each of the liquefaction fields corresponds to a prior New Madrid seismic zone event, the observed liquefaction features

would not support the presence of a distinct seismic source along the Saline River in southeastern Arkansas.

2.5.1.1.5.10 Non-Tectonic Structural Features

In addition to the tectonic features described above, non-tectonic (non-seismogenic; Reference 141) processes also produced structural and topographic features in the Site Region. These features locally deformed Gulf Coastal Basin sediments and include volcanic domes, salt diapirs, and growth faults. The timing and processes controlling these features are described in the following sections.

2.5.1.1.5.10.1 Volcanic Domes

The Jackson Dome is a circular, 16-mile-diameter volcanic plug located at the southern margin of the Mississippi Embayment near the city of Jackson in west-central Mississippi (Figure 2.5-3). The dome was formed by the arching of strata above a deep-seated igneous intrusion. The dome became active in the Early Cretaceous, continued to rise through post Oligocene time, and has a total structural relief of about 10,000 feet. Outcrops of the Oligocene Vicksburg Group, including the Glendon Limestone are preserved on the dome's northwestern flank (Reference 142). Although the dome appears to be dormant, radiometric dates in the State #2 Fee well show a 26-million-year gap in activity between 101- and 75-million year old igneous rocks suggesting long intervals between periods of activity (Reference 142). Interpreted seismic lines along the flanks of the Jackson Dome have identified several faults in the Jackson area, including an east-west-trending fault south of Florence, Mississippi, and six additional northwest-southeast trending faults that extend from the dome's eastern flank (Reference 34). The youngest strata offset by these faults is the Upper Cretaceous Eutaw Formation. Bograd speculated that a 1927 earthquake that shook houses as far away as Meridian, Mississippi occurred on a fault in the Jackson area (Reference 143). However, there is no clear association of earthquake activity with faults associated with the Jackson Dome.

The Monroe Uplift is a volcanic dome that straddles southern Arkansas, northern Louisiana, and west central Mississippi (Figure 2.5-3). The northern margin of the Gulf Coast Basin and southwestern extent of the Mississippi Embayment coincides with the Monroe Uplift. The circular area of the dome is approximately 93 miles in diameter and is characterized by the arching of strata above a deep-seated igneous intrusion. The Monroe Uplift initially became active in the Jurassic and experienced continued movement into post-Miocene time. There is no topographic expression of the Monroe Uplift at the surface. However, Burnett and Schumm (Reference 144) evaluated fluvial geomorphic features distributed across the uplift and concluded that the rivers were adjusting to modern deformation. Upstream of the uplift the river had less bank erosion, a reduced sinuosity, lower channel and valley gradient, and lower channel depth than downstream (Reference 144). Additionally, they found that the river terraces showed a convex pattern across the Monroe Uplift and inferred active uplift in the Pleistocene and Holocene.

The Sabine Uplift is a volcanic dome located in east Texas and western Louisiana (Figure 2.5-3). The dome has a roughly oval shape, approximately 124-miles long in the north-south direction and 93-miles wide in the east-west direction. The uplift is a flat-topped structural high that was active in post-Middle Eocene time. No active faulting or seismicity has been associated with the Sabine Uplift.

2.5.1.1.5.10.2 Salt Diapirs

Salt migration structures or salt domes occur in two subprovinces within the Gulf Coastal Plain, the Interior Salt Basin and the Coastal Salt Basin (Figure 2.5-3). Salt migration produced anticlinal structures, ridge-like diapiric folds, and piercement domes in these subprovinces. Salt originated from the Middle Jurassic Louann Salt and salt migration structures are concentrated in an approximately 100-mile-wide zone extending from southwestern Alabama to eastern Texas (Figure 2.5-3). The source depth for the Louann Salt is around 15,000 feet and becomes progressively deeper to the south (Reference 30). Salt Domes in the Interior Salt Basin were active from Late Cretaceous to Oligocene and have not been active since (Reference 30).

Salt Domes in the Coastal Salt Basin began to form in the Miocene and have been active through the Quaternary. The source depth for the Louann Salt in the Coastal Salt Basin is around 35,000 feet and approaches 65,000 feet in the vicinity of the southernmost offshore salt domes.

Salt migration in the Coastal Salt Basin deforms the ground surface. The Five Islands structural uplift is a northwest-southeast trending line of salt domes in south central Louisiana. These domes are expressed at the surface and deform a subsurface Quaternary gravel suggesting Pleistocene activity (Reference 17).

2.5.1.1.5.10.3 Growth Faults

East-west-trending growth faults along the southern margin of the Gulf Coastal Basin are referred to as the Gulf Margin Normal faults. These faults include the Tepetate-Baton Rouge, Denham Springs-Scotlandville, Lake Hatch, Golden Meadow, Lake Sand, Grand Chenier, Lake Arthur and Mamou faults, as well as many other un-named faults. Seismicity within the zone is sparse, with only nine felt earthquakes in historic time (Reference 145).

The opening of the Gulf of Mexico formed a south–facing, rifted margin during the Triassic. Along this margin, a thick package of Jurassic and younger sediment was deposited including the Louann Salt, and overlying carbonate and clastic marine sediments. This sedimentary sequence is in excess of seven miles thick in the vicinity of the Gulf Margin Normal faults. The Louann Salt is inferred to form a sliding layer on which the overlying sedimentary section has mobilized forming a series of Tertiary and Quaternary growth faults. Because the faults are located in poorly lithified rocks and sediments, they may not be able to support the stresses required for the propagation of significant seismic ruptures that could cause damaging ground motions (Reference 113).

Faults generally dip between 50 and 70 degrees at the surface and shallow to less than 50 degrees at depth (Reference 29). Additionally, strata increase in thickness on the downthrown side of faults and displacements increase with depth. Periods of movement on the faults range in age from late Eocene to Holocene depending on the location of the Mississippi River depo-center. The current Gulf Margin Normal faults are localized along the subsurface Cretaceous shelf edge and experience high rates of aseismic slip.

Slip rate estimates for the Baton Rouge fault vary from a Pleistocene rate of 0.05-0.08 mm/yr (References 113; 146) to a Holocene rate of 9 mm/yr determined by leveling surveys conducted by the Louisiana Water Research Institute (Reference 16). Rates as high as 4 cm/yr have been measured from Global Positioning System (GPS) data (Reference 147). The largest earthquakes recorded in Louisiana were two M 4.4 events that occurred on the same day in April, 1964, however, the majority of the recorded earthquakes in Louisiana range in magnitude from 2.5 to 3.5 (Reference 148). The most recent and best located event occurred on October

16, 1983. The depth determination for this event shows that it occurred at approximately 8.5 miles (Reference 148; 149), possibly in basement materials beneath the sedimentary prism.

2.5.1.1.6 Regional Seismicity

Much of the central and eastern U.S. seismicity appears to occur due to reactivation of older Rift bounding faults and sutures between exotic terranes (References 164, 165). Historical seismicity in the region is most strongly concentrated in the Reelfoot Rift and New Madrid Seismic Zone north of the Gulf Coastal Plain. Small magnitude earthquakes also occur along the general trend of the Ouachita Orogenic Belt and Appalachian Mountains. In the areas south of the Ouachita Orogenic Belt and Appalachian Mountains there is a very low rate and a random spatial distribution of epicenters.

Due to the regions tectonic stability, there have been relatively few recorded earthquakes. Reference 78 compared the seismicity of the central U.S. to that of the southern California. The activity rate of magnitude 4 earthquakes in the 3,000,000 km^2 area of the central U.S. is more than a factor of 10 lower than that of a 200,000 km^2 area of southern California. The rate of magnitude 6 earthquakes is about a factor of 30 lower. This low rate of activity has characterized the seismicity of the Gulf Coastal Plain for over 150 years, and most likely throughout the Quaternary.

Because the south central United States is a passive continental margin, there are *no plate boundary fault systems* that accommodate relative plate motion, focus earthquake activity, and produce repeated large magnitude events. Earthquake activity appears to be concentrated along reactivated older tectonic elements such as the Reelfoot Rift. Furthermore, no faults have been mapped within approximately 90 miles of the proposed location of the new facility at the Grand Gulf Nuclear Station.

2.5.1.1.6.1 Location and Distribution

The location of seismicity is shown on Figure 2.5-5. The seismicity shown on this figure is for the period 1627 to 1984, which covers the period used in the 1986 EPRI analysis, and 1985 to 2003, which covers the period since the EPRI study. The updated EPRI Seismicity catalog is described in section 2.5.2.1.4. As can be seen on Figure 2.5-5, the current seismicity trends are very similar to the location and distribution of seismicity for the period considered in the EPRI study (Reference 9). The events are concentrated along the Reelfoot Rift, Ouachita Orogenic Belt, and Appalachian Mountains, primarily in regions underlain by continental crust. Few earthquakes have occurred within the Gulf Coast Basin, and no earthquakes have been recorded within the Site Vicinity or Site Location.

2.5.1.1.6.2 Historical Events in Site Region

The Site Region is characterized by very low rates of seismic activity. Only two earthquakes of $3.3<m_b<3.9$ have been recorded within 100 miles of the site since 1627 and only 39 earthquakes of $m_b>3.3$ have been recorded in the entire 200 mile radius around the site. Most earthquakes in the site region occur in areas underlain by crystalline basement rock of the North American craton, and within the buried Ouachita Orogenic Belt, or Appalachian Mountains.

Since the 1986 EPRI study, only five earthquakes of $m_b>3.3$, the lower limit used in the EPRI study, have been recorded in the Site Region.

2.5.1.1.6.3 Historical Events in Site Vicinity

Historical seismicity records for the Site Region extend back to A.D. 1627. Based on our review and analysis of these historical seismicity records there have been no earthquakes recorded within the Site Vicinity. The nearest earthquake to the site occurred approximately 25 miles to the north near Vicksburg, Mississippi.

2.5.1.2 Site Geology

This section presents information on the physical setting, geological history and subsurface conditions within the Site Area (5-mile radius) and Site Location (0.6-mile or 1-km radius) of the proposed new facility at the Grand Gulf Nuclear Station. Engineering Report ER-02 (Reference 15) provides the results of detailed field and laboratory investigations performed at the proposed location of the new facility during this study.

2.5.1.2.1 Site Physiography and Geomorphology

The Site Area and Site Location straddle the western boundary of the Loess Hills physiographic subprovince (Figure 2.5-2). The proposed location of the new facility is approximately 1.1 miles east of the Mississippi River and adjacent to the Mississippi River flood plain (Figures 2.5-9 and 2.5-27). The boundary between the Mississippi Alluvial Valley and Loess Hills physiographic subprovinces crosses the Site Location and is defined by the approximately 65- to 80-foot-high north-trending erosional escarpment at the edge of the Mississippi River flood plain.

As shown on Figure 2.5-27, the topography of the Loess Hills in the Site Area is characterized by steep-walled stream valleys, flat-topped ridgelines, and dendritic drainage systems. Large river terraces occur along river floodplains and valley bottoms. Older terraces are present between elevations of about 140 and 200 feet along the tributary valleys of Bayou Pierre and Big Black River, and along the eastern margin of the Mississippi Valley (Figures 2.5-9 and 2.5-27). The topography of the Mississippi Alluvial Valley in the Site Area is relatively flat and characterized by flood plain, cut-banks, point bars, and oxbow lakes. The 0.6-mile radius of the Site Location does not extend to the active channel of the Mississippi River.

The proposed location of the new facility encompasses approximately 30 acres (Figure 2.5-27). The location does not represent the footprint of the proposed power block, but a larger area for overall construction purposes that envelops all potential facility footprints being considered. The proposed location straddles two previously graded surfaces at elevations of 132 feet and 155 feet, separated by a 23-foot high engineered cut-slope (Figure 2.5-28). The graded surfaces were former parking lots and lay-down areas used during construction of the existing Grand Gulf Nuclear Station.

The proposed facility location is bounded on the east by existing internal plant roads and parking lots (Figure 2.5-28). The location is bounded on the west by the erosional escarpment at the edge of the Mississippi River flood plain and on the north and south by two ravines that drain the Site Location.

2.5.1.2.2 Site Geologic History

The geological formations underlying the Site Area and Site Location record a long history of tectonic stability and deposition. The formations include both marine and terrestrial sediments that reflect distinct changes in depositional environments, climatic conditions, and glacial-eustatic cycles over the past 36 Ma. Deposits of at least Oligocene and younger age dip very gently southward and are laterally continuous across the Site Region (Figures 2.5-6, 2.5-11 and 2.5-12). These deposits are not deformed and thus document long term tectonic stability. The

geological history of the Site Area and Site Location from the Oligocene period to the present is discussed below; regional geological history and descriptions of events that are older than Oligocene are presented in Section 2.5.1.1.

The Oligocene depositional environment in the Site Area was dominated by shallow marine seas, in which the Glendon Limestone and Byram Marl formations of the Vicksburg Group were deposited (Reference 16). These deposits primarily consist of limestone and marl with interbedded calcareous sands and clays. The Byram Marl was overlain by the late Oligocene Bucatunna Clay Formation, possibly representing a transition to a deep water or estuarine environment. The Glendon Limestone occurs at a depth of approximately 300 feet beneath the Site Area (Figure 2.5-15; Reference 16). These deposits are overlain unconformably by the Miocene Catahoula Formation.

In the Miocene, the depositional environment at the site changed from a marine to a marginal shoreline environment, in which the Catahoula Formation was deposited (Reference 16). These deposits consist of silty to sandy clays, clayey silts, and sands. The surface of the Catahoula Formation was deeply eroded at the site prior to deposition of the Pliocene to Pleistocene age Upland Complex based on the structural contour map shown on Figure 2.5-29.

In the Pliocene and Pleistocene, the depositional environment again changed from a marginal shoreline to an alluvial environment, in which alluvial deposits correlative with the Upland Complex were deposited. These deposits consist of coarse sand and gravel derived from both glacial and non-glacial sources (Reference 17). Pliocene-Pleistocene Upland Complex deposits unconformably overlie the eroded surface of the Catahoula Formation (Figures 2.5-30, and 2.5-31).

Late Pleistocene terraces were deposited in response to Wisconsin-age glacial cycles that supplied large volumes of sediment to the Mississippi Alluvial Valley (References 17; 31; 32). Subsequent stream incision eroded the terraces along north-northeast trending valleys that cross the Site Location (Figure 2.5-32).

At various periods in the late Pleistocene, strong seasonally prevailing winds transported silt from unvegetated glacial outwash in the central United States (Reference 17). As a result, the Peoria, Ferndale, Roxanna, and Lovelend loess sheets were deposited in the Site Vicinity and Site Area, between Vicksburg and Natchez (Figure 2.5-8). The youngest loess sheet, the Peoria Loess, is late Wisconsin in age (Reference 21). The average thickness of loess in the Site Location is about 65 feet; however, individual loess sheets have not been differentiated in the Site Location. Throughout the Holocene, loess deposits were deeply eroded by tributary streams to the Mississippi River. During this time alluvial sediment also was deposited on the Mississippi River flood plain in the western part of the Site Area and Site Location, and in tributary stream valleys along the northern and southern portions of the Site Area and Site Location (Figures 2.5-9 and 2.5-27). Deposition of alluvial deposits during peak glacial outwash may have changed local base-levels, blocking stream outlets and leading to the ponding or deposition of silt and alluvium in tributary valleys. The subsequent drop in river-level in the current interglacial period is inferred to have caused incision and formation of the terraces remnants along Bayou Pierre and Big Black River.

The Oligocene and younger deposits demonstrate a long period of tectonic stability and the absence of tectonic deformation in the Site Area and Site Location. As shown on Figures 2.5-9, there are no faults or folds in the Site Area. A structure contour map on the surface of the Oligocene Glendon Limestone (Figure 2.5-15) also documents the absence of post-Miocene

age deformation. Figure 2.5-12, a cross-section through the Site Area, documents the lateral continuity of strata, and therefore the absence of faulting within the Site Area.

2.5.1.2.3 Site Geologic Conditions

The characteristics of the individual deposits that occur in the Site Area and Site Location are described below in Section 2.5.1.2.4.1. Geologic maps of the Site Area and Site Location are shown on Figures 2.5-9 and 2.5-27, respectively. Geologic cross-sections are shown on Figures 2.5-11 for the Site Vicinity, and Figures 2.5-30 and 2.5-31 for the Site Location.

2.5.1.2.3.1 Site Stratigraphy

Extensive geological and geotechnical data for the Site Area and Site Location are available as a result of the investigations completed for the existing Grand Gulf Nuclear Station (Reference 16). During this investigation, 275 borings were drilled within the Site Area to a maximum depth of 447 feet. The borings were completed to document geological and geotechnical conditions of the Site Area. In addition, 22 seismic refraction surveys were completed. The seismic refraction surveys were completed to document the lateral continuity and seismic velocity characteristics of the subsurface stratigraphy.

In addition to the existing database for the Grand Gulf Nuclear Station, three new soil borings, four Cone Penetrometer Tests (CPT), two down-hole geophysical surveys, and geological field observations were completed during this study to evaluate subsurface conditions at the proposed location of the new facility and to provide input parameters to assess dynamic response of subsurface materials (Sections 2.5.2 and 2.5.4). The new soil borings were advanced to depths ranging from 141 to 238 feet and penetrated strata ranging in age from the Holocene to the Miocene. The CPTs were advanced to depths of 60 to 80 feet terminating in sands and gravels of the terrace deposits of probable Pleistocene age.

2.5.1.2.3.1.1 Quaternary Deposits

Holocene and Pleistocene age gravels, sands, silts, and clays occur within the Site Area and Site Location (Figures 2.5-9 and 2.5-27). These deposits are related to fluvial processes along the Mississippi River and its tributaries, and eolian processes that formed the Loess Hills along the eastern margin of the Mississippi Alluvial Valley. The Quaternary deposits described in this section typically have an unconformable depositional relationship with the underlying Pliocene to Pleistocene Upland Complex, or Tertiary Catahoula deposits, described below.

2.5.1.2.3.1.1.1 Holocene Series

Holocene sediments consist of fluvial deposits on the flood plain of the Mississippi River, alluvium and terrace deposits in tributary valleys, and colluvium along hill slopes in the Loess Hills. Holocene fluvial deposits of the Mississippi River flood plain occur between the Mississippi River and the Loess Hills bluff, and represent the filling of at least two abandoned river channels (Reference 16). Hamilton and Gin lakes, which lie within or adjacent to the Site Location, are oxbow lakes that represent abandoned Mississippi River meander scars. The area between Hamilton Lake and the Loess Hills bluff is underlain by backswamp deposits (Hb) shown on Figure 2.5-9.

Holocene alluvium and terrace deposits in the Site Area occur along Bayou Pierre and small tributary streams (Figure 2.5-9). Terrace deposits along Bayou Pierre lie at elevations of approximately 120 feet and form well-defined planar surfaces above the modern flood plain. Remnants of Holocene terraces also occur along the Loess Hills bluff and along the tributary valley that crosses the Site Location (Figure 2.5-27). Holocene alluvial deposits in the Site Area

range in thickness from 22 to 182 feet and unconformably overlie the Miocene Catahoula Formation (Reference 16).

Holocene colluvial deposits in the Loess Hills drape the base of the bluffs and valley walls along the flood plain and tributary valleys of the Mississippi River. The colluvial deposits consist of brown silt, clayey silt, or silty clay derived from erosion of the loess materials and are up to 47 feet thick (Reference 16).

2.5.1.2.3.1.1.2 Pleistocene Series

The distribution of Pleistocene sediments within the Site Area and Site Location is shown on Figures 2.5-9 and 2.5-27, respectively.

Terrace Deposits

Pleistocene terrace deposits occur in the Site Area along the Loess Hills bluff, Bayou Pierre, and small tributary streams (Figures 2.5-9, 2.5-33). Although not within the Site Area, Pleistocene terraces also occur along the Big Black River. The Pleistocene terraces in the Site Area were mapped in a generalized manner (undifferentiated), as shown on Figure 2.5-8 (Reference 44). Figures 2.5-9 and 2.5-27 present more detailed mapping of the Pleistocene terraces. The terraces shown on Figures 2.5-9 and 2.5-27 were identified based on aerial photograph interpretation, topographic analysis, and field observations.

Terraces are recognized as broad very low relief surfaces up to 0.75-miles across that are dissected by dendritic surface drainage systems (Figure 2.5-33). The back-edges of the terraces are defined by topographic breaks in hillslopes. In the Site Area, terraces occur at elevations of approximately 140, 160, and 180 feet. The elevations of the terrace treads vary by plus or minus 10 feet. Additional discontinuous remnants of terraces may occur at elevations in excess of 200 feet, though distinguishing these from older pediment surfaces is difficult.

The location of the proposed new facility lies on an inferred latest Pleistocene terrace surface at an elevation of approximately 150 feet. Based on subsurface data from borings completed at the site (Figures 2.5-34 through 2.5-37), the Pleistocene terrace surface is underlain by up to 75 feet of loess. The loess is underlain by coarse-grained alluvial sand and gravel deposits of the Upland Complex (described below).

The Pleistocene terraces appear to be formed on the loess deposits or have incorporated reworked loess within the alluvial systems. Therefore, these surfaces are inferred to be of late Pleistocene (late-Wisconsin) age, the age of the loess sheets in the Site Area (Reference 21).

The Pleistocene terraces are inferred to have formed through a combination of processes. During the late-Wisconsin the Mississippi River was a much higher energy river and as such would have a higher base level to tributary drainages (Reference 17). The model involves either erosion of loess deposits within the tributary valleys, or ponding of loess within tributary valleys, as a result of the higher base level in the Mississippi River. Transport of course-grained valley train deposits during the late-Wisconsin also could have dammed or bridged the mouths of tributary streams causing formation of fill terraces or lakes. The late-Wisconsin Lake Monroe is an example of a lake formed by natural damming of an alluvial valley by the valley train deposits (Reference 17).

Incision of alluvial systems within tributary valleys where fluvial terraces are preserved is related to a lowering of base level along the Mississippi River. This change in base-level may be partly related to the fall in river base-level following de-glaciation. Elevation differences between Pleistocene valley train deposits and the Holocene meander belts indicates a minimum base-

level change of 16 to 32 feet. Flexural bending of the crust due to large sediment loads in the Mississippi River delta also may have caused uplift and subsequent stream incision. Land leveling data indicate that uplift is occurring with rates of 0.039 in/yr (1 mm/yr) to 0.078 in/yr (2 mm/yr) extending as far north as Jackson, Mississippi (Reference 158), which encompasses the Site Area. A rate of 0.039 in/yr (1 mm/yr) extrapolated over the past 18 thousand years would result in approximately 60-feet (18-meters) of uplift. The combination of base-level change following deglaciation and uplift due to flexural bending provides a sufficient change in relative base-levels (i.e. 76 to 92 feet) to have caused incision and preservation of the fluvial terraces observed in Bayou Pierre and the smaller tributary valleys in the Site Area. The formation and preservation of Pleistocene terraces in the Site Area is interpreted to have occurred due to the combination of these non-tectonic processes.

Loess

Three distinct Pleistocene age loess sheets occur between Vicksburg and Natchez in the Site Vicinity. These include the Peoria, Roxanne, and Loveland loess sheets (Reference 21). Within the Site Area, the loess deposits are undifferentiated. Loess deposits are up to 100 feet thick and consist of well sorted, yellowish brown, damp, medium stiff sandy to clayey silt with weak blocky structure. Below depths of about 12 to 15 feet, the loess has a slightly darker color, becomes more calcareous and massive with depth, and contains zones of gastropods and shell fragments. Zones with shell fragments are interpreted to represent either reworked surficial deposits or small ponds and depressions in the loess surface that supported gastropods. The loess unconformably overlies Upland Complex deposits.

2.5.1.2.3.1.2 Tertiary Deposits

2.5.1.2.3.1.2.1 Pliocene – Pleistocene Series

Upland Complex deposits occur beneath the loess deposits in the Site Area (Figure 2.5-9; Reference 17, 32, 33). This complex consists of interbedded alluvial gravel, sand, and clay (Reference 17). Individual depositional units and unit ages within the Upland Complex are not differentiated.

Borings advanced in the Site Location encountered two alluvial units (Figures 2.5-30 and 2.5-31); these alluvial deposits are mapped as part of the Upland Complex (Reference 44). At the proposed location of the new facility, the upper alluvial deposit is first encountered between 68 to 71 feet elevation and ranges from 46 to 85 feet thick. The upper alluvial deposit consists of light gray to brownish yellow sand to silty sand. The silty sand consists of fine- to medium-grained well-sorted quartz grains with silt, and is massive, dense, and friable to very friable.

The lower alluvial deposit is first encountered between elevations of 24 to –14 feet and ranges from 11 feet to 89 feet thick across the proposed facility location. The variation in the thickness of the lower alluvial deposit is due to the amount of relief on the underlying and eroded Catahoula Formation surface (Figure 2.5-29). The lower alluvial deposit consists of stratified thinly bedded sands, silty clays, and gravels. The silty clay beds range in thickness from a few inches to feet, and are yellowish brown to brown. Sand beds are similar to the upper alluvial deposit described above, but generally are better sorted, finer grained, and have a greater degree of oxidation. Gravel layers range in thickness from one foot to tens of feet, and are composed of fine- to medium-grained, sub-rounded gravel with localized cobbles.

2.5.1.2.3.1.2.2 Miocene Series

Miocene deposits are not mapped at the surface in the Site Area or Site Location, but underlie terrace and loess deposits at shallow depth (Figures 2.5-29, 2.5-30, and 2.5-31). In the subsurface, Miocene deposits include the shallow marine sediments of the Catahoula Formation. These deposits consist of hard to very hard, gray to gray-green, silty to sandy clay, and clayey silt and sand, with some locally indurated or cemented clay, sand, and silt seams (Reference 22). The Catahoula Formation occurs about 125- to 175-feet below the Site Location (-20 to -30 feet elevation) and has a maximum thickness of 320 feet in the Site Area (Reference 16). The Catahoula Formation unconformably underlies the Upland Complex and loess, and overlies the Oligocene Vicksburg Group. The Catahoula Formation is identified as the load-bearing stratum for the existing major plant structures at the Grand Gulf Nuclear Station (Reference 16).

2.5.1.2.3.1.2.3 Oligocene Series

Oligocene deposits do not occur at the ground surface in either the Site Area or Site Location. The Oligocene deposits in the subsurface include sediments of the Vicksburg Group and the Forest Hill Formation (Figures 2.5-5 and 2.5-11). The Vicksburg Group consists of four formations, which from youngest to oldest include the Bucatunna, Byram Marl, Glendon Limestone, and Mint Spring formations. These deposits were encountered in two previous borings in the Site Location (B-4 and B-84; Reference 16) and two previous borings in the Site Area (G-3 and G-4; Reference 16). Lithologic descriptions of the Vicksburg Group formations are presented below.

The Bucatunna Formation consists of stiff to hard greenish-black to black clay with thin, gray, fine sand seams. This formation occurs at an elevation of -250 feet and unconformably overlies the Byram Marl. The Byram Marl Formation consists of hard to very hard, green to gray, fine sandy, calcareous clay, is discontinuous, and conformably overlies the Glendon Limestone. The Glendon Limestone consists of interbedded, light gray, fossiliferous limestones, and hard to partly indurated, grayish-green, fine sandy, calcareous clays. This formation occurs between elevations of –260 and –340 feet, and unconformably overlies the Mint Springs Marl. The Glendon Limestone Formation is laterally continuous beneath the Site Area and provides an excellent marker horizon to construct a structure contour map from which to evaluate the presence or absence of tectonic deformation (Figure 2.5-15). The Mint Springs Marl consists of hard, grayish green fossiliferous, glauconitic sand and clay and is at least 45 feet thick beneath the Site Location. The Mint Springs Formation unconformably overlies the Forest Hill Formation.

2.5.1.2.4 Site Structure

2.5.1.2.4.1 Faults and Folds

Laterally continuous deposits of Oligocene and younger age extend in the subsurface across the Site Area (Reference 16). These deposits have a gentle southward depositional gradient and are undeformed (Figures 2.5-10, 2.5-30 and 2.5-31). No faults are mapped within the 5-mile radius of the Site Area (Figure 2.5-9; References 52; 53).

The continuity of subsurface deposits demonstrates the tectonic stability of the Site Area and Site Vicinity from at least Oligocene time, approximately 30 Ma, to present. For example, the top of the Glendon Limestone surface shows no morphology indicative of tectonic deformation (Reference 16). The top of the Glendon Limestone Formation within the Vicksburg Group slopes to the southeast from elevations of approximately -140-feet in the northwestern part of the Site Area to -440-feet in the southeastern part of the Site Area (Figure 2.5-15). The surface appears

to have been eroded, forming a buried drainage basin morphology. The lateral continuity of the formation and the absence of faults or folds documents the absence of post-Oligocene deformation in the Site Area and Site Location. No new information has been developed since the original investigations for the Grand Gulf Nuclear Station (Reference 16) that would suggest the presence of faulting within the Site Area.

The Oligocene Vicksburg Group was eroded and unconformably overlain by deposits of the Miocene Catahoula Formation. The top of the Catahoula Formation in the Site Location forms a gentle southwestward sloping surface (Figure 2.5-29). The Catahoula surface morphology preserves a Pliocene to Pleistocene erosion surface of the ancestral Mississippi Alluvial Valley, as well as a former tributary valley that extended across the Site Location; variations in elevations across the surface of the Catahoula Formation reflects former stream erosion. The top of the Catahoula Formation shows no morphology indicative of tectonic deformation, and no new information is available since the original investigations for the Grand Gulf Nuclear Station (Reference 16) that would suggest the presence of faulting within the Site Area.

Upland Complex deposits in the Site Location are eroded and two west-trending drainages cross the Site Location (Figure 2.5-32). These drainages are the current active channels in the Site Location. As discussed above, the Upland Complex is unconformably overlain by loess. The surface of the Upland Complex shows no morphology indicative of tectonic deformation, and no new information is available since the original investigations for the Grand Gulf Nuclear Station (Reference 16) that would suggest the presence of faulting within the Site Area.

2.5.1.2.4.2 Unconformities

With the exception of the conformable contact between the Oligocene Glendon Limestone and Byram Marl formations of the Vicksburg Group, all of the subsurface deposits in the Site Area and Site Location are separated by erosional unconformities. The unconformities indicate that erosion rather than tectonic deformation is responsible for elevation differences across the surfaces of the Upland Complex alluvial deposits, Catahoula Formation, and the Glendon Limestone Formation (Figures 2.5-15, 2.5-29, and 2.5-32).

2.5.1.2.4.3 Other Structures

2.5.1.2.4.3.1 Salt Domes

The proposed location of the new facility at the Grand Gulf Nuclear Station is located along the northern margin of the Mississippi Salt Basin (Figure 2.5-3). However, no salt domes occur in the Site Area or Site Location. The nearest salt domes are the Bruinsburg Dome located 6.5 miles southwest of the site, and the Galloway Dome located 8 miles northeast of the site (Figure 2.5-8). The depth to salt of the Bruinsburg Dome is 2020 feet, and the depth to salt of the Galloway Dome is 4196 feet (Reference 16). The Bruinsburg and Galloway domes have upwarped the Glendon Limestone strata in the Site Vicinity (Figure 2.5-15), but do not affect the Miocene Catahoula Formation.

2.5.1.2.5 Geotechnical Properties of Subsurface Materials

On the basis of review of existing UFSAR and site investigation data, the proposed ESP location appears to be suitable for support and good performance of the new facility. Plant foundations should be supported on dense alluvium, old alluvium, or Catahoula Formation below the surficial loess soils. Because the Catahoula Formation claystone was encountered at a significant depth below the ESP Site (greater than 170 feet deep), unreasonably deep excavations extending well below the water table would be required to place foundations in this

material. It is more likely that dense layers within the alluvium or old alluvium will be considered for foundation support of the new plant. The alluvium primarily consists of medium dense to dense sands that should be suitable for foundation support provided that future quantitative analyses confirm that liquefaction or cyclic pore pressure increases will not adversely affect foundations. The old alluvium consists of sandy and clayey strata that appear to be in a dense to very dense (very stiff to hard) condition, and are similar to the materials described as supporting the existing GGNS foundations. According to the UFSAR, the operating GGNS has performed well without adverse foundation movements (Reference 16).

As discussed previously, a plant design has not been selected, and the footprint and embedment depth of the plant have not been determined. It is anticipated that any new facility will maintain the existing plant grade of approximately Elevation 132, but that the plant will be founded in alluvium, at or below the bottom of the loess deposits, at approximately Elevation 80, or lower, where the average shear wave velocity exceeds 1,000 feet per second. If the bottom of the plant is located above this elevation, then the natural soils should be excavated to below the loess and replaced with engineered fill that has a minimum shear wave velocity of 1,000 feet per second. Any excavation outside the structural walls of the plant would also be backfilled with engineered fill. All engineered fill would be compacted to a density that would preclude settlement or, should it be below the water table, liquefaction under dynamic loading conditions. The ESP site envelopes all potential plant layouts and embedment depths. Additional site exploration, laboratory testing, and geotechnical analyses will be performed specifically to characterize site conditions for geotechnical analyses and foundation design for the Construction and Operating License (COL) phase of the project after a plant design has been selected. These additional studies should include the following:

- Additional conventional SPT and mud rotary borings on a pattern throughout the plant footprint area;
- Additional CPT and geophysical surveys;
- Additional laboratory index, strength and consolidation testing;
- Quantitative liquefaction, bearing, and settlement analyses;
- Dynamic soil-structure interaction;
- Stability analyses for planned cuts and foundation excavations;
- Groundwater and potential excavation seepage studies;
- Confirmatory site-response analysis.

2.5.1.2.5.1 Static Properties

Static soil properties are described in Section 2.5.4.1, and are summarized on Table 2.5-7. These properties include: moisture content, dry density, Atterberg Indices, mechanical sieve and hydrometer grain size analyses, and consolidated undrained (CU) triaxial shear testing.

No swelling or consolidation tests were conducted for the ESP study, but the UFSAR for the existing plant (Reference 16) states that: *"Tests were performed to evaluate the swell potential of the Catahoula Formation. Swell tests and X-ray diffraction indicate the Catahoula Formation is nonexpansive and the swell deformation potential is negligible. The natural moisture content is near the plastic limit, which indicates preconsolidation. The Catahoula Formation is a*

granular-cohesive material which is insensitive, the compressibility is low, and the overconsolidation ratio is in excess of 2."

An overconsolidation ratio of 2 referenced in the UFSAR (Reference 16) appears to actually be a lower bound value based on both the geologic history of the site and the material properties. As described in Section 2.5.1.2.5.2, generally good agreement was obtained between the field and laboratory shear wave velocity measurements of the Upland Complex upper and lower alluvial deposits. Laboratory measurements were made when specimens were reconsolidated assuming a Ko value of 1.0, consistent with an overconsolidation ratio of 4 to 8 (Reference 162). Additionally, as described in Section 2.5.4.1.5, the CPT results suggests that the alluvium and loess are overconsolidated. Quantitative determination of the overconsolidation ratio for materials underlying the proposed site location should be performed during the COL phase on the basis of additional field and laboratory testing.

In summary, from a geotechnical and foundation engineering point of view, the loess is a clayey silt which exhibits moderately high strengths and stands vertically in cuts because of weak cementation when dry. However, the loess is potentially susceptible to gully erosion and collapse when saturated, and is not suitable for support of heavy or safety-related structures. The Upland Complex alluvium is a fairly clean coarse to fine sand, and the old alluvium is a clayey sand and silt with claystone clasts derived from the underlying Catahoula Formation. Both are relatively old and stiff and could serve as the foundation support layer for the facility designs being considered.

2.5.1.2.5.2 Dynamic Properties

Dynamic properties for "equivalent linear" site response analysis are: (1) shear wave velocity or low strain shear modulus; and (2) relationships that define the "equivalent linear" or secant shear modulus and the damping ratio as a function of cyclic shear strain. For convenience, the secant shear modulus is usually normalized to the low strain shear modulus. The required relationships are usually referred to as shear modulus reduction and damping curves. These curves are needed for each material type and, since these properties may vary with confining pressure, for as many depth ranges as is necessary. Shear wave velocity profiles for the ESP site are shown in Figures 2.5-34 through 2.5-37. Shear modulus reduction and damping curves are presented and discussed in Section 2.5.4.1.4.

2.5.2 Vibratory Ground Motion

This section describes the data and methodology used to develop the Safe Shut-down Earthquake (SSE) ground motion for the proposed new unit at the existing Grand Gulf Nuclear Station (GGNS) in Grand Gulf, Mississippi (hereafter referred to as the "Site"). Regulatory Guide 1.165 (Reference 4) "Identification and Characterization of Seismic Sources and Determination of Safe Shutdown Earthquake Ground Motion" states that the SSE ground motion can be developed using either the Electric Power Research Institute (EPRI) Seismicity Owners Group (SOG) project or Lawrence Livermore National Laboratory (LLNL) Probabilistic Seismic Hazard Analyses (PSHA) methodologies (References 8 and 9), updated through a comprehensive review of the geology, seismology and geophysics of the Site Region (200-mile radius around the site). If review of existing data shows a significant change to either the seismic source model or ground motion model (i.e., attenuation relationships), then Regulatory Guide 1.165 recommends that an updated PSHA be performed to develop the SSE ground motion.

Regulatory Guide 1.165 (Reference 4), therefore, provides the following four-step process to develop the SSE ground motion:

1. Review and update the EPRI or LLNL seismic source model with new information, as appropriate.
2. Review and update the EPRI or LLNL ground motion model with new information, as appropriate.
3. Perform an updated PSHA utilizing the updated seismic source model and/or ground motion model, if appropriate.
4. Develop the SSE ground motion using the original or updated EPRI or LLNL PSHA results corrected for site-specific soil properties, as required.

This process has been completed and documented for the GGNS ESP site. Section 2.5.2.1 describes the seismic source model used in the analysis. Section 2.5.2.2 describes the ground motion model and development of the vibratory rock ground motion from the PSHA. Sections 2.5.2.3 and 2.5.2.4 describe the site-response analysis and development of the SSE ground motion for the GGNS ESP site.

For the GGNS ESP application, the EPRI SOG methodology was adopted to develop the SSE ground motion, including use of the 1986 EPRI SOG seismic source model developed by six Earth Science Teams (EST's), an updated EPRI ground motion model (Reference 13), and the EPRI EQHAZARD software (Reference 14). Following review of the data and information developed since publication of the EPRI SOG results in 1986, significant new information regarding seismic sources and earthquake ground motion attenuation in the Site Region was identified. To address new information and approaches for ground motion attenuation modeling, EPRI (Reference 13) developed a new ground motion attenuation model for the central and eastern United States, including the Gulf Coast region. These new relationships were used in the PSHA and are described in Section 2.5.2.2

The seismic source model used to develop the SSE ground motions for the Site was developed following a comprehensive review of geological, seismological and geophysical data related to active tectonic features in the Site Region (Section 2.5.1). In particular, data were reviewed to identify any significant changes in: (1) source geometry – primarily in terms of changes of source to site distance; (2) maximum earthquake magnitude; and (3) earthquake recurrence. Based on the review of literature and syntheses of regional data (e.g. Reference 86), there are no newly identified features of tectonic origin with convincing evidence of Quaternary activity in the Site Region. Wheeler and Crone (Reference 86) identify four features, the Wiggins Arch, Gulf Margin Normal faults, Monroe Uplift, and Saline River source zone that display evidence of Quaternary activity, but which appear to have originated from non-tectonic processes or lack convincing evidence to conclude that they are seismogenic.

With two exceptions, our review and analysis of existing data shows that all tectonic features in the GGNS Site Region, and northern extension including the Reelfoot Rift Complex, are adequately characterized by the EPRI SOG seismic source model. The two exceptions identified in our review of existing data are (1) identification of the Saline River source zone within the Site Region, and (2) revision of source parameters for the New Madrid Seismic Zone (NMSZ), which lies within the Reelfoot Rift Complex north of the Site Region. Revisions to the NMSZ source parameters include changes in source geometry, maximum magnitude, and earthquake recurrence since publication of the 1986 EPRI SOG source model.

Based on the new information on seismic sources and new ground motion attenuation modeling that have been published since the 1986 EPRI SOG study, the EPRI PSHA has been updated for use in this ESP application. The EPRI PSHA was updated by revising the seismic source

model, adding the ground motion attenuation model developed by EPRI (Reference 13), and updating the EPRI EQHAZARD software that was published in 1986 (Reference 14).

The seismic source model developed for input to the PSHA for the Site adopts the 1986 EPRI SOG source model, updated through addition of the Saline River source zone and a characteristic earthquake model for the NMSZ. The new information for the Saline River source zone and NMSZ do not replace any of the existing EPRI SOG source zones, but are added, or "layered", onto the EPRI SOG seismic source model. The details of this model are described in Section 2.5.2.1.

Regulatory Guide 1.165 recommends that a PSHA be performed to define the median rock ground motion at the site that has an annual probability of exceedance of 10^{-5}, and for soil sites, that a site-response analysis be performed to develop the SSE ground motion. The PSHA used to develop the 10^{-5} median rock ground motions is described in Section 2.5.2.2. Because the Site is underlain by soils rather than rock, a site-specific site-response analysis was conducted following the methodology described in NUREG/CR-6728 (Reference 7). The site-specific site-response analysis is described in Sections 2.5.2.3 and 2.5.2.4. The site investigations and laboratory analyses that were completed to provide the soil parameters for the site-response analysis are described in Section 2.5.4. The seismic source characterization, site investigation and laboratory analyses, and site-response analysis also are described in Engineering Reports ER-01, ER-02, and CP-02, respectively.

2.5.2.1 Seismic Source Characterization

As described in Section 2.5.1, a comprehensive review of available geological, seismological, and geophysical data was performed for the GGNS ESP site and region. This review generally shows that the existing EPRI 1986 seismic source model adequately captures the source information and uncertainty associated with new data and knowledge developed since the mid-1980's. No new information was found that would suggest significant modification to the EPRI 1986 seismic source model, with two exceptions:

1. The average recurrence interval for large magnitude earthquakes in the New Madrid source zone is approximately 300 to 800 years based on new paleoseismic and paleoliquefaction information, as opposed to several thousand years in the EPRI seismic source model, and the geometry of the source zone has been modified to include three distinct fault segments imbedded within the source zone. New maximum magnitude information also has been developed for the source zone and a characteristic earthquake model is used to estimate recurrence for the fault segments.
2. The Saline River source zone represents a new postulated seismic source in southern Arkansas. The closest approach of this new source zone is approximately 90 miles to the GGNS ESP site.

These two revisions to the EPRI source model are described in Sections 2.5.2.1.2 and 2.5.2.1.3, respectively.

Conducting a PSHA requires information on the location of seismic source zones, maximum earthquake magnitudes, and earthquake recurrence intervals for each seismic source zone included in the model area. The estimated value for each of these parameters is presented in a seismic source model. Seismic source zones are characterized using a logic tree approach to explicitly document the range of estimated parameter values considered and to assign weights to each parameter estimate to indicate the degree of certainty that a given estimate is the correct alternative (Reference 166 and 167). The seismic source parameters for the EPRI SOG

model are presented in Table 2.5-8, and are described in detail in EPRI (Reference 9). In addition to the EPRI seismic source model, we provide new logic tree characterizations for the Saline River source zone and the revised NMSZ.

Logic trees are composed of a series of nodes and branches. Each node represents an assessment of an input parameter value necessary to perform the analysis. Each branch leading from the node represents one possible alternative for the state of nature or parameter value being assessed. In practice, a sufficient number of branches are placed at a given node to adequately express the range of uncertainty in the parameter characterization. Each branch of the logic tree, therefore, represents a credible model of the behavior of a seismic source that has a certain probability that it is the correct representation of that seismic source.

Weights are assigned to each branch of the logic tree and represent a probability that the branch is the correct estimate of the input parameter. Because the available data are typically too limited to allow for objective statistical analyses, weights are assigned subjectively on the basis of scientific judgment. The logic tree approach simplifies the subjective assessments because the uncertainty of a single parameter is considered individually assuming that all other parameters leading up to that parameter assessment are known with certainty. Thus, the nodes of the logic tree are sequenced to provide for the conditional dependencies among the parameters and to provide a logical progression from general to specific in defining the input parameters for an evaluation.

In order to compute the SSE ground motion for the Site, we have developed a seismic source model that describes the seismic source zones and related parameters for the Site Region, and includes the NMSZ that extends approximately 300-miles farther northward (Figure 2.5-38). As described in greater detail below, we have not modified the original EPRI SOG seismic source model, but have added the Saline River source zone and the NMSZ characteristic earthquake model as new sources to the 1986 EPRI SOG source model. This is a conservative approach that preserves the integrity of the seismic source model developed by the six EPRI EST's, while incorporating the new geological, seismological, and geophysical data of the Site Region.

The remainder of this section provides descriptions of the seismic source model used to compute ground motions at the proposed location of the new facility at the Grand Gulf site and includes a general description of the EPRI SOG seismic source model, and detailed descriptions of the Saline River source zone, and revised NMSZ.

2.5.2.1.1 Summary of EPRI Seismic Source Model

This section summarizes the seismic sources and parameters used in the 1986 EPRI SOG project (Reference 9) and subsequent PSHA completed by EPRI in 1989 (Reference 10). The descriptions of seismic sources is limited to those within 200 miles of the ESP Site (the "Site Region") and those at distances greater than 200 miles that may significantly contribute to the ground motion hazard at the Grand Gulf ESP Site.

For the EPRI SOG project, six ESTs evaluated geologic, geophysical, and seismological data to develop seismic source zones in the Central and Eastern United States (CEUS). These source zones were used to model the occurrence of future earthquakes and evaluate earthquake hazards at nuclear power plant sites across the CEUS. The six ESTs involved in the EPRI project were the Bechtel Group, Dames & Moore, Law Engineering, Rondout Associates, Weston Geophysical Corporation, and Woodward-Clyde Consultants. Each team produced a report (Volumes 5 through 10 of Reference 9) providing detailed descriptions of how they identified and defined the seismic source zones in the CEUS. For the computation of hazard in

the 1989 study, a few of the seismic source parameters were modified or simplified from the original parameters developed by the six ESTs during the 1986 EPRI SOG study. The parameters used in 1989 PSHA calculations are the primary source for the seismicity parameters used in this study.

The seismic source models developed for each of the six EPRI teams are shown on Figures 2.5-39 through 2.5-44. The spatial relationship between seismicity and regional tectonic features is illustrated on Figure 2.5.5. The earthquake epicenters shown on this figure includes events from the EPRI SOG earthquake catalog for the period between 1627 and 1984, updated with seismicity for the period between 1985 and 2003, as described in Section 2.5.1.1.6. The plot shows events greater than body-wave magnitude (m_b) > 3.3, the lower magnitude cut-off used in the EPRI SOG (Reference 9) study used to estimate a- and b-values.

The maximum magnitude, closest distance, and probability of activity of each ESTs seismic sources are summarized in Tables 2.5-8a through 2.5-8f. These tables list the parameters assigned to each source and specify whether or not the source was included in the site hazard in the original EPRI 1989 seismic hazard analyses. The tables also indicate whether new information has been identified that would lead to a revision of the source's geometry, maximum earthquake magnitude, or recurrence parameters. The seismicity recurrence parameters (a- and b-values) used in the EPRI seismic hazard study were computed for each 1-degree latitude and longitude cell that intersects any portion of a seismic source.

The EPRI SOG seismic hazard study expressed maximum magnitude (Mmax) values in terms of m_b, whereas most modern seismic hazard analyses describe Mmax in terms of moment magnitude (M_w). To provide a consistent comparison between magnitude scales, the average of three individual magnitude conversion relations is used (References 168, 169, and 170) to convert m_b to M_w and vice-versa. Throughout this section, the largest assigned values of Mmax distributions assigned by the ESTs to seismic sources are presented for both magnitude scales, to give perspective on the maximum earthquakes that were considered possible in each source. As shown on Tables 2.5-8a through 8f, the estimate of Mmax established by the ESTs for sources in the Site Region often are less than m_b 5.0 or in the range from m_b 5.1 to 5.3. in the conversion from m_b to M_w, these values would convert to M_w of less than 5.0. In the conversion from m_b to M_w, therefore, for the purpose of hazard calculations, we do not allow M_w to be less than 5.0.

The following sections describe the most significant EPRI sources for each of the six ESTs, with respect to the ESP Site. The nomenclature used by each EST to describe the various seismic sources in the CEUS varies from team to team. Therefore, a number of different names may be used by the EPRI EST to describe similar tectonic features, or one team may describe seismic sources that another team does not. For example, the Dames & Moore team describes the source of the 1811-1812 New Madrid earthquake sequence as the New Madrid Compression Zone while the Rondout team describes this source as the New Madrid Seismic Zone, and the Bechtel team describes this source as the New Madrid fault zone. The reader is referred to the original 1986 EPRI report for the data and rational used by each EST to define each seismic source zone.

2.5.2.1.1.1 Bechtel Team

The Bechtel team identified five seismic source zones within the Site Region (Table 2.5-8a and Figure 2.5-39). Although outside of the 200-mile Site Region, they also identified the New Madrid fault zone, which contributes to the hazard at the Site.

The site is located within Bechtel's Gulf Coast Region background source zone "BZ1". This source zone was defined based on geopotential and seismic data, and magnetic and gravity anomaly data. The Bechtel team assigned a maximum earthquake magnitude of m_b 5.4-6.6 (M_w 5.0-6.5) to this source.

The Northern Plains Region, background source zone "BZ3" is located 30 miles northeast of the Grand Gulf Site. The Bechtel team assigned a maximum earthquake magnitude of m_b 5.4-6.6 (M_w 5.0-6.5) to this source.

The Ouachita source zone is located 70 northwest of the Grand Gulf Site. This source was defined based on geopotential data outlining the crystalline core of the fold belt, historical seismicity above the background level, and the surface exposure of the Ouachita Mountains in Arkansas and Oklahoma. The western boundary of the source zone was defined as the intersection of the Ouachita Mountains with the rocks of the Wichita-Arbuckle system. The Bechtel team assigned a maximum earthquake magnitude of m_b 5.4-6.6 (M_w 5.0-6.5) for this source zone and determined that known faults of the Ouachita feature were not favorably oriented in the contemporary stress field for reactivation.

The New Madrid region background source zone "BZ0" is located 140 miles north of the Grand Gulf Site. This source zone was defined based on the possibility of moderate-to-large earthquakes occurring outside of recognized source zones contained within the background zone. The Bechtel team assigned a maximum earthquake magnitude of m_b 5.7-6.6 (M_w 5.3-6.5) to this source.

The Reelfoot Rift source zone is located 190 miles north of the Grand Gulf Site. This source was defined based on geophysical and geopotential data (magnetic and gravity anomalies), which identified ancient structures that parallel local seismicity trends. The Bechtel team assigned a maximum earthquake magnitude of m_b 5.7-6.6 (M_w 5.3-6.5) to this source zone. Association of the Reelfoot Rift with moderate-to-large earthquakes was based on spatial association and a favorable orientation for reactivation in an east-west compressive stress field.

The New Madrid fault zone is located 235 miles north of the Grand Gulf Site. This source was defined based on distinct microseismicity patterns, seismic reflection profiles, and the occurrence of the 1811 and 1812 earthquake sequence. The Bechtel team assigned a maximum earthquake magnitude of m_b 7.4-7.5 (M_w 7.9-8.0) to this source.

New information on seismic sources in the Site Region, published since the 1986 EPRI SOG study, was compiled and reviewed to evaluate whether the source geometry, Mmax, or source recurrence parameters should be updated. The reviewed information identifies a potential seismic source in southeastern Arkansas, the Saline River source zone. The characteristics of this potential seismic source are discussed in Section 2.5.2.1.3. New information also is available regarding the magnitude estimates and earthquake recurrence intervals for 1811-1812 "type" earthquakes on the NMSZ, discussed in Section 2.5.2.1.2. This new information has been accounted for by adding new seismic source zones over the existing EPRI SOG seismic source model. The EPRI SOG source zones for each of the six ESTs that are overlain by the new source zones are indicated by a "yes" in the right-hand columns of Table 2.5-8a through 2.5-8f.

2.5.2.1.1.2 Dames & Moore Team

The Dames & Moore team identified six seismic source zones within the Site Region (Table 2.5-8b and Figure 2.5-40). Although outside of the 200-mile Site Region, they also identified the New Madrid Compression Zone, which makes a significant contribution to the hazard at the Site.

The site is located within Dames & Moore's Southern Coastal Margin source zone. This source zone was defined based on its fairly low, diffuse seismicity and represents the down warping miogeosynclinal wedge of sediment that accumulated within the Gulf Coast Basin since the Cretaceous. The Dames & Moore team assigned a maximum earthquake magnitude of m_b 5.3-7.2 (M_w 4.9-7.5) to this source zone. The team did not provide a tectonic basis to explain the occurrence of seismicity in this source zone. The Saline River source zone partially overlies the northern part of the Southern Coastal Margin zone.

The Ouachita fold belt source zone is located about 60 miles northwest of the Grand Gulf Site. This source zone was defined based on historical and instrumental patterns of recent microseismicity. The Dames and Moore team considered the historical and instrumental seismicity rates to be indicative of future activity. Kinks or bends in the source zone geometry were defined based on the margin of failed arms of former continental rifts. The Dames & Moore team assigned a maximum earthquake magnitude of m_b 5.5-7.2 (M_w 5.1-7.5) to this source zone. The Saline River source zone partially overlies the southeastern part of the Ouachita fold belt.

The Indiana-Illinois Block source zone is located about 165 miles north of the Grand Gulf Site. This source zone was defined based on geophysical anomalies, basement structural boundaries, and diffuse seismicity. However, the team lacked confidence in identifying a tectonic basis to explain the diffuse seismicity. The block is bound on the north and east by basement warps including the Kankakee Arch, Cincinnati Arch, and Nashville Dome, on the northwest by the Illinois Basin/Lasalle Anticlinal Belt, and on the west by the trend of the Mississippi Embayment/Reelfoot Rift-Southern Indiana Arm Eocambrian rifts. The Dames & Moore team assigned a maximum earthquake magnitude of m_b 5.7-7.2 (M_w 5.3-7.5) to this source zone.

The Reelfoot Rift source zone is located about 165 miles north of the Grand Gulf Site. This source zone was defined based on the pattern of linear, segmented seismicity, and earthquake structure within the zone. The Dames & Moore team assigned a maximum earthquake magnitude of m_b 6.9-7.2 (M_w 7.0 to 7.5) to this source zone.

The Appalachian fold belt source zone is located about 170 miles northeast of the Grand Gulf Site. This source zone was defined based on historical and instrumental seismicity. The Dames & Moore team assigned a maximum earthquake magnitude of m_b 6.0-7.2 (M_w 5.7-7.5) to this source zone.

The Eastern Marginal Basin source zone is located about 175 miles northeast of the Grand Gulf Site. This source zone was defined based on the occurrence of several moderate-sized earthquakes and diffuse background seismicity. The Dames & Moore team assigned a maximum earthquake magnitude of m_b 5.6-7.2 (M_w 5.2-7.5) to this source zone.

The New Madrid compression zone is located about 250 miles from the Grand Gulf Site. This source was defined as an independent source within the Reelfoot Rift source zone based on the long, linear zone of microseismicity between Marked Tree, Arkansas and the area north of New Madrid, Missouri. The Dames & Moore team assigned a maximum earthquake magnitude of m_b 7.2-7.5 (M_w 7.5-8.0) to the New Madrid compression zone. The Dames & Moore team also considered the New Madrid compression zone combined with the Reelfoot Rift as an optional source geometry. A new source characterization for the NMSZ has been overlain on the New Madrid compression zone source of Dames & Moore.

2.5.2.1.1.3 Law Engineering Team

The Law Engineering team identified four seismic source zones within the Site Region (Table 2.5-8c and Figure 2.5-41). Although outside of the 200-mile Site Region, they also identified the Postulated Faults in Reelfoot Rift source zone, which makes a significant contribution to the ground motion hazard at the Site.

The Grand Gulf Site is located within Law Engineering's Southern Coastal Block source zone. The southern boundary of this source zone was defined based on broad wavelength magnetic anomalies that extend from the southeast Texas-Mexico border to the continental shelf offshore Florida. The northern boundary of this source zone was defined by the Paleozoic edge of the North American craton (Reference 171). The Law Engineering team assigned a maximum earthquake magnitude of m_b 4.6-4.9 (M_w 4.2-4.5) to this source zone. The Saline River source zone partially overlies Law Engineering's Southern Coastal Block.

The Mississippi Embayment source zone is located about 80 miles northeast of the Grand Gulf Site. This source was defined based an anomalously broad gravity high that extends into the central United States up the Mississippi Valley (Reference 171). The Law Engineering team assigned a maximum earthquake magnitude of m_b 5.2-5.7 (M_w 4.8-5.3) to this source zone.

The Eastern Basement source zone is located about 140 miles east of the Grand Gulf Site. This source was defined based on an area of buried Precambrian-Cambrian normal faults developed in the North American craton and includes the Giles County-Eastern Tennessee seismic zone, the Pennsylvania Aulacogen, and the Scranton Gravity High. The Law Engineering team assigned a maximum earthquake magnitude of m_b 5.7-6.8 (M_w 5.3-6.8) to this zone.

The Reelfoot Rift source zone is located about 170 miles north of the Grand Gulf Site. This source zone was defined based on gravity and magnetic anomalies. The Law Engineering team assigned a maximum earthquake magnitude of m_b 6.2-6.8 (M_w 5.9-6.8) to this zone.

The Postulated Faults in Reelfoot Rift source zone is located about 230 miles north of the Grand Gulf Site. This source zone was defined based on the occurrence of the 1811-1812 earthquakes. The Law Engineering team assigned a maximum earthquake magnitude of m_b 7.4 (M_w 7.9) to this source zone. A new source characterization for the NMSZ has been overlain on the Postulated Faults in Reelfoot Rift source zone of Law Engineering.

2.5.2.1.1.4 Rondout Team

The Rondout team identified six seismic source zones within the Site Region (Table 2.5-8d and Figure 2.5-42). Although outside of the 200-mile Site Region, they also identified the New Madrid seismic zone, which makes a significant contribution to the ground motion hazard at the Site.

The Grand Gulf Site is located within Rondout's Gulf Coast/Bahamas source zone. This source zone was defined based on the unique, rapid accumulation of sediments in the Gulf Coastal basin and differences in the orientation of the stress regime between the Paleozoic crust within the zone and the Appalachian crust of roughly the same age to the east and northeast. The Rondout team assigned a maximum earthquake magnitude of m_b 4.8-5.8 (M_w 4.4-5.4) to this source zone. The new Saline River source zone partially overlies Rondout's Gulf Coast/Bahamas source zone.

The Southern Oklahoma Aulacogen-Ouachita source zone is located about 100 miles northwest of the Grand Gulf Site. This source was defined based on an association with complex disturbed crust related to the Eocambrian Southern Oklahoma Aulacogen (Reference 172; Reference

173), Ouachita and Arbuckle Mountains, and Arkoma and Anadarko Basins. The zone also was defined based on seismicity; however, the Rondout team did not present a correlation between specific tectonic features and observed seismicity. The Rondout team assigned a maximum earthquake magnitude of m_b 5.8-6.8 (M_w 5.4-6.8) to this zone. The new Saline River source zone partially overlies Rondout's Southern Oklahoma Aulacogen-Ouachita source zone.

The Pre-Grenville PreCambrian Craton source zone is located about 110 miles northeast of the Grand Gulf Site. This source was defined as all "older-than-Grenville crust" that was not previously included in a seismic source zone. The Rondout team assigned a maximum earthquake magnitude of m_b 4.8-5.8 (M_w 4.4-5.4) to this background source zone.

The Grenville Crust source zone is located about 125 miles east of the Grand Gulf Site. This source zone was defined based on a level of background seismicity higher than other Grenville Crust areas and all areas of Grenville crust not previously captured in other source zones. The Rondout team assigned a maximum earthquake magnitude of m_b 4.8-5.8 (M_w 4.4-5.4) to this source zone.

The New Madrid Rift Complex (Reelfoot Rift) source zone is located about 170 miles north of the Grand Gulf Site. This source was defined based on geological, geophysical, and seismicity data (Reference 174) that divide the Reelfoot Rift into three arms. These arms include the Rough Creek Graben, Southern Indiana Arm, and Saint Louis Arm. An earthquake density contour map (Reference 175) was used to define the margins of the Southern Indiana and Saint Louis Arms. The Rough Creek Graben was excluded from the source zone because it is not favorably oriented for reactivation by the prevailing east-west horizontal stress field. The Rondout team assigned a maximum earthquake magnitude of m_b 6.6-7.0 (M_w 6.5-7.2) to this source zone.

The Southern New York-Alabama Lineament source zone is located about 180 miles northeast of the Grand Gulf Site. This source was defined based on a major discontinuity in the basement rocks underlying the western part of the Appalachians fold belt (Reference 176). The discontinuity corresponds to a change in strike of the magnetic anomaly pattern and intensity of seismicity. The Rondout team assigned a maximum earthquake magnitude of m_b 5.2-6.5 (M_w 4.8-6.3) to this source zone.

The is located about 255 miles north of the Grand Gulf Site. This source was defined based on the location of the 1811-1812 earthquake sequence, and the boundary of intense seismicity presented in Stauder (Reference 177). The zone was divided into three elements roughly coincident with the 1811-1812 earthquakes. The Rondout team assigned a maximum earthquake magnitude of m_b 7.1-7.4 (M_w 7.3-7.9) to this source zone. A new source characterization for the NMSZ has been overlain on the New Madrid seismic zone of Law Engineering.

2.5.2.1.1.5 Weston Geophysical Corporation Team

The Weston Geophysical Corp. team identified five seismic source zones within the Site Region (Table 2.5-8e and Figure 2.5-43). Although outside of the 200-mile Site Region, they also identified the New Madrid fault zone, which makes a significant contribution to the ground motion hazard at the Site.

The Grand Gulf site is located within their Gulf Coast background source zone. This source zone was defined as an independent background source that does not contain any other seismic source regions. The Weston Geophysical Corp. team assigned a maximum earthquake

magnitude of m_b 5.4-6.0 (M_w 5.0-5.7) to this background source zone. The new Saline River source zone partially overlies Weston's Gulf Coast background source zone.

The South Central background source zone is located about 60 miles northeast of the Grand Gulf Site. This source was defined based on boundaries with other source zones including the Reelfoot Rift on the west, Southern Appalachian background to the east, Pickens-Gilberttown fault zone to the south, and Rough Creek Graben-Kentucky River fault zone to the north. The Weston Geophysical Corp. team assigned a maximum earthquake magnitude of m_b 5.4-6.6 (M_w 5.0-6.5) to this background source zone. The new Saline River source zone partially overlies the South Central background source zone.

The Ancestral Rockies source zone is located 100 miles northwest of the Grand Gulf Site. This source was defined based on a region of seismicity coincident with the Wichita-Ouachita Uplifts and the Anadarko-Arkoma Basins. The Weston Geophysical Corp. team assigned a maximum earthquake magnitude of m_b 5.4-6.6 (M_w 5.0-6.5) to this source zone. The new Saline River source zone partially overlies the Ancestral Rockies source zone.

The Southern Appalachian background source zone is located about 160 miles northeast of the Grand Gulf Site. This source zone was defined based on physiographic province boundaries that include the western terminus of the Valley and Ridge thrust belt and the eastern margin of the Towaliga, Lowdenville, and Kings Mountain fault trends. The Weston Geophysical Corp. team assigned a maximum earthquake magnitude of m_b 5.4-6.6 (M_w 5.0-6.5) to this source zone.

The Reelfoot Rift source zone is located about 185 miles north of the Grand Gulf Site. This source was defined based on interpretation of geophysical and seismicity data. The Weston Geophysical Corp. team assigned a maximum earthquake magnitude (M_{max}) of m_b 7.2 (M_w 7.5).

The New Madrid fault zone is located about 235 miles north of the Grand Gulf Site. This source was defined based on a dense pattern of microseismicity. The Weston Geophysical Corp. team assigned a maximum earthquake magnitude (M_{max}) of m_b 7.2 (M_w 7.5) to this source zone. The team also considered the New Madrid fault combined with the Reelfoot Rift as an optional source geometry. A new source characterization for the NMSZ has been overlain on the New Madrid fault zone of Weston Geophysical Corporation.

2.5.2.1.1.6 Woodward Clyde Consultants Team

The Woodward Clyde Consultants team identified three seismic source zones within the Site Region (Table 2.5-8f and Figure 2.5-44). Although outside of the 200-mile Site Region, they also identified the Saint Louis Arm and "None of the Above" (NOTA), Southern Indiana Arm and NOTA, and Disturbed Zone of Reelfoot Rift, which make a significant contribution to the ground motion hazard at the Site. The NOTA incorporates the alternative *"that none of the identified seismic sources were associated in a genetic manner"* with observed earthquakes.

The Grand Gulf Site is located within Woodward Clyde Consultants' River Bend regional background source zone. This source zone was defined as an independent background source that does not contain any other seismic source regions. The Woodward Clyde Consultants team assigned a maximum earthquake magnitude of m_b 5.0 (M_w 4.6) to this source zone. The new Saline River source zone partially overlies the River Bend regional background source zone.

The Reelfoot Rift -New Madrid Rift Complex source zone is located about 130 miles north of the Grand Gulf Site. This source zone was defined as the portion of the New Madrid rift system that extends to the southwest from the Cottage Grove-Rough Creek fault zone, and was based on

aligned gravity and magnetic anomalies along its edges (Braile et al., 1982). The Woodward Clyde Consultants team assigned a maximum earthquake magnitude of m_b 5.4-7.2 (M_w 5.0-7.5) to this source zone. The team also considered the Reelfoot Rift-New Madrid Rift Complex combined with the Disturbed Zone of Reelfoot Rift (described below) as an optional source geometry.

The New Madrid Rift Loading Volume source zone is located about 135 miles north of the Grand Gulf Site. This source zone was defined based on scattered seismicity outside of the concentrated seismicity associated with the Disturbed zone of Reelfoot Rift. The Woodward Clyde Consultants team assigned a maximum earthquake magnitude of m_b 5.6-6.9 (M_w 5.2-7.0) to this source zone.

The Disturbed Zone of Reelfoot Rift source zone is located about 225 miles north of the Grand Gulf Site. This source zone was defined based on the occurrence of the 1811-1812 earthquake sequence, strong localization of microseismicity, seismic reflection data (Reference 178), and distribution of abundant liquefaction sand blows. The Woodward Clyde Consultants team assigned a maximum earthquake magnitude of m_b 7.2-7.9 (M_w 7.5-8.7) to this source zone. A new source characterization for the NMSZ has been overlain on the New Madrid fault zone of Woodward Clyde Consultants.

The Southern Indiana Arm and NOTA source zone is located about 310 miles north of the Grand Gulf Site. This source zone was defined as the northeast-trending arm of the New Madrid rift system that extends from New Madrid into south-central Indiana, and was based on gravity and magnetic anomalies and scattered seismicity. The Wabash Valley fault zone defines the northwestern border of the southwestern half of the Southern Indiana Arm. The Woodward Clyde Consultants team assigned a maximum earthquake magnitude of m_b 5.8-7.4 (M_w 5.4-7.9) to this source zone.

The Saint Louis Arm and NOTA source zone is located about 325 miles north of the Grand Gulf Site. This source zone was defined as the rift arm that extends northwesterly from New Madrid to Saint Louis, and was based on magnetic and gravity anomalies and scattered seismicity centered on the rift arm. The Woodward Clyde Consultants team assigned a maximum earthquake magnitude of m_b 6.2-7.2 (M_w 6.1-7.6) to this source zone.

2.5.2.1.2 Characterization of the New Madrid Seismic Zone

A characteristic earthquake model for the NMSZ has been added to the existing EPRI SOG seismic source model. The characteristic earthquake model is added to incorporate new data on source geometry, estimated maximum earthquake magnitude, and earthquake recurrence interval. The NMSZ characteristic earthquake model identifies specific fault segments within the NMSZ, maximum earthquake magnitudes, and earthquake recurrence intervals rather than treating the NMSZ as a single areal source zone with an exponential earthquake recurrence model. The logic tree for the NMSZ (Figure 2.5-45) describes the range of values considered for the following parameters: (1) Source geometry; (2) Maximum magnitude; and (3) Recurrence (note: numbers refer to nodes shown on the logic tree).

2.5.2.1.2.1 Source Geometry

Node 1 considers the source geometry used in the hazard calculation. The source geometry for the NMSZ is defined by the closest approach (modeled as a point source) of the three fault segments that approximate the locations of the 1811-1812 earthquake events (Reference 123; Reference 179; Reference 180). From closest to furthest from the Site, the three fault segments include: (1) the Blytheville Arch fault (BAF); (2) the Reelfoot fault (RF); and (3) the East Prairie

fault (EPF) (Figure 2.5-18). Because the maximum magnitude earthquakes for each of the three fault sources are conservatively modeled as occurring at the closest approach to the Site, additional alternative fault geometries are not considered. The points of closest approach were identified using the fault geometries of Johnston (Reference 179), Crone (Reference 102), Van Arsdale et al. (Reference 121), and Champion et al. (Reference 181) and are summarized in Table 2.5-9 and Figure 2.5-18. The three fault segments are modeled as point sources at the southernmost end of each fault due to the large source to site distances and the subparallel northward trend of the NMSZ with respect to the directional bearing to the Site.

2.5.2.1.2.2 Characteristic Earthquake Magnitude

As summarized in Table 2.5-10, significant differences exist in the estimated magnitudes of the largest historical events in the NMSZ. Hough et al. (2000, Reference 180) and Bakun and Hopper (Reference 115) discuss factors that may contribute to the uncertainty in magnitude estimates. These factors include: (1) the lack of instrumental data on large magnitude events from the NMSZ; (2) the paucity of intensity data, especially west of the Mississippi River, and the sparse, and sometimes inconsistent intensity data east of the Mississippi River; (3) the subjective nature of interpretation of felt reports and contouring of damage intensity data, especially with sparse and or old reports; (4) the lack of large recent earthquakes in the eastern United States to calibrate the intensity attenuation relation; and (5) the potential bias introduced by site response in the intensity assignments. In addition, magnitude estimates based on liquefaction features have considerable uncertainty due to the variability of local soil conditions, site-response effects, and the broad uncertainties associated with empirical relations based on world-wide databases (e.g. Reference 126; Reference 182; Reference 183).

For this study, maximum magnitudes assigned to each of the major faults within the NMSZ are considered on Node 2 of the logic tree (Figure 2.5-45). The southern segment is alternatively considered in the literature as either the Blytheville Arch/Bootheel Lineament or Blytheville Arch/Cotton Grove fault. For our purposes, the southern termination of both alternatives is the same (Figure 2.5-45). The characteristic maximum earthquake magnitudes for the southern segment are assigned the following values: M_w 7.3 (0.4), M_w 7.7 (0.5), and M_w 8.1 (0.1). The highest value of M_w 8.1 represents the preferred value of Johnston (Reference 118 and 114) for the December 1811 event based on isoseismal areas and a common attenuation relationship developed for a worldwide database of all stable continental regions. The lowest value of M_w 7.3 reflects the magnitude estimate of Hough et al. (Reference 180) after adjusting intensities for site amplification. The M_w 7.3 estimate also corresponds to the magnitude derived using the empirical relationship for magnitude vs. area of Wells and Coppersmith (Reference 184) as cited in Cramer (Reference 130), assuming a 117-km rupture length and 15-km rupture width. This value also agrees with the preferred magnitude estimated by Bakun and Hopper (Reference 115) for this event. The intermediate value of M_w 7.7 reflects the current magnitude estimate for the largest events of the 1811-1812 sequence used by the U.S. Geological Survey in their recent PSHA for the United States (Reference 19). The M_w 7.7 estimate also corresponds to the magnitude derived using the empirical relationship for magnitude vs. area of Sommerville and Sakia (Reference 185) as cited in Cramer (Reference 130), assuming a 117-km rupture length and 19-km rupture width. Frankel et al. (Reference19) also note the general similarity in the isoseismals with distance between the 2001 Bhuj India earthquake (M_w 7.6-7.7) and those of the December 1811 New Madrid event, although they caution that there may be differing rates of attenuation of intensities for the eastern U.S. and India.

The characteristic maximum magnitudes assigned to the Reelfoot fault encompass the range of published estimates for the February 1812 event. In addition, consideration is given to estimates

based on the constraints for the geometry and extent of the Reelfoot fault (e.g., Reference 123; Reference 130). The following magnitude distribution is assigned to this fault: M_w 7.2 (0.2), M_w 7.4(0.4), M_w 7.6 (0.3) and M_w 8.0 (0.1). The lowest value is based on the estimated moment and magnitude presented by Mueller and Pujol (Reference 123) that uses fault geometry, slip rate, and displacement data from seismicity, geomorphic, and trench data. The M_w 7.4 and M_w 8.0 values reflect the estimated magnitudes from isoseismal contours of this event as given by Hough et al. (Reference 180) and Johnston (Reference 118), respectively. The M_w 7.4 value also represents the preferred value of Bakun and Hopper (Reference 115). The M_w 7.6 value captures the weighted average value assigned to the February 1812 Reelfoot fault event by experts in the general research community for the US Geological Survey model (Reference 19).

The characteristic maximum magnitudes assigned to the East Prairie fault encompass the range of published estimates for the January 1812 event. The following magnitude distribution is assigned to this source: M_w 7.0 (0.4), M_w 7.4 (0.5), and M_w 7.8 (0.1). The high and low values reflect estimates of Johnston (Reference 118) and Hough et al. (Reference 180), respectively. The intermediate value captures the upper range of values estimated by Bakun and Hopper (Reference 115). The M_w 7.4 estimate also corresponds to the magnitude derived using the empirical relationship for magnitude vs. area of Somerville and Sakia (Reference 185) as cited in Cramer (Reference 130), assuming a 59-km rupture length and 19-km rupture width. The lower and middle magnitude values are judged to be more consistent with the preferred fault length and downdip width (~15 km based on microseismicity) and, therefore, are given higher weight than the highest value estimated from intensity data.

In addition to the intensity based magnitude estimates described above, we have also considered in our assignment of magnitude weights the physical process of strain accumulation and release, and the relationship between earthquake magnitude and recurrence interval. Given the relatively short 200-800 year earthquake recurrence interval for 1811-1812 earthquake sequences, we consider it more likely that the correct estimate of earthquake magnitude is represented by the lower or middle values in the distribution (Figure 2.5-45). This interpretation is supported by geologic slip rate and coseismic displacement data. These data do not support the occurrence of earthquakes of magnitude greater than M_w 7.7 with recurrence intervals of 200 to 800 years. A discussion of the dependency of earthquake recurrence on magnitude is presented in Section 2.5.2.1.2.3.

As discussed in the next section, the present interpretation of the paleo-earthquake data is that the penultimate and pre-penultimate events prior to the 1811-1812 sequence also consisted of multiple large-magnitude earthquakes within the NMSZ. Therefore, for this assessment, the "characteristic" event is considered to be a clustered rupture of all three faults in the NMSZ within a short period of time. Therefore, a set of five alternative magnitude sets, or clusters of characteristic ruptures were developed from the distributions for each fault. These magnitude clusters are shown in the logic tree on Figure 2.5-45.

2.5.2.1.2.3 Recurrence

For this study, characteristic earthquakes for the NMSZ are considered on Node 3 of the logic tree (Figure 2.5-45). The best constraints on recurrence of characteristic NMSZ events are direct paleoseismic data from studies of the Reelfoot fault (Reference 109) and the New Madrid North (East Prairie) fault (Reference 99), and are supported by paleoliquefaction studies throughout the entire New Madrid region (Reference 125). Paleoseismic data are considered the most reliable data source because paleoseismic investigations document and date discrete displacements of geologic features. The paleoseismic data from the

Reelfoot fault indicate that there have been three events within the past 2,400 years. The most recent event was associated with the 1811-1812 earthquake sequence. The penultimate event is estimated to have occurred between A.D. 1260 and 1650. The pre-penultimate event is estimated to have occurred prior to about A.D. 780-1000 (Reference 108). Kelson et al. (Reference 109) estimated a preferred recurrence interval of about 400 to 500 years for the Reelfoot fault.

Baldwin et al. (Reference 99) conducted paleoseismic investigations to identify possible evidence of surface deformation related to the January 1812 earthquake. The available information is currently insufficient to determine whether the observed features represent the primary trace of the New Madrid North fault, secondary deformation, or solely liquefaction-related features. However, the available data do not support the presence of a major fault with repeated M>7.8 earthquakes occurring with an average recurrence interval of 500 years.

Investigations in the NMSZ also have identified paleoliquefaction features associated with the 1811-1812 earthquake sequence, as well as two prior events at approximately A.D. 1450 and A.D. 900 (Reference 125; Reference 126). Based on the liquefaction data, Tuttle et al. (Reference 125) estimate recurrence intervals for 1811-1812 type events to be 200 to 800 years with a best estimate of 500 years. In addition, the composite characteristics of sand blow features are interpreted by Tuttle et al. (Reference 125) to indicate that the previous earthquake cycles involved multiple earthquake events similar to the 1811-1812 earthquake sequence. Similarity in the size of the liquefaction fields (Reference 125) and amount of displacements observed from paleoseismic trench investigations (Reference 109) indicate that the previous events were of similar size to the 1811-1812 earthquake sequence.

The composite characteristics of the sand blows suggests that rupture of the NMSZ occurs as an event sequence, and therefore all three fault segments are modeled as rupturing within a short period of time in a cluster of events. Based on the paleoseismic and paleoliquefaction data we have assigned recurrence times and probabilities for these event clusters of 200 years (0.1), 500 years (0.6), and 800 years (0.3). The minimum and maximum values are assigned based on the paleoliquefaction data, and the middle value is assigned based on consideration of both the paleoseismic and paleoliquefaction data.

2.5.2.1.3 Saline River Source Zone Characterization

The logic tree for the Saline River source zone (Figure 2.5-46) describes the range of values considered for the following parameters: (1) Probability of Existence (also called Probability of Activity in the EPRI SOG methodology); (2) Source Geometry; (3) Maximum Magnitude; (4) Recurrence Model; (5) Geological Approach for Estimating Recurrence; and (6) Recurrence (note: numbers refer to nodes shown on the logic tree).

2.5.2.1.3.1 Probability of Existence

Node 1 of the logic tree (Figure 2.5-46) considers the probability that the Saline River source zone is an independent seismic source or whether the features observed in the Saline River area can be explained by the seismic source models by the ESTs either as part of activity in background source zones, by earthquake activity in the NMSZ, or by other non-tectonic processes. We assign a 50% probability to this branch to express the large uncertainty in the existence of the source. The coincidence of liquefaction, sparse seismicity, late Tertiary and possibly Pleistocene fault rupture, and geomorphic asymmetry of drainage basins suggests that

a local seismic source may be present (Section 2.5.1). However, it is equally likely that the liquefaction features observed in southeastern Arkansas were produced from: (1) infrequent moderate magnitude events in the background source zone; or (2) distant ground shaking related to events along the NMSZ.

Alternatively, the geomorphic drainage basin asymmetry may be caused by regional tectonic arching, glacio-eustatic rebound, or non-tectonic processes related to sediment loading in the Mississippi River delta. Geologic evidence of faulting is not sufficient to define with certainty that a distinct capable fault is present within the Saline River source zone. Only one fault shows conclusive evidence for repeated late Quaternary activity (Site 4; Table 2.5-13 and Figure 2.5-20). Deformation along other faults is inferred to be Pliocene to early Pleistocene age (Upland Complex time). Based on the information presented in Cox et al. (Reference 151), neither the type of fault or sense of displacement is well known. Furthermore, each of the observed faults appears to be short, with minimal displacement, and variable orientation. Based on the available data it is not possible to confirm the existence, with certainty, of a distinct throughgoing fault.

2.5.2.1.3.2 Source Geometry

Node 2 describes the geometry of the Saline River source zone (Figures 2.5-19 and 2.5-46). We define an areal source zone for the Saline River source zone that encompasses all of the geomorphic, liquefaction, seismicity, and geologic data that suggest the existence of a localized seismic source. The source zone is defined by the intersection of the southwestward extension of the Proterozoic Reelfoot Rift and the Paleozoic Ouachita Orogenic Belt. The source zone geometry is defined based on the interpretation that northeast-trending faults within the Reelfoot Rift in the continental basement may structurally interact with northwest-trending faults in the overlying Ouachita Orogenic Belt. As with the NMSZ, faults within this zone of intersection may be reactivated due to east-northeast directed regional compressive stress (Section 2.5.1.2.2.1).

The northwestern boundary of the zone is defined based on the Northern Boundary fault of the Reelfoot Rift (Reference 188). The southeastern boundary is defined based on the southward projection of recently identified Reelfoot Rift-related marginal faults (Reference 189). The southwestern boundary of the seismic zone is defined based on the southern rifted margin of the North American craton. The Reelfoot Rift is a Proterozoic structure within the continental basement of the North American craton and was truncated by southward-directed rifting of the Gulf of Mexico in Triassic time. Therefore, the southern continuation of the Reelfoot Rift system is constrained by the limit of the North American continental crust. The northeastern boundary of the seismic zone is defined by the northernmost occurrence of basin asymmetry along the Arkansas River.

2.5.2.1.3.3 Characteristic Earthquake Magnitude

Node 3 describes the characteristic maximum earthquake magnitude for the Saline River source zone (Figure 2.5-46). The characteristic earthquake magnitude is estimated taking into consideration the observations of faulting from trenches along the Saline River fault (Reference 151), and the extent of liquefaction features observed in Ashley and Desha counties (Reference 152).

The range of characteristic magnitudes and weightings are M_w 6.0 (0.3), M_w 6.5 (0.6), and M_w 7.0 (0.1). The M_w 6.0 and 6.5 estimates are based on the empirical relationship between size of a liquefaction field and earthquake magnitude (Reference 182) and encompass the upper bound estimate provided by Cox et al. (Reference 151). The liquefaction field observed in Ashley County is approximately 9-miles (15 kilometers) across. The Ambraseys (Reference

182) relationship predicts a M_w 5.5 for a liquefaction field of this size; to be conservative we assign a magnitude of M_w 6.0 for the lower bound maximum magnitude. If the liquefaction features observed at the Kelso (Desha County) and Montrose (Ashley County) sites occurred during a single event the liquefaction field would be approximately 30-miles (50-kilometers) across corresponding to a magnitude estimate of M_w 6.5 (Reference 182). The occurrence of M_w 6.5 earthquakes along the Saline River source zone also is consistent with the observation of minor surface fault rupture. The limited occurrence of liquefaction features and evidence for minor discontinuous surface fault ruptures are consistent with earthquake magnitudes in the M_w 6.0 to 6.5 range.

A M_w 7.0 characteristic earthquake also is considered in the magnitude assessment. Although the occurrence of a larger magnitude event is a possibility, the geological data do not support the occurrence of an earthquake of this size. The repeated occurrence of M_w 7.0 earthquakes in this region would have produced more pronounced geomorphic expression of tectonic deformation, and also would have produced much more pronounced and extensive surface manifestation of liquefaction in susceptible deposits along the Arkansas, Saline, Ouachita, and Mississippi Rivers. As a sensitivity analysis, we calculated the size of the 0.1g isoseismal contour for a M_w 7.0 event. This area represents the likely size of the area that would exhibit surface manifestation of liquefaction in susceptible deposits. The radius of the 0.1g isoseismal using the 2-sigma ground motion attenuation relations (Reference 13) is about 70 miles (120 kilometers). Therefore, if there had been repeated Holocene M_w 7.0 events, the distribution of liquefaction features would be far more extensive than the limited extent of features observed in Ashley and Desha counties. The lack of these extensive liquefaction features, and minor expression of evidence of surface faulting supports the higher weighting on the M_w 6.0 to 6.5 characteristic earthquake magnitude than the M_w 7.0 magnitude.

2.5.2.1.3.4 Earthquake Recurrence

Node 4 describes the models used to compute earthquake recurrence. We consider both the exponential earthquake recurrence model (Reference 186) and the characteristic earthquake recurrence model (Reference 190) and weight these 0.1 and 0.9, respectively.

The characteristic earthquake recurrence model is given a predominant weighting of 0.9 because there is a record of several earthquake cycles, and a sequence of geomorphic terraces that provide a geological basis to estimate rates of tectonic deformation. The exponential recurrence model is given a lower weighting of 0.1 because of the sparse seismicity in the area and incomplete historical record.

2.5.2.1.3.5 Characteristic Earthquake Recurrence Model

Node 5 describes the geological approach for estimating the characteristic earthquake recurrence. The characteristic earthquake recurrence is estimated using both paleoliquefaction data and fault slip-rate data. The recurrence of the characteristic earthquake using paleoliquefaction data is assigned a weight of 0.6. The recurrence of the characteristic earthquake using fault slip-rate data is assigned a weight of 0.4. We assign a higher weight of 0.6 to the recurrence model using paleoliquefaction data because these data are better constrained through paleoseismic investigations, and several earthquake cycles are recorded.

2.5.2.1.3.5.1 Paleoliquefaction

In Node 6 of the logic tree (Figure 2.5-46), the recurrence times for characteristic earthquakes based on the paleoliquefaction data are estimated at 390, 1,725, and 3,500 years. We assign weights of 0.2, 0.4, and 0.4 respectively, to these recurrence estimates. The shortest recurrence

time of 390 years represents the average recurrence time for five events during the period 150 yr B.P. (A.D. 1800) to 1,700 yr B.P., the shortest allowable time period. The 1,725 year recurrence time represents the average recurrence time for five events occurring between 150 and 5,320 yr B.P. (Table 2.5-14). The 3,500 year recurrence time represents the maximum recurrence based on the dated maximum interval between liquefaction events at the Montrose site in Ashley County.

2.5.2.1.3.5.2 Slip-Rate and Recurrence Model

The recurrence times for characteristic earthquakes based on slip-rate data are estimated for each characteristic earthquake magnitude (M_w 6.0, 6.5 and 7.0), also shown in Node 6. The recurrence time is estimated by dividing the characteristic displacement by the slip rate. The recurrence calculations are summarized in Table 2.5-13. Characteristic displacement is derived from the empirical relationship between earthquake magnitude and average displacement from Wells and Coppersmith (Reference 184).

Fault slip rates estimated for the Saline River seismic zone were derived from both geomorphic analysis (Figures 2.5-23) and paleoseismic investigations conducted by Cox (Reference 151). The rates obtained using incision as a proxy for uplift rate (Section 2.5.1.1.5.9.1) varies from 0.05 to 1.7 mm/yr. The rates obtained from paleoseismic studies using offset piercing points observed in trenches range from 0.008 mm/yr to 0.03 mm/yr (Section 2.5.1.1.5.9.4.3). The values and weights (in parentheses) selected for use in the recurrence model are 0.01 mm/yr (0.1), 0.05 mm/yr (0.3), and 0.1 mm/yr (0.6).

The minimum slip rate value of 0.01 mm/yr for the earthquake recurrence model was estimated from data obtained during paleoseismic investigations along the Saline River fault zone (Reference 151). The fault slip rate is estimated to be 0.008 to 0.03 mm/yr, based on the 30-meter offset of a secondary fault within Upland Complex deposits exposed in the trench and a 1- to 4-million year age range of the Upland Complex (Sites 3 and 4 of Reference 151). This age range has been approximated and assigned a slip rate value of 0.01 for the recurrence analysis. This value is considered a reasonable minimum slip rate value and is assigned a low weight of 0.1 in the hazard analysis.

The middle fault slip rate value of 0.05 mm/yr was estimated based on a combination of both the 0.03 mm/yr rate derived from the paleoseismic data, and the lower bound rate of 0.05 mm/yr rate derived from incision of the 800 to 1,300 Ka Intermediate Complex terrace (Figure 2.5-23). Because the value of 0.05 mm/yr is approximated by both the geomorphic data and paleoseismic data, a significant weight of 0.3 for the hazard analysis is assigned.

The upper fault slip rate value of 0.1 mm/yr was estimated from the incision rate analysis (Figure 2.5-23). This value was estimated based on the upper bound rate of 0.09 mm/yr for incision of the 800 to 1,300 Ka Intermediate Complex terraces and the lower bound rate of 0.3 mm/yr for incision of the 70 to 120 Ka Prairie Complex (Figure 2.5-23). This upper fault slip rate of 0.1 is considered a reasonable maximum slip rate value and was assigned the highest weight of 0.6 for the hazard analysis.

The higher fault slip rates approximated by incision of the 18 to 30 Ka Deweyville terraces (0.8 to 1.7 mm/yr) and the upper bound rate for the 70 to 120 Ka Prairie Terrace (0.5 mm/yr) were not included in the recurrence model. These rates are not considered to be reasonably consistent with other lines of evidence used to approximate the fault slip rates. Faults with high slip rate values, such as these, would be expected to produce clearer expression of active tectonic deformation due to repeated moderate to large magnitude earthquakes. The estimated

rates of incision for the Deweyville and Prairie terraces were considered to have been affected by changes in hydrologic regime during the Wisconsin glacial periods (Reference 17), and/or isostatic response to crustal unloading. In addition, field reconnaissance in the Saline River area identified discrepancies in the mapping of Deweyville terraces. The existing mapping is regional and preliminary in nature with large associated uncertainties. The mapping uncertainty may have resulted in misidentification of the Deweyville and Prairie Complex terraces leading to overestimation of incision rates. Therefore, we consider the incision rates associated with the Intermediate Complex terraces, and lower bound values associated with the Prairie Complex terraces, were considered to be more representative of the inferred fault slip rates than the upper bound rates associated with the Prairie Complex, or the full range of rates associated with the Deweyville terraces.

The earthquake recurrence times for each of the Mw 6.0, 6.5 and 7.0 characteristic earthquakes were calculated based on the slip rates described above and the displacements estimated based on the empirical relationships between magnitude and displacement (Reference 184). The recurrence intervals vary because the amount of displacement required to produce these earthquakes varies; larger earthquakes require greater displacement than smaller earthquakes. The Mw 6.0 characteristic earthquake recurrence times for the range of slip rates and assigned weights (described above) are 1,000 years (0.6), 2,000 years (0.3), and 10,000 years (0.1), respectively. For Mw 6.5 characteristic earthquakes the recurrence times and assigned weights are 3,000 years (0.6), 6,000 years (0.3), and 30,000 years (0.1), respectively. For Mw 7.0 characteristic earthquakes the recurrence times and assigned weights are 12,500 years (0.6), 25,000 years (0.3), and 125,000 years (0.1), respectively.

2.5.2.1.4 Effect of Updating the Earthquake Catalog on the EPRI SOG Seismicity Parameters

The EPRI earthquake catalog, updated to include seismicity from 1985 to 2002, was examined to evaluate possible correlation of seismicity to geologic structures, possible changes to the EPRI source geometry or seismicity parameters (a and b values), and any possible new or previously unrecognized seismic source. The original EPRI catalog covers earthquakes in the CEUS for the time period up to 1984 (Reference 206). This catalog was updated for the period 1985 to 2002 for the region within 200 miles of the site (within the latitude interval from 28.5 to 35.5 degrees North and longitude interval from 87.5 to 94.5 degrees West).

Table 2.5-14 identifies 6 earthquakes for magnitude 3.0 and greater (m_b) that have occurred since 1984 within 200 miles of the site. These events were added to the EPRI earthquake catalog. All of the events were assumed to be main events. Figure 2.5-38 shows the distribution of earthquake epicenters from both the EPRI (pre-1984) and updated (post-1984) earthquake catalogs in comparison to major tectonic features and geologic structures in the Site Region. Evaluation of the updated earthquake catalog yields the following conclusions:

1. No new earthquakes of magnitude greater than m_b 3.0 have occurred within approximately 100 miles of the ESP Site since 1985;
2. The updated catalog does not show any earthquakes within the site region that can be correlated with a known geologic structure. The majority of seismicity appears to be occurring in areas underlain by continental crust that coincide with either the Appalachian Mountains, Ouachita Orogenic Belt, or Reelfoot Rift/NMSZ;
3. The updated catalog does not show a unique cluster of seismicity that would suggest a new seismic source outside of the EPRI source model;

4. The updated catalog does not show a pattern of seismicity that would require significant revision to the EPRI seismic source geometry;
5. The updated catalog does not show any increase in M_{max} for any of the EPRI sources;
6. The updated catalog does not show any increase in the estimated rate of earthquake occurrences.

Seismicity parameters (a- and b-values) for the seismic sources defined by the Earth Science Teams were based on an analysis of the earthquake catalog developed as part of the EPRI SOG project. To evaluate the sensitivity of the updated EPRI earthquake catalog to estimated earthquake recurrence rates, the EPRI program EQPARAM was used. EQPARAM is part of the EPRI EQHAZARD software package. Calculations were performed for the Woodward Clyde background source around the GGNS site. The GGNS site is located at the center of this source which is defined as a square polygon, 6 degrees on a side. An evaluation of the change in seismicity parameters for this seismic source provides a measure of the effect of the updated earthquake catalog. The EQPARAM evaluation was performed using the same seismicity options specified by the Woodward Clyde team (Reference 10).

Figure 2.5-47 shows a comparison of the estimated frequency of earthquake occurrences for the Woodward Clyde background seismic source based on the original EPRI earthquake catalog and the catalog updated to 2002. The results indicate that the earthquake frequencies based on the updated catalog are slightly lower than the frequencies based on the original EPRI SOG seismic parameters. For this reason, it was concluded it was not necessary to update the EPRI SOG source seismicity parameters. Therefore, the original EPRI seismicity parameters (a- & b- values) were used to calculate seismic hazard at the ESP site with the EPRI seismic sources.

Possible changes in the seismicity parameters for the New Madrid seismic source zones were not evaluated. Because the New Madrid source zone for all EST's were updated to include a characteristic event and current estimates of the frequency of these events, an update of the seismicity parameters for events smaller than the characteristic earthquake (associated with the exponential part of the earthquake recurrence model) is not necessary.

2.5.2.2 GGNS Probabilistic Seismic Hazard Analysis

A probabilistic seismic hazard analysis (PSHA) was performed for the GGNS following the procedure provided in RG 1.165 (Reference 4). The results were deaggregated in terms of earthquake magnitude (M_w) and distance to determine the controlling earthquakes for the site. The PSHA calculations were performed for rock site conditions. The PSHA results were input to a site response analysis to determine the free-field surface ground motion and Safe Shutdown Earthquake (SSE).

2.5.2.2.1 Seismic Source Characterization

The GGNS PSHA was performed using the EPRI SOG seismic sources listed in Tables 2.5-8a through 2.5-8f, the New Saline River seismic source described in Section 2.5.2.1.3 and the revised New Madrid seismic source described in Section 2.5.2.1.2. As described in Section 2.5.2.1, the Saline River seismic source and revised New Madrid seismic source are added to the EPRI SOG seismic sources without revision to these sources. The potential double-counting of hazard using this approach is conservative. The parameters for these sources are presented in Figures 2.5-45 and 46.

2.5.2.2.2 Magnitude Conversion

In the EPRI SOG study earthquake occurrences were defined in terms of body-wave magnitude, m_b (Reference 9). Modern seismic hazard studies define seismicity with respect to moment magnitude (M_w). Similarly, the new EPRI recommended ground motion models (Section 2.5.2.2.3) are based on moment magnitude. For the new Saline River seismic source developed in this analysis and for the updated seismicity parameters for the New Madrid characteristic events, seismicity also is defined in terms of moment magnitude. To perform the PSHA calculations, the seismicity parameters specified for seismic sources in the EPRI SOG study were input as originally defined and converted to moment magnitude as part of the calculation. To account for the uncertainty in this conversion, three alternative m_b– M_w models were used: Atkinson and Boore (1995), EPRI (1993), and Johnston et al. (1996). These models were assigned equal weight in the analysis.

2.5.2.2.3 Ground Motion Attenuation Models

The ground motion attenuation models developed as part of an EPRI-sponsored project were used in the PSHA (Reference 13). The EPRI 2003 ground motion models estimate ground motions for rock sites and include, for a given ground motion frequency (e.g., spectral acceleration (S_a) 1 Hz), alternative estimates of the median and aleatory uncertainty in ground motion. The alternative models of the median and aleatory uncertainty and their probability weights represent the epistemic uncertainty in ground motions.

The EPRI 2003 ground motion model provides median ground motion models for the Mid-continent and the Gulf region of the central and eastern U.S. (Reference 13). In addition, the model is defined for different seismic source types, including General Area sources, and Fault sources or sources capable of generating large magnitude ($M_w > 7$) events. In addition, specific ground motion models were defined for fault sources in rifted and non-rifted regions (Reference 191).

For the New Madrid seismic source, the Mid-continent, rifted ground motion attenuation models were used. For this case there are 12 estimates of the median ground motion, and 4 estimates of the aleatory uncertainty. This produces 48 ground motion model estimates. For seismic sources located in proximity to the GGNS, the General Area ground motion models for the Gulf region were used. For this case there are 9 estimates of the median ground motion, which combine with 4 aleatory variability models to produce 36 ground motion model estimates.

As described in the EPRI (2003) ground motion report, when General Area sources and Fault sources (also sources capable of generating large magnitude events at large distances) are included in a seismic source combination (i.e., both seismic source types are simultaneously active), these models are correlated (Reference 13).

2.5.2.2.4 Lower-Bound Magnitude

The PSHA calculations were performed using a lower-bound magnitude of 5.0 M_w. This value is consistent with the findings in EPRI (Reference 11) which recommended a lower-bound magnitude for PSHA calculations performed for well-engineered facilities such as nuclear power plants. The study recommended a lower-bound magnitude of 5.0 M_w. At the time, a lower-bound magnitude of 5.0 M_w was estimated to correspond to a lower-bound magnitude of 5.3 in terms of m_b. Thus, the lower-bound of m_b 5.0 used in the EPRI SOG study was slightly conservative..

The deaggregation of the seismic hazard at the GGNS ESP site was performed for seven magnitude and seven distance bins. The magnitude-distance bins are:

Magnitude (M_w): 5.0-5.5, 5.5-6.0, 6.0-6.5, 6.5-7.0, 7.0-7.5, 7.5-8.0, 8.0, and greater,

Distance (km): 0.0-15, 15-25, 25-50, 50-100, 100-200, 200-300, 300, and greater.

The distance bins are defined in terms of epicentral distance.

2.5.2.2.5 PSHA Calculations

The seismic hazard calculations for the GGNS PSHA were performed using the EPRI EQHAZARD software which has been upgraded to include the characteristic earthquake model, the EPRI 2003 ground motion model, expanded logic tree modeling capabilities, and the calculations described in RG 1.165.

2.5.2.2.5.1 Results

The seismic hazard results for rock site conditions are shown in Figures 2.5-48 to 2.5-54 for each ground motion frequency (0.5 Hz, 1 Hz, 2.5 Hz, 5 Hz, 10 Hz, 25 Hz and PGA). The results are provided in terms of the 0.15, 0.50 and 0.85 fractiles and the mean. Table 2.5-15 shows the 10^{-5} median uniform hazard response spectra (UHS) for the GGNS for rock site conditions.

Following the procedure in RG 1.165 the median hazard results were deaggregated for low (1 and 2.5 Hz) and high frequencies (5 and 10 Hz). Figure 2.5-57 shows the low-frequency magnitude-distance deaggregation. The results show that the majority of the contribution for low frequency hazard is produced by characteristic earthquake events associated with the New Madrid seismic source zone. The high-frequency deaggregation results are shown in Figure 2.5-58. The results show that the majority of the contribution to high frequency hazard also is produced by events associated with the characteristic earthquakes on faults within the New Madrid seismic source zone.

To manage the execution time of these calculations one simplification was introduced. For seismic sources defined in the original EPRI SOG study that have multiple seismicity options (e.g., alternative models for the a- and b-values of the exponential recurrence relationship), the mean hazard for these options was calculated and used in the final hazard calculation. This simplification reduced the number of branches in the logic tree and significantly reduced the computation time. This simplification is reasonable due to the low sensitivity of the median hazard to alternative seismicity options defined by the ESTs (Reference 10). The sensitivity of the Grand Gulf median seismic hazard estimates was evaluated and determined to be small as shown in Figures 2.5-55 and 2.5-56 for spectral accelerations of 1 and 10 Hz, respectively

2.5.2.2.5.2 Controlling Earthquakes

Following the procedure recommended in RG 1.165, the controlling earthquakes for low and high-frequency ground motions were determined. The magnitudes and distances for the controlling earthquakes for 1-2.5 Hz and 5-10 Hz are listed in Table 2.5-16. For the GGNS, the contribution of large distant events (distances greater than 100 km) to low frequency ground motions was greater than 5 percent. Therefore, as recommended in RG 1.165, the controlling event for distances greater than 100 km and for 1-2.5 Hz was calculated. This event also is listed in Table 2.5-16. Deaggregation plots for the hazard analysis are shown on Figures 2.5-57 and 2.5-58. The response spectra for each of the controlling earthquakes are listed in Tables 2.5-17 through 2.5-19.

For each controlling earthquake, a median response spectrum shape was determined using the EPRI (Reference 13) ground motion models. These median response spectra are shown in Figure 2.5-59 with the median 10^{-5} UHS. As shown, the response spectra from the S_a (1-2.5 Hz)

(including all distances) and the S_a (5-10 Hz) controlling earthquakes approximate well the shape and amplitude of the UHS for frequencies greater than 1 Hz. At frequencies greater than approximately 12 Hz, the high frequency spectrum underpredicts the UHS amplitudes. This underprediction is greatest at 25 Hz.

The rock response spectra for the S_a(1-2.5Hz) (including all distances) and the S_a(5-10Hz) controlling earthquakes are used in the site response analysis to determine the site transfer function and the resulting soil ground motions. This analysis is described in Sections 2.5.2.3 and 2.5.2.4.

2.5.2.3 Seismic Wave Transmission Characteristics of The Site

The rock outcrop UHS as well as the associated 1 to 2.5 Hz and 5 to 10 Hz scaled spectra presented in Section 2.5.2.2 (Figure 2.5-59) are based on updated CEUS attenuation relations for hard rock site conditions (Reference 13). The hard rock site conditions reflect a mid-continent crustal structure (Reference 170, 191) with a defined shear-wave velocity of 2.83 km/sec. This high velocity is generally associated with very competent crystalline or metamorphic basement material, which occurs at the GGNS ESP site at depths exceeding 10,000 ft, where Paleozoic basement material is encountered (Section 2.5.1).

To develop the SSE at the surface, site response analyses must accommodate the effects of the local shallow soils as well as deeper soils and soft rock to a depth where the shear-wave velocity reaches about 2.8 km/sec (see Calculation Package CP-02, Reference 207). Since the UHS and consequently the SSE are defined to 0.5 Hz (2 seconds) as the lowest frequency, accommodation of the deeper materials is required to depths which results is capturing the amplification to the lowest frequency of interest (Reference 170, 192, 193, 194). For typical deep firm profiles, maximum amplification at 0.5 Hz is reached at depths of about 1,000 ft (305m), at low levels of loading (Reference 193). To conservatively accommodate potential low frequency amplification, the local soil profile is extended to a depth of 3,300 ft (1 km) and Approach 2A of McGuire et al. (Reference 194) is used to accommodate the effects of both the local soils and deeper materials as well as their variabilities on the design ground motions. The use of Approach 2A is considered appropriate due to the narrow range in earthquake magnitudes contributing to the UHS at 1 to 2 Hz and at 5 to 10 Hz. Approach 2B, which considers the effects of a range in magnitude contributions at 1 to 2 Hz and at 5 to 10 Hz on soil response, is appropriate for hazard conditions where there is a very wide range in magnitudes at both low- and at high-frequency and where the control motions and soil conditions result in highly nonlinear response.

The shear-wave velocity profile at the site was based on three suspension log surveys, with the deepest extending to a depth of about 225 ft (Section 2.5.2.4). The base case profile as well as the suspension log profiles are shown in Figure 2.5-60. These shallow materials consist of about 75 ft of loess, 85 ft of young alluvium, with old alluvium to a depth of about 200 ft where claystones of the Catahoula formation were encountered. Both the old and young alluvium comprise the terrace deposits of the Uplands Complex. To extend the profile to a depth of about 3,000 ft, a generic Mississippi embayment shear-wave velocity profile was used. This generic profile was developed for ground shaking studies in the embayment by Professor Glenn Rix of the MAE Center (Reference 195). The profile is based on a large number of shallow and several deep velocity surveys and extends to a depth of 3,600 ft (1,100m). For the site base case profile, the shallow velocities to a depth of about 225 ft (Figure 2.5-60) replaced those of the generic Mississippi embayment upland profile, which had similar velocities (about 2,000 ft/sec) at these depths. For deep shear-wave velocities below the local site explorations, no

measurements are known to exist within tens to hundreds of kilometers of the site. Within the southern embayment, old water wells as well as oil exploration boreholes exist, some possibly with stratigraphy, but these are of little added value since the overall stratigraphy (geology) of the Mississippi embayment is quite uniform laterally. The notable exceptions are Crowley's Ridge, located within the northeastern embayment and the roughly north-south division between the lowlands and uplands. Based on rather extensive measurements near the Memphis area and surrounding regions, the differences in stratigraphy and velocities between the lowlands and uplands extends only to shallow depths (upper several hundred feet), is reasonably well characterized, and is generally considered uniform throughout the embayment. A number of surface wave analyses as well as low-frequency site amplification studies suggest generally uniform (laterally) soil column properties throughout the embayment. As a result, ground motion hazard maps are computed with regional soil columns which differentiate lowlands and uplands and, for long periods, depth to paleozoic basement, which diminishes to zero near Cairo, Illinois as well as in easterly and westerly directions from the Mississippi river, the approximate center of the embayment. The general lateral uniformity of the deeper velocities (deeper than several hundred feet) is consistent with other large basins, e.g. Los Angeles and Imperial Valley, California and provides a basis for employing a generic deep profile beneath the local site profile. Since the profile is randomized, expected fluctuations are accommodated in the mean amplification, consistent with a probabilistic hazard analysis. Additionally, differences in a mean shear-wave velocity profile gradient would result in very little difference in mean motions. This arises because the low-strain damping in the deep profile largely controls the response for frequencies above about 1 Hz, and this will be constrained by a kappa value based on observations of motions recorded in shallower (3,000 to 6,000 ft) portions of the embayment. For lower frequencies, the amplification is controlled by the average column shear-wave velocity and depth to basement. This defines the fundamental column resonance. Any revisions in the deep velocity profile will only affect mean amplification for periods longer than the revised fundamental resonance. As a result, differences in the deep profile gradient has little impact on design motions, provided the overall damping is constrained (kappa) and the profile is deep enough to accommodate the lowest frequency of interest. The empirical kappa value to be employed is considered conservative as a deeper sedimentary column (over 10,000 ft at the site) over hard rock is expected to show larger kappa values (more cumulative damping) compared to shallower sedimentary columns.

The complete base case profile is shown in Figure 2.5-61 to a depth of 1 km, where shear-wave velocity is set to 2.8 km/sec, appropriate for hard rock conditions.

Nonlinear dynamic material properties, G/Gmax and hysteretic damping curves, are based on laboratory testing of undisturbed samples taken during the site exploration program (Section 2.5.4). Generally, the laboratory dynamic test results showed similarity with the EPRI (Reference 170) G/Gmax and hysteretic damping curves for cohesionless soils. Specifically, samples within the loess (approximately top 75 ft) were similar to the EPRI (Reference 170) curves for depths of 120 to 250 ft while the test results for the alluvium and old alluvium were similar to EPRI (Reference 170) curves for depths of 250 to 500 ft and 500 to 1,000 ft, respectively (Section 2.5.4). Due to the similarity between the laboratory dynamic testing results and those developed by EPRI (Reference 170), the EPRI (Reference 170) curves were adopted for use and are shown in Figure 2.5-62. The deeper EPRI (Reference 170) curves (500-to-1,000 ft) were used to a depth of 500 ft, below which linearity was assumed (Reference 194). To constrain the damping below 500 ft, the kappa value at the surface was assumed to be 0.04 sec, a conservative estimate for this region of the Mississippi embayment (Reference 196).

2.5.2.4 Site Response Analysis

The site response analyses followed Approach 2A recommended in McGuire et al., 2001 (Reference 194) in which the 1 to 2 Hz and 5 to 10 Hz controlling earthquake spectra (R.G. 1.165) scaled to the UHS are used as control motions (Figure 2.5-63). Transfer functions, soil surface-to-hard rock outcropping, are developed for each controlling earthquake, enveloped, and the envelop applied to the rock UHS. This process is intended to conservatively maintain the hazard level of the rock outcrop UHS while incorporating variability in site-specific dynamic material properties (Reference 194).

Variability in the base case shear-wave velocity profile is accommodated through development of 60 randomized profiles for each control motion. The profile randomization scheme is based on an analysis of variance of over 500 measured profiles (Reference 194; Reference 197), and randomly varies both shear-wave velocity as well as layer thickness. To provide for uncertainty in depth to hard rock, depth is randomized using a uniform distribution from 850m to 1,150m.

To accommodate variability in modulus reduction and hysteretic damping curves, the curves are independently randomized about the base case values. A log normal distribution is assumed with a σ_{ln} of 0.30 at a cyclic shear strain of 3×10^{-2}%. These values are based on an analysis of variance on a suite of laboratory test results. An upper and lower bound truncation of 2σ is used to prevent modulus reduction or damping models that are not physically possible. The random curves are generated by sampling the transformed normal distribution with a σ_{ln} of 0.30, computing the change in normalized modulus reduction or percent damping at 3×10^{-2}% shear strain, and applying this factor at all strains. The random perturbation factor is reduced or tapered near the ends of the strain range to preserve the general shape of the median curves (Reference 198).

The ensemble average, or mean transfer function, for each of two control motions (1 to 2 Hz and 5 to 10 Hz), then reflects the best estimate effect of the soil/soft rock column, accommodating site specific variability in dynamic material properties as well as depth to basement material. For the top of loess, the two mean transfer functions (5% damped response spectra), corresponding to the 1 to 2 Hz and 5 to 10 Hz control motions (Figure 2.5-63), are shown in Figure 2.5-64 along with their envelop. To accommodate the possibility of removing the surficial loess to a depth of about 50 ft for structure embedment, transfer functions were also estimated considering the top of 1,000 ft/sec material as surficial outcrop (Figure 2.5-60). The corresponding estimate of the mean transfer function is shown in Figure 2.5-65 and shows little impact of the top 50 ft (Figure 2.5-64).

2.5.2.5 Safe Shutdown Earthquake

Applying the envelop mean transfer function for the top of loess and top of 1,000 ft/sec material (Figure 2.5-64 and 2.5-65 respectively) to the rock UHS results in horizontal soil motions that are consistent with the median 10^{-5} APE hard rock UHS. These expected soil motions are shown in Figure 2.5-66 along with the hard rock UHS. Design horizontal ground motions are taken as the envelope of the two expected soil motions and are shown in Figure 2.5-67 (solid line). For comparison, the R.G. 1.60 spectrum scaled to 0.3g is shown also in the Figure.

As a preliminary estimate of vertical motions, the V/H ratio of R.G. 1.60 was applied to the horizontal design motions. This ratio is 2/3 at low frequency (0.1 Hz to 0.3 Hz) increasing with frequency to unity near 8 Hz. With the deaggregation suggesting little contribution for sources within about a 50 km distance (Section 2.5.2.2) use of the R.G. 1.60 V/H ratio is considered to

conservatively reflect expected vertical soil motions (Reference 197) and is shown in Figure 2.5-68.

2.5.2.6 Operating Basis Earthquake

The Operating Basis Earthquake (OBE) ground motion spectrum is assumed to be one third of the SSE ground motion spectrum in accordance with Appendix S to locFR50.

2.5.3 Surface Faulting

There is no potential for surface fault rupture at the Grand Gulf Site Location, and there are no capable tectonic sources within a 5-mile radius of the site (Site Area). A capable tectonic source is a tectonic structure that can generate both vibratory ground motion and tectonic surface deformation such as faulting or folding at or near the Earth's surface in the present seismotectonic regime (U.S. NRC, 1997). The following sections provide the data, observations and reference citations to support this conclusion. The information contained in these sections was developed in accordance with Appendix D of Regulatory Guide 1.165 "Geological, Seismological, and Geophysical Investigations to Characterize Seismic Sources" (U.S. NRC, 1997) and is intended to satisfy 10CFR100.23 "Geologic and Seismic Siting Criteria" (U.S. NRC, 2002).

2.5.3.1 Geological, Seismological, and Geophysical Investigations

Investigations performed to assess the potential for surface fault rupture at the Grand Gulf Site and Site Area included: (1) compilation and review of existing data; (2) interpretation of aerial photography; (3) discussions with researchers familiar with the geology of the Site Area; (4) review of seismicity; and (5) field reconnaissance. In particular, an extensive body of existing information is available for the Grand Gulf Site and Site Area. This information derives from three principal sources: (1) work performed as part of the existing Grand Gulf Nuclear Station (GGNS) and reviewed and accepted previously by NRC staff; (2) published and unpublished geologic mapping performed primarily by the U.S. Geologic Survey, States of Mississippi and Louisiana, and researchers from the University of Memphis; and (3) seismicity data compiled from published journal articles and evaluated as part of this study.

This existing information was supplemented by field reconnaissance and air photo interpretation of the Site Area and Site Location. In particular, an updated map of surficial deposits and geomorphology was prepared for the Site Location (Figure 2.5-27). The new geologic map was used in combination with existing maps showing the surface of buried stratigraphic horizons to provide direct evidence documenting the absence of surface or subsurface faulting or other forms of tectonic and non-tectonic deformation at the site.

2.5.3.2 Previous Site Investigations

Previous site investigations performed for the existing Grand Gulf Nuclear Station are presented in the Updated Final Safety Analysis Report (UFSAR) (Reference 16). These previous studies provide extensive subsurface data illustrating the distribution of buried stratigraphic horizons across the site. In particular, structure contour maps of the top of the Oligocene age Glendon Limestone (Figure 2.5-15), Miocene Catahoula Formation (Figure 2.5-29), and Pliocene to Pleistocene Upland Complex (Figure 2.5-32) show that these stratigraphic horizons, although eroded, are not deformed by faulting, folding, or tilting across the Site Location and Site Area. In addition, these subsurface data document the absence of salt diapirs beneath the Site Location, collapse structures, volcanic intrusions, or other forms of non-tectonic deformation.

New information developed since the original Grand Gulf site investigation confirms that no active faults exist within the Site Area (5-mile radius). Significant revisions to our knowledge of active faulting and tectonic process have been made since the early investigations of the Mississippi Alluvial Valley (Reference 31; Reference 163). Models of faulting proposed by Fisk and Krinitzsky were initially addressed during the original Grand Gulf site investigations (Reference 16), and new additional data have been developed that further support the conclusions of the Grand Gulf investigations (Reference 17; Eversull, 1984).

Fisk was the first to address Quaternary faulting in the Mississippi Alluvial Valley (Reference 31). He postulated that the Mississippi Alluvial Valley was crossed by a dense rectilinear pattern of northeast-southwest- and northwest-southeast-trending fractures. This interpretation was heavily influenced by the prevailing belief by geologists of Fisk's era that the earth's crust contained a world-wide grid pattern of faults caused by planetary-scale influences (Krinitzsky, 1950). Fisk interpreted the association of photographic lineaments with geomorphic criteria including sharp river bends, linear lake margins, topographic breaks, and oriented drainages to infer the presence of faults in the region.

Krinitzsky (Reference 163) mapped the distribution of several hundred inferred faults in the Mississippi Alluvial Valley and Delta Plain regions. His mapping was primarily based on physiographic evidence. However, at three localities, he used closely spaced borings to verify the presence of faults in uppermost Tertiary deposits. The three localities include sites at Big Creek and Old Town Lake west of Friars Point, Mississippi, and a site west of Reelfoot Lake, south of New Madrid, Missouri.

The development of plate tectonic theory over the last several decades dramatically updated the tectonic models prevalent in Fisk's era. Since 1950, detailed Quaternary mapping and numerous site-specific engineering geologic investigations have disproved the presence of the majority of the faults and fault zones indicated by Fisk (Reference 31) and Krinitzsky (Reference 163), although high-resolution seismic surveys identified some faults in Tertiary and Cretaceous formations. In the Site Region, these older faults lack surface expression in Quaternary deposits, providing evidence that they have not been active during Quaternary time (Reference 17).

Fisk (Reference 31) suggested that two possible fault zones may intersect about 3 miles north of the site, near the mouth of the Big Black River. These potential fault zones were evaluated during the original Grand Gulf site investigation using borings, geologic mapping, literature review, and LANDSAT imagery (Reference 16). A cross section was constructed using Boring G-3 from the original site investigation and borings AH-5 and E-161 previously drilled by the Mississippi State Geological Survey. Differences in formation contact elevations across the inferred faults were attributed to the regional dip of stratigraphic units rather than fault offset along the Big Black River (Reference 16). The second lineament identified by Fisk in the Site Vicinity coincided with the alignment of Bayou Pierre; however, continuous stratigraphy documented from borings drilled north and south of Bayou Pierre demonstrates the continuity of subsurface deposits and the absence of faulting (Reference 16). These investigations disproved the existence of Fisk's previously inferred fault zones and verify that no faults exist within 5 miles of the site (Reference 16).

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

As previously discussed, there is no evidence of Quaternary fault offset in the Site Location or the Site Area. Furthermore, there is no evidence of non-tectonic deformation at the site or in the Site Area. The closest Holocene active fault to the site are growth faults in the Gulf Coast Basin

province about 90 miles south-southwest of the site. The closest postulated Quaternary active tectonic fault is the Saline River Lineament approximately 90 miles north-northwest of the site (Figure 2.5-19) (referred to as the Saline River source zone, Section 2.5.1). Two salt diapers, the Bruinsburg salt dome and the Galloway salt dome, are within approximately 8.5 miles to the southwest and northeast of the site, respectively (Figure 2.5-9).

2.5.3.4 Correlation of Earthquakes with Capable Tectonic Sources

There are no reported earthquake epicenters that can be associated with any fault within 5 miles of the site. The closest earthquake of M_w 3.0 or larger is located 25 miles north of the site (Figure 2.5-5).

2.5.3.5 Characterization of Capable Tectonic Sources

There are no capable tectonic sources within 5 miles of the Grand Gulf Site. As described in Section 2.5.1, the Site Area is underlain by approximately 500 feet of Oligocene and younger sediments that were deposited within the Gulf Coastal Plain (Figure 2.5-9). These deposits are gently warped forming a broad synclinal structure, the limbs of which dip less than one degree and extend from western Alabama to western Louisiana (Figures 2.5-4 and 2.5-11). The axis of this syncline approximately follows the current position of the Mississippi Alluvial Valley, and also forms the axis of the Mississippi Embayment to the north. The downwarping of the Mississippi Alluvial Valley is a slow, ongoing process related to deposition of the thick sedimentary sequence. Although the axis of the syncline trends through the Site Area, this is not considered a seismogenic feature, but rather is related to slow isostatic adjustment of the crust due to sediment loading in the Mississippi Alluvial Valley and Gulf Coastal Plain (Reference 17).

Although pre-Quaternary faults are mapped in the Site Region, none are mapped within the Site Vicinity or Site Area. Tertiary faults of the Pickens-Gilbertton and Southern Arkansas fault zones are mapped approximately 80 miles northeast of the Site Area, and approximately 100 miles northwest from the Site (Figure 2.5-5). The Saline River lineament in northern Louisiana and southeastern Arkansas is approximately 90 miles from the Site, and the growth faults in southern Louisiana are also approximately 90 miles from the Site at their closest approach (Figure 2.5-5). The growth faults in southern Louisiana are related to gravitational collapse of the Mississippi delta complex. The faults in the eastern and western portions of the Site Region are exposed in Eocene or older deposits and do not affect Quaternary deposits. The Saline River lineament in northern Louisiana is the only potentially active Quaternary tectonic fault in the Site Region, but is not mapped across the Mississippi Alluvial Valley (References 17; 44). There are no faults mapped closer than 90 miles to the site, or within either the Site Vicinity or Site Area (References 52; 53).

Investigations by the Army Corps of Engineers (Reference 204) were conducted to document subsurface geological conditions along the Mississippi River. Based on a series of geotechnical borings, the Army Corp developed geologic cross sections of Quaternary and Holocene alluvium in the Mississippi River channel. The boring data support previous conclusions that Quaternary deposits in the Site Area are unfaulted. The Army Corp data also support the interpretation that the faults previously mapped by Fisk (Reference 31) along the Big Black River and Bayou Pierre are not present (Reference 204).

Subsurface borings completed for the existing Grand Gulf Nuclear Station document the absence of faulting in the Site Area (Reference 16). Oligocene and younger deposits decrease in elevation from north to south, are laterally continuous, and have a constant gradient across the Site Area. No faults are identified along this section (Figure 2.5-16; Reference 16).

Additional subsurface data from deep exploration borings across the Site Vicinity in eastern Louisiana also document lateral continuity of Tertiary and younger deposits (Reference 205).

The continuity of subsurface deposits demonstrates the tectonic stability of the Site Location, Site Area, and Site Vicinity from at least Oligocene time, approximately 30 Ma to the present. the top of the Oligocene Glendon Limestone Formation slopes to the southeast (Figure 2.5-15). The surface appears to have been eroded, forming a buried drainage basin morphology, but does not show morphology indicative of tectonic deformation (Reference 16).

The top of the Miocene Catahoula Formation in the Site Location forms a gentle westward sloping surface (Figures 2.5-29). The surface morphology preserves the Pliocene to Pleistocene age erosion surface of the ancestral Mississippi Alluvial Valley, and a former tributary valley across the Site Location. The morphology of the surface of the Catahoula Formation is related to former stream erosion. The top of the Catahoula surface shows no morphology indicative of tectonic deformation (Reference 16).

As shown on Figure 2.5-32, the surface of the Pliocene to Pleistocene Upland Complex deposits have been eroded during the Pleistocene and Holocene forming two west-trending drainages that cross the property. These drainages are the current active channels in the Site Location. The surface of the terrace deposits shows no morphology indicative of tectonic deformation (Reference 16).

2.5.3.6 Zones of Quaternary Deformation Requiring Detailed Fault Investigation

There are no zones of Quaternary deformation requiring detailed investigation within the Site Area.

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

As discussed above, geologic cross sections and structure contour maps of the Site Vicinity, Site Area, and Site Location demonstrate the continuity of deposits of Oligocene and younger age, and the long-term tectonic stability of the Site Area. Therefore, the potential for surface-fault rupture at the site is considered negligible. In addition, there is no evidence of non-tectonic deformation in the Site Location or Site Area such as collapse structures, salt diapirs, growth faults, volcanic intrusion, etc.

2.5.4 Stability of Subsurface Materials and Foundations

2.5.4.1 Detailed Site Investigation Program

An engineering geologic and geotechnical site investigation (geotechnical investigation) was performed for the proposed location of the new facility to: (1) characterize site conditions to develop site-specific seismic design criteria; and (2) evaluate potential seismically-induced ground failure and hazard. The information also was used for an initial screening assessment of foundation conditions. The locations of the site explorations are shown on Figure 2.5-69 and 2.5-70, and the detailed results from the geotechnical investigation are included in Engineering Report ER-02 "Geologic, Geotechnical, and Geophysical Field Exploration and Laboratory Testing, Grand Gulf Early Site Permit" (Reference 15). At this time, a plant design has not been selected, and the footprint and embedment depth of the plant have not been determined. Additional site exploration, laboratory testing, and geotechnical analyses will be performed to develop final plant design criteria for the Construction and Operating License (COL) phase of the project after a plant design has been selected.

The exploration and testing activities were specifically developed to comply with:

- NRC Regulatory Guide 1.165 "Identification and characterization of seismic sources and determination of safe shutdown earthquake ground motion" (Reference 4).

The site investigation also is in partial compliance with:

- Regulatory Guide 1.132 (and proposed revision Draft Regulatory Guide, DG-1101), Site Investigations for Foundations of Nuclear Power Plants (Reference 5, 212); and,
- Regulatory Guide 1.138 (and proposed revision Draft Regulatory Guide, DG-1109), Laboratory Investigations of Soils and Rocks for Engineering Analysis and Design of Nuclear Power Plants (Reference 6, 213).

The COL phase investigations and testing will include additional exploratory borings throughout the planned excavation and building footprint area to obtain information for foundation design and site grading in full compliance with Regulatory Guides 1.132 and 1.138 and Draft Regulatory Guides D-1101 and D-1109.

2.5.4.1.1 Borings and Sampling

Four exploratory borings (Borings WLA B-1, B-2, B-2A, and B-3) were drilled at the proposed site location to depths of between 141.5 and 238.0 feet to characterize subsurface geologic conditions, perform in situ testing and borehole geophysical surveys, and to obtain laboratory geotechnical test samples. Figure 2.5-70 shows the locations of the exploratory borings, and Tables 2.5-20 and 2.5-21 summarize the characteristics of the exploratory borings and general site stratigraphy. Figures 2.5-34 through 2.5-74 are summary logs of encountered conditions. Detailed boring logs are included in Engineering Report ER-02 (Reference 15). Geologists classified the rock and soil materials according to standard engineering classification, and also assigned geologic units, inferred ages, and made interpretations of genesis for each stratum.

2.5.4.1.2 Site Geotechnical Profile

Geologic cross sections in Figures 2.5-75 through 2.5-77 show the site stratigraphy and subsurface conditions. Subsurface materials were classified into four different geologic units: late Pleistocene loess, Pliocene to Pleistocene Upland Complex alluvium (Qa), Upland Complex old alluvium (Qoa), and Miocene Catahoula Formation claystone based on field examination of recovered samples. In addition to these geologic units, localized fill was placed in the former topographic swales that crossed the site (Figure 2.5-69, Rev. 1) to develop the current level pads. This fill is variable in thickness, and appears to consist mainly of excavated on-site loess that was removed from cut parts of the pads. Boring WLA B-3 is located in the approximate axis of one of the infilled swales. The materials encountered in the boring consist of massive silt similar to natural loess deposits, and exhibit similar field SPT and CPT response and laboratory index values (Figure 2.5-76, Rev. 1). Therefore, the fill could not be differentiated from the natural loess, and was grouped together with the loess for site ground motion response and hazard analysis. The fill encountered in Boring WLA B-3, therefore, is not broken out as a separate unit, and is not described separately. This estimated thickness and extent of swale infill is shown on Figure 2.5-69, Rev. 1.

The classification of deposits is based on textural composition, degree of sorting, relative density, color, and structures according to standard geologic interpretive procedures described in Compton (Reference 200). Each geologic unit is separated by a laterally continuous, subhorizontal, erosional unconformity that represent a hiatus in the depositional phase of each unit, and/or intervening period of erosion. The unconformable contacts, therefore, represent the former land surface at different times during the late Pliocene, Pleistocene, and Holocene.

Structural contour maps showing the elevation of the unconformable contacts between old alluvium and alluvium, and alluvium and loess, are included in Figures 2.5-78 and 2.5-79, respectively.

The stratigraphy encountered generally agrees with the stratigraphy shown on the UFSAR boring logs, with the exception that the UFSAR borings describe the alluvium as "terrace alluvium", and old alluvium as "Catahoula Formation". Accounting for the differences in unit nomenclature between this study and UFSAR borings, material descriptions and contacts generally are consistent between the two data sets.

2.5.4.1.3 Material Engineering Properties

Standard Penetration Tests (SPT) were obtained at various intervals in the borings to provide estimates of the in situ density/consistency of site materials, obtain disturbed samples for index testing, and to use as a screening tool to evaluate potential liquefaction susceptibility and foundation properties. All SPT blow counts reported for this study are uncorrected for equipment and confining stress. SPT blow counts are summarized and compared against the blow counts from the GGNS UFSAR data on the geologic cross sections in Figures 2.5-75 through 2.5-77. In general, the blow counts from this investigation are somewhat lower than reported in the UFSAR for GGNS borings. The differences may be related to different equipment and techniques used during this study and earlier studies, such as different hammer efficiencies. Automatic trip hammers were used for this investigation and may have higher impact force efficiency than hammer systems used for the UFSAR investigations.

Ranges and averages of SPT blow counts for different geologic layers underlying the proposed site are summarized in Table 2.5-22.

2.5.4.1.3.1 Loess

Loess was encountered in each of the borings, and forms the surface layer across the site. The loess ranges from about 55- to 85-feet thick, and consists of relatively uniform, yellow-brown, slightly- to moderately-plastic silt to clayey silt (ML) with some silty clay (CL) intervals, weak blocky structure and pervasive small root pores and voids. Small gastropod and clam(?) shells commonly occur in discrete beds or zones. The silt typically exhibited a silky feel, is micaceous, and has low to moderate plasticity. The loess exhibits coarse layering defined by differences in clay content, color, shell content, and consistency. However, the engineering properties of the different loess layers do not differ significantly, and the index engineering properties fall within a narrow range throughout the deposits. Regionally and locally, the loess exhibits a slight carbonate cementation, and soil structure that allows it to stand vertically in cuts and stream banks. In borehole samples, the loess characteristically exhibits a moderate reaction to hydrochloric acid, documenting the weak calcium carbonate cementation. Typically, loess deposits contain calcium carbonate cementation as precipitates in root pores and voids, and may gain additional cohesion from clay films on silt grain surfaces (Reference 203). Testing performed for the UFSAR (Reference 16) showed that the loess has a honeycomb structure. Some weakly-developed paleosol layers marked by slightly clayier zones may separate individual pulses of loess deposition. The CPT soundings show that the loess exhibits individual layers that are between about 6-inches and 40-feet thick. SPT data show that the loess is medium stiff to stiff, with estimated undrained shear strengths on the order of 750 to 1,500 pounds per square foot (fps). The CPT-determined undrained shear strength of loess ranged between 2000 and >8000 psf (maximum instrumental range), increasing with depth. Shear wave velocities in loess ranged between 590 and 1,450 fps.

2.5.4.1.3.2 Alluvium (Upland Complex)

The alluvium consists of light yellow brown and gray, interbedded sand and silty sand (SP, SM) with lesser clayey sand (SC), gravelly sand (SW), and sandy gravel (GW) lenses. Discontinous layers ranged between about 6-inches and 3-feet thick. Individual layers could not be traced between the borings and CPT soundings. Sand grains are subrounded to subangular, fine- to medium-grained, and consisted of quartz with lesser feldspar and mafic lithologies. The alluvium typically is well sorted with low fines content, and low plasticity. The alluvium was readily drilled with mud rotary equipment, but some sandy layers below the water table caused caving problems in Boring WLA B-2A. SPT blows in the alluvium indicate that it is in a medium dense to dense condition. CPT refusal was met in the alluvium in each sounding after penetration of between 5 and 30 feet into the alluvium (10-ton capacity CPT rig). CPT shear strength values ranged between 4,000 to >8,000. Shear wave velocities in the alluvium ranged between 740 and 1,750 fps.

2.5.4.1.3.3 Old Alluvium (Upland Complex)

The old alluvium consists of interbedded, green to dark gray (gleyed) clayey sand, sandy clay, silty sand, and clean to gravelly sand. The old alluvium was poorly to well sorted, typically exhibiting much poorer grading than the overlying alluvium. Layering in the old alluvium ranged between about 3-inches and 3- to 4-feet thick, and some layers contained dark manganese and carbon streaks and pods, with some relict plant remains. Gravel-size clasts included a large percentage of soft clay and claystone rip-up clasts. Finer-grained layers exhibited low to moderately high plasticity. Drilling was moderately easy to moderately hard (slow), and some sandier zones appeared to have locally ravelled into the holes. SPT blow counts in the old alluvium indicate that it is dense to very dense. Shear wave velocity ranged between 530 and 3,360 fps.

2.5.4.1.3.4 Catahoula Formation

The Catahoula Formation was only encountered in Boring WLA B-2A (the deepest boring for this investigation), and consists of gray-green, hard clay to claystone that exhibited a slight degree of induration and somewhat brittle behavior. The claystone has a partial blocky structure, and contains silica-coated fractures. Some of the broken surfaces in the recovered core exhibited randomly-oriented slickensides, and the core slaked in water after several tens of minutes of saturation. The claystone is highly plastic. Drilling was hard (slow, near-refusal), and the sole SPT sample had a blow count of 82. This SPT value correlates with a very hard (very dense) consistency, and is typical for soft rock-like material. Shear wave velocity in the Catahoula Formation ranged between 1,500 and 2,830 fps. The claystone Plasticity Index (PI) and clay content suggest that it may be expansive.

2.5.4.1.4 Borehole Geophysical Velocity Surveys (P-S)

Borehole geophysical surveys were performed in three borings (WLA B-1, B-2A, and B-3) upon completion of drilling between July 29 and August 17, 2002 by GEOVision Geophysical Services (GEOVision) and under observation by the WLA geologists. The surveys were performed with an OYO Model 170 Suspension Logging system that measures both compression wave (P) and horizontal shear wave (V_{SH}) velocity in formation materials comprising the borehole walls. A description of the equipment, procedures, and detailed survey results are provided in Engineering Report ER-02 (Reference 15). The results of the surveys are summarized as velocity-depth plots on Figures 2.5-80. All P-S surveys were performed in

uncased holes because this results in better resolution of stratigraphic velocity layers. A thick mud was used to maintain the holes during the P-S logging.

The P-S velocity survey obtains a vertical velocity profile of the stratigraphy along borehole walls using both compressive (Vp) and shear (Vs) waves. Ranges of compression and shear wave velocities for the site geologic materials are shown in Table 2.5-23.

No clear velocity differences were observed between the loess and Upland Complex alluvium, or the Upland Complex alluvium and old alluvium. Rather, velocities typical increased gradationally in the various geologic layers (Figure 2.5-80). A well-defined velocity increase was observed in the lower half of the old alluvium that is not marked by a significant stratigraphic change based on the borehole logging data. It is possible that the higher velocities occur in more-dense and indurated sublayers within the old alluvium that are not marked by a lithologic change. Velocities remained relatively high in the Catahoula Formation.

The P-S datalogger used for this study represents a marked improvement and advancement of technique over the cross-hole seismic velocity techniques and equipment that were used for the operating GGNS in the 1970's (Reference 16). Therefore, a direct comparison cannot be made between the two data sets. However, the velocities for the various geologic layers generally fall within similar ranges, if the UFSAR data for the Catahoula Formation are compared against the velocity data for the Upland Complex Old Alluvium. A comparison between the shear wave velocities is made below.

2.5.4.1.5 Cone Penetrometer Test (CPT) Surveys

Four cone penetrometer test (CPT) soundings were performed by Eustis Engineering Company, Inc. (Eustis) in the proposed site location (Figure 2.5-70) to depths of between 79.0 and 95.3 feet. Summary CPT logs are shown on Figure 2.5-81, and the detailed results from the CPT surveys are included in Engineering Report ER-02 (Reference 15). Each sounding was advanced to practical refusal, which occurred in the upper part of the Upland Complex alluvium. Because of refusal within the Upland Complex alluvium, CPT data could only be obtained for the loess, and uppermost part of the alluvium. No CPT data was obtained in the Upland Complex old alluvium or Catahoula Formation. The first CPT sounding (CPT-1) was located adjacent to boring WLA B-1 for calibration purposes. Comparisons of subsurface materials and contacts between boring WLA B-1 and CPT-1 were very good.

Tip resistance values in the loess were relatively uniform and below 100 tons per square foot (tsf). Tip resistance increased markedly at or near the top of the Upland Complex alluvium below the base of the loess, and were greater than 200 to 400 tsf. The loess exhibited typical friction resistance values of between 300 and 1,600 pounds per square foot (psf). The Upland Complex alluvium exhibited typical frictional resistance values from 2,400 psf to greater than CPT rig refusal (10 tons), but some local finer-grained layers had frictional values similar to those for loess.

The published relationships of Robertson (Reference 199) were used by Eustis to classify materials based on the CPT data. The CPT material classification roughly matched field and laboratory classifications, but tended to be somewhat coarser (sandier) than the field classifications and laboratory testing results. The CPT classifications and tip results show that the grain size and consistency of the loess are relatively homogenous, and the loess exhibits a generally coarse layering with individual strata on the order of several feet to up to about 40-feet thick. This is in agreement with the field borehole and laboratory data. Finer layering and increasing variability in tip and friction resistance occurred in the lower parts of the loess near

the contact with the underlying Upland Complex alluvium. The finer stratigraphy and variability appear to be the result of possible paleosols at the top of the alluvium, and/or different pulses of sedimentation and reworking of the alluvium during initiation of loess deposition. The Upland Complex alluvium exhibited fine to medium stratigraphic layering, but was predominantly classified as sand with some gravelly layers.

Undrained shear strength estimates from CPT data were made by Eustis according to Lunne et al. (Reference 201), and using a Cone Factor value of 15 which Eustis has found to be regionally applicable for projects in Mississippi and Alabama. The CPT-determined undrained shear strength of loess ranged between 2,000 and >8,000 psf, and increased with depth. CPT undrained shear strength values for Upland Complex alluvium ranged between 4,000 to >8,000 psf. Estimated SPT blow counts from CPT data were made by Eustis according to correlations by Lunde (Reference 201), and are in general agreement with the range of SPT blow counts obtained in the exploratory borings. Equivalent SPT N60 values were calculated from CPT data by Eustis according to Lunne et. al. (Reference 201), and ranged between about 10 and 20 for the loess, and typically were greater than 40 for the alluvium. Evaluation of CPT data according to methodology of Andresen et al. (Reference 202) suggests that the overconsolidation ratios of loess and Upland Complex alluvium are both considerable, possibly in the ranges of greater than 2 for loess, and about 1.5 to 5 for Upland Complex alluvium.

2.5.4.1.6 Static Laboratory Analysis

Sixty samples of loess, Upland Complex alluvium, and Catahoula Formation bedrock from site borings were tested by Eustis for basic geotechnical properties in their Metairie, Louisiana laboratory. Index properties also were measured for the six samples submitted to the University of Texas, Austin (UTEXAS) for dynamic testing. The samples were shipped to Eustis by Federal Express (FedEx), and were transported to UTEXAS in a passenger vehicle. Both sample sets were documented with a chain-of-custody form. Engineering Report ER-02 (Reference 15) contains descriptions of the laboratory test methods, equipment, and data results. The scope of the laboratory index testing program included the following:

- fifty nine moisture content (ASTM D 2166)
- twenty four dry density (ASTM D 2216)
- seventeen Atterberg Indices (ASTM D 4318)
- forty nine mechanical sieves (ASTM D 422)
- fifteen hydrometer (ASTM D 422)
- six consolidated, undrained triaxial test series (1 to 3-point series; ASTM D 4767)

Tables 2.5-24 and 2.5-25 summarize the laboratory test program and testing data. Figures 2.5-82 and 2.5-83 summarize the results from the moisture content and grain size testing, respectively.

2.5.4.1.6.1 Laboratory Results for Loess

Twenty six samples of loess were tested for static geotechnical properties. Water content in the loess samples varied between 15.7% and 29.5%, with an average of 22.8%. Dry densities of loess ranged between 85.8 pcf and 104.7 pcf, with an average of 94.8 pcf. These dry densities show that the loess is relatively stiff, with relative densities ranging on the order of greater than 50% to about 75% (Reference 203). The densities suggest that the loess has a moderately low

to low potential for saturation-induced settlement from particle structure collapse and dissolution of cementation (Reference 203). The loess is subject to gully erosion and possible piping, as evidenced by steep-walled erosional gullies in loess.

Plasticity Indices (PIs) for loess samples ranged between 3% and 16%, with an average of 10.5%, with corresponding Liquid Limits (LL) of between zero and 32%. These values indicate that the loess classifies as a low plasticity silt (ML). The fines percentage (silt and clay; minus 200 sieve) of loess samples ranged between 73.2 and 99.8, with an average of 97%. The clay-size fraction determined from hydrometer testing ranged between 8.2% and 11.1%, and show that the loess primarily consists of silt-size grains. The grain size distribution of the loess samples was quite uniform (Figure 2.5-83), and typical for loess deposits.

Two triaxial CU test series performed on loess samples indicate total stress cohesion of zero and internal friction angles of between 32 and 33 degrees. Effective strength internal friction angles were between 33 and 34 degrees. The results of these strength tests are on the high end for published values for loess (e.g., Reference 203), and indicate a high degree of grain interlocking and cementation. Locally, steep and vertical road cuts in loess soils appear to be quite stable, suggesting that some cementation and apparent cohesion exists in the natural, undisturbed loess.

2.5.4.1.6.2 *Laboratory Results for Upland Complex Alluvium*

Twenty one samples of Upland Complex alluvium were tested for static geotechnical properties. Water content in the alluvium samples varied between 9.9% and 25.5%, with an average of 19.2%. Dry densities ranged between 93.2 and 129.4 pcf, and averaged 106.0 pcf. These densities are typical for medium dense to dense silty and clean sands (Reference 203). PIs for alluvium samples ranged between 0% and 4% and LLs ranged between zero and 21%. This indicates that Upland Complex alluvium is essentially non-plastic.

The Upland Complex alluvium consisted primarily of sand to silty sand (SM-SP). Sand percentages ranged between 2% and 95.3%, with an average of 68.6%. Two samples contained significant gravel content (24.3% and 41.6% gravel); other samples had either zero, or less than 5%, gravel. The fines content of Upland Complex alluvium ranged between 4.7% and 92.9%, with an average of12%, and the clay-size fraction determined by hydrometer analysis ranged between 2.8% and 10.6%. The hydrometer test results show that the fines in the Upland Complex alluvium consist primarily of silt-size material. The grain size distribution of the alluvium samples was relatively uniform, primarily poorly-graded to silty sands (Figure 2.5-83). The grain size and sorting is typical for moderate-energy alluvial deposition and point bar deposits typical along the modern Mississippi River.

Three triaxial CU test series performed on Upland Complex alluvium samples indicate total stress cohesions of between zero and 1.16 psf, and internal friction angles of between 36 and 40 degrees. Effective strength cohesion was zero, and friction angles varied between 36 and 41 degrees. These results are relatively high for alluvium with silty sand to poorly graded sand consistency (Reference 203), and suggest that the alluvium is quite dense with interlocking packed grains.

2.5.4.1.6.3 Laboratory Results for Upland Complex Old Alluvium

Fifteen samples of Upland Complex old alluvium were tested for static geotechnical properties. Water content in the old alluvium ranged between 5.6% and 36.1%, and averaged 23.4 %. Two dry density determinations were 89.3 (sand layer) and 94.9 pcf (clay layer). These densities are low for sandy alluvium, but in the typical range for clayey alluvium (Reference 203). PIs for the

fines component of the old alluvium ranged from zero to 16%, and averaged 9%. The corresponding LLs were between 17 and 42%. These results indicate that the Upland Complex old alluvium is non-plastic to moderately plastic, and that the fines classify as ML-CL soils. The fines in the old alluvium generally exhibit a higher plasticity than the fines in the overlying alluvium, suggesting differing sediment sources and/or weathering histories.

The Upland Complex old alluvium samples classify as a range of soil types, including lean clay and silt (CL and ML), silty and clayey sand (SM and SC), and poorly graded sand (SP). The sand content of the old alluvium samples ranged between zero and 89.2%, with an average of 34.0%. In general, the Upland Complex old alluvium has a lower percentage of sand, and higher clay content, than the overlying alluvium unit. Two samples had significant gravel content: 8.5% gravel; and 22% gravel. Other samples had zero or less than 0.3% gravel. Fines content in old alluvium samples ranged between 3 and 99%, with and average of 54.4%. The clay content of hydrometer samples ranged between 6.2 and 12.2% with an average of 9.4%. The hydrometer analyses show that the fines fraction in the old alluvium is primarily silt-size. The grain size distribution of Upland Complex old alluvium samples is significantly more poorly-sorted than the overlying alluvium, and samples typically contain a wide range of grain sizes commonly associated with sediments that are not transported far from the source deposits.

No triaxial strength tests were performed on old alluvium samples.

2.5.4.1.6.4 Laboratory Results for Catahoula Formation

Only one acceptable sample of Catahoula Formation claystone was obtained from the exploratory borings for laboratory testing. This sample had a moisture content of 21.5%, PI of 35%, LL of 54%, and fines content of 80.6%. No hydrometer or triaxial strength tests were performed on samples of Catahoula Formation. The PI of the Catahoula Formation sample is significantly higher than any of the other tested materials, and plots in the zone of highly plastic clay in the UCSC classification. The PI and grain size of the Catahoula Formation claystone suggest that it is an expansive material, and classifies as a fat clay (CH).

2.5.4.1.6.5 Comparison of ESP and UFSAR Laboratory Test Results

Results from the ESP laboratory testing are in a similar range to the results from the UFSAR laboratory testing for layers with similar composition and texture. Figures 2.5-84 through 2.5-86 are comparison plots of some index properties between the ESP and UFSAR testing programs. Index values for the ESP samples generally fall within the ranges of those determined for the UFSAR samples. Loess, in particular, exhibits quite similar properties (Figure 2.5-84) for moisture content, liquidity index, and dry density. The laboratory data show that the loess is uniform across the proposed site location. The Upland Complex alluvium unit exhibits higher dry densities, and lower moisture contents, than the UFSAR terrace alluvium samples (Figure 2.5-85). This may be due, in part, to local variations in the sand content of the alluvium. The moisture content and liquidity index for the Upland Complex old alluvium and Catahoula Formation samples are generally within the ranges reported for the UFSAR samples, but depart from the UFSAR data for ESP samples in the elevation range of between about zero and 20 feet (Figure 2.5-86). The differences may be because of a thin coarser-grained zone that exhibits locally higher moisture contents.

2.5.4.1.7 Dynamic Soil Testing

Shear modulus reduction and damping curves for the upper part of the site soil column were obtained from torsional shear and resonant column (TSRC) testing of six relatively undisturbed samples at the UTEXAS laboratory under the direction of Professor K.H. Stokoe II. Dynamic

testing was performed to obtain dynamic modulus reduction curves and damping data in site soils for site response analysis. Testing was constrained to materials that could be successfully sampled in a relatively undisturbed state with thin walled Shelby tubes, and included 2 tests of eolian silt, 2 tests of Upland Complex alluvium, and 2 tests of Upland Complex older alluvium. The Catahoula Formation claystone could not be successfully sampled for dynamic testing. Table 2.5-26 summarizes the properties of the samples, and Figure 2.5-80 shows the locations of the samples and comparisons between borehole and laboratory-measured shear wave velocities. The dynamic testing results are summarized in Figures 2.5-87 through 2.5-96.

All dynamic test samples were relatively undisturbed Shelby tube samples that were transported to the laboratory in a passenger vehicle. A chain-of-custody form was filled out and maintained to document sample transportation.

Each test specimen was subjected to a suite of tests at varying confining pressures and cyclic strain levels. Specimens were driven in the torsion shear mode of the TSRC equipment at increasing cyclic strain levels up to the limit of the equipment and were then excited in the resonant column mode to obtain results at higher strain levels. In order to obtain resonance of these specimens the frequencies of excitation were somewhat higher than those used in the torsional shear mode. General properties of the specimens are shown in Table 2.5-26.

Table 2.5-26shows the estimated in situ confining pressure for each test specimen. A K_o value of 0.5 was used for the loess specimens, and a value of 1.0 used for the Upland Complex alluvium and older alluvium. The ratio of the shear wave velocity measured in the laboratory at small strains and the shear wave velocity measured in the field at the same depth are shown in the last two columns of the table both for laboratory test specimens consolidated to the estimated in situ confining pressure and four times the estimated in situ confining pressure. Ideally this ratio should approach unity. It appears that the estimate of K_o that was used for the loess specimens may have been too low. A better approximation of the field conditions was obtained by testing these samples at four times the estimated in situ confining pressure. The two specimens of alluvium showed a better match to the shear wave velocities measured in the field when tested at the estimated in situ confining stress. Reconsolidation to four times the estimated in situ confining stress appears to have over-corrected for the effects of stress release and sample disturbance.

The results of the TSRC tests are shown in Figures 2.5-87 through 2.5-96as: (1) a function of the cyclic shear strain as values of the modulus reduction ratio (G/Gmax), that is the shear modulus divided by the low strain shear modulus; and (2) the damping ratio. The ESP data are plotted on the family of depth dependent modulus reduction and damping ratios developed by EPRI (Reference 170). The pattern of the ESP data is generally similar to the shape of the EPRI curves, however the ESP data are generally more linear. This is likely because the EPRI curves were developed for normally consolidated Holocene silty and clayey sands, whereas the soils at the proposed site location are both older (Pliocene to Pleistocene) and overconsolidated. The dynamic test results were evaluated with respect to the geologic origin and index properties of each test specimen to identify logical groupings of results for assigning modulus reduction and damping parameters for site response analyses.

Because the shape of the modulus reduction and damping curves defined by the site-specific laboratory tests is similar to the shape of the depth dependent EPRI curves, certain of the EPRI curves have been adopted for use in the site response analyses. EPRI curves that represent greater depths of normally consolidated soils were used to represent the aged and overconsolidated soils at the Grand Gulf site. The results from the laboratory testing at four times the estimated in situ

confining stress were given preference for selection of the equivalent EPRI curves to correct for the effects of stress release and sample disturbance. The EPRI curves for depths of 120 to 250 feet were used to represent the loess, the EPRI curves for depths of 250 to 500 feet were used to represent the alluvium, and the EPRI curves for depths of 500-1000 feet were used to represent the old alluvium and the underlying materials to a depth of 500 feet. The curves that were adopted for analysis are shown as RED lines in Figures 2.5-87 to 2.5-96.

2.5.4.2 Site Groundwater Occurrence

Because water was continuously injected into the hole during drilling operations, elevation of the groundwater table could not be directly evaluated in the borings. However, borehole seismic velocity P-S surveys allowed estimation of the groundwater table location using prominent increases in compression wave velocity that are not matched by shear wave velocity increases. The P-S determined groundwater table ranged between 70 and 100 feet deep, and corresponded to elevations of between 55 and 63 feet. The groundwater table exhibits a southwestward flow towards the Mississippi River floodplain with a gradient on the order of a 1-foot drop over a 100 to 125 foot distance (gradients of between 0.008 and 0.009) (Section 2.4). The groundwater levels and gradient are shown on the cross sections in Figures 2.5-75 through 2.5-77. It is possible that shallow perched water could form in parts of the loess during periods of high rainfall, especially over finer-grained zones. Such perched zones likely would dissipate rapidly after cessation of heavy rainfall.

2.5.4.3 Response of Soil to Dynamic Loading

Based on results from the geotechnical site investigation, the geologic materials underlying the proposed site location are not prone to dynamically-induced failure or excessive strength loss or deformation. The susceptibility of the deposits to liquefaction is low, as specifically addressed in Section 2.5.4.4. The preliminary assessment of bearing capacity and settlement are discussed in Section 2.5.4.5.2. The dynamic shear modulus reduction and damping of site soils are discussed in Section 2.5.4.1.4.

2.5.4.4 Liquefaction Potential and Seismic Site Stability

Geologic deposits underlying the proposed site location range in age from Miocene (Catahoula Formation), late Pliocene to Pleistocene (Upland Complex old alluvium and alluvium), and late Pleistocene (loess). These deposits all appear to be overconsolidated, and have acquired a certain level of liquefaction resistance by aging effects. No unconsolidated Holocene, sandy or silty deposits that are susceptible to liquefaction were identified at the site location, or are expected to occur based on extensive existing subsurface data. Obermeier et al. (Reference 126) report that the vast majority of identified liquefaction occurrences during the New Madrid earthquakes in 1811-1812 were within Holocene floodplain sediments. No Holocene floodplain deposits underlie the proposed site, and no reported paleoliquefaction features have been found at the GGNS or within the Site Vicinity.

Although the grain size and density of loess are within the range of potentially liquefiable deposits (Figure 2.5-83), it is Pleistocene in age, cemented, and above the groundwater table at the proposed site. Additionally, future plant structures would be founded below the loess. The Upland Complex alluvium and old alluvium are saturated and contain silt and sand-size material within the grain size and sorting range of potentially liquefiable deposits (Figure 2.5-83). However, both the alluvium and old alluvium are overconsolidated, and are Pliocene to Pleistocene in age. The age and past loading history of these deposits makes them resistant to liquefaction. SPT blow counts (Table 2.5-22; Figures 2.5-75 through 2.5-77) also show that the

alluvium is in a medium dense to dense condition, and the old alluvium is in a dense to very dense condition. The density of the Upland Complex alluvial deposits make them very resistant to liquefaction. The Catahoula Formation claystone is Miocene in age, and partially lithified, and is not susceptible to liquefaction.

The influence of aging reduces liquefaction susceptibility in the Upland Complex alluvium and old alluvium. This process is reflected by the modulus reduction and damping characteristics described in 2.5.4.1.4 that show that these materials are significantly overconsolidated.

2.5.4.5 Static Site Stability

The proposed site location is on a bluff overlooking the Mississippi River that has been stable since at least late Pleistocene time when the loess deposits were laid down over the Upland Complex alluvium. It is not anticipated that the plant construction would significantly affect the site's static stability. Long term monitoring of the bluff for the existing GGNS indicates that there has been no appreciable instability during the monitoring period.

2.5.4.5.1 Bearing Capacity and Settlement

Detailed calculations of bearing capacity and settlement will be made during the COL phase of the project. Based on the known site conditions, the bearing capacity and settlement properties of the Upland Complex alluvium are expected to be suitable for a new nuclear power plant, and are not anticipated to provide any obstacles to construction. As noted in Section 2.5.4.3, it is anticipated that any new facility will maintain the existing plant grade of approximately elevation 132 feet, but that the plant will be founded in the Upland Complex alluvium, at or below the bottom of the loess deposits, at approximately elevation 80 feet, or lower, where the average shear wave velocity exceeds 1000 feet per second, or if the bottom of the plant is located above this elevation, that the natural soils would be excavated to this elevation and replaced with engineered fill that has a minimum shear wave velocity of 1000 feet per second. Consolidation tests will be performed on relatively undisturbed samples, particularly of the more clayey materials, to more precisely define the material overconsolidation ratios for quantitative settlement analyses. Any localized clayey layers present in the upper portion of the Upland Complex alluvium will be excavated and replaced with engineered fill as necessary.

2.5.4.5.2 Foundation Rebound

Excavation though the loess deposits into the Upland Complex alluvium will result in the removal of a minimum of about 7 kips per square foot (ksf) overburden. Up to several inches of predominantly elastic rebound may occur as a result of the excavation. This is insufficient to threaten stability of the excavation. Construction of the plant structure and backfilling of the excavation will cause reversal of much of the rebound. Construction of the existing plant required removal of approximately 11 ksf of overburden to reach the bearing stratum identified in the UFSAR as the Catahoula Formation. The rebound was estimated to be about 4 inches and was observed to be approximately 2 inches. A conservative estimate of the possible area of influence for excavation-related rebound is shown on Figure 2.5-69.

2.5.4.5.3 Lateral Earth Pressures and Hydrostatic Loading

Design of the structure will take account of the fact that short-term lateral earth pressures will be increased by heavy compaction of the backfill. Should the plant be embedded below the water table, hydrostatic and dynamic loadings will be evaluated during the COL phase using currently accepted standards of practice.

2.5.4.6 Design Criteria

Design criteria for plant foundations and excavations will be developed during the COL phase of the project, and will be based on additional subsurface exploration, laboratory testing, and geotechnical analysis. Bearing capacity analysis will be performed during the COL project phase. Refer to Section 2.5.4.5.1 for a general discussion of bearing capacity.

2.5.5 Stability of Slopes

The site is relatively flat, and not subject to large-scale landsliding or slope failures (Figure 2.5-70). The location of the proposed new facility encompasses two flat graded surfaces that are separated by an approximately 22-foot high, 3:1 (20 degrees) cutslope in loess soils. The cutslope is inclined at an angle less than laboratory-determined internal friction angle of the loess (32 to 34 degrees), and is stable without evidence of instability since it was constructed in the early 1970's. Although the entire proposed location of the new facility lies within the graded flat areas and cut slope, the area is bounded on the west by the 65-foot high erosional escarpment (bluff) that descends to the Mississippi River floodplain. Portions of the bluff are subject to surficial slumps and creeping soils that are confined within the loess soils in the face of the bluff slope. A possible slump scar on the bluff extends approximately 100 feet into the southwest corner of the site (Figure 2.5-70). No evidence of active or incipient slope movements, such as ground cracks or distressed facilities, were observed above or around the possible slump scar. Because the surficial slumping and erosion in the bluff slope are restricted to the loess soils, future instability in the bluff slope should not affect the planned facilities. It is likely that the future plant footprint will be sited at least 100 feet from the top of this possible slump feature, and the plant foundations would extend through the loess soils into underlying Upland Complex alluvium or old alluvium well below the elevation of the possible slide planes or toe of the bluff slope.

Specific stability analyses will be performed during the COL phase to evaluate the stability of deep foundation excavations for future facilities at the proposed site. However, no unstable conditions or materials were found underlying the site that should cause unusual stability problems for excavations, and standard shoring techniques were successfully used to stabilize deep foundations through the loess and alluvial soils at the operating GGNS site. Because foundation levels for the proposed new facility likely will be over 80-feet below grade in the area near the river bluff to reach suitable foundation materials, and the height of nearby slopes are less than about 60 feet, it is unlikely that any future slope failures would undermine or encroach within the foundation zone of the facility. Engineering solutions can be developed for any potential slope instability at the proposed site location and the hazard due to slope instability at the proposed new facility location is considered to be low. Potential hazards due to encroachment of slope failures will be evaluated during the COL phase of the project. It is not anticipated that there will be any permanent excavated slopes that might adversely affect the stability of the plant. Design of excavated slopes and /or tieback walls or other forms of temporary construction support are not anticipated to pose any obstacles to construction. Specific stability analyses will be performed during the COL phase to evaluate the stability of deep foundation excavations for future facilities at the proposed site. However, no unstable conditions or materials were found underlying the proposed site that could cause unusual stability problems for excavations, and standard shoring techniques were successfully used to stabilize deep foundations through the loess and Upland Complex alluvial soils at the operating GGNS site.

2.5.6 Embankments and Dams

Within the Site Location, there are no earth, rock, or earth and rock fill embankments used for plant flood protection or for impounding cooling water that could affect the safety of the proposed new facility. Furthermore, there are no impoundment structures within the Site Area that could pose a hazard to the proposed new facility. Therefore, the hazard due to embankment failure and surface water inundation of the proposed location of the new facility at the Grand Gulf Nuclear Station is negligible.

2.5.7 References

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3.0 SITE SAFETY ASSESSMENT

As required by 10 CFR 52.17(a)(1), an application for an early site permit (ESP) must contain a description and safety assessment of the site on which a new facility would be located. The assessment must contain an analysis and evaluation of the major structures, systems, and components of the facility that bear significantly on the acceptability of the site under the radiological consequence evaluation factors identified in 10 CFR 50.34(a)(1). That site characteristics comply with 10 CFR 100 must also be demonstrated.

Preceding sections provide detailed descriptions, assessments, and analyses of the proposed ESP Site (i.e., the Grand Gulf Nuclear Station (GGNS) site), and the ESP Facility as defined in Chapters 1.0 and 2.0 of this report.

This section provides an assessment of conformance with 10 CFR 100 requirements, including applicable parts of 100.10, 100.11, 100.20, 100.21 and 100.23, with respect to evaluation of the ESP Site for an Early Site Permit under Part 52. Specifically, this section demonstrates that radiological doses from normal operation and postulated accidents will be acceptably low, that natural phenomena and potential man-made hazards important to the design of the plant have been identified, that adequate security measures to protect the plant can be developed, and that there are no physical characteristics unique to the proposed site that could pose a significant impediment to the development of emergency plans for the ESP Facility.

3.1 Non-Seismic Siting Criteria

3.1.1 Exclusion Area and Low Population Zone

The ESP Site exclusion area authority and control thereof is described in Section 2.1.2. The ESP Site exclusion area boundary (EAB) includes an area encompassed by a circle of about 841 meters radius. The boundary line for the proposed EAB is shown in Figure 2.2-1. The ESP Site exclusion area meets the definition for an exclusion area provided in 10 CFR 100.3.

The ESP Site low population zone (LPZ) is described in Section 2.1.3.4. The ESP Site LPZ includes an area encompassed by a circle of approximately 2-mile radius (3219-m). The approximate LPZ is shown in Figure 2.1-3. The ESP Site LPZ meets the definition for an LPZ provided in 10 CFR 100.3.

3.1.2 Population Center Distance

The ESP Site population center distance is described in Section 2.1.3.5. The closest population center for the ESP Site is Vicksburg, Mississippi, located approximately 25 miles north-northeast of the site, with a 2000 population of 26,407. The ESP Site nearest population center is in accordance with the definition of a population center (more than a population of about 25,000 residents) provided in 10 CFR 100.3. In addition, it satisfies the criteria provided in 10 CFR 100.21(b) as being at least one-and-one-third times the distance from the proposed reactor location to the outer boundary of the low population zone or, in this case, approximately 2.7 mi.

3.1.3 Site Atmospheric Dispersion Characteristics and Dispersion Parameters

The site atmospheric dispersion characteristics and dispersion parameters for the ESP Site are described in Section 2.3.4 for the short term diffusion estimates used in assessing the site suitability (radiological consequences) associated with postulated accidents and Section 2.3.5 for the long term diffusion estimates used in evaluating the normal radiological effluent release limits.

The potential consequences and acceptance criteria for the postulated accidents used in the evaluation of the ESP Site are provided in Section 3.3. As demonstrated therein, the dose limits at the EAB and LPZ meet the requirements of 10 CFR 50.34(a)(1)(ii)(D)(1) and 10 CFR 50.34(a)(1)(ii)(D)(2), respectively.

The potential consequences and acceptance criteria for the normal operations gaseous radiological effluent release limits are provided in Section 3.2, where it is shown that the applicable regulatory limits, provided in 10 CFR 20 and 10 CFR 50, Appendix I, are satisfied for the ESP Site.

3.1.4 Physical Site Characteristics – Meteorology, Geology, Seismology, and Hydrology

3.1.4.1 Meteorology

The meteorological characteristics of the ESP Site are described in detail in Sections 2.3.1 and 2.3.2. Regional, local and site data were used to establish average and extreme meteorological parameters for the site.

Section 2.3.1 describes the regional meteorological characteristics of the general site based on long-term historical observations from National Weather Service Stations located in Jackson, Mississippi, and in Vicksburg, Mississippi, both of which are within 55 mile of the ESP Site. Recent data from these weather stations and from the National Oceanographic and Atmosphere Administration (NOAA) National Climatic Data Center (NCDC) data systems are provided as appropriate. Regional historical information for the site area includes data for temperature, relative humidity, wind, and precipitation (rain and snowfall). Severe weather information for the area is also summarized in this section for hurricanes (frequency of occurrence and wind speeds), thunderstorms (frequency of occurrence), hail (frequency and distribution in the region), and lightning (predicted stroke density), all of which have been characterized for consideration in the design of site structures, systems and components as required. Tornadoes (predicted frequency and intensity) and severe winds (maximum speed) were characterized to provide the site parameters to be considered in association with these events (including maximum linear and rotational wind speeds, pressure drop, and rate of pressure drop). Heavy snow (frequency and intensity), and freezing rain / ice (frequency and intensity) were characterized to provide worst-case accumulations of snow and ice to be accounted for in the design of site structures.

Section 2.3.2 describes the local and site-specific meteorological characteristics of the ESP Site as obtained from the Vicksburg weather station, and from an on-site meteorological monitoring system operated continuously by Entergy since 1972. A detailed description of the on-site monitoring system is provided in Section 2.3.3. Data from the on-site monitoring system was used to establish normal and extreme values of wind speed and direction, temperature, atmospheric moisture (wet bulb temperature, relative humidity, and dew point temperature), precipitation, and atmospheric stability. Site-specific meteorological data were also used to supplement the regional and local data, as well as to facilitate the development of site-specific atmospheric dispersion characteristics and dispersion parameters for routine and accidental gaseous releases from the ESP Facility, as described in Sections 2.3.4 and 2.3.5.

The information contained in Sections 2.3.1 and 2.3.2, on regional and local meteorology were evaluated to provide representative average and extreme meteorological information characteristic of the ESP Site.

3.1.4.2 Geology

The geological, seismological and geophysical characteristics of the proposed location of the new facility at the existing GGNS are described in Section 2.5. The geology of the Site Region (200-mile-radius) and Site Vicinity (25-mile-radius) is described in Section 2.5.1.1. The geology of the Site Area (5-mile radius) and Site Location (0.6-mile radius) is described in Section 2.5.1.2. Descriptions of the geological characteristics of the ESP Site are based on a compilation, review and analysis of existing data, as well as the results of a geological and geotechnical site investigation and laboratory testing program. The evaluation of the site geology included a review of results of geotechnical explorations and laboratory analyses completed as part of the original site evaluations documented in the PSAR for GGNS Units 1 and 2. The previous subsurface exploration program included 275 borings drilled to a maximum depth of 447 feet. The field investigation completed during this ESP investigation is described in Section 2.5.4 and included:

- Drilling and sampling of four borings to depths between 141.5 and 238.0 feet;
- Four Cone Penetrometer (CPT) soundings to depths of between 75 and 98 feet; and,
- Three bore-hole P-S velocity surveys.

The ESP Site is underlain by a sequence of Quaternary eolian and alluvial deposits overlying Miocene Catahoula Formation bedrock. Four units were differentiated at the site, including: (1) an upper layer of late Pleistocene silt and clayey silt ("loess") ranging from 55- to 70-feet thick; (2) an intermediate layer of stiff to very stiff Pleistocene alluvium ranging from 50- to 100-feet thick; (3) a deeper layer of very stiff to hard older alluvium ranging from 40- to 90-feet thick; and (4) Catahoula formation partly-lithified stiff clay claysone.

The results of the data review and site investigations indicate that the geological and geotechnical conditions of the ESP Site are consistent with the information presented in the GGNS UFSAR. The ESP Site soil profile is relatively consistent across the footprint of the existing GGNS Unit 1 facility and the location of the power block for the proposed new facility.

Section 2.5.3 discusses the potential for surface fault rupture in the Site Area. The ESP Site is located within the tectonically quiescent Gulf Coastal Plain province and is underlain by unfaulted deposits of at least Oligocene age. No faults are mapped within the 5-mile radius of the ESP Site. The closest mapped faults in the Study Region occur in southeastern Arkansas, located approximately 90 miles north-northwest from the ESP Site. Deformation associated with salt migration has occurred in the Site Region. However, no salt domes occur within either the 5-mile radius or 0.6-mile radius of the ESP Site.

Results of the geological and geotechnical investigations conclude that the physical characteristics of the site pose no undue risk to the siting of a new facility at the proposed location. No geological hazards from surface fault rupture (Section 2.5.3), slope instability, or ground subsidence from sinkholes or mine collapse were identified either during the original PSAR site evaluations for GGNS Units 1 and 2 or during this ESP Site investigation (Section 2.5.5). Due to the position of the site on topographically high ground, and lack of surface water impoundments, there is no risk to the site from flooding or inundation (Section 2.5.6). There have been no reports of unusual or unacceptable behavior of the existing GGNS facility relative to geologic or geotechnical conditions during its nearly 20 years of operation. Subsurface materials exist beneath the ESP Site that are suitable bearing layers for the foundation of a new facility at the proposed location.

3.1.4.3 Seismology

Section 2.5.1 describes the seismotectonic environment of the Site Region and Section 2.5.2 describes the data and methodology used to develop the Safe Shutdown Earthquake (SSE) ground motion for the proposed location of a new facility at the existing GGNS site.

The Site Region is characterized by extremely low rates of earthquake activity. Only 39 earthquakes of magnitude greater than m_b 3.3 have been recorded within the entire Site Region. Only two earthquakes of magnitude greater than m_b 3.3 have been recorded within approximately 100-miles of the ESP Site.

Because the ESP Site is underlain by soils, investigations were completed to establish the soil profile, e.g., seismic wave transmission effects, for the site-specific site-response analysis and development of the SSE. In addition to the four borings and four CPT probes, the site investigation included:

- Borehole P-S seismic velocity surveys in three of the exploratory borings;
- Laboratory engineering index testing of sixty ESP borehole samples; and,
- Dynamic resonant column testing of six boring samples.

The average shear wave velocity for the ESP site ground motion site-response analysis was developed by normalizing the three borehole surveys to a common elevation, and then averaging the receiver-to-receiver shear wave velocities. The resulting averaged velocity plot (Section 2.5.4) was visually examined to identify discrete interval velocities that correspond, in part, to the geologic unit layers, and that have relatively distinct average velocity increases or breaks. Four interval velocities were differentiated from the P-S velocity survey profile:

- Loess – 770 fps;
- Upland Complex Alluvium and Loess-Alluvium Interface – 1,004 fps;
- Upland Complex Old Alluvium – 1,378 fps; and,
- Catahoula Formation – 2,118 fps.

The average velocities are within typical ranges for similar materials reported in published literature (e.g., Hunt, 1984).

The P-S datalogger used for the ESP study represents a marked improvement and advancement of technique over the cross-hole seismic velocity techniques and equipment that were used for the initial site evaluation for GGNS in the 1970s. Therefore, a direct comparison cannot be made between the two data sets. However, the velocities for the various geologic layers generally fall within similar ranges, if the GGNS data for the upper Catahoula Formation are compared against the velocity data for the Upland Complex Old Alluvium. A comparison between the shear wave velocities is shown below.

MATERIAL	ESP Vs (fps)	UFSAR Vs (fps)
Loess	590 to 1,450	670
Upland Complex Alluvium	740 to 1,750	1,100 to 1,600
Upland Complex Old Alluvium	530 to 3,360	1,640 to 1,720
Catahoula Formation	1,500 to 2,830	1,640 to 1,720

3.1.4.4 Hydrology

The hydrologic conditions of the ESP Site and vicinity are described in detail in Section 2.4. The descriptions include hydrologic features and characteristics that should be accounted for in the design of the ESP Facility. These hydrologic engineering characteristics include floods, ice effects, cooling water supply, low-water considerations, accidental releases in surface water, and ground water.

Section 2.4.2 presents information on the flooding history, flood design considerations, and the effects of local intense precipitation. The probable maximum precipitation event was determined to control facility flood design. Therefore, safety-related structures of the ESP Facility will need to be above the flood elevation or be designed to withstand the effects of flooding. The effects of and development of the probable maximum precipitation are presented in Section 2.4.2.3 and 2.4.3.1.

Section 2.4.3 describes the probable maximum flood characteristics for local streams and for the Mississippi River, and Section 2.4.10 discusses the flooding protection requirements. As described in Section 2.4.3, the maximum flood elevation of the river is about 103 ft msl, based on the height of the flood control levees on the west side of the river. Floods in the river would not affect the ESP Facility, the location of which is proposed at a similar grade elevation as that of the existing GGNS Unit 1 facility, on the bluffs east of the river.

Section 2.4.7 describes the effects of ice formation in the river at the location of the ESP Site, and the probable maximum winter flood on the river level. In Section 2.4.8 of the NRC Safety Evaluation Report (NUREG-0831) for GGNS Unit 1, the NRC concluded that the occurrence of a major ice jam on the Mississippi River is very unlikely, and concurred that ice flooding was not a design basis consideration for the GGNS site. Therefore, ice flooding is similarly not a design basis consideration for the ESP site.

Section 2.4.11 describes low river water considerations for the site, including the evaluation of plant requirements and ultimate heat sink (UHS) dependability requirements. The ultimate heat sink for the ESP Facility would be provided from closed-loop cooling systems utilizing basin type reservoirs, and would not rely on the river intake for cooling capability. Therefore, the UHS would be unaffected by a low river stage.

Section 2.4.13 describes the potential effects on ground water from accidental radiological releases. The evaluation for GGNS Unit 1 in their UFSAR indicated that strontium and cesium isotopic concentrations for a design basis accidental spill would be below the maximum permissible concentration at a distance of 57 feet from the location of the spill. An estimated ground water travel time to the Mississippi River was determined as about 12.5 years. Since the proposed location of the ESP Facility, like the GGNS Unit 1 facility, is approximately 3,200 feet from the Mississippi River, the isotopic concentrations from a similar spill into the ground water

should be well below the maximum permissible concentration before they reach the Mississippi River. Therefore, the potential for effluents to reach a surface water body and surface water users is minimal.

Section 2.4.12 describes the regional and local aquifers, their formation, sources and sinks. Section 2.4.12.1 describes plant requirements from the ground water system and describes ground water quality. Section 2.4.12.2 describes the site hydrogeologic systems including the aquifers present and their characteristics (depth, permeability, potentiometric levels and velocity), and present and projected future ground water users. The design basis for subsurface hydrostatic loading is presented in Section 2.4.12.4.

The information contained in Section 2.4 on surface water and ground water conditions was evaluated and was determined to be adequate in support of the ESP Facility. These data would be used as appropriate in the design of the ESP Facility to ensure that no hydrology related site parameters would pose an undue risk to the operation of the ESP Facility.

3.1.5 Potential Off-site Hazards

The potential offsite hazards for the ESP Facility are described in Section 2.2. The description includes nearby industrial, transportation and military facilities.

Sections 2.2.1 and 2.2.2.5 addresses area airports and associated air transportation routes, as they may affect the ESP Facility. No commercial airport facilities are located within 10 miles of the GGNS site. The nearest commercial airport is located in Jackson, MS, approximately 65 miles northeast of the site. There are 5 general/public aviation airports located within the vicinity of the site. These general/public aviation airports are used only for small planes.

As noted in Section 2.2.3, highway accidents are not a concern for the ESP Site. The ESP Site area is accessible by U. S. Highway 61 and State Highway 18 which connect Port Gibson (5 miles southeast of the site) with Natchez, Jackson, and Vicksburg. U. S. Highway 61 passes approximately 4.5 miles east-southeast of the GGNS site at its closest point. The distance beyond which an exploding truck will not have an adverse effect on plant operations, nor prevent safe shutdown, is calculated to be 1,658 feet (0.31 miles). Since the closest point of U. S. Highway 61 to the ESP Site is about 4.5 miles, there is no hazard to the plant due to an accident on U.S. Highway 61.

There are currently no active rail lines in the vicinity of the ESP Site. Therefore, potential accidents involving railway traffic are not evaluated.

The nearest bank of the river is approximately 1.1 miles from the proposed location for the ESP Facility on the GGNS ESP Site. In addition, a new facility would be located on the bluffs to the east of the river, which are approximately 65 feet above the normal river level. As noted above for the GGNS Unit 1 plant, this bluff would provide an earthen shield against possible explosions originating from river barge traffic. Based on the combination of distance from the river bank and the intervening bluff, this would preclude any damage to the structures of the ESP Facility at the proposed location, resulting from an explosion originating from a ship or barge on the river.

Section 2.2.3.1 discusses explosions due to pipelines and nearby industrial facilities. Evaluation of the existing pipelines, their proximity to the site and the materials passing through them resulted in the determination that they do not represent a design concern for facilities at the ESP Site. There are no existing industrial facilities potentially representing an explosive source which would constitute a design consideration for the ESP Site.

Section 2.2.3.1 discusses explosions due to onsite hydrogen storage, and due to liquid-hydrogen delivery truck accidents/explosions. Liquefied hydrogen is delivered to the GGNS site by United States Department of Transportation (USDOT) approved truck, with a maximum capacity of 17,000 gallons. There are no regulations specifying a minimum distance between a liquid-hydrogen delivery truck and a safety-related structure. The current truck route on the GGNS (ESP) Site results in about 400 ft separation from the outer boundary of the proposed location for the power block of the ESP Facility, which is less than the minimum separation distance of 1285 ft calculated per Regulatory Guide 1.91 (Reference 1). However, the probability of an accident resulting in a hydrogen explosion calculated per the Regulatory Guide 1.91 methodology is 4.1×10^{-7} per year. Therefore, according to the guidelines presented in Regulatory Guide 1.91 (criteria is less than 10^{-6} per year), a liquid-hydrogen truck explosion event need not be considered a design basis accident for the ESP Facility on the site.

The presence of the 20,000 gallon liquid-hydrogen storage tank located in the north end of the abandoned GGNS Unit 2 cooling tower basin (Figure 2.2-4) presents a potential hazard of an explosion. An analysis was performed to determine the safe separation distance between the liquid-hydrogen storage tank and any GGNS Unit 1 safety-related structure. These calculations are valid for the ESP Facility at the GGNS ESP Site, so long as the minimum separation distances stated in the report are maintained, or structures are appropriately designed for the expected blast pressure. The proposed area for construction of the ESP Facility is beyond the minimum separation distance requirements given in the calculation for both blast considerations and gaseous cloud considerations.

Toxic chemicals are discussed in Section 2.2.3.1.2. The closest point of U.S. Highway 61 to the GGNS site is 4.5 miles. Therefore, an accidental release of toxic chemicals transported on U. S. Highway 61 would not endanger the safe operation of the ESP Facility at its proposed location on the ESP Site. In the year 2000, the majority of the hazardous materials transported near the GGNS site were fuel products moving on the Mississippi River. The 6-year onsite wind frequency distribution data (1996-2001) reported in Section 2.3 shows that the winds that originated from compass sectors W-SW, W, W-NW and NW, that would carry the hot plume from a fire caused by explosion to the proposed location for a new facility, had speeds generally under 20 mph. An analyses presented in the GGNS Unit 1 UFSAR concluded that a wind speed greater than 70 mph would be required to direct a plume toward GGNS Unit 1. The proposed location for the ESP Facility is on the bluffs above the river and about 1.1 miles inland. Since the proposed location for the ESP Facility is very near to that of the existing GGNS Unit 1, no toxic hazard to the ESP Facility would be expected.

There are no military installations, chemical or munitions plants, stone quarries, or major gasoline-storage areas located within 5 miles of the ESP site. Therefore, they do not need to be considered as a hazard for the ESP Facility on the ESP Site.

Section 2.2.3.1.3 discusses the possible offsite fire hazards to an ESP Facility on the GGNS ESP Site. It was concluded that offsite fires do not pose a design basis threat to a new facility on the site.

A collision (by river traffic) with the proposed cooling system intake is not considered likely and not a design basis event for the ESP Facility as discussed in Section 2.2.3.1.4.

Liquid spills on the Mississippi River do not pose a threat to safe shutdown of the ESP Facility, as the river intake is utilized only for non-safety related water supply. Any potential intrusion of hazardous chemicals or liquids into the proposed embayment and makeup water system could be mitigated by orderly shutdown of the facility, if required.

3.1.6 Site Characteristics - Security Plans

The ESP Facility power block proposed location (approximate center of the power block area) is approximately 1200 ft west and 1000 ft north of the existing GGNS Unit 1 Facility. A site plot plan is provided in Figure 2.1-1.

3.1.6.1 Land Sufficient To Implement The Criteria Of 10 CFR 73.55

Based upon the general location at the GGNS site on which the nuclear unit or units would be located; e.g., in the general vicinity of the GGNS Unit 1, there is sufficient land and distance to the site boundary and appropriate topography to implement the criteria of 10 CFR 73.55 relating to the development of a security plan. This conclusion is based in part on the fact that GGNS Unit 1 has implemented a security plan meeting the requirements of 10 CFR 73.55 and the interim compensatory measures required by the NRC's Order of February 25, 2002. While GGNS Unit 1 is still in the process of implementing the requirements of the revised design basis threat (DBT) Order of April 25, 2003, preliminary evaluations would indicate that neither the amount of land, the particular location of the GGNS site in relation to the topography and site boundaries or the distances to the site boundary or other natural features, would preclude compliance with the revised DBT.

It should be noted that existing commercial nuclear power plants, such as GGNS Unit 1, were designed to meet evolving 10 CFR 73.55 requirements, including effective changes in the DBT and revised DBT, on an "add-on" basis after completion of the initial physical design. Even given these circumstances, plants such as GGNS Unit 1 are capable of meeting the evolving NRC security requirements. For a plant which would be built in the future, security considerations (e.g., barriers, access, fences) would be incorporated as initial design requirements and inputs and integrated into the overall design as an important element, making it reasonable to conclude that such a facility will be able to meet NRC security requirements.

Given the opportunity to design security into a new facility, the distance specified in Regulatory Guide 4.7 would be sufficient to satisfy the criteria of 10 CFR 73.55 although a larger distance could be used at the GGNS ESP site, and even a smaller distance could be accommodated.

3.1.6.2 Site Characteristics That May Require Mitigation

No site characteristics that require significant mitigation in order to control close approaches to the proposed location of a new facility have been identified. As indicated Figure 2.1-1, the nearest public road is about 3000 feet from the general area of the proposed power block building site. The Mississippi river is approximately 1 mile from the proposed power block building site. Safety-related structures necessary for the ultimate heat sink would not be located on an accessible, navigable waterway.

3.1.6.3 Identification of Potential Hazards in the Site Vicinity

Initially, given the successful implementation of a security plan by Entergy Operations for GGNS Unit 1, there are no potential hazards in the site vicinity which would preclude the development of a security plan for the new unit or units. The new reactor or reactors will be sited at some distance from the existing GGNS Unit 1, and provisions will be made such that construction activities at a new facility will not adversely affect the ability of GGNS Unit 1 or any new operating unit to meet NRC security requirements. Similarly, the design of the security plan and defensive strategy will be such that during operation or other activities on site, the security plans of the units on site positively reinforce each other, or will be independent with regard to their individual ability to meet NRC security requirements and the design basis threat, as revised.

3.1.6.4 Law Enforcement Agencies

Given the location of a new facility in relationship to GGNS Unit 1 which has, as part of its security plan, made provisions with relevant local law enforcement agencies, there is high assurance that similar provisions can be made with regard to any new facility, in that the jurisdictions and local law enforcement agencies are the same as for GGNS Unit 1.

In summary, given the proposed location of a new facility near GGNS Unit 1, and the ability to assure compliance with NRC provisions through design, there is a high assurance that NRC security requirements can be met for a new facility.

3.1.7 Site Characteristics - Emergency Plans

Information regarding emergency planning capability is provided in the ESP Application, Emergency Planning Information, Part 4. The GGNS Unit 1 evacuation time estimate (ETE) performed in 1986 was re-evaluated in support of this application. This re-evaluation included an assessment of updated population levels and distributions and transportation networks. As part of the effort, each major roadway was driven and traffic count data was obtained, as appropriate. Improvement in several key roadways was noted, and updated roadway capacities were estimated to support this evaluation. Local Mississippi and Louisiana emergency management agency officials, as well as state department of transportation representatives, were consulted and provided their concurrence regarding the findings. Based on this re-evacuation of the ETE, it was determined that there are no physical characteristics unique to the GGNS site that could pose a significant impediment to the development of the required emergency plans for the ESP Facility.

3.1.8 Population Density

As described in Section 2.1.1 and Section 2.1.3.6, the ESP Site is located in a mostly rural, low population density, area. The most densely populated area within 30 miles of the site is to the north-northeast with an average projected population density of about 238 people per square mile in the year 2030. This population density is projected to increase to only about 268 persons per square mile in the year 2070. The current and projected population density in this area is well below the NUREG-0800 guidance of 500 people per mi^2.

3.1.9 References

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