Progress Energy

Serial: NPD-NRC-2009-001 10CFR52.79
January 12, 2009

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

SHEARON HARRIS NUCLEAR POWER PLANT, UNITS 2 AND 3
DOCKET NOS. 52-022 AND 52-023
SUPPLEMENT 2 TO RESPONSE TO REQUEST FOR ADDITIONAL INFORMATION LETTER NO. 030 RELATED TO BASIC GEOLOGIC AND SEISMIC INFORMATION

Reference: Letter from Manny Comar (NRC) to James Scarola (PEC), dated October 14, 2008, "Request for Additional Information Letter No. 030 Related to SRP Section 02.05.01 for the Harris Units 2 and 3 Combined License Application"

Ladies and Gentlemen:

Progress Energy Carolinas, Inc. (PEC) hereby submits our response to the Nuclear Regulatory Commission's (NRC) request for additional information provided in the referenced letter.

A partial response to the NRC request is provided in Enclosure 1. An initial submittal of responses was provided by letter dated December 26, 2008. An additional submittal with additional responses (Supplement 1) was provided by letter dated December 30, 2008. This submittal provides the remaining responses. See page 1 of Enclosure 1 for details. Enclosure 1 also identifies changes that will be made in a future revision of the Shearon Harris Nuclear Power Plant Units 2 and 3 (HAR) application.

Enclosure 2 provides a list of files included on the attached CD. The files have been prepared in accordance with NRC electronic submittal guidance. A pre-flight report is included as Enclosure 3.

If you have any further questions, or need additional information, please contact Bob Kitchen at (919) 546-6992, or me at (919) 546-6107.

I declare under penalty of perjury that the foregoing is true and correct.

Executed on January 12, 2009.

Sincerely,

Garry D. Miller
General Manager
Nuclear Plant Development

Enclosures/Attachments

Progress Energy Carolinas, Inc.
P.O. Box 1551
Raleigh, NC 27602

D084
NRO

cc (w/2 of attached CD):	Mr. Manny Comar, U.S. NRC Project Manager
cc (w/o attached CD):	U.S. NRC Director, Office of New Reactors/NRLPO U.S. NRC Office of Nuclear Reactor Regulation/NRLPO U.S. NRC Region II, Regional Administrator U.S. NRC Resident Inspector, SHNPP Unit 1

bc (w/o attached CD):

Robert Kitchen, Manager-Nuclear Plant Licensing
Chris Kamilaris, Director-Fleet Support Services
Tillie Wilkins, NPD-Licensing
John O'Neill, Jr. (Pillsbury Winthrop Shaw Pittman, LLP)
A. K. Singh (Sargent & Lundy, LLC)
Jim Steele (CH2M HILL)
John Archer (WorleyParsons)
Mark Steele (Sargent & Lundy, LLC)
NPD Document Control Inbox (Records: Correspondence)
File: NGG-NPD (Betsy Cox)

**Shearon Harris Nuclear Power Plant Units 2 and 3
Supplement 2 to Response to NRC Request for Additional Information Letter No. 030
Related to SRP Section 02.05.01 for the Combined License Application, dated October 14, 2008**

NRC RAI #	Progress Energy RAI #	Progress Energy Response
02.05.01-1	H-0138	December 26, 2008; NPD-NRC-2008-067
02.05.01-2	H-0139	December 26, 2008; NPD-NRC-2008-067
02.05.01-3	H-0140	December 26, 2008; NPD-NRC-2008-067
02.05.01-4	H-0141	December 26, 2008; NPD-NRC-2008-067
02.05.01-5	H-0142	December 26, 2008; NPD-NRC-2008-067
02.05.01-6	H-0143	December 26, 2008; NPD-NRC-2008-067
02.05.01-7	H-0144	December 26, 2008; NPD-NRC-2008-067
02.05.01-8	H-0145	December 26, 2008; NPD-NRC-2008-067
02.05.01-09	H-0146	December 30, 2008; NPD-NRC-2008-095
02.05.01-10	H-0147	Response enclosed – see following pages
02.05.01-11	H-0148	Response enclosed – see following pages
02.05.01-12	H-0149	Response enclosed – see following pages
02.05.01-13	H-0150	December 26, 2008; NPD-NRC-2008-067
02.05.01-14	H-0151	December 26, 2008; NPD-NRC-2008-067
02.05.01-15	H-0152	December 30, 2008; NPD-NRC-2008-095
02.05.01-16	H-0153	Response enclosed – see following pages
02.05.01-17	H-0154	December 30, 2008; NPD-NRC-2008-095
02.05.01-18	H-0155	December 30, 2008; NPD-NRC-2008-095
02.05.01-19	H-0156	December 30, 2008; NPD-NRC-2008-095
02.05.01-20	H-0157	December 26, 2008; NPD-NRC-2008-067
02.05.01-21	H-0158	December 26, 2008; NPD-NRC-2008-067
02.05.01-22	H-0159	December 26, 2008; NPD-NRC-2008-067
02.05.01-23	H-0160	December 26, 2008; NPD-NRC-2008-067
02.05.01-24	H-0161	December 26, 2008; NPD-NRC-2008-067
02.05.01-25	H-0162	December 26, 2008; NPD-NRC-2008-067
02.05.01-26	H-0163	December 26, 2008; NPD-NRC-2008-067
02.05.01-27	H-0164	December 26, 2008; NPD-NRC-2008-067
02.05.01-28	H-0165	December 26, 2008; NPD-NRC-2008-067
02.05.01-29	H-0166	December 26, 2008; NPD-NRC-2008-067
02.05.01-30	H-0167	December 26, 2008; NPD-NRC-2008-067
02.05.01-31	H-0168	December 26, 2008; NPD-NRC-2008-067

Attachments	Associated NRC RAI #	Attachment on CD
Figure 2.5.1-213 (Revised)	02.05.01-1,6,7,8,9,10,19	December 26, 2008
RAI 02.05.01-08 Figure 1	02.05.01-8	December 26, 2008
RAI 02.05.01-9 Figure 3	02.05.01-9,10	December 30, 2008
RAI 02.05.01-10 Figure 1	02.05.01-10	Attachment 02.05.01-10A
RAI 02.05.01-10 Figure 2	02.05.01-10	Attachment 02.05.01-10B
RAI 02.05.01-10 Figure 3	02.05.01-10	Attachment 02.05.01-10C
RAI 02.05.01-10 Figure 4	02.05.01-10	Attachment 02.05.01-10D
RAI 02.05.01-10 Figure 5 (Sh. 1&2)	02.05.01-10	Attachment 02.05.01-10E
RAI 02.05.01-10 Figure 6	02.05.01-10	Attachment 02.05.01-10F
RAI 02.05.01-10 Figure 7	02.05.01-10	Attachment 02.05.01-10G
RAI 02.05.01-10 Figure 8	02.05.01-10	Attachment 02.05.01-10H
RAI 02.05.01-10 Figure 9	02.05.01-10	Attachment 02.05.01-10I
RAI 02.05.01-10 Figure 10	02.05.01-10	Attachment 02.05.01-10J
RAI 02.05.01-10 Figure 11	02.05.01-10	Attachment 02.05.01-10K
RAI 02.05.01-10 Figure 12	02.05.01-10	Attachment 02.05.01-10L
RAI 02.05.01-10 Figure 13	02.05.01-10	Attachment 02.05.01-10M
RAI 02.05.01-10 Figure 14	02.05.01-10	Attachment 02.05.01-10N
RAI 02.05.01-10 Figure 15	02.05.01-10	Attachment 02.05.01-10O
Revised Figure 2.5.1-238	02.05.01-10	Attachment 02.05.01-10P
RAI 02.05.01-10 Figure 16 (Sh. 1&2)	02.05.01-10	Attachment 02.05.01-10Q
Revised Figure 2.5.1-218	02.05.01-10	Attachment 02.05.01-10R
RAI 02.05.01-11A1 Fig. 1(Sh. 1 of 6)	02.05.01-11	Attachment 02.05.01-11A1
RAI 02.05.01-11A2 Fig. 1(Sh. 2 of 6)	02.05.01-11	Attachment 02.05.01-11A2
RAI 02.05.01-11A3 Fig. 1(Sh. 3 of 6)	02.05.01-11	Attachment 02.05.01-11A3
RAI 02.05.01-11A4 Fig. 1(Sh. 4 of 6)	02.05.01-11	Attachment 02.05.01-11A4
RAI 02.05.01-11A5 Fig. 1(Sh. 5 of 6)	02.05.01-11	Attachment 02.05.01-11A5
RAI 02.05.01-11A6 Fig. 1(Sh. 6 of 6)	02.05.01-11	Attachment 02.05.01-11A6
RAI 02.05.01-11 Fig. 2	02.05.01-11	Attachment 02.05.01-11B
Figure 2.5.1-220(Sh.1of4)(Revised)	02.05.01-10,11,12	Attachment 02.05.01-11C1
Figure 2.5.1-220(Sh. 2of4)(Revised)	02.05.01-10,11,12	Attachment 02.05.01-11C2

Figure 2.5.1-220(Sh. 3of4)(Revised)	02.05.01-10,11,12	Attachment 02.05.01-11C3
Figure 2.5.1-220(Sh. 4of4)(Revised)	02.05.01-10,11,12	Attachment 02.05.01-11C4
RAI 02.05.01-12 Figure 1	02.05.01-12	Attachment 02.05.01-12A
RAI 02.05.01-12 Figure 2	02.05.01-12	Attachment 02.05.01-12B
RAI 02.05.01-12 Figure 3	02.05.01-12	Attachment 02.05.01-12C
RAI 02.05.01-12 Figure 4	02.05.01-12	Attachment 02.05.01-12D
RAI 02.05.01-12 Figure 5	02.05.01-12	Attachment 02.05.01-12E
Figure 2.5.1-219 (Revised)	02.05.01-10,12,14	December 26, 2008
RAI 02.05.01-16 Figure 1	02.05.01-16	Attachment 02.05.01-16A
RAI 02.05.01-16 Figure 2	02.05.01-16	Attachment 02.05.01-16B
RAI 02.05.01-16 Figure 3	02.05.01-16	Attachment 02.05.01-16C
RAI 02.05.01-16 Figure 4	02.05.01-16	Attachment 02.05.01-16D
RAI 02.05.01-16 Figure 5	02.05.01-16	Attachment 02.05.01-16E
Figure 2.5.1-237, Sheet 1(Revised)	02.05.01-10,18,21	December 26, 2008

NRC Letter No.: HAR-RAI-LTR-030

NRC Letter Date: October 14, 2008

NRC Review of Final Safety Analysis Report

NRC RAI #: 02.05.01-10

Text of NRC RAI:

FSAR section 2.5.1.1.4.2.5.5 provides a discussion about the three segments of East Coast Fault System (ECFZ). The FSAR states that most of the evidence in the literature is in support of the southern segment with increasingly less support for the central and northern segments.

In order to discount the central segment of the ECFS proposed by Marple and Talwani, provide an alternative, non-tectonic interpretation or additional data to the contrary of Marple and Talwani's interpretation similar to what was presented previously for the northern segment for the North Anna ESP. Please discuss the different types of evidence used to infer late Quaternary movement on all segments of the ECFZ but specifically the central segment and the possible alternative explanation for such evidence.

In addition please provide the following:

a) There are several statements in this section that are vague and made without listing or explaining the evidence for them and without appropriate references. Examples include: "any significant geomorphic changes", "it does not seem warranted base on review of the data", "performed in this study suggest that the postulated ECFS-C may not exist, or has very low probability of activity if is does exist". Please provide related specifics for these statements.

b) The FSAR presents a major conclusion about seismic activity on the ECFS based on an EIS and an ESP (FSAR ref 2.5.1-263; FSAR ref 2.5.1-264). Please provide specific details from those documents to justify the findings stated in this FSAR such as: "The evaluation for the Vogtle ESP (Rev2) judged the ECFS-S (FSAR ref 2.5.1-264) to have a relatively low likelihood of producing Charleston-type earthquakes." Please summarize why the ECFZ-S is a possible seismic source of low likelihood; include an explanation of what low likelihood means.

c) The FSAR (p. 2.5-44) cites a sensitivity analysis performed for the North Anna site on the ECFS-N. Please provide some specific results or conclusions in this FSAR.

d) Evaluate how the types of evidence have been used along the central fault segment to argue for recent movement.

e) The FSAR states that Wheeler stated that he found no evidence for sudden uplift anywhere along the fault system. Please provide information about what criteria would be used to determine sudden uplift. What is the implication of sudden uplift to seismicity rates or size of earthquakes along the ECFS.

f) The FSAR (p 2.5-42) states: "The feature that Marple and Talwani describe as a fault or flexure in basement appears to coincide with such a merged escarpment, and it is likely that the feature is related to shoreline erosion rather than faulting." Please describe and locate on a map which basement feature from Marple and Talwani is being correlated with a buried, merged escarpment. Where exactly is the merged escarpment and how did you determine that it was shoreline erosion and not faulting.

g) Provide a discussion of how the LiDAR data affects the evaluation of features used as evidence of the ECFS.

h) Text about new LiDAR data analysis on page 2.5-42 states that there are no river anomalies save the Cap Fear River observed in this data. Other river course changes at the boundary of the ECFS-C in other rivers or tributaries are not explained in this section:

   - Unnamed river (sw of Lumbar River) has sharp river course change to NE.
   - South River shows sinuosity greatly increased to the west of ECFS.
   - Mill Creek shows an arc to SE and back to earlier trend.
   - Neuse River shows the confluence of 4 rivers at the upstream boundary as well as a sharp turn to the SW along the upstream side of ECFS boundary.

   Please explain these features.

i) FSAR (p. 2.5-43) provides a discussion of paleoliquefaction sites at the SC/NC state border. For Amick et al. (1990a; Reference 2.5.1-270) the areas searched are not specified nor how those sites were selected. There is no detail about the liquefaction susceptibility for those areas. The FSAR provides no detail for the Quaternary terrace mapping project by Owens et al. (1989; Reference 2.5.1-271). Please provide more specific details for these two investigations. To what degree do these two studies preclude large earthquakes near the Harris site?

PGN RAI ID #: H-0147

PGN Response to NRC RAI:

FSAR Section 2.5.1.1.4.2.5.5 summarized conclusions regarding the existence and activity of the southern and northern segments of the ECFS based on studies conducted in support of the Southern Nuclear Vogtle ESP and Dominion North Anna ESP applications, respectively (References 2.5.1-264 and 2.5.1-272). Additional discussion of the observations and conclusions cited in these documents regarding the general assessment of the probability that these segments of the ECFS exist and if they do exist are active is provided in this response and in updated text to be added to FSAR Section 2.5.1.1.4.2.5.2.2 in a future revision. Independent analysis of the evidence for the postulated central segment of the ECFS (ECFS-C) that is 55 km (35 mi.) at closest distance from the HAR site was completed as part of the HAR site studies. Additional text and figures are provided in this response to support the general conclusion cited in the FSAR that the ECFS-C has a low probability of existence as a regional fault (weight of 0.1) and a low probability given it does exist of being a capable tectonic source (weight of 0.1).

a) Statements in this section that were questioned by the NRC Staff as vague and made without listing or explaining the evidence for them and without appropriate references have been reviewed and will be modified in a future revision to add sufficient supporting information and documentation.

b) The Vogtle ESP (Reference 2.5.1-264) judged the ECFS-S to have a relatively low likelihood of producing Charleston-type earthquakes because there is not sufficient geologic evidence to demonstrate tectonic faulting or Quaternary slip associated with the ECFS-S along its entire extent and many of the river anomalies may be due to non-tectonic processes. The informed community that were polled by the USGS during a workshop to discuss the seismic source model for the Charleston area and the northern half of the ECFS-S is not included in the current seismic source model for the National Seismic Hazard Maps (Reference RAI 02.05.01-10 01). The possibility that the ECFS-S in its entirety is the source of repeated large magnitude Charleston earthquakes was therefore given a low weight (0.10) in the updated Charleston seismic source model (UCSS). It should be noted, however, that the southern portion of the ECFS-S, which lies in the meizoseismal region of the Charleston earthquake is also included in the Charleston area local faults source zone (Zone A) (given a weight of 0.7), and both alternative configurations of the larger areal source zone that encompasses the most of the tectonic features and liquefaction data in the greater Charleston area (Zones B and B', with weights of 0.1 and 0.1, respectively) (Figures 2.5.2-212 and 2.5.2-213). Therefore, that part of the ECFS-S with the most convincing evidence for a candidate structure, associated seismicity, and possible evidence for associated surface deformation is included in all possible source geometries in the updated Charleston seismic source.

c) Although geomorphic analyses and aerial reconnaissance performed for the Dominion North Anna ESP application indicate that the northern segment of the East Coast fault zone (ECFS-N) probably does not exist or has a very low probability of activity if it does exist, given the proximity of the fault to the North Anna ESP site and uncertainty regarding the existence and activity of the fault, a sensitivity analysis was performed to evaluate the fault's potential contribution to hazard at the North Anna ESP site. The fault was assumed to have a probability of existence of 0.1 and a probability of activity (given existence) of 0.1. The probabilities of existence and activity were assigned low weights because the existence of the fault is not well documented and was judged to be highly uncertain, and because there is no direct geologic, geomorphic, or seismologic evidence that the fault exists as a tectonic feature or is active, if it does exist.

   The effects of the ECFS-N (northern) and ECFS-S (southern) fault segments were examined by calculating seismic hazard from these two fault segments and comparing this seismic hazard to that from the 1989 EPRI seismic sources. The results of this sensitivity analysis, which are specific to the North Anna site, are summarized as follows. The sensitivity analyses showed that including the ECFS-S fault increases the total median and mean hazard by several percent at the 10^{-5} hazard level. This fault therefore was included in seismic hazard calculations for the North Anna ESP site. The ECFS-N fault, however, results in much lower hazard than from the 1989 EPRI seismic sources, so this fault was not included in the final calculations. A similar comparison for 10 Hz spectral acceleration showed that neither the ECFS-S nor ECFS-N fault indicates much increase in seismic hazard. The 10 Hz ground motion is dominated by closer sources than 1 Hz ground motion, so the distant ECFS-S and ECFS-N faults have little effect on seismic hazard at the North Anna ESP site.

d) The different types of evidence used by Marple and Talwani (Reference 2.5.1-243) to argue for recent movement along the ECFS include: uplift and cross-valley tilt of river terraces along the Cape Fear River; increase in channel sinuosity downstream on several rivers; incision through Pleistocene floodplain deposits; alignment of river anomalies; coincidence with buried faults; alignment with magnetic anomalies; and evidence of brittle faulting. Based on the independent review of the specific lines of evidence used to argue for the existence and activity of the various segments of the ECFS provided in the revised FSAR Section 2.5.1.1.4.2.5.2.2 that will be included in a future revision, the only part of the ECFS that exhibits good evidence of potential surface deformation associated with reactivated bedrock structures is the southern half of the ECFS-S. There is no evidence for a thoroughgoing regional fault zone in the pre-Coastal Plain bedrock along the central or northern segments of the postulated ECFS. The geomorphic evidence cited in support of such a fault system is non-unique to the postulated ECFS, and specific geomorphic features can be explained by nontectonic fluvial responses to differing bedrock or base level changes related to climatic or more regional isostatic adjustments. The section of the FSAR that discusses the ECFS will be reorganized in a future revision to provide a more detailed assessment of the validity of the different types of evidence that have been presented to argue for recent movement along the postulated ECFS-C.

e) Wheeler (Reference 2.5.1-259) states that there is no evidence of sudden uplift along the ECFS, and that such evidence alone can distinguish between deformation that occurs seismically, or more slowly by nonseismic processes. The term 'sudden uplift' is typically a discrete uplift event that occurs as the result of co-seismic surface faulting or fold deformation, which would argue for the presence of a tectonic source capable of generating a moderate to large magnitude earthquake. McCalpin (Reference RAI 02.05.01-10 02) provides a summary of geomorphic features that form in response to surface faulting and strong ground motion. These include: fault scarps; faulted or folded strata; fissures; folds; moletracks; pressure ridges; sand blows; landslides; sand dikes; tilted surfaces; uplifted shorelines; drowned shorelines; tsunami deposits; and soft-sediment deformation. Clear geologic evidence of co-seismic surface deformation, either primary (e.g., faulting or folding associated with primary or secondary tectonic structures) or off fault-related deformation triggered by strong ground motion (e.g., liquefaction features, landslides) that can be clearly associated with the ECFS has not been demonstrated along the ECFS, with the possible exception of the southern part of ECFS-S, which is associated with seismicity, displacement of pre-Cretaceous geologic units in the subsurface, and abundant paleoliquefaction features (see above discussion of specific features observed along the different segments of the ECFS).

f) The Hoffman and Carpenter (Reference 2.5.1-268) publication, cited by Marple and Talwani (Reference 2.5.1-243) as the original source of the evidence for a fault or flexure in basement at the northern end of the ECFS-C segment, interprets terracing of the basement surface at this location to be related to marine planation surfaces formed during Pliocene sea level transgressions. This publication describes an escarpment that separates a lower terrace with an elevation of approximately 160 -180 ft. from a higher surface with an elevation of 230-250 ft. The escarpment wraps around a circular region of higher relief in the southwestern part of the area studied, which is underlain by granitic rocks of the Sims pluton (RAI 02.05.01-10 Figures 1 and 2A). The curvilinear nature of the scarp, which appears to be directly related to the location of outcropping granite, and the general elevation of the base of the scarp at approximately 200 ft. around the granite outcrop support the interpretation that this is a shoreline-related scarp. The scarp coincides only very locally with the northern end of the ECFS-C (RAI 02.05.01-10 Figure 3). There is not a systematic step in the crystalline basement surface across the projected trend of the ECFS-C (RAI 02.05.01-10 Figure 3A).

   Deposits overlying the crystalline basement are divided into two units (RAI 02.05.01-10 Figure 1), the lower Yorktown formation and overlying sediments that are interpreted to have been deposited during the early Pliocene transgressive-regressive event, respectively. Cross sections and a structure contour map on the top of the transgressive deposits of the lower unit (Yorktown formation) suggest that there are three terrace surfaces (RAI 02.05.01-10 Figure 2). Two distinct terraces occur at 180 to 200 ft. and at 250 to 280 ft and generally overlie the two terraces described from the crystalline basement surface contours. A more subtle terrace is developed at 230 to 240 ft. These terraces are separated by escarpments. Around the outcropping Sims pluton the 240-ft. terrace is absent or very narrow and the escarpments merge. There is no systematic scarp in the top of the lower unit along the projected trend of the ECFS-C (RAI 02.05.01-10 Figure 3B).

Based on sedimentologic and stratigraphic relationships observed in drilling and mapping of areas of heavy mineral deposits, Hoffman and Carpenter (Reference 2.5.1-268) outlined the following sequence of events:

- Transgression to at least 280 to 290 ft.—deposition of the lower unit (blanket of poorly sorted clastic debris)
- Regression to 240 to 250 ft.—fine-grained dune and nearshore deposits of upper unit prograded seaward across the lower unit.
- Rapid regression with scarp development—The steep slope between 240 to 250 ft. down to 200 ft. suggests more rapid regression. Wave erosion caused a scarp in the lower unit or locally into the underlying crystalline rocks. The upper unit generally was left stranded on the upper surface, but locally the upper unit deposits prograded across the escarpment.
- Continued slow regression—From 200 ft. down to 175 ft. the lower unit is a gradually sloping unit covered by a fine-grained regressive sand suggestive of a period of slow regression.
- Continued regression and subsequent erosion.

Hoffman and Carpenter (Reference 2.5.1-268) concur with earlier workers in correlating the escarpment between the upper and lower surfaces with the Orangeburg scarp (and its equivalent, the Coats scarp). They view the feature as having developed during the early Pliocene transgressive-regressive event that deposited the Yorktown formation and overlying sediments (referred to as the lower and upper units, respectively). Revised Figure 2.5.1-219 also shows that the postulated ECFS-C does not coincide with the Orangeburg or Coats scarps, except for very locally near the northern end.

g) The LIDAR data, which is available for most of the State of North Carolina, provides a uniform digitial elevation model (DEM) for much of the HAR site region, which in turn facilitates the development of topographic and longitudinal stream profiles that can be used to evaluate potential neotectonic features. Longitudinal stream profiles were created from LIDAR data for eleven streams that cross the ECFS-C (Revised Figure 2.5.1-220). There are only minor changes in stream gradient at a few of the streams that were profiled where they cross the ECFS-C (e.g., Mill Creek and Mocassin Creek/Contentrea Creek), but there are no significant or consistent elevation changes along the entire ECFS-C, and adjacent streams show no apparent anomalies or changes in the profiles.

Topographic profiles generated across the ECFS-C on interfluve areas, which are shown relative to statewide geologic and more detailed Quaternary map units, (RAI 02.05.01-10 Figures 4 and 5) also do not show systematic uplift associated with the ECFS-C. A summary of observations and interpretations of these profiles is as follows.

A Profiles (RAI 02.05.01-10 Figure 6)

This series of profiles is located in the interfluve region between the Lumber and Cape Fear Rivers. As shown on RAI 02.05.01-10 Figure 4, the interfluve area is underlain by Cretaceous Black Creek formation (Kb) capped locally by Pliocene Yorktown formation (Tpy). Owens (Reference 2.5.1-271) identifies the Pliocene unit as the Duplin formation (Td) and shows it mantling a larger area (RAI 02.05.01-10 Figure 5). The profiles in aggregate show a general eastward slope west of station 20000. The relatively higher surfaces east of station 20000 coincide with the area where the Pliocene deposits are mapped (RAI 02.05.01-10 Figure 4), the interfluve area is underlain by Cretaceous Black Creek formation (Kb) capped locally by Pliocene. There is no indication of a systematic up-to-the west scarp associated with the ECFS-C, nor is there evidence of a north-plunging fold or tilt (i.e., no systematic decrease in the general elevation of profiles going from south to north) as suggested by Marple and Talwani (Reference 2.5.1-243) based on their tectonic interpretation of the meander bend and slip-off terraces observed along the Lumber and Cape Fear Rivers.

Profile A7 (RAI 02.05.01-10 Figure 7)—Incision from local tributaries that is apparent from station 6500 to 20000 make it difficult to identify or preclude small displacements or deformation across the ECFS-C. The back edge (shoreline) of the Tertiary Bear Bluff unit appears to be at an elevation of approximately 46 m (151 ft.) at this location. Incision from the Big Swamp River at ~32000 m results in a 5m (16 ft.) elevation drop.

Profile A13 (RAI 02.05.01-10 Figure 8)—There are no major elevation changes across this profile that can be correlated with mapped structural features. The profile intersects an incised area related to the Big Swamp River. The elevation of the Bear Bluff back edge as mapped is approximately 43 m (141 ft.), but could be higher if the surface west of Big Swamp River is underlain by Bear Bluff deposits.

B Profiles (RAI 02.05.01-10 Figure 9)

This series of profiles is located in the region between the Cape Fear and South rivers (RAI 02.05.01-10 Figure 4). The location of these profiles relative to mapped Quaternary terraces is shown on RAI 02.05.01-10 Figure 5. The southeastern half of each of the profiles cross the Waccamaw terrace (Qw, estimated to be 730 ka to 165 -1.75 Ma, Reference 2.5.1-266 and Reference RAI 02.05.01-10 08), which is relatively uniform at an elevation of 36-38 m (118 -125 ft.). Higher surface elevations are observed between stations 14000 and 18000 on profiles B1, B3, and B4. The general elevation of these surfaces at approximately 46 m (151 ft.) is similar to the elevation (44-45 m [145-148 ft.]) of the older Bear Bluff terrace (Qb, 2.75 Ma, Reference 2.5.1-266) at the northern limit of the Owens map (Reference 2.5.1-271). Markewich (Reference 2.5.1-265) describes islands of the highest terrace along the Cape Fear River surrounded by younger terraces. If the higher surfaces at 46 m (151 ft.) correlate to the Qb terrace, it would suggest that there has been little or no vertical displacement of the early Pleistocene Bear Bluff terrace across the ECFS-C. Likewise, apparent surfaces at approximately 38-39 m (125 -128 ft.) east of the ECFS-C and northeast of the Cape Fear River channel may be correlative with the Qw surface; this also would suggest that there is no vertical deformation of this terrace across the ECFS-C. There is no evidence of antiformal folding or systematic decrease in the general elevation of the Qw surface from profile B1 to B4 to suggest northeast tilting.

Profile B1 (RAI 02.05.01-10 Figure 10) —The prominent drop in the surface elevation from elevations of over 40 m (131 ft.) to 45 m (148 ft.) at station 18000 occurs at the western limit of the ZRA-C (ECFS-C) zone. As noted above, this apparent step may represent a fluvial terrace scarp between the Qw terrace and a higher terrace remnant (possibly Qb). The Qw surface is relatively flat southeast of station 18000 across the central part of the ECFS-C. No evidence of folding or warping is observed.

Profile B2 (RAI 02.05.01-10 Figure 10)—The Qw surface across the ECFS-C is relatively consistent, but exhibits some erosional relief. The Qw surface along this profile is generally slightly higher overall than the other profiles, which may be due to greater thickness of terrace cover and less erosion. There is no significant variation in elevation across the ECFS-C to suggest significant tectonic surface deformation.

C Profiles (RAI 02.05.01-10 Figure 11)

This series of profiles is located in the interfluve region south of the Black Creek (a tributary of the Neuse River) (RAI 02.05.01-10 Figure 4). The Coats scarp is approximately located near station 10000. This scarp probably marks the general location of the upper limit of the lower Pliocene sea level transgression, which Hoffman and Carpenter (Reference 2.5.1-268) infer extended up to elevations of at least 85 to 88 m (280 to 290 ft.). Eastward from this location, there appear to be relatively flat surfaces at elevations of approximately 59 m (193 ft.) and 63 m (206 ft.). These elevations are consistent with general marine surfaces identified by Hoffman and Carpenter (Reference 2.5.1-238) in the vicinity of Bailey, North Carolina (RAI 02.05.01-10 Figure 3).

Profile C2 (RAI 02.05.01-10 Figure 12)—There is an apparent step in the general elevation of the surface across the ECFS-C near station 19000, which goes from the 63 m (206 ft.) surface down to the 59 m (193 ft.) surface. If this is a tectonic scarp, it would suggest approximately 4 m (13 ft.) of cumulative displacement in a surface that is probably early Pliocene in age based on the studies of Hoffman and Carpenter (Reference 2.5.1-238) near Bailey. Alternatively, this apparent step is a marine terrace shoreline-related feature.

D Profiles (RAI 02.05.01-10 Figure 13)

This series of profiles is located in the interfluve region between the upper tributaries of the Neuse River and Toisnot Swamp (RAI 02.05.01-10 Figure 4). The profiles cross the area previously studied by Hoffman and Carpenter (Reference 2.5.1-238). Comparison of the surface profiles to structure contour maps on the top of crystalline basement and the top of the lower Pliocene unit are shown on RAI 02.05.01-10 Figure 2 and RAI 02.05.01-10 Figure 3. Profiles D1 and D4, which show the least incision across the ECFS-C show no evidence of significant surface offset across the ECFS-C. The high region to the southeast of the ECFS-C zone that is most prominent on profiles D1, D2, and D3 is coincident with the Sims pluton (RAI 02.05.01-10 Figure 1). Base level and the general amount of incision along tributaries flowing into an unnamed drainage directly southwest of the line of profiles appear to be similar suggesting that there is not a marked change in the degree of stream incision across the ECFS-C.

Profile D4 (RAI 02.05.01-10 Figure 14) —Profile D4 crosses the ECFS-C where the fault zone as mapped by Marple and Talwani (Reference 2.5.1-243) is narrowly constrained. There is no apparent significant change in the elevation of the upland surface across the ECFS-C. The slight increase in the elevation of the ground surface from approximately 80 m to 87 m (262 to 285 ft.) likely reflects varying thickness of sediment overlying the crystalline basement surface (RAI 02.05.01-10 Figure 3). The 70-73 m (230-239 ft.) elevations observed both northwest and southeast of the ECFS-C may be correlative with an intermediate surface (with recessional sediment cover) on the top of a lower Pliocene unit identified by Hoffman and Carpenter at a general elevation of approximately 67 m (220 ft.).

In summary, our conclusions based on interpretation of topographic profiles constructed across the ECFS-C at four interfluve areas from south of the Cape Fear River to the vicinity of Bailey, North Carolina are:

- There are no consistent or systematic changes in topographic surfaces in the interfluvial areas along the ECFS-C that indicate the presence of a localized uplift, tilting, or folding along the ECFS-C.
- In the vicinity of the large meander bend in the Cape Fear River that Marple and Talwani (Reference 2.5.1-243) conclude is due to localized folding (north-northeast plunging anticline associated with a buried strike-slip fault zone) there is no evidence of northeast-tilting of the Early Pleistocene Qw terrace (Profiles B, RAI 02.05.01-10 Figure 10). There is no evidence of vertical displacement of the Qw terrace of as much as 18 m (59 ft.) inferred by Marple and Talwani based on incision of the Cape Fear River below the Wando terrace. Depending on the age of the terrace remnant at an elevation of 46 m (151 ft.) at the northwest limit of the ZRA-C on Profile B1, there is either no appreciable vertical displacement in 2.75 Ma (assuming the remnant is correlative to the Qb terrace that is assigned an age of 2.75 Ma by Soller [Reference 2.5.1-266]) or apparent vertical displacement of the Waccamaw (Qw) terrace (estimated to be 730 ka to 165 -1.75 Ma, Reference 2.5.1-266 and Reference RAI 02.05.01-10 08) is on the order of 10 m or less.
- Topographic escarpments observed on the Profile sets C and D are generally consistent with the elevations of littoral scarps and features associated with the transgression/regression of Pliocene sea level.

h) The NRC Staff note that streams other than the Cape Fear River display river deflection, changes in sinuosity, and confluences of several streams coincident with the ECFS. Examination of Revised Figure 2.5.1-219 shows that such features are not unique to the ECFS-C. Such variations of channel characteristics can be attributed to downstream variations in discharge, sediment load, and the type of sediment moved through the channel or to local geology (Reference RAI 02.05.01-10 03). Many of these changes in stream geomorphology are coincident with the transition from the Piedmont to the Coastal Plain provinces. Locally, such changes coincide with the Orangeburg and Coats scarps. As discussed above in response to item f, Hoffman and Carpenter (Reference 2.5.1-268) show that bedrock escarpments formed during marine planation associated with Pliocene transgressions are associated with these scarps. Elsewhere in the Coastal Plain region of South Carolina and North Carolina, the Orangeburg scarp distinctly and reliably delineates two contrasting regions of the Coastal Plain, and rivers are entrenched where they exit the higher upland northwest of the Orangeburg scarp (Reference 2.5.1-209). Many of the geomorphic features that coincide with the postulated ECFS-C therefore also coincide with changes in bedrock lithologies and relic littoral scarps (Revised Figure 2.5.1-219). These factors in addition to climatically-influenced base level changes related to Pliocene and Pleistocene eustatic sea level fluctuations will have influenced the development of the stream patterns observed in the upper Coastal Plain region.

   The sharp change in river course on the unnamed river southwest of the Lumber River is not atypical of meanders observed elsewhere in this part of the Coastal Plain (Revised Figure 2.5.1-219). For example, the Lumber River, itself, has a similar trend where it bends to the southeast just south of the ZRA-C (ECFS-C).

   The change in sinuosity on the South River near the ECFS, which is coincident with a large tributary (shown on the Dunn and Wade 7.5-minute topographic quadrangles) joining the South River from the northwest, may be due to fluvial response to changes in sediment load and stream flow.

The change in the orientation of Mill Creek that is coincident at the ECFS-C is typical of a stream meander and is minor compared with changes in orientation of the creek that occur further east.

The confluence of several streams near the ECFS-C along the Neuse River is coincident with a change from Paleozoic metamorphic rocks to Cretaceous Coastal Plain deposits and the location of the relic littoral scarps of probably Pliocene age based on mapping of Hoffman and Carpenter (Reference 2.5.1-268) (Revised Figure 2.5.1-219). Several escarpments in the top of crystalline basement in this area appear to be due to marine planation during the early Pliocene transgression. The location of the shoreline may have been influenced in part by the distribution of more resistant granite. The stream pattern may reflect the lithology of the underlying basement rocks and general thickness of overlying sediments rather than tectonism. No changes in stream gradient or vertical steps in the stream channel are seen along this part of the Neuse River (Revised Figure 2.5.1-220).

i) This RAI item requests additional clarification about paleoliquefaction studies in the site region and Quaternary mapping investigations by Owens (Reference 2.5.1-271) in the Cape Fear River area.

A detailed investigation by Amick et al. (Reference 2.5.1-270) shows locations and describes morphologies of the paleoliquefaction features in the Charleston region. Liquefaction features in the Charleston area were found to occur primarily in beach, back-barrier, or fluvial deposits. They note that the sand-blow explosion craters are the most common of the liquefaction features associated with the 1886 Charleston earthquake. Further, beach settings were the most favorable depositional environment for the generation and preservation of liquefaction features, found nearly exclusively in beach ridge and near-shore marine deposits (Reference 2.5.1-270). The locations for the study of 103 paleoliquefaction sites were derived from a catalog that was based on the detailed review of historical accounts of the 1886 earthquake and 20th century field investigations (Reference 2.5.1-270). RAI 02.05.01-09 Figure 3 shows where paleoliquefaction deposits were identified. Amick et al. note that no conclusive paleoliquefaction evidence of large prehistoric earthquakes originating outside of South Carolina has been identified (Reference 2.5.1-270).

Paleoliquefaction features have been identified at two sites in North Carolina: the Calabash site of Amick et al. (Reference 2.5.1-270) and the South Port site of Talwani and Schaeffer (Reference 2.5.1-301). The Calabash site was one of eight liquefaction sites identified north of the meizoseismal area of the 1886 Charleston earthquake. Detailed investigations were conducted at five of the eight sites, but the Calabash site was not included in this five. The only site-specific information Amick et al. (Reference 2.5.1-270) provide on the Calabash site is "several pre-1886 features" as a note on a map showing the location of the site (Reference 2.5.1-270, Figure 11.1). The general mapping approach employed by Amick et al. and the types of deposits targeted for reconnaissance are discussed in RAI 02.05.01-09.

Owens et al. (Reference 2.5.1-271) present a 1:250,000 scale geologic map of the Cape Fear River valley that differentiates Quaternary terrace deposits as well as older units. A portion of the map is shown on Figure RAI 02.05.01-10 Figure 5. The map was compiled with the primary objective of determining the tectonic activity on the Cape Fear Arch. Soller (Reference 2.5.1-209) supplemented this mapping with additional studies to evaluate weathering and soil profiles to correlate terraces and analyze longitudinal terrace profiles in the Cape Fear River valley. From this study, it was estimated that localized uplift rates on the Cape Fear arch since the late Pliocene have ranged from 0.06 m to perhaps as much as 6 m/100,000 years (0.2 to 20 ft./100,000 years), whereas a more regional uplift associated with the arch or Coastal Plain in general has been at a rate of approximately 0.6 m/100,000 years (2 ft./100,000 years) (Reference 2.5.1-209).

Neither of these studies provides direct evidence for large recent earthquakes on the postulated ECFS. These studies document a pattern of relatively continuous west-to southwestward migration of the Cape Fear River throughout Pliocene and Pleistocene time, which is consistent with the regional tilt on the flank of the Cape Fear arch. Markewich (Reference 2.5.1-265), who also cites geomorphic evidence for Pliocene-Pleistocene uplift in the area of the Cape Fear arch, concludes that gradients of Cape Fear River terraces suggest a flexure across the Cape Fear River valley from somewhere near Fayetteville to confluence of the Black and Cape Fear rivers (a distance of approximately 120 km [75 mi.]). Based on analysis of stratigraphic and geomorphic data, Markewich (Reference 2.5.1-265) suggests that a line from Rockfish Creek, to between Dunn and Lillington, to Smithfield marks either the position of a fault associated with the flexure, or simply the top of the flexure. The geomorphic observations described by Markewich, can be explained by more regional flexural bend models, such as presented by Pazzaglia (Reference 2.5.1-267). Analysis of the evidence for the existence and activity of the postulated ECFS-C, which generally coincides with the top of the flexure, indicates that there is not a thoroughgoing fault as suggested by Markewich (Reference 2.5.1-265).

The results of mapping and stratigraphic investigations of the Cape Fear River valley presented by Owens (Reference 2.5.1-271) and Soller (Reference 2.5.1-209) do not describe evidence of discrete faulting or other indications of strong ground motion in any of the Quaternary terraces in the Cape Fear River Valley. Soller (Reference 2.5.1-209) notes differences in the character of fluvial sediments beneath terraces relative to those underlying the floodplain of the Cape Fear River. Fluvial sediments beneath terraces reflect a river at grade and are unlike sediments beneath the floodplain, which were deposited as sea level rose and the channel backfilled. The pre-Holocene deposits are coarser and generally a fining-upward sequence of channel sands and overbank silts and clays, capped by dune sand is preserved. In some cases, the overbank silts and clays are absent or are intercalated with channel sands. Power auger samples into the floodplain deposits at two locations, Wilmington and Elizabethtown, N. C. provided information on the age of sea level rise in the lower Cape Fear River channel. The Holocene section at Wilmington is largely tidal marsh peat, deposited since approximately 7,270 yr BP in the floodplain adjacent to the Cape Fear River channel as the sea level rose. At Elizabethtown, channel aggradation began about 3,540 yr BP, when silt and clay with lesser interbedded sand filled the incised channel. Between 12 and 13.7 m (40 and 45 ft.) of sediment was deposited at both localities. These general descriptions suggest that at least locally there may be deposits associated with fluvial terraces that would be susceptible to seismically induced liquefaction along the Cape Fear River if groundwater conditions are favourable (i.e., the sands below the silt cap are saturated). Evidence of paleliquefaction was not noted in previous investigations, however, and to our knowledge detailed paleoliquefaction surveys have not been conducted along the Cape Fear River or other major rivers in North Carolina.

Associated HAR COL Application Revisions:

The following changes will be made to HAR FSAR Chapter 2 in a future revision:

Revise FSAR Section 2.5.1.1.4.2.5.5 from:

"2.5.1.1.4.2.5.5 Postulated East Coast Fault System (Class C)

A postulated north/northeast/south/southwest-trending buried fault system in the Coastal Plain of the Carolinas and Virginia, named the East Coast fault system (ECFS) was identified by Marple and Talwani (Figure 2.5.1-213) (Reference 2.5.1-243). Based on geomorphic analyses of Coastal Plain rivers, three nearly collinear, approximately 200-km-(125-mi.-) long segments (ECFS-S, ECFS-C, and ECFS-N) that were initially referred to as the southern, central, and northern zones of river anomalies (ZRA-S, ZRA-C, and ZRA-N) were differentiated (Figure 2.5.1-217). The southern segment is located primarily in South Carolina, the central segment is located primarily in North Carolina and is located approximately 55 km (35 mi.) from the HAR site, and the northern segment extends from northeastern North Carolina through Virginia (Figure 2.5.1-213). Identification of the postulated fault system is based on the alignment of geomorphic changes along streams, areas of uplift, and local evidence of faulting. Marple and Talwani concluded that the ZRAs were produced by gentle late Quaternary uplift along an approximately 600-km (370-mi.) long-buried fault system and that because most of the river anomalies occur in unconsolidated floodplain sediments of upper Pleistocene (<130 ka) or younger age, deformation occurred during this period and may be ongoing (Reference 2.5.1-243).

Marple and Talwani initially identified and proposed the southern segment, located in South Carolina, as a possible source of the 1886 Charleston earthquake (Reference 2.5.1-262). At its southern end, this segment is associated with microseismicity, a linear aeromagnetic anomaly, and buried faults interpreted from seismic reflection data (Reference 2.5.1-243). The postulated ECFS-S segment is considered to be a possible source of repeated large-magnitude earthquakes in the Charleston region, as outlined in Subsection 2.5.2. Wheeler evaluated the evidence for the East Coast fault system, noting that the southern segment is surrounded by sites at which prehistoric paleoliquefaction features document the occurrence of large earthquakes (see the descriptions of the Charleston and Georgetown liquefaction features, previously, and the discussion in Subsection 2.5.1.1.4.3) (Reference 2.5.1-259). Wheeler states that the evidence for recent uplift and possible buried faulting along the southern segment of the fault system is good; however, there is no demonstration of sudden uplift anywhere along the fault system (Reference 2.5.1-259). The 1886 and prehistoric liquefying earthquakes in South Carolina demonstrate the occurrence of repeated Quaternary tectonic faulting, but the link between those events and the postulated East Coast fault system remains speculative. Accordingly, the postulated East Coast fault system is assigned to Class C. (Reference 2.5.1-259) The existence and evidence for activity for the postulated ECFS-S segment is judged to be low to moderate based on a recent evaluation of that segment as part of studies to support the Southern Nuclear Company Advanced Light Water Reactor (ALWR) Early Site Permit (ESP) (see discussion in Subsection 2.5.1.1.4.3) (Reference 2.5.1-263). The evaluation for the Vogtle ESP (Rev. 2) judged the ECFS-S to have a relatively low likelihood of producing Charleston-type earthquakes (Reference 2.5.1-264).

Marple and Talwani extended the ZRA-S northward into North Carolina citing studies by Markewich and Soller that interpreted an approximately 95 km (60 mi.) long north-northeast-trending buried fault or flexure based on evidence from fluvial geomorphology, soil profiles, and surface fault exposures (Reference 2.5.1-243, Reference 2.5.1-265, Reference 2.5.1-266). Marple and Talwani extended this zone and referred to it as the central segment of the postulated ECFS (Reference 2.5.1-243). A possible tectonic origin was inferred based on the following lines of evidence: uplift and cross-valley tilt of river terraces along the Cape Fear River; increase in channel sinuosity downstream on several rivers; incision through Pleistocene floodplain deposits; alignment of river anomalies; coincidence with buried faults; alignment with magnetic anomalies; and evidence of brittle faulting. Postulated geomorphic anomalies used to support their hypothesis are listed in Table 2.5.1-202. Some of these features can be explained by credible nontectonic mechanisms or factors as noted in the table notes and the following discussions.

Although many of these observations are consistent with lithospheric flexure (i.e., long-wavelength bending or warping of the lithosphere), these observations do not clearly demonstrate the presence of an active regional-scale, crustal fault that is localizing seismicity in the present tectonic regime. For example, based on mapping and longitudinal profiles on terraces estimated to range in age from 2.75 to 0.1 Ma, Soller interprets that the locus and intensity of local tectonism in the vicinity of the Cape Fear River has varied with time. (Reference 2.5.1-266) Soller concludes that since at least 750 ka, the valley northwest of Elizabethtown near the Piedmont has been uplifted while subsidence is likely for the river's lower course (Reference 2.5.1-266). An inflection point southeast of Elizabethtown may mark the boundary between these two regimes and a simple tilting of the Coastal Plain along the valley length, up from the direction of the Piedmont, could account for changes in uplift rate measured along the river on terraces of differing ages. A small scale flexure, related to larger scale tectonism on the Cape Fear arch, can explain the pattern of uplift (Figure 2.5.1-218). Additionally, an apparent bulge in basement structure contours that is subparallel to and superimposed on the broad outline of the Cape Fear arch may represent a localized flexure that accounts for the uplift patterns (Figure 2.5.1-218). (Reference 2.5.1-266) This feature does not coincide with or subparallel the postulated ECFS-C as interpreted by Marple and Talwani (Reference 2.5.1-243). Geodynamic models, as described by Pazzaglia that simulate flexural deformation along the U.S. Atlantic margin in response to erosion in the Appalachian Mountains and sediment loading in the offshore regions, also could explain in part the possible broad zone of flexure or localized uplift described by Markewich (Reference 2.5.1-267, Reference 2.5.1-265). Pazzaglia describes a similar broad, flexural warp, centered across the Fall Zone, between the upwarped central Appalachians and subsided Salisbury Embayment in the region to the north of the Norfolk arch (Reference 2.5.1-267). Smaller tectonic features, such as the small displacement Cretaceous and Cenozoic faults and possible seismicity, may coincide with this zone of flexture, which coincides with a more prominent, well-defined Fall Zone in the vicinity of the Susquahanna River (Reference 2.5.1-267). However, the complex interaction between the regional and flexural stress field and their relationship to pre-existing faults is poorly constrained (Reference 2.5.1-267).

In addition to the river anomalies, Marple and Talwani report coincidences with buried faults, magnetic anomalies, and surface faults in Cretaceous and post-Cretaceous sediments as evidence for the existence and activity of the postulated ECFS-C (Reference 2.5.1-243). It is noted that the northern end of the postulated ECFS-C (near Bailey, North Carolina) coincides with a 7-km- (4-mi.-) long west-side-up fault or flexure in the Piedmont basement rocks beneath 6 - 12 m (20 – 40 ft.) of sediments, and with a 40-km- (25-mi.-) long linear magnetic high between Smithfield and the Tar River; the relief across the inferred structure is ~7 m (~23 ft.) (Reference 2.5.1-243). However, Hoffman and Carpenter, cited as the original source of the evidence for a fault or flexure in basement, describe the feature as terracing of the basement surface and observe that younger terraces generally overlie the two terraces developed in the crystalline basement surface (Reference 2.5.1-268). It is noted that the terraces are separated by escarpments and, in places such as where a possible intermediate terrace is absent, the escarpments locally merge (Reference 2.5.1-268). The feature that Marple and Talwani describe as a fault or flexure in basement appears to coincide with such a merged escarpment, and it is likely that the feature is related to shoreline erosion rather than faulting. Hoffman and Carpenter correlate this scarp with the Orangeburg scarp, and view it as a feature developed during the early Pliocene transgressive-regressive event (Reference 2.5.1-268).

Additionally, six faults exposed in roadcuts (faults 46, 48, 52, 53, 55, and 56 of Prowell) (Table 2.5.1-201) are reported to offset Pliocene-Pleistocene sediments less than a few meters (tens of feet) thick along the postulated ECFS-C north of Smithfield (Reference 2.5.1-256). These faults trend slightly more north than the postulated ECFS-C, as noted by Marple and Talwani (Reference 2.5.1-243). These faults also are not localized along the ECFS-C, but rather are distributed across an approximately 50-km- (35-mi.-) wide zone at the boundary between the upper Coastal Plain and the Piedmont physiographic provinces (Figures 2.5.1-213 and 2.5.1-219). More recent studies indicate that there is not strong evidence for the age of faulting. The postulated ECFS-C segment is not coincident with any regional scale basement fault as inferred from subsurface borings and interpretation of geophysical (magnetic) data (Reference 2.5.1-251, Figure 2.5.1-213). Stream profiles developed for this study based on new and more detailed topographic data from a LIDAR survey show no consistent vertical anomalies in the modern drainage where the postulated ECFS-C crosses the profiles (see Figures 2.5.1-219 and 2.5.1-220 and discussion in Subsection 2.5.1.1.4.2.5.6) (Reference 2.5.1-269). An apparent vertical down-to-the-southeast step is apparent along the Cape Fear River channel, but is not observed in the Lumber River profile to the south. Aerial reconnaissance conducted for this study also did not reveal any significant geomorphic changes along the central segment of the postulated ECFS.

Marple and Talwani infer uplift rates along the entire postulated ECFS from upwarped floodplains and terraces (Reference 2.5.1-243). These generally range from 0.02 to 0.3 millimeter per year (mm/yr) (0.0008 to 0.01 inch per year [in/yr]); faster uplift rates of 0.14 to 1.8 mm/yr (0.006 to 0.07 in/yr) and 0.05 to 0.65 mm/yr (0.002 to 0.026 in/yr) are inferred for the central segment based on the amounts of incision along the Cape Fear River (18 m [59 ft.] in 10 – 130 ka) and warping of a terrace surface (6.5 m [21 ft.] in 10 – 130 ka), respectively. The basis for concluding that the incision and warping all occurred during Holocene time, which leads to the higher values, is not provided by Marple and Talwani, and it does not seem warranted based on review of the data. Soller suggests that uplift along the Cape Fear River increases gradually from 32 km (20 mi.) downstream to 32 km (20 mi.) upstream from Elizabethtown (Reference 2.5.1-266). Marple and Talwani state that the uplift rate of ~0.64 mm/yr (~0.025 in/yr) along the Wando terrace (120 – 70 ka) measured downstream of the postulated ECFS-C is probably low because the location is downstream from the area of greatest incision (Reference 2.5.1-243). Assuming that the maximum incision observed upstream from this area (18 m [59 ft.]) is due to uplift on the postulated ECFS-C as defined by Marple and Talwani, a better estimate of the long-term slip rate across this structure would be to subtract the estimated uplift rate downstream (~0.06 mm/yr [~0.002 in/yr]) from the post-Wando incision rate (18 m [59 ft.] per 70 to 130 ka = 0.26 to 0.14 mm/yr [0.01 to 0.006 in/yr]) measured where the postulated ECFS-C is assumed to cross the Cape Fear River. This would suggest a maximum slip rate of 0.08 to 0.2 mm/yr (0.003 to 0.008 in/yr) for the postulated ECFS-C. Lower slip rates are suggested by the 6.5 m (21.3 ft.) and 2 m (6.6 ft.) of warping of the 70 – 130 ka terrace across the South River (of 0.05 to 0.065 mm/yr [0.002 to 0.0026 in/yr]) and Little Pee Dee (i.e., 0.02 mm/yr [0.0008 in/yr]), respectively (Reference 2.5.1-243). There is no direct geologic evidence to suggest that large-magnitude earthquakes have occurred along the postulated ECFS-C segment.

Except for paleoliquefaction sites observed in beach and near-shore marine deposits at the South Carolina/North Carolina border, no evidence for paleoliquefaction was observed during regional reconnaissance investigations conducted by Amick et al.

(Reference 2.5.1-270). No paleoliquefaction features were reported by Owens, Soller, or Markewich, who conducted detailed mapping of Quaternary terraces along the Cape Fear River (Reference 2.5.1-271, Reference 2.5.1-266, Reference 2.5.1-265).

More detailed review and analysis of the geologic, seismologic, and geomorphic evidence presented by Marple and Talwani to support the existence of the northern segment of the ECFS-N was performed as part of the Dominion Nuclear North Anna, LLC (Dominion), North Anna Early Site Permit Application (Reference 2.5.1-243, Reference 2.5.1-272). According to NUREG-1835, Nuclear Regulatory Commission staff agreed with Dominion's conclusion that most of the geologic data cited by Marple and Talwani in support of their postulated ECFS did not apply to the postulated ECFS-N, and that there is little evidence for the existence of or recent activity on the northern segment.

The central and northern segments of the postulated ECFS were not included as Quaternary active faults in the 2002 USGS hazard model; in recent studies by Crone and Wheeler, and Wheeler; or in models for the Trial Implementation Program (TIP), which characterized seismic sources for two nuclear power plants in the southeastern United States (Reference 2.5.1-258, Reference 2.5.1-259, Reference 2.5.1-272). The implication that the southern segment may be the source of the 1886 Charleston earthquake suggests that the central and northern segments may produce earthquakes of similar size (Reference 2.5.1-243). Despite lack of evidence for the northern segment, a sensitivity analysis was performed to evaluate the potential contribution to the hazard at the North Anna site (Reference 2.5.1-272). The observations and lines of evidence presented by Marple and Talwani do not provide convincing arguments in support of a buried north-northeast-trending strike-slip fault (the postulated ECFS-C) through the North Carolina Coastal Plain region (Reference 2.5.1-243). Geomorphic analyses and aerial reconnaissance of the postulated ECFS-C performed in this study suggest that the postulated ECFS-C may not exist, or has very low probability of activity if it does exist."

To read:

"2.5.1.1.4.2.5.2.2 East Coast Fault System

A postulated north/northeast/south/southwest-trending buried fault system in the Coastal Plain of the Carolinas and Virginia, named the East Coast fault system (ECFS) was identified by Marple and Talwani (Figure 2.5.1-213) (Reference 2.5.1-243). Based on their geomorphic analyses of Coastal Plain rivers, three nearly collinear, approximately 200-km- (125-mi.-) long segments (ECFS-S, ECFS-C, and ECFS-N) that were initially referred to as the southern, central, and northern zones of river anomalies (ZRA-S, ZRA-C, and ZRA-N) were differentiated (Figure 2.5.1-217). The southern segment is located primarily in South Carolina, the central segment is located primarily in North Carolina and is located approximately 55 km (35 mi.) from the HAR site, and the northern segment extends from northeastern North Carolina through Virginia (Figure 2.5.1-213). Identification of the postulated fault system is based on the alignment of geomorphic changes along streams, areas of uplift, and local evidence of faulting. Marple and Talwani concluded that the ZRAs were produced by gentle late Quaternary uplift along an approximately 600-km (370-mi.) long-buried fault system and that because most of the river anomalies occur in unconsolidated floodplain sediments of upper Pleistocene (<130 ka) or younger age, deformation occurred during this period and may be ongoing (Reference 2.5.1-243).

The conclusions reached by Marple and Talwani (Reference 2.5.1-243) suggest that the ECFS should be considered as a potential capable tectonic source, and seismic hazard studies conducted in support of the National Hazard Seismic Hazard Mapping Program as well as other ESP and COL applications have assessed various segments of the ECFS as a potential seismic source. The general conclusions reached by these studies are as follows:

<u>National Seismic Hazard Mapping Program (2002 and 2008)</u> - One of the two alternative equally weighted areal source zones that are used to account for the uncertainty in the location of the source of future earthquakes in the Charleston, South Carolina region is a geographically narrow zone that follows the Woodstock lineament and an area of river anomalies (Reference 2.5.1-347 and Reference RAI 02.05.01-10 01). This zone, correlates to the southern 100 km (62mi.) of the ECFS-S segment. There is no discussion or documentation of the reasons for limiting the source zone to the southern half of the ECFS-S segment. The northern part of the ECFS-S, as well as the ECFS-C and ECFS-N, were not specifically modeled as fault sources.

In an update to the USGS compilation of known or suggested Quaternary tectonic faulting in the CEUS, Wheeler (Reference 02.05.01-259) noted that evidence for the southern section is strongest, with evidence becoming successively weaker northward (Reference 02.05.01-259). Wheeler evaluated the evidence for the East Coast fault system, noting that the southern segment is surrounded by sites at which prehistoric paleoliquefaction features document the occurrence of large earthquakes (see the descriptions of the Charleston and Georgetown liquefaction features in Subsection 2.5.1.1.4.2.5.3.2) (Reference 2.5.1-259). Wheeler states that the evidence for recent uplift and possible buried faulting along the southern segment of the fault system is good; however, there is no demonstration of sudden uplift anywhere along the fault system. The 1886 and prehistoric liquefying earthquakes in South Carolina demonstrate the occurrence of repeated Quaternary tectonic faulting, but the link between those events and the postulated East Coast fault system remains speculative. Accordingly, the postulated East Coast fault system is assigned to Class C. (Reference 2.5.1-259)

<u>Dominion North Anna ESP Application</u> – A comprehensive review of the reported evidence for the northern segment of the ECFS (ECFS-N) was completed for the Dominion North Anna ESP Application (Reference 2.5.1-274). From this study, which included geomorphic analyses and aerial reconnaissance in addition to the critical evaluation of the evidence cited by Marple and Talwani (Reference 2.5.1-243), it was concluded that the northern segment of the East Coast fault zone (ECFS-N) probably does not exist or has a very low probability of activity if it does exist. The probabilities of existence and activity were assigned low weights because the existence of the fault is not well documented and was judged to be highly uncertain, and because there is no direct geologic, geomorphic, or seismologic evidence that the fault exists as a tectonic feature or is active, if it does exist. In a sensitivity analysis performed to evaluate the fault's potential contribution to hazard at the ESP site, the ECFS-N fault was assumed to have a probability of existence of 0.1 and a probability of activity (given existence) of 0.1. A summary of the observations and conclusions from this study regarding the assessment of the ECFS-N as a capable tectonic source are provided below.

The NRC Staff in their review of the North Anna ESP Application concluded that the geologic, seismologic, and geomorphic evidence for the ECFS-N presented by Marple and Talwani (2000) is questionable and that the majority of data presented apply only to the southern and central segments of the ECFS. The NRC staff concluded that although the evidence for the ECFS-N is low, it should be included as a possible contributor to the seismic hazard for the North Anna ESP site, and that a 10 percent probability of existence is an acceptable value. (Reference 02.05.01-10 04)

Southern Nuclear Company (SNC) Vogtle ESP Application - The southern segment of the ECFS was evaluated and included as a possible source of repeated large magnitude earthquakes in the updated Charleston seismic source model developed for this application. The evaluation for the Vogtle ESP (Reference 2.5.1-264) judged the ECFS-S to have a relatively low likelihood of producing Charleston-type earthquakes because there is not sufficient geologic evidence to demonstrate tectonic faulting or Quaternary slip associated with the ECFS-S and many of the river anomalies may be due to non-tectonic processes. The possibility that the ECFS-S in its entirety is the source of repeated large magnitude Charleston earthquakes, therefore, was given a low weight (0.10) in the updated Charleston seismic source model (UCSS) model. The southernmost portion of the ECFS-S, however, which lies in the meizoseismal region of the Charleston earthquake also is included in the Charleston area faults source zone (Zone A) (given a weight of 0.7) and the larger onshore portion of the Coastal Zone (Zone B) (given a weight of 0.2) (Figures 2.5.2-212 and 2.5.2-213).

Duke Energy Carolinas, LLC William States Lee III Nuclear Station Units 1 and 2 COL Application - Following the characterization of the updated Charleston seismic source developed by SNC Vogtle ESP Application, the Duke Energy William States Lee COL Application also considers the ECFS-S as a possible source of repeated large magnitude earthquakes in the Charleston region. Based on examination of gravity and aeromagnetic maps along the northern part of the ECFS-S segment, it also was concluded that if the ECFS exists as mapped, then it has not accumulated sufficient displacement to juxtapose rocks of varying magnetic susceptibility or density, and thus does not produce an observable magnetic or gravity anomaly at the scale of maps used for the evaluation.

In the updated PSHA for the HAR COLA, an evaluation of the evidence for the postulated ECFS was undertaken to assess whether this postulated fault system qualifies as a capable tectonic source or a new seismic source that should be included in an updated PSHA. The criteria used were those that were judged to be the most important in the EPRI-SOG evaluations, including spatial association with instrumental and historical seismicity or paleoseismic events, geometry and sense of slip relative to the present stress regime, deep crustal expression, and evidence for brittle slip on the feature. These criteria were applied to the postulated ECFS-C segment, which lies closest to the HAR site. Based on this assessment the ECFS-C like the ECFS-N segment was assigned a low probability (0.1) that the source exists and a probability of 0.1 that it is active if it exists. Both the ECFS-C and the ECFS-N are included as possible fault sources in the updated PSHA for the HAR site. The southern segment of the postulated fault zone (ECFS-S) was included as a possible alternative fault source for the UCSS following the characterization that was developed by Southern Nuclear Company (FSAR Section 2.5.2.4.1.1.2).

Evaluation of the Evidence Presented by Marple and Talwani (2000)

Geologic, geophysical, seismological and geomorphic data used by Marple and Talwani (Reference 2.5.1-243) to infer the presence of the southern, central, and northern segments of the ECFS are reviewed and evaluated in the following sections.

East Coast Fault System-Southern (ECFS-S) Segment

Marple and Talwani initially identified and proposed the southern segment, located in South Carolina, as a possible source of the 1886 Charleston earthquake (Reference 2.5.1-262). At its southern end, this segment is associated with microseismicity, a linear aeromagnetic anomaly, and buried faults interpreted from seismic reflection data (Reference 2.5.1-243).

The Woodstock fault, which is inferred to be a reactivated fault associated with the eastern margin of a Mesozoic basin, is identified in the subsurface, based on interpretation of seismic profiles, associated seismicity as indicated by detailed analysis of seismicity using double difference methods, and assessment of possible related surface deformation that may have occurred during the 1886 Charleston earthquake. The approximately 30 km (19 mi.) long Woodstock fault lies within the southern part of the ECFS-S. The apparent coincidence of the Woodstock fault with higher topography and the Summerville scarp has been cited as evidence of Quaternary reactivation of the fault (see Subsection 2.5.1.1.4.3).

Farther to the north, Marple and Talwani present evidence for faulting or folding of Upper Cretaceous units including structure contours on a Black Creek clay horizon (interpreted from resistivity well logs) and interpretations of possible offset reflectors in seismic reflection profiles at two locations between the Santee and Lynches rivers. In the northern most seismic line located between Black Creek and the Lynches River, the interpreted faulting is shown to extend upwards into the lower Coastal Plain units.

North of the Lynches River there are no mapped faults that coincide with ECFS-S (Revised Figure 2.5.1-219). A strand of the Eastern Piedmont fault system crosses the northern end of the postulated ECFS-S, but there are no nearby faults that parallel or coincide with the postulated ECFS-S (Figure 2.5.1-213).

The Duke Energy William States Lee III FSAR (Reference RAI 02.05.01-10 04) states that the northern part of the mapped trace of the southern segment of the East Coast fault system (ECFS) is not expressed in the gravity field and cuts across anomalies with wavelengths on the order of tens of miles without noticeable perturbation. This implies that the southern segment of the ECFS, if present, has not accumulated sufficient displacement to systematically juxtapose rocks of differing density, and thus produce an observable gravity anomaly. The magnetic data do not show evidence for any Cenozoic structures in the Duke Energy Lee site region and generally are not of sufficient resolution to identify or map discrete faults such as border faults along the Triassic basins. In particular, the southern segment of the ECFS has no expression in the magnetic field and cuts across anomalies with wavelengths on the order of tens of miles without noticeably perturbing or affecting them. If the ECFS exists as mapped, then it has not accumulated sufficient displacement to juxtapose rocks of varying magnetic susceptibility, and thus does not produce an observable magnetic anomaly.

East Coast Fault System-Central (ECFS-C) Segment

Marple and Talwani (Reference 2.5.1-243). extended the zone of river anomalies that characterize the ECFS northward into North Carolina citing studies by Markewich (Reference 2.5.1-265) and Soller (Reference 2.5.1-266) that interpreted an approximately 95 km (60 mi.) long north-northeast-trending buried fault or zone of flexure based on evidence from fluvial geomorphology, soil profiles, and surface fault exposures.

The features described by Marple and Talwani (Reference 2.5.1-243) to support the continuation of a regional structure or presence of buried faults beneath the North Carolina Coastal Plain include uplift and cross-valley tilt of river terraces along the Cape Fear River; increase in channel sinuosity downstream on several rivers; incision through Pleistocene floodplain deposits; alignment of river anomalies; coincidence with buried faults; alignment with magnetic anomalies; and evidence of brittle faulting. The observations and data sets, which can be grouped into geological, seismological, geomorphological categories, are reviewed in light of published information, seismological data, and independent analysis of topographic and stream profiles generated from LIDAR data completed for HAR COL Application as follows.

Geological and Geophysical Data

Marple and Talwani report coincidences with buried faults, magnetic anomalies, and surface faults in Cretaceous and post-Cretaceous sediments as geological evidence for the existence and activity of the postulated ECFS-C (Reference 2.5.1-243). However, geological evidence to support the presence of a throughgoing bedrock fault associated with the ECFS-C segment is not presented by Marple and Talwani (Reference 2.5.1-243).The primary evidence cited for faulting associated with the postulated ECFS-C is distributed brittle faulting north of Smithfield in an area above the Fall Zone, where bedrock is locally exposed (Figure 2.5.1-213; RAI 02.05.01-10 Figure 15). In addition to surface faults exposed in road cuts that offset post-Cretaceous sediments included in a Prowell (Reference 2.5.1-256) Cretaceous and post-Cretaceous fault compilation, two brecciated phyllite and argillite zones (site B1 and B2 in RAI 02.05.01-10 Figure 14) are reported in the vicinity of the postulated ECFS-C. Both breccias have varying strike and dip that deviate from the regional structural trends. None of the brecciation sites or fault exposures is associated with topographic scarps (Reference 2.5.1-243).

Table 2.5.1-201 shows summary information (fault trace identification number, fault type, strike and dip orientations, and basement rock and sedimentary rocks affected) for the faults included in the Prowell compilation (Reference 2.5.1-256). Thirty three faults were identified between the latitude of 38°03' and 34°05'. These faults are not localized along the ECFS, but rather are distributed across an approximately 50-km- (35-mi.-) wide zone at the boundary between the upper Coastal Plain and the Piedmont physiographic provinces (Figures 2.5.1-213 and 2.5.1-219). Of the 33 faults reported in this region, Marple and Talwani report offsets of Pliocene-Pleistocene sediments of less than a few meters for six of the faults (faults 46, 48, 52, 53, 55, and 56) that are proximal to the postulated ECFS-C (Figure 2.5.1-219) (Reference 2.5.1-256). Most of the faults are interpreted by Prowell as near-vertical reverse faults (Reference 2.5.1-243). With the exception of one fault (fault 46 that is reported to displace the Coharie formation of Pliocene-Pleistocene age approximately 2.8 m (9 ft.) and fault 48 that disrupts Upper Cretaceous to questionable Pliocene sediments 1.5 m (5 ft.), the other four faults cited by Marple and Talwani are reported only to offset sediments of Upper Cretaceous to questionable Pliocene age an unknown amount (Table 2.5.1-201). Given the distributed nature and small displacements exhibited by these faults, the presence of brittle faulting in association with the postulated ECFS-C is not strong evidence for a major active strike fault capable of generating large magnitude earthquakes.

Marple and Talwani also report that the northern end of the postulated ECFS-C (near Bailey, North Carolina) coincides with a 7-km- (4-mi.-) long west-side-up fault or flexure in the Piedmont basement rocks beneath 6 - 12 m (20 – 40 ft.) of sediments and with a 40-km- (25-mi.-) long linear magnetic high between Smithfield and the Tar River. The relief across the inferred fault or flexure is interpreted to be approximately 7 m (23 ft.) (Reference 2.5.1-243). Marple and Talwani do not provide details regarding the evidence for the fault or flexure zone. Hoffman and Carpenter, cited as the original source of the evidence for a fault or flexure in basement, describe evidence for marine planation (terracing) of the crystalline basement surface during an early Pliocene transgression and the development of subsequent recessional shoreline deposits and erosional escarpments in this area (Reference 2.5.1-268). Based on a structure contour map on the top of crystalline basement defined by numerous auger holes and surface outcrops, there are at least two planation surfaces with an intervening curvilinear escarpment (RAI 02.05.01-10 Figure 2). Based on examination of these structure contour maps and cross sections presented by Hoffman and Carpenter, there does not appear to be a consistent scarp coincident with the ECFS-C. The curvilinear nature of the basement scarp, which appears to be directly related to the location of outcropping granite, and the general elevation of the base of the scarp at approximately 60 m (200 ft.) around the granite outcrop support the interpretation that this is a shoreline-related scarp. The scarp coincides only very locally with the northern end of the ECFS-C (RAI 02.05.01-10 Figure 2).

The magnetic anomaly described by Marple and Talwani (Reference 2.5.1-243) as coincident with the northern end of the ECFS-C corresponds to the eastern margin of the Rolesville Batholith, and is not continuous along most of the ECFS-C (Figure 2.5.1-238).

The postulated ECFS-C fault is not expressed as a throughgoing feature in the gravity or magnetic data as shown on Figures 2.5.1-237 and 2.5.1-238 suggesting that if the ECFS exists as mapped, then it has not accumulated sufficient displacement to juxtapose rocks of varying magnetic susceptibility or density, and thus does not produce an observable magnetic or gravity anomaly at the scale of maps used for the evaluation.

The postulated ECFS-C segment does not coincide with any of the basement structures identified by Lawrence and Hoffman (Figure 2.5.1-213). In addition, the postulated fault crosscuts geologic units, structure contours on the top of basement, and locally diabase dikes as mapped by Lawrence and Hoffman (Reference 2.5.2-235) with no apparent offset (RAI 02.05.01-10 Figure 16).

In summary, the above observations support the conclusion that the postulated ECFS-C fault does not appear to have deep crustal expression or continuity on a regional extent.

Seismological and Paleoseismological Data

The ECFS-C is not associated with alignments or concentrations of seismicity or moderate size historical earthquakes (RAI 02.05.01-08 Figure 1). There is no direct geologic evidence to suggest that large-magnitude earthquakes have occurred along the postulated ECFS-C segment. Except for isolated paleoliquefaction sites observed in beach and near-shore marine deposits at the South Carolina/North Carolina border approximately 100 km (60 mi.) east of the ECFS-C segment, no evidence for paleoliquefaction was observed during regional reconnaissance investigations conducted by Amick et al. (Reference 2.5.1-270) along much of the North Carolina coastline region. Although detailed focused paleoliquefaction surveys have not been conducted in much of Coastal Plain region adjacent to the ECFS-C segment, no paleoliquefaction features have been reported by Owens, Soller, or Markewich, who conducted detailed mapping of Quaternary terraces along the Cape Fear River (Reference 2.5.1-271, Reference 2.5.1-266, Reference 2.5.1-265).

Geomorphic Data

Geomorphic evidence presented by Marple and Talwani for the ECFS-C is summarized in Table 2.5.1-202 and includes channel incision, upward displaced fluvial surfaces, cross-valley tilt, changes in sinuosity, anastomosing stream patterns, and river deflection. Most of the features described below can be explained by non-tectonic geomorphic processes or more regional patterns of flexure or differential uplift/subsidence rather than localized fault-specific tectonic deformation. An evaluation of the geomorphic and geologic evidence for the postulated ECFS-C presented by

Marple and Talwani (Reverence 2.5.1-243) and alternative interpretations is presented below.

River Incision and Upwarped Displaced Fluvial Surfaces

Channel incision and changes in graded profile concavity and reach-scale slope is dictated by changes in rock uplift, downstream changes in base level, and upstream changes in basin-scale hydrology (Reference 2.5.1-267). The fluvial systems in the Piedmont and the Coastal Plain regions of North Carolina likely have evolved in response to all of the above. Changes in sediment supply and overall base level related to fluctuating climates and sea level changes during the formation of fluvial terraces, therefore, are factors in addition to tectonically-induced uplift that may give rise to apparent stream channel anomalies.

As tablulated by Marple and Talwani, channel incision is not reported for all of the major streams along the ECFS-S, nor is there a systematic relationship among the observations of channel incision and reported displacements in associated fluvial surfaces along these drainages denoted as 'upward displaced fluvial surfaces' (Table 2.5.1-202). Channel incision is noted only for three of the six rivers studied by Marple and Talwani, (Reference 2.5.1-243). The amounts of reported incision range from 3 m (10 ft.) of Holocene to post-130-70 ka incision along the Lumber River, to 18 m (59 ft.) of post-130-70 ka incision along the Cape Fear River, to 35-40 m (115 -131 ft.) of incision of a surface of unknown age along the Neuse. Details regarding the incision along the Lumber and Neuse River are not provided by Marple and Talwani (Reference 2.5.1-243). In the vicinity of the Neuse River, the ECFS-C generally coincides with the Coats scarp, which may be a relic littoral feature correlative with the Orangeburg scarp of early Pliocene age. As noted by Soller and Mills (Reference 2.5.1-209) rivers are entrenched where they exit the higher upland northwest of the Orangeburg scarp. The incision noted by Marple and Talwani along the Neuse River, therefore, may represent long-term incision related to regional uplift and Pleistocene sea level fluctuations rather than localized tectonic uplift.

A map denoting the reach of anomalous river incision and representative topographic profiles across the Cape Fear River and its youngest terrace (Wando, early Pleistocene) shown by Marple and Talwani (Figure 8 in Reference 2.5.1-243) indicates that incision occurs well upstream and downstream of the ZRA-C. The pattern of incision, which occurs over a reach of the river approximately 50 km (30 mi.) upstream and at least 7 km (4.3 mi.) downstream as mapped by Marple and Talwani to possibly 35 km (22 mi.) based on profile 7, which shows incision into the Wando terrace at a location downstream of Elizabethtown, is more consistent with simple tilting of the Coastal Plain along the valley length (up from the direction of the Piedmont that caused deep entrenchment of the Cape Fear River into the Wando terrace in the upper valley concurrent with subsidence in the lower valley) as proposed by Soller (Reference 2.5.1-266) than is localized deformation along a strike-slip or oblique slip fault centered on the postulated ECFS-C. Soller (Reference 2.5.1-266) further suggests that the terrace pattern in the upper Cape Fear River valley, which may indicate a more localized zone of higher uplift, is related to a small-scale flexure that is parallel to and superimposed on the southern flank of the Cape Fear arch. Most of the Cape Fear River valley lies over the local bulge, which is inferred from a bulge in the basement structure contours (Figure 2.5.1-218). This localized uplift lies in the correct position relative to the Cape Fear River valley to account for the uplift history of the valley, and is therefore considered by Soller to be the source of the uplift that shaped the valley.

Marple and Talwani imply that channel incision is associated with localized tectonic uplift along the ECFS-C, but there is no consistent relationship between the amount of channel incision and the amount of 'upward displaced fluvial surface' deformation recorded along individual rivers. The only locality in which the amount of reported Holocene incision (3 m [10ft.]) is roughly correlative with the 'upward displaced fluvial surface' measurement (2 m [7 ft.]) is along the Lumber River. However, inspection of the Pembroke, NW Lumberton, SW Lumberton, SE Lumberton, and Evergreen 7.5-minute quadrangles shows that distinct stream incision is not apparent as suggested by Marple and Talwani (Figure 2.5.1-217). There are no examples of confirmatory measurements of multiple surfaces to support the hypothesis that incision is occurring in response to ongoing tectonic uplift associated with the ECFS-C. Similar evidence for differential uplift of older fluvial surfaces of the same magnitude or greater amount is not evidenced by systematic warping or deformation of associated floodplains or fluvial terraces.

Examples of convex-upward longitudinal valley profiles along the South, Lumber, and Little Pee Dee rivers are cited as another possible indicator of vertical uplift (Figure 10 in Reference 2.5.1-243). It appears that most of the 'upward displaced fluvial surfaces' identified by Marple and Talwani (Reference 2.5.1-243) are in fact such convexities rather than discrete displacements. Although convexities in longitudinal profiles may be produced by localized uplift of a channel and adjacent floodplain, other nontectonic processes can perturb a stream from an equilibrium condition and produce a convexity in its longitudinal profile (Reference RAI 02.05.01-10 03). For example, apparent convexities in a stream profile may occur at the confluence of two streams where increased discharge and sediment load downstream of the confluence commonly lead to a steeper gradient. This may be the cause of the convexities in the profiles of the floodplains along the Lumber and Little Pee Dee rivers. Major tributaries to the Lumber River and the Little Pee Dee River intersect these drainages in the vicinity of the ZRA-C (ECFS-C) (RAI 02.05.01-10 Figure 5). The cause of the apparent convexity in the floodplain of the South River that Marple and Talwani cite as evidence for a 6.5 to 8 m (21 to 26 ft.) displacement is not clearly associated with a major tributary confluence; however a small tributary joins the South River a few km upstream of the ECFS-C, and may influence sedimentation in the South River (Figure 2.5.1-219). The width of this anomaly (approximately 80 km [50 mi.]) extends well beyond the 20 km- (6 mi.-) width of the ZRA-C as designated by Marple and Talwani (Reference 2.5.1-243). The inferred tectonic displacement is assumed to have occurred subsequent to deposition of the fluvial terrace, which is estimated to be either Holocene or late Pleistocene (130-70 ka). However, there is no associated reported channel incision or inflections in the present channel (Profile PP', Revised Figure 2.5.1-220) to suggest a discrete uplift event associated with oblique slip fault movement along the ECFS-C. An influx of sediment to the South River from increased erosion and reworking of the thick older Pliocene and younger eolian sand deposits in the upper reaches of the South River triggered by changing Pleistocene climates is another possible mechanism that could result in stream disequilibrium and development of a convex stream profile.

Marple and Talwani infer uplift rates along the entire postulated ECFS from these inferred upwarped floodplains and terraces (Reference 2.5.1-243). These generally range from 0.02 to 0.3 millimeter per year (mm/yr) (0.0008 to 0.01 inch per year [in/yr]); faster uplift rates of 0.14 to 1.8 mm/yr (0.006 to 0.07 in/yr) and 0.05 to 0.65 mm/yr (0.002 to 0.026 in/yr) are inferred for the central segment based on the amounts of incision along the Cape Fear River (18 m [59 ft.] in 10 – 130 ka) and inferred warping of a terrace surface along the South River (6.5-8 m [21 ft.] in 10 – 130 ka), respectively.

The overall uplift rates, particularly the high rates based on assumed Holocene ages of incision, that Marple and Talwani suggest for the ECFS-C are not consistent with the general elevation of the Piedmont and Coastal Plain and long term rates of uplift inferred from older Pliocene and early Quaternary terrace surfaces. Assuming that the uplift rates suggested for the region between the Cape Fear River and South River are correct, older surfaces such as the Bear Bluff (approximately 2.75 Ma) and Waccamaw (1.25 Ma to 1.65-1.75 Ma) (Reference 2.5.1-266; Reference RAI 02.05.01-10 08) should exhibit significant vertical displacement across the ECFS-C. Along the Cape Fear River the inferred rates of 0.14 to 1.8 mm/yr over the past 1.25 Ma to 730 ka, which Marple and Talwani postulate to be the age of the inception of the faulting along the ECFS-C, would suggest localized vertical offset of 102 -1314 m (335-4310 ft.) across these surfaces. This is not observed in the topography of the interfluve region or in the general elevation of the projected Bear Bluff and Waccamaw surfaces above the modern channel upstream of the postulated ECFS-C. Topographic profiles on the Waccamaw terrace where it transects the ECFS-C suggest that there may be less than approximately 10 m (33 ft.) of cumulative vertical displacement across the postulated ECFS-C

The basis for concluding that the incision and warping all occurred during Holocene time in response to localized tectonic uplift is not provided by Marple and Talwani, and does not seem warranted based on review of the data. Stream profiles developed for the HAR FSAR based on topographic data from a LIDAR survey show no consistent vertical anomalies in the modern drainages where the postulated ECFS-C crosses the profiles (see Figures 2.5.1-219 and 2.5.1-220 and discussion in Subsection 2.5.1.1.4.2.5.6). A small apparent vertical down-to-the-southeast step may be present along the Cape Fear River channel, but is not observed in the Lumber River profile to the south. Aerial reconnaissance conducted for this study also did not reveal any obvious topographic expression (e.g., escarpments or lineaments) of the postulated ECFS across interfluve areas.

Marple and Talwani state that the uplift rate of ~0.64 mm/yr (~0.025 in/yr) along the Wando terrace (120 – 70 ka) measured downstream of the postulated ECFS-C is probably low because the location is downstream from the area of greatest incision (Reference 2.5.1-243). As noted above, this statement suggests that uplift is not localized at the ECFS-C as suggested by Marple and Talwani. Soller suggests that uplift along the Cape Fear River increases gradually from 32 km (20 mi.) downstream to 32 km (20 mi.) upstream from Elizabethtown (Reference 2.5.1-266).

The high vertical rates based on the assumed maximum rates of incision assigned to the postulated ECFS-C are not warranted. Assuming that the maximum incision observed upstream from this area (18 m [59 ft.]) is due to uplift on the postulated ECFS-C as defined by Marple and Talwani, a better estimate of the long-term slip rate across this structure if it exists would be to subtract the estimated uplift rate downstream (~0.06 mm/yr [~0.002 in/yr]) from the post-Wando incision rate (18 m [59 ft.] per 70 to 130 ka = 0.26 to 0.14 mm/yr [0.01 to 0.006 in/yr]) measured where the postulated ECFS-C is assumed to cross the Cape Fear River. This would suggest a maximum slip rate of 0.08 to 0.2 mm/yr (0.003 to 0.008 in/yr) for the postulated ECFS-C. Assuming that the inferred 'upward displaced fluvial surface' measurements are tectonic, lower slip rates are suggested by the 6.5 m (21.3 ft.) and 2 m (6.6 ft.) of warping of the 70 – 130 ka terrace across the South River (of 0.05 to 0.065 mm/yr [0.002 to 0.0026 in/yr]) and Little Pee Dee (i.e., 0.02 mm/yr [0.0008 in/yr]), respectively (Reference 2.5.1-243). Based on interpretation of topographic profiles constructed on the Waccamaw terrace as mapped by Owens (Reference 2.5.1-271) and Soller (Reference 2.5.1-266) and possible upstream terrace correlations, there may be no or less than 10 m (33 ft.) of possible vertical offset of this surface across the ECFS-C.

In conclusion, the evidence of incision and localized uplift along the ECFS-C are not consistent along strike, are not evidenced in the topography of the interfluve regions, and in the case of the 'upward displaced fluvial surfaces' may be related to non-tectonic fluvial responses to factors other than localized tectonic uplift on the postulated ECFS-C. The high rates of uplift, particularily those based on assumed Holocene ages, are not supported by other geologic data and therefore are judged not to be viable.

Cross Valley Change

Marple and Talwani (Reference 2.5.1-243) cite cross-valley changes in the morphology of the Lumber and Cape Fear River valleys across the ZRA-C as evidence for Quaternary tectonic tilting and folding. Specifically, Marple and Talwani suggest that the large, isolated, entrenched meander of the Cape Fear River within the Wando terrace was deflected 6 km (3.7 mi.) northeastward toward the Cape Fear arch axis in response to a gentle cross-valley tilt in contrast to the southward migration of the channel downstream of the postulated ZRA-C. The scroll pattern and interpreted northeastward tilt of terrain inside the meander are given as evidence that the meander formed by northeastward river migration along the ZRA-C during late Pleistocene (130-70 ka) before becoming deeply entrenched. Alternative non-tectonic explanations of the development of the meander loop and slip off terrace along the Cape Fear River are not considered by Marple and Talwani. There is no consideration, for example, of the fact that a large tributary intersects the Cape Fear River just upstream of the meander bend and that sediment influx from this tributary may have been a factor in the northward migration of the channel during deposition of the Wando terrace.

Marple and Talwani also cite an abrupt change from a relatively symmetric cross-valley shape upstream from the ZRA to a down-to-the-southwest cross-valley tilt as evidence for localized uplift and tilting along the ZRA-C (ECFS-C) (Reference 2.5.1-243). Soller (Reference 2.5.1-266), however, presents an alternative model in which the Cape Fear River terraces have been uplifted and preserved in response to (1) a persistently low rate of uplift from the north to northeast, transverse to the valley length that is largely responsible for the succession of unpaired terraces in the central part of the valley, and (2) uplift from the direction of the Piedmont (parallel to the valley length) that has been intermittently active and most recently tilted up to the northwest and down to the southeast, causing deep entrenchment of the Cape Fear arch into the Wando terrace and burial of terraces beneath the floodplain in the lower valley.

River Deflection, Change in Sinuosity and Anastomosing Stream Patterns

The interpretation of the inferred river anomalies as neotectonic features is questionable. Weems (Reference 2.5.1-273) does not identify anomalies in the river profiles that would coincide with the central segment of the zone of river anomalies that Marple and Talwani cite as evidence for the existence and activity of the postulated ECFS-C (Figure 2.5.1-213) (Reference 2.5.1-243). A recent unpublished compilation map by Dr. Weems showing possible neotectonic features in the Coastal Plain includes only the postulated ECFS-S as a possible neotectonic feature.

Many of the streams in the vicinity of the ECFS-C display river deflection, changes in sinuosity, and confluences of several streams coincident with the ECFS-C. Many of these changes in stream geomorphology are coincident with the transition from the Piedmont to the Coastal Plain provinces and may be due to nontectonic fluvial responses to steps in the underlying elevation of basement associated with terrace shoreline features or changes in lithology that may have influenced the location of such shorelines. Variations of channel characteristics can be attributed to downstream variations in discharge, sediment load, and the type of sediment moved through the channel or to local geology (Reference RAI 02.05.01-10 03) Marple and Talwani cite the abrupt change from an entrenched, V-shaped cross valley profile to a broad flood plain along the Neuse River as evidence for tectonic uplift across the ZRA-C. The Neuse River and a number of tributaries coalesce at the postulated ECFS-C. The Coats scarp, which wraps around the southern margin of the Rolesville batholith, also is roughly coincident with the ECFS-C where it intersects the Neuse River, Buffalo Creek, and Little River (Revised Figure 2.5.1-219). The confluence of several streams near the ECFS-C along the Neuse River is coincident with a change from Paleozoic metamorphic rocks to Cretaceous Coastal Plain deposits and may reflect a lithology change rather than tectonism. No changes in stream gradient or vertical steps in the present stream channel are seen along this part of the Neuse River.

Marple and Talwani (Reference 2.5.1-243) report changes in sinuosity that they associate with the ECFS-C only along the Lumber and Cape Fear Rivers. As noted above, the intersection of tributaries just upstream of the ZRA-C as mapped along both of these rivers may be responsible for variations in discharge and sediment influx that could influence the downstream channel morphology. A change in sinuosity on the South River near the ECFS also is coincident with a tributary joining the River from the northwest, and may be due to fluvial response to changes in sediment load and stream flow.

Changes in the stream pattern from anastomosing to meandering are cited as evidence of differential uplift along the ZRA-S, but are not noted along the ZRA-C.

Marple and Talwani conclude that the abrupt southwestward deflection of the Neuse River just upstream of the ZRA-C toward the Cape Fear arch axis was produced not by channel migration, but instead may have been offset by right-lateral strike-slip faulting. Although it cannot be precluded that the channel is coincident with a Paleozoic fold or minor fault, a diabase dike interpreted from magnetic anomalies and Paleozoic boundaries marking differing grades of metamorphishm at the margin of the Roseville batholith extends across the river deflection without significant right-lateral offset (RAI 02.05.01-10 Figure 16).

Lithospheric Flexure Models

Although the geomorphic features cited in support of the ECFS-C do not clearly demonstrate the presence of an active regional-scale, crustal fault that is localizing seismicity in the present tectonic regime, the evidence of uplift and tilting may be consistent with a tectonic mechanism, that of lithospheric flexure (i.e., long-wavelength bending or warping of the lithosphere). As suggested by Soller (Reference 2.5.1-266) the distribution of terraces along both the Cape Fear and Pee Dee Rivers may be the cumulative effect of several variables. For example, based on mapping and longitudinal profiles on terraces estimated to range in age from 2.75 to 0.1 Ma, Soller interprets that the locus and intensity of local tectonism in the vicinity of the Cape Fear River has varied with time. (Reference 2.5.1-266) Soller concludes that since at least 750 ka, the valley northwest of Elizabethtown near the Piedmont has been uplifted while subsidence is likely for the river's lower course (Reference 2.5.1-266). An inflection point southeast of Elizabethtown may mark the boundary between these two regimes and a simple tilting of the Coastal Plain along the valley length, up from the direction of the Piedmont, could account for changes in uplift rate measured along the river on terraces of differing ages. A small scale flexure, related to larger scale tectonism on the Cape Fear arch, can explain the pattern of uplift (Figure 2.5.1-218). Additionally, an apparent bulge in basement structure contours that is subparallel to and superimposed on the broad outline of the Cape Fear arch may represent a localized flexure that accounts for the uplift patterns (Revised Figure 2.5.1-218). (Reference 2.5.1-266) This feature does not coincide with or subparallel the postulated ECFS-C as interpreted by Marple and Talwani (Reference 2.5.1-243).

Geodynamic models, as described by Pazzaglia that simulate flexural deformation along the U.S. Atlantic margin in response to erosion in the Appalachian Mountains and sediment loading in the offshore regions, also could explain in part the possible broad zone of flexure or localized uplift described by Markewich, which Marple and Talwani link to the ECFS-C (Reference 2.5.1-267, Reference 2.5.1-265). Pazzaglia describes a similar broad, flexural warp, centered across the Fall Zone, between the upwarped central Appalachians and subsided Salisbury Embayment in the region to the north of the Norfolk arch (Reference 2.5.1-267). Smaller tectonic features, such as the small displacement Cretaceous and Cenozoic faults and possible seismicity, may coincide with this zone of flexture, which coincides with a more prominent, well-defined Fall Zone in the vicinity of the Susquahanna River (Reference 2.5.1-267). However, the complex interaction between the regional and flexural stress field and their relationship to pre-existing faults is poorly constrained (Reference 2.5.1-267).

Marple and Talwani (Reference 2.5.1-243) discount the possibility that isostatic uplift of the Appalachians to the west and sediment loading offshore is a viable cause because the ZRA-C's trend is oblique to the Appalachian trend, sediment loading offshore and in the outer Coastal Plain of the Carolinas is too widely distributed, and the hinge zone is approximately 200-250 km east of the area. The first of these objections presupposes that the observations that define the ZRA-C as a unique and well-constrained feature as mapped are valid. As noted in the previous discussions, this is not the case. Unloading of the crust from erosion in the Appalachians and deposition of the sediment in depocenters adjacent to the Cape Fear arch likely does result in broad regional flexure that influences major drainages such as the Cape Fear River. Marple and Talwani acknowledge that migration of the river to the southwest is still occurring in the lower reaches of the Cape Fear River in response to such regional flexure. They do not, however, acknowledge a more complex pattern that would factor in higher uplift upstream towards the Piedmont as suggested by Soller (Reference 2.5.1-266).

<u>East Coast Fault System-Northern (ECFS-N) Segment</u>

The following discussion of evidence cited in support of the ECFS-N segment is summarized from the Dominion North Anna FSAR and supporting documentation (References RAI 02.05.01-10 06 and RAI 02.05.01-10 07).

Geological Data

It was noted in the Dominion North Anna assessment that most of the data used by Marple and Talwani (Reference 2.5.1-243) to support their interpretation of the ECFS apply exclusively to the southern and central segment of the fault (ZRA-S and ZRA-C). The actual number and quality of the data used to infer the presence of the northern segment of the fault system (ZRA-N) is significantly less than that for the ZRA-S and ZRA-C segments The only geologic evidence cited by Marple and Talwani in support of the ECFS-N is its coincidence with the westward termination of the axis of the Norfolk Arch axis, which was originally depicted by Pazzaglia (Reference 2.5.1-267). The westward termination of the Norfolk arch axis, however, was modified by Marple and Talwani to end approximately 25 km (15 mi.) east of the ECFS-N with no additional references, interpretations or data to justify the modification of the location. Dominion concludes that "the location of the Norfolk arch axis, as presented by Marple and Talwani (Reference 2.5.1-243), does not provide independent geologic evidence in support of the ECFS-N, and therefore there is no known geologic evidence to support the existence of ECFS-N" (Reference 2.5.1-272 and Reference RAI 02.05.01-10 05).

Geophysical and Seismological Data

Geophysical data presented by Marple and Talwani (Reference 2.5.1-243) is an east-west trending seismic reflection profile along Interstate 64 in central Virginia that was originally presented by Pratt et al. (Reference 2.5.1-323). Pratt et al. interpret an east-dipping shear zone approximately 30 km (19 mi.) beneath the inferred location of the ECFS-N, but do not interpret a steeply dipping crustal shear zone in the vicinity of the ECFS-N. The seismic data, therefore, do not support the interpretation by Marple and Talwani. The Dominion application further states that the I-64 seismic reflection profile is the only geophysical or seismological data presented by Marple and Talwani (Reference 2.5.1-243) and that Marple and Talwani (Reference 2.5.1-243) do not associate any seismicity with the ZRA-N.

Geomorphic Data

The geomorphic data used by Marple and Talwani to postulate the ECFS-N are inferred river anomalies, including channel incision, upward displaced fluvial surfaces, cross-valley change, sinuosity change, anastomosing stream pattern and stream deflections. Dominion examined each of the river anomaly categories with reference to the ECFS-N to weigh evidence for its existence and concluded that there was no evidence of a fault and that there is direct stratigraphic evidence against the types of deformation postulated by Marple and Talwani (Reference 2.5.1-243).

The key observations and conclusions from the Dominion assessment are summarized as follows:

- No consistent co-occurrence of two or more anomalies along each of the drainages was observed, as may be expected if they have developed in response to uplift of the ZRA-N.
- There is no consistent pattern of anomalies along the trend of the ZRA-N, as expected if the structure was active along its entire length.
- It was not possible to verify or duplicate geomorphic observations, such as channel incision.
- The "upward displaced fluvial surfaces" are inferred only from qualitative analysis of convexities of river profiles, and therefore, this type of "anomaly" does not provide evidence for tectonic uplift and is inconsistent with other geomorphic observations. These features in most cases are more objectively characterized as convexities, or local increases in the gradient of the longitudinal profiles of floodplains due to the intersection of concave profiles at river confluences.
- Direct stratigraphic evidence for no Quaternary deformation was documented in the vicinity of a large meander of the Nottoway River that Marple and Talwani (Reference 2.5.1-243) interpreted to have formed in response to systematic folding and northeastward tiling.

- The fluvial geomorphic features cited by Marple and Talwani (Reference 2.5.1-243) are likely produced by non-tectonic fluvial processes, are not anomalous, and thus do not support their interpretation of the presence and activity of the ZRA-N (ECFS-N).

Summary of Assessment of the East Coast Fault System as a Capable Tectonic Source

There is supporting geological, geophysical, and seismological information to suggest that geomorphic anomalies identified along the southern half of the ECFS-S segment may be associated with Quaternary displacement on the Woodstock fault and that this fault may be the source of the Charleston earthquake (Reference RAI 02.05.01-16-03).

There is no similar evidence to suggest that the northern part of the ECFS-S, ECFS-C and ECFS-N segments are capable tectonic structures as defined by RG 1.208.

The observations and lines of evidence presented by Marple and Talwani (Reference 2.5.1-243) do not provide convincing arguments in support of a buried north-northeast-trending strike-slip fault (the postulated ECFS-C) through the North Carolina Coastal Plain region. Evidence of neotectonic deformation (i.e., differential uplift of the Piedmont relative to the Coastal Plain regions, regional tilting, and broad zones of tilting or flexure) can be explained by lithospheric flexure (i.e., long-wavelength bending or warping of the lithosphere) related to regional patterns of erosion and Cenozoic deposition. Localized Cenozoic faulting observed near the Piedmont-Coastal Plain boundary may be related to stresses in the region of greatest flexure (Reference 2.5.1-267). The possibility that some local structures along the general trend of the East Coast fault system may be present and may be favorably oriented for reactivation in the present tectonic setting cannot be precluded given the available data. There is no geological data, however, to demonstrate Quaternary surface faulting. There is no associated seismicity or reported evidence of paleoliquefaction to indicate activity along the ECFS-C segment. The implication that the postulated central and northern segments of the ECFS if they exist may produce earthquakes of a similar size to the 1886 Charleston earthquake as inferred by Marple and Talwani (Reference 2.5.1-243) is not demonstrated. Therefore, the ECFS-C and ECFS-N segments are included in the updated PSHA for the HAR site with low probability of existence (weight of 0.1) and activity given the fault exists (weight 0.1)."

Table 2.5.1-202
Postulated Geomorphic Anomalies for the ZRA-C Cited as Evidence for the Postulated ECFS-C

River	Age of Fluvial Surface[a]	Amount of Channel Incision[b]	Upward Displaced Fluvial Surface[c]	Cross-Valley Change[d]	Sinuosity Change[e]	Anastomosing Stream Pattern (u = upstream; d = downstream)	River Deflection[f]
Little Pee Dee	Holocene 130-70 ka	No	3 m	No	No	No	None
Lumber:	Holocene						
floodplain	130-70 ka	3 m	2 m	T1	S1	No	C-NNE
terrace	240-200 ka	—	—	T1	—	—	C-NNE
Cape Fear	130-70 ka	18 m	7 m[g]	T1, T2	S1	No	SW C-NNE[h]
South	130-70 ka	No	8 m	No	No	No	SW

River	Age of Fluvial Surface[a]	Amount of Channel Incision[b]	Upward Displaced Fluvial Surface[c]	Cross-Valley Change[d]	Sinuosity Change[e]	Anastomosing Stream Pattern (u = upstream; d = downstream)	River Deflection[f]
Neuse	Unknown	35 – 40 m	—	T3	—	No	SW
Turkey Creek	Unknown	No	—	No	—	No	SW

Notes:

a) Ages of fluvial surfaces taken from (1) Colquhoun et al. (1987) (Reference RAI 02.05.01-10 07).(2) Owens (1989) (Reference 2.5.1-271), (3) Marple and Talwani (2000) (Reference 2.5.1-243).

b) Incision along the Little Pee Dee and Cape Fear rivers was measured relative to the Wando terrace.

c) Amount of upward displacement along Little Pee Dee and Cape Fear rivers was measured relative to Wando terrace.

d) T1: Down-to-the-north-northeast cross-valley tilt along zone; T2: abrupt change from a relatively symmetric cross-valley shape upstream from ZRA to a down-to-the-southwest cross-valley tilt downstream; T3: abrupt change from a V-shaped valley upstream from ZRA to a broad valley downstream with a wide floodplain.

e) S1: Decreased sinuosity along ZRA followed by a sinuosity increase downstream.

f) River deflection types: SW: deflection to the southwest; C-NNE: curves in river valleys that are convex to the north-northeast.

g) Derived for Wando terrace ~7 km downstream from ZRA-C.

h) The large north-northeast-convex mender along Cape Fear River is superimposed on the river's southwest deflection.

— = parameter not measured.

ZRA = zone of river anomalies.

Source: modified from Reference 2.5.1-243, Table 1

References:

Reference RAI 02.05.01-10 01

Petersen, M. D., A.D. Frankel, S. C. Harmsen, C. S. Mueller, K.M. Haller, R. L. Wheeler, R.L. Wesson, Y. Zeng, O.S. Boyd, D.M. Perkins, N. Luco, E.H.Field, C.J.Wills, and K. S. Rukstales, 2008, "Documentation for the 2008 Update of the United States National Seismic Hazard Maps," U. S. Geological Survey Open-File Report 2008-1128, 127 pp.

Reference RAI 02.05.01-10 02

McCalpin, J.P., 1996, Paleoseismology, Elsevier Publishers, 588 pp.

Reference RAI 02.05.01-10 03

Schumm, S.A., J.F. Dumont, and J.M. Holbrook, 2008 "Active Tectonics and Alluvial Rivers," 2000, 275 pp.

Reference RAI 02.05.01-10 04

William States Lee III Nuclear Station Final Safety Analysis Report, 2008.

Reference RAI 02.05.01-10 05

US NRC, Safety Evaluation Report for an Early Site Permit (ESP) at the North Anna ESP Site, NUREG-1835, 2006, 108 pp.

Reference RAI 02.05.01-10 06

Dominion Nuclear North Anna, LLC, North Anna Early Site Permit Application Response to Request for Additional Information No.3, 2004, 114 pp.

Reference RAI 02.05.01-10 07

Colquhoun, D. J., Fridell, M. S.,Wheeler, W. H., Daniels, R. B., Gregory, J. P., Miller, R. A., and Van Nostrand, A. K., 1987, Quaternary geologic map of the Savannah 4° ´ 6° quadrangle, United States, *in* Richmond, G. M., Fullerton, D. S., and Weide, D. L., eds., U.S. Geological Survey Miscellaneous Investigations Map I-1420 (NI-17), scale 1:100 000,1 sheet.

Reference RAI 02.05.01-10 08

McCartan, L., 1990, Studies related to the Charleston, South Carolina, earthquake of 1886—Neogene and Quaternary lithostratigraphy and biostratigraphy: Introduction, *in* Studies related to the Charleston, South Carolina, earthquake of 1886—Neogene and Quaternary lithostratigraphy and biostratigraphy: U.S. Geological Survey Professional Paper 1367, p. 1–5.

Attachments/Enclosures:

Attachment 02.05.01-01B:	Revised Figure 2.5.1-213
Attachment 02.05.01-10A:	RAI 02.05.01-10 Figure 1
Attachment 02.05.01-10B:	RAI 02.05.01-10 Figure 2
Attachment 02.05.01-10C:	RAI 02.05.01-10 Figure 3
Attachment 02.05.01-14A:	Revised Figure 2.5.1-219
Attachment 02.05.01-11C:	Revised Figure 2.5.1-220 (Sheets 1 through 4)
Attachment 02.05.01-10D:	RAI 02.05.01-10 Figure 4
Attachment 02.05.01-10E:	RAI 02.05.01-10 Figure 5 (Sheets 1 and 2)
Attachment 02.05.01-10F:	RAI 02.05.01-10 Figure 6
Attachment 02.05.01-10G:	RAI 02.05.01-10 Figure 7
Attachment 02.05.01-10H:	RAI 02.05.01-10 Figure 8
Attachment 02.05.01-10I:	RAI 02.05.01-10 Figure 9
Attachment 02.05.01-10J:	RAI 02.05.01-10 Figure 10
Attachment 02.05.01-10K:	RAI 02.05.01-10 Figure 11
Attachment 02.05.01-10L:	RAI 02.05.01-10 Figure 12
Attachment 02.05.01-10M:	RAI 02.05.01-10 Figure 13
Attachment 02.05.01-10N:	RAI 02.05.01-10 Figure 14
Attachment 02.05.01-09E:	RAI 02.05.01-09 Figure 3
Attachment 02.05.01-10O:	RAI 02.05.01-10 Figure 15
Attachment 02.05.01-10P:	Revised Figure 2.5.1-238
Attachment 02.05.01-21B1:	Revised Figure 2.5.1-237
Attachment 02.05.01-10Q:	RAI 02.05.01-10 Figure 16 (Sheets 1 and 2)
Attachment 02.05.01-08C:	RAI 02.05.01-08 Figure 1
Attachment 02.05.01-10R:	Revised Figure 2.5.1-218

NRC Letter No.: HAR-RAI-LTR-030

NRC Letter Date: October 14, 2008

NRC Review of Final Safety Analysis Report

NRC RAI #: 02.05.01-11

Text of NRC RAI:

The FSAR sections 2.5.1.1.4.2.5.5 and 2.5.1.1.4.2.5.6 discuss stream profiles derived from recent LiDAR data to makes various arguments in the case of the ECFZ and the Falls Lines (FSAR Figure 2.5.1-220). The FSAR states that the LiDAR data show "no consistent vertical anomalies in the modern drainage." However, the scale of the profiles in Figure 2.5.1-220 is too small to show any anomalies that might be there. The graph does not provide a high enough resolution to support the discussion of neotectonic expression along portions of stream profiles. Neotectonic uplift is not going to be on the scale of 10s of meters. Please provide a comparison of stream profiles used by Marple and Talwani with the newly created stream profiles from the LiDAR data at the same scales. Please explain in more detail how points used to construct the profiles were measured from the imagery.

PGN RAI ID #: H-0148

PGN Response to NRC RAI:

The original stream profiles shown on FSAR Figure 2.5.1-220 were created from the statewide North Carolina LIDAR data with a grid spacing of 46 m (150 ft.). New stream profiles that are developed from county-scale LIDAR data with a grid spacing of 6 m (20 ft.) and the National Hydrography Dataset (Reference RAI 02.05.01-11 01) for the locations of the streams, will be included in a future revision. The new profiles are shown on RAI 02.05.01-11 Figure 1 at the same scale as longitudinal stream profiles of Marple and Talwani (Reference 2.5.1-243) that are shown on RAI 02.05.01-11 Figure 2. The stream profiles created from the higher resolution LIDAR data are shown at a greater vertical exaggeration than the previous figures shown on FSAR Figure 2.5.1-220 to provide greater resolution to identify potential neotectonic features.

The new stream profiles were created using the following methods:

1) LIDAR data with a 6m- (20-ft.) grid spacing was downloaded from the North Carolina Department of Transportation website (Reference 2.5.1-269; http://www.ncdot.org/it/gis/DataDistribution/ContourElevationData/default.html).
2) Stream lines were downloaded from the USGS National Hydrography Dataset website (Reference RAI 02.05.01-11 01; http://nhd.usgs.gov/data.html).
3) Stream profile locations were selected to cross features of interest in and near the site vicinity. Profile lines were then converted into 3D lines using the ArcGIS 3D Analyst extension.
4) Profiles were created using ArcGIS 3D Analyst "Create Profile Graph" tool.
5) Graph data was then exported as a numerical table into Microsoft Excel.
6) It was observed that LIDAR profiles had artificial spikes due to: inaccuracies in the location of the thalweg as shown in the stream data set as compared to the LIDAR data;

noise in the vertical accuracy of the LIDAR data; or features such as bridges, roads, and dams.

7) Two levels of filtering were applied to the profiles using Excel to minimize these artificial spikes. The filtering process involved:
   a) Lowering the sampling spacing for each profile to 116 m ±6 m (380 ft ± 20 ft.)
   b) Comparing the elevation at each profile sampling point to the neighboring upstream sampling point to see if the elevation of the downstream point was lower. This was done using the formula: if (ZCP > ZUSP, ZCP = ZUSP else ZCP), where ZCP is elevation at current point, ZUSP is the elevation at neighboring up stream sampling point.
   c) Repeating the above formula on all points 5 to 15 times based on the level of noise
8) The graphic profiles were created in Microsoft Excel.
9) The graphics were then imported into Adobe Illustrator for further annotation.
10) Locations where lineaments, faults and dams cross the profile lines was measured in ArcGIS and inserted into the figures in Adobe Illustrator.

Associated HAR COL Application Revisions:

The following changes will be made to HAR FSAR Chapter 2 in a future revision:

Revise Figure 2.5.1-220 (attached).

References

Reference RAI 02.05.01-11 01

US Geological Survey National Hydrography Dataset web site, http://nhd.usgs.gov/data.html, accessed 12/03/2008.

Attachments/Enclosures:

Attachment 02.05.01-11A1:	RAI 02.05.01-11A1 Figure 1 (Sheet 1 of 6)
Attachment 02.05.01-11A2:	RAI 02.05.01-11A2 Figure 1 (Sheet 2 of 6)
Attachment 02.05.01-11A3:	RAI 02.05.01-11A3 Figure 1 (Sheet 3 of 6)
Attachment 02.05.01-11A4:	RAI 02.05.01-11A4 Figure 1 (Sheet 4 of 6)
Attachment 02.05.01-11A5:	RAI 02.05.01-11A5 Figure 1 (Sheet 5 of 6)
Attachment 02.05.01-11A6:	RAI 02.05.01-11A6 Figure 1 (Sheet 6 of 6)
Attachment 02.05.01-11B:	RAI 02.05.01-11 Figure 2
Attachment 02.05.01-11C1:	Figure 2.5.1-220 (Sheet 1 of 4) (Revised)
Attachment 02.05.01-11C2:	Figure 2.5.1-220 (Sheet 2 of 4) (Revised)
Attachment 02.05.01-11C3:	Figure 2.5.1-220 (Sheet 3 of 4) (Revised)
Attachment 02.05.01-11C4:	Figure 2.5.1-220 (Sheet 4 of 4) (Revised)

NRC Letter No.: HAR-RAI-LTR-030

NRC Letter Date: October 14, 2008

NRC Review of Final Safety Analysis Report

NRC RAI #: 02.05.01-12

Text of NRC RAI:

FSAR section 2.5.1.1.4.2.5.6 provides an extensive discussion of the Fall lines of Weems (1998). The FSAR cites a conclusion made in the North Anna ESP that the seven fall lines do not represent a capable tectonic source.

a) The FSAR (p 2.5-45) states that a comparison was made of the Falls Lines (Weems, 1998) with recent geologic mapping. There is no description of this mapping in the text and no reference is provided. Please provide the references and summarize the results.

b) Figure 2.5.1-220 provides the longitudinal stream profiles. The figure has omissions: H & J profiles are not mark with DFL; M profile is obscured at the point of interest by a graphics element; B profile needs to zoom in on the point of interest. Since this information is essential to follow the text please provide clarification or revision.

c) In the text (p 2.5-45), in the discussion of the DFL, a zone of mapped faults is cited as a reason for the fall line to correlate through a section close to SHNPP. The faults are shown on Figure 2.5.1-219. However, reference to the original documentation for the faults is not provided in the text. The references provided on the figure are not listed in the reference section and so are incomplete. Are these faults Mesozoic faults? What do the river terraces in this area look like with the idea of neotectonism in mind.

PGN RAI ID #: H-0149

PGN Response to NRC RAI:

a) The fall lines of Weems (Reference 2.5.1-273) were compared to the 1985 Geologic Map of North Carolina (Reference 2.5.1-208) and to faults and folds from the unpublished Raleigh 100k quadrangle (Reference 2.5.1-275) as shown in Attachment 02.05.01-14A (Revised Figure 2.5.1-219). The text will be revised in a future revision to refer to this map and to clarify relationships of the fall lines to geologic mapping.

b) Profiles shown on a revised Figure 2.5.1-220 in a future revision will be based on higher resolution data (6 m versus 46 m [20 ft. versus 150 ft.]) and will be presented at a profile scale comparable to that shown in Figure 11 of Marple and Talwani (RAI 02.05.01-11 Figure 1, see Attachments 02.05.01-11A1 through A6) (Reference 2.5.1-243). The DFL is not shown on Profiles H and J because these profiles do not cross the DFL. The graphics will be revised on profiles M and B so that all elements of the profile are visible.

c) The text will be revised in a future revision to include a description of the Mesozoic faults that cross the DFL near the site area (see updated FSAR Section 2.5.1.2.4.1.1, Response to RAI 02.05.01-20).

   As shown by Weems (Reference 2.5.1-273) the DFL, which coincides with the western margin of the Durham basin north of the Cape Fear River, cut across the northern end and eastern boundary of the Sanford basin (RAI 02.05.01-12 Figure 1). In an updated map, Weems (Reference RAI 02.05.01-12 01) revised the location of the southern part of the DFL to follow the western boundary of the Sanford basin, which is bordered by a series of Mesozoic faults (RAI 02.05.01-12 Figure 2 and revised Figure 2.5.1-219). In contrast, faults along the western boundary of the Durham basin, intersect the basin boundary at more oblique angles (Revised Figure 2.5.1-219). Along the Haw River, the DFL coincides with one of these structures, an approximately N70E- trending fault that extends into the basin as an intrabasinal fault. This fault, which intersects the Bonsal-Morrisville fault, was shown on the 1985 geologic map and is retained on more recent, more detailed unpublished mapping by the NCGS (Reference 2.5.3-208). Although more recent studies could not identify the fault in the field it was retained in more recent mapping because high-angle bedding measurements, "different"-looking strata than the rest of the basin (possibly Lithofacies Association I), and abundant fractures were seen in the area of the mapped fault. Additionally, seismic reflection studies by Bain and Harvey (Reference RAI 02.05.01-12 02) indicated anomalous seismic reflectors in that area. No evidence of post-Triassic movement on this structure is reported in the literature or has been documented by recent mapping by the NCGS. The fault is interpreted to have formed in the same tectonic stress field as the other better studied Mesozoic rift faults in the site area (e.g., the Jonesboro fault, the Harris fault, and the faults in the LLRW and borrow pit study areas). Based on the absence of evidence for post-Triassic deformation and the structural association with noncapable faults, this fault is judged not to be a capable tectonic source.

Approximately 5 km south of this fault, the DFL crosses two approximately N70E- trending Mesozoic faults that locally bound the western margin of the Deep River basin and juxtapose Paleozoic metamorphic rocks to the west against Triassic sediments to the east (Revised Figure 2.5.1-219). The northernmost of these faults is located just upstream of the Jordan dam, which impounds another major tributary of the Cape Fear River. The southernmost of these faults parallels the Deep River.

Like most river systems in the Piedmont, the Haw, Rough Creek, and Deep rivers are characterized by bedrock, rather than alluvial channels. Detailed mapping of these channel systems, which lie beyond the site area, was not conducted for this study. Terraces if present likely would be bedrock strath surfaces or veneered with a thin mantle of patchy alluvium or more likely colluvium. Such surfaces are difficult to map and correlate, making assessments of neotectonic surface deformation based on their distribution and downstream continuity and slope highly uncertain.

Associated HAR COL Application Revisions:

The following changes will be made to HAR FSAR Chapter 2 in a future amendment:

Revise FSAR Section 2.5.1.1.4.2.5.6 from:

"2.5.1.1.4.2.5.6 Fall Lines of Weems (Class C)

Weems examined longitudinal profiles of large drainages that generally flow northwest to southeast across the Piedmont and Blue Ridge provinces in North Carolina, Virginia, and southeastern Tennessee. Weems identified and named seven fall lines, or short stream segments, that have anomalously steep gradients and typically contain rapids or waterfalls. The fall lines generally trend northeastward, parallel to the regional structural grain, and merge together toward the northeast. Warping of the late Pliocene fluvial terraces associated with the fall zones suggests probable formation within the past 2 m.y. Although evidence is minimal, Weems proposes that the available evidence favors neotectonic control of the fall lines, perhaps by intermittent faulting (Figure 2.5.1-216). The Durham and Nutbush fall lines are located within the site vicinity and are defined based on steps in topography and changes in gradient along stream profiles (Figure 2.5.1-219). (Reference 2.5.1-273)

Based on more detailed evaluation of the fall lines that was conducted as part of the North Anna Early Site Permit Application, Dominion presented observations and analyses to support the conclusion that the seven fall lines defined by Weems do not represent a capable tectonic source (Reference 2.5.1-274). The observations and conclusions include the following:

- The features are not defined by formal, consistently applied criteria, and thus are not as well defined and laterally continuous as depicted.
- In some cases, various features were electively correlated to form a laterally continuous fall line, while in other cases similar features were not correlated.
- Differential erosion due to variable bedrock hardness is a more viable and plausible explanation than Quaternary tectonism.
- There is no complementary geomorphic expression of tectonism, such as tectonic escarpments, along the trend of the fall lines between drainages, where it would be expected that such features would be better preserved.

Based on these arguments and detailed geomorphic analyses of the two fall lines within the North Anna ESP site vicinity (the Tidewater and Central Piedmont fall lines), NRC staff concurred with Dominion's interpretation that differential erosion is a more plausible explanation, as detailed in NUREG-1835. Additionally, Wheeler states that the identification of the fall zones is subjective and the criteria for recognizing them are not stated clearly enough to make the results reproducible (Reference 2.5.1-259). Accordingly, it was concluded that tectonic faulting is not demonstrated, and fall lines are assigned to Class C (Reference 2.5.1-259).

Comparison of the fall lines with recent geologic mapping, and more detailed topographic data based on LIDAR, suggests that although in places the fall lines coincide with or cross tectonic features, these features are not as well defined or continuous as suggested by Weems (Figures 2.5.1-219 and 2.5.1-220) (Reference 2.5.1-208, Reference 2.5.1-275, Reference 2.5.1-269, Reference 2.5.1-273). Thirteen stream profiles (Lower Little River, Crane Creek, Upper Little River, Rocky River, Haw and Cape Fear rivers, Mill Creek, Neuse River, Swift Creek and Neuse River, Buffalo Creek, Little River, Mocassin/Contentrea Creek, Tar River, and Toisnot Swamp) were created based on stream locations from the North Carolina Center for Geographic Information and Analysis (NCCGIA) and LIDAR data to evaluate stream changes across the fall lines and other faults present within the area (Reference 2.5.1-276, Reference 2.5.1-269). Northeast of the Cape Fear and Haw rivers, the Durham Fall Line (DFL) coincides with the western margin of the Triassic basin (Figure 2.5.1-219). The most pronounced step in the Durham fall line is where it crosses the western margin of the Deep River basin at the Haw River, which also correlates with a zone of mapped faults (Figure 2.5.1-219) and with lithologic changes across the western basin margin, going from harder igneous and metamorphic rocks to softer Triassic sediments. Weems now shows the DFL following the western border of the Triassic basin in the site vicinity, rather than cutting across the basin at the south end of Jordan Lake (Figure 2.5.1-219). Weems shows sharp changes in stream gradient along the DFL at the Tar, Neuse, and Cape Fear rivers (Reference 2.5.1-273). Based on stream profiles derived from LIDAR data, near its northern end where it crosses the Neuse and Tar rivers, the DFL is marked by changes in stream gradient; near the southern end of the DFL where it crosses the Little River and Crane Creek, it is much less defined and is marked by negligible changes in stream gradient (Figure 2.5.1-220). The Nutbush Fall Line (NFL) is located approximately 11.3 km (7 mi.) east of the Jonesboro fault and coincides with a Paleozoic mylonite shear zone (Figure 2.5.1-219). A reverse fault in terrace gravels interpreted to be Pliocene-Pleistocene in age was observed by Parker along the general trend of this shear zone, but is no longer visible due to grading and vegetative cover (Reference 2.5.1-228). Weems shows the NFL marked by down-east topographic steps on the Dan, Tar, Neuse, Nottoway, and Cape Fear rivers; however, analysis of stream profiles based on recent LIDAR data for the Neuse, Cape Fear, and Upper Little rivers does not indicate such steps (Figure 2.5.1-220) (Reference 2.5.1-273).

Similar to observations presented above by the North Anna Early Site Permit Application, Dominion Nuclear North Anna, analysis of the two fall lines within the site vicinity suggests that where the fall lines do coincide with changes in stream gradient, the changes are more likely the result of differential erosion (Reference 2.5.1-274). Additionally, although the fall lines correspond with stream gradient changes in places, new topographic data indicate that in many cases there are no marked changes where the fall lines cross the streams, and changes in stream gradient of similar magnitude to the fall lines also exist where no fall lines are mapped (Figure 2.5.1-220)."

To read:

"2.5.1.1.4.2.5.2.3 Fall Lines of Weems

Weems (Reference 2.5.1-273) examined longitudinal profiles of large drainages that generally flow northwest to southeast across the Piedmont and Blue Ridge provinces in North Carolina, Virginia, and southeastern Tennessee. Weems identified and named seven fall lines, based on correlation of fall zones (short stream segments that have anomalously steep gradients and typically contain rapids or waterfalls) along adjacent streams and rivers. The fall lines generally trend northeastward, parallel to the regional structural grain, and merge together toward the northeast. Apparent warping of the late Pliocene fluvial terraces associated with the fall zones was cited by Weems to suggest probable formation within the past 2 m.y. Although evidence is minimal and other hypotheses for the origin of these features (i.e., variable erosion of rocks of varying hardness or response to late Cenozoic climatic and sea level fluctuations) were considered, Weems proposes that the available evidence favors neotectonic control of the fall lines, perhaps by intermittent faulting (Figure 2.5.1-216).

Based on more detailed evaluation of the fall lines that was conducted as part of the North Anna Early Site Permit Application, Dominion presented observations and analyses to support the conclusion that the seven fall lines defined by Weems do not represent a capable tectonic source (Reference 2.5.1-274; Reference RAI 02.05.01-12 03). The observations and conclusions include the following:

- The features are not defined by formal, consistently applied criteria, and thus are not as well defined and laterally continuous as depicted.
- In some cases, various features were electively correlated to form a laterally continuous fall line, while in other cases similar features were not correlated.
- Differential erosion due to variable bedrock hardness is a more viable and plausible explanation than Quaternary tectonism.

- There is no complementary geomorphic expression of tectonism, such as tectonic escarpments, along the trend of the fall lines between drainages, where it would be expected that such features would be better preserved.

Based on these arguments and detailed geomorphic analyses of the two fall lines within the North Anna ESP site vicinity (the Tidewater and Central Piedmont fall lines), NRC staff concurred with Dominion's interpretation that differential erosion is a more plausible explanation, as detailed in NUREG-1835. Additionally, Wheeler states that the identification of the fall zones is subjective and the criteria for recognizing them are not stated clearly enough to make the results reproducible (Reference 2.5.1-259). Accordingly, it was concluded that tectonic faulting is not demonstrated, and fall lines are assigned to Class C (Reference 2.5.1-259).

Fall Lines in the HAR Site Vicinity (40 km- [25 mi.-] radius)

Additional analysis of the fall lines within 80 km (50 mi.) of the HAR site was completed for this study. Longitudinal stream profiles derived from LIDAR data were compared with underlying geologic units as shown on the 1985 Geologic Map of North Carolina (Reference 2.5.1-208), with faults and folds mapped by the NCGS (Reference 2.5.1-275), and with zones of steeper gradients identified by Weems (Reference 2.5.1-273) (Figures 2.5.1-219 and 2.5.1-220). Sixteen stream profiles (Lower Little River [AA'], Crane Creek [BB'], Upper Little River [CC'], Rocky River [DD'], Haw and Cape Fear rivers[EE'], Mill Creek [FF'], Neuse River [GG'], Swift Creek and Neuse River [HH'], Buffalo Creek [II'], Little River [JJ'], Mocassin/Contentrea Creek [KK'}, Toisnot Swamp [LL'] , Tar River [MM'], Cape Fear [NN'], Lumbar [QQ'], and South River [PP'] were created using stream locations from the US Geological Survey National Hydrography Dataset and LIDAR data to evaluate stream channel morphology across the fall lines and other faults present within the area (Reference 2.5.1-276, Reference 2.5.1-269).

The Durham and Nutbush fall lines (designated DFL and NFL, respectively) are located within the HAR site vicinity and were defined by Weems based on steps in topography and changes in gradient along stream profiles (Reference 2.5.1-273) (RAI 02.05.01-12 Figures 1 and 3). Observations regarding these two proposed fall lines are summarized as follows.

- Although designated as a single line on the regional map, the width of the anomalies as shown on longitudinal profiles presented by Weems vary from less than 1.2 km (2 mi.) to 22 km (13.5 mi.) (RAI 02.05.01-12 Figure 3). The criteria used by Weems to define the location and width of fall zones does not appear to be consistently applied in the case of fall zones upstream and downstream of the Durham and Sanford basins. For example, in the case of the NFL anomaly along the Tar River, Weems shows the anomaly to include a double inflection with a lower gradient stretch across the intervening Durham basin. A similar situation, albeit wider zone, along the Cape Fear River shows a much narrower NFL that does not encompass the Triassic basin or the adjacent inflection upstream of the basin.
- Northeast of the Cape Fear and Haw rivers, the Durham Fall Line (DFL) coincides with the western margin of the Triassic basin (Figure 2.5.1-219). Weems originally showed the DFL diverging from the basin boundary to the south where it cut across the basin and eastern boundary of the Sanford basin (Reference 2.5.1-273). On a more recent unpublished map Weems (Reference 2.5.1- RAI 02.05.01-11 01) relocated the southern part of the DFL to follow the western border of the Sanford basin south of the Cape Fear River. (Figure 2.5.1-219). In the new interpretation a previously uncorrelated fall zone (labeled ifz on Profile 11, Figure RAI 02.05.01-12 Figure 3) likely represents the DFL. This highlights the difficulty in correlating fall

zones between different river systems, and suggests that correlations may not be unique.

- Weems (Reference 2.5.1-273) shows sharp changes in stream gradient along the DFL at the Tar, Neuse, and Cape Fear rivers. The anomaly mapped as the DFL along the Tar River on RAI 02.05.01-12 Figure 3 is a misinterpretation of the typically steep headwaters reach of a drainage as a fall zone. Similar steep upper reaches along Crane Creek (profile BB') and Rocky River (profile DD') on Figure 2.5.1-220 are roughly coincident with the DFL and CPFL, respectively, suggesting these features may not be anomalous features that would qualify as 'fall zones'. As noted in the Dominion North Anna assessment (Reference RAI 02.05.01-12 03) such steep upper river reaches are not anomalous because the gradients of all streams typically steepen dramatically in the upstream third of their profiles, especially with proximity to the headwaters. The upstream increase in gradient is a logarithmic function, and is characteristic of the typical concave longitudinal profile of a stream. The logarithmic increase in gradient with proximity to the headwaters is especially pronounced by the vertical exaggeration in Weems' profiles, contributing to the appearance of a fall zone. Weems (Reference 2.5.1-273) does not explain why these particular headwater reaches should be considered anomalous, and thus characterized as fall zones. In addition, Weems (Reference 2.5.1-273) does not explain why steep headwater reaches of the majority of other rivers in the study area are not considered fall zones.
- The most pronounced step occurs along the Haw and Cape Fear rivers where the DFL crosses the western margin of the Durham basin (RAI 02.05.01-11 Figure 1[Sheet 2 of 6]). Where the DFL crosses the Haw River, a major tributary of the Cape Fear river, it coincides with the dam at the southern end of Jordan Lake, making it difficult to evaluate the original stream morphology across the DFL (Profile EE', Figure 2.5.1-220),.This location generally correlates with a zone of Mesozoic basin-bounding faults (designated MF) that extend into the basin to the north as intrabasinal faults (Figure 2.5.1-219); these western basin margin faults juxtapose bedrock lithologies of differing strength and erosional resistance, going from harder igneous and metamorphic rocks upstream to softer Triassic sediments within the basin. The northernmost of these western basin margin faults is an approximately N70E-trending fault that extends into the basin and is referred to as an unnamed intrabasinal fault (See Subsection 2.5.1.2.4.1.1). Approximately 5 km (3 mi.) south of this unnamed fault, the DFL crosses two approximately N70E-trending Mesozoic faults that locally bound the western margin of the Deep River basin and juxtapose Paleozoic metamorphic rocks to the west against Triassic sediments to the east. The DFL fall zone anomaly as defined by Weems (Reference 2.5.1-273) is not a narrowly constrained feature that suggests reactivation of a single fault or fault zone. There is no reported evidence to suggest that faults along the western boundary of the Sanford basin have been reactivated or are capable tectonic sources.
- Detailed mapping of the Farrington 7.5-minute quadrangle (Reference RAI 02.05.01-12 04; RAI 02.05.01-12 Figure 4) along the western margin of the Durham basin provides additional information to evaluate the DFL. The DFL in this region cross cuts the strong northeast-trending structural fabric, the northeast-trending Bush Creek fault, and numerous northeast-trending lithologic boundaries within the Proterozoic to early Paleozoic Carolina lithotectonic belt. Differential uplift across the DFL is not expressed in the upland terrain adjacent to the river drainages along this

margin. These observations do not support a tectonic interpretation of a continuous DFL as a neotectonic structure that is localizing uplift across this boundary.

- Weems (Reference 2.5.1-273) notes that the DFL in eastern North Carolina like the CPFL in Virginia marks the eastern boundary of uplifted areas that were eroded to produce numerous inselbergs. The flatter upper reaches of the Rocky River (from its headwaters to approximately 40 km downstream, Profile DD') and the Haw River (from upstream of the CPFL to approximately 40 km downstream, Profile EE') have the appearance of older graded profiles that have been uplifted. The steeper, more concave downstream sections may represent the adjustment of the profile to lower base level related to eustatic fluctuations or sediment loading and isostatic adjustments in the Coastal Plain embayments. These observations are consistent with a model of more regional rock uplift of the Appalachian Piedmont due to erosion, isostatic adjustments, and eustatic fluctuations and development of long-wavelength flexural deformation in the general vicinity of the fall zone between the Piedmont and Coastal Plain regions (Reference 2.5.1-267).

- The Nutbush Fall Line (NFL), which is located approximately 11.3 km (7 mi.) east of the Jonesboro fault roughly coincides with a Paleozoic mylonite shear zone (the Nutbush fault zone) along much of its mapped length (Figure 2.5.1-219). Weems (Reference 2.5.1-273) notes this strong correlation and states that this represents the most consistent geographic correlation between a fall line and a known tectonic structure. There are anomalies in the stream profiles that coincide with the Nutbush Creek fault zone at some locations (e.g., Profiles EE', GG', Figure 2.5.1-220). However, as shown on the Tar River stream profile (Profile MM', Figure 2.5.1-220), there is not an anomaly coincident with the mapped Nutbush Creek fault at this location. The toe of the anomaly upstream of the fault identified on the Weems stream profile (Profile 9, RAI 02.05.01-12 Figure 3) appears to correlate to a lithologic boundary. The stream profile across the buried Nutbush Creek fault zone also does not show an anomaly at or upstream of the NFL (Profile CC', Figure 2.5.1-220).Thus, there does not appear to be a consistent step coincident with the mapped fault trace.

- Where the NFL crosses Swift Creek, a major tributary to Neuse River, it coincides with the Paleozoic Nutbush Creek fault zone, which juxtaposes felsic mica gneiss (CZfg) against injected gneiss (CZig). The reach of the drainage upstream of this intersection subparallels an east-west-trending Mesozoic fault. Further downstream, where the channel crosses another east-west-trending Mesozoic fault, the Swift Creek fault, there is a small step in the stream profile (Profile GG', Figure 2.5.1-220). Both of these steps in the stream profile coincide with lithologic boundaries and may be due to differences in the hardness of and erosional resistance of different units. No evidence of Quaternary reactivation of either the Nutbush Creek or Swift Creek faults have been reported or documented from recent geologic mapping investigations and both faults are judged to be not capable tectonic sources (see Subsections 2.5.1.1.4.4.2 and 2.5.1.2.4.1.2).

- To the south where the NFL crosses the Fuquay-Varina quadrangle (Reference RAI 02.05.01-11 05), the mapped NFL coincides with the Leesville fault zone (along the projected trend of the Nutbush Creek fault zone) in the northern part of the quadrangle, but diverges from it in the southern part of the quadrangle. There are no aligned scarps or topographic expression of faulting in Coastal Plain sediments in the interfluve areas along the NFL or the Leesville fault zone as shown by unpublished mapping (Reference RAI 02.05.01-12 05; RAI 02.05.01-12 Figure 5)..

- There is evidence of post-Cretaceous faulting proximal to the NFL at the Parker locality (Nos. 49 and 150 , Figure 2.5.1-219) The relationship of this reverse fault, which is oriented N15°W to the northeast-trending Nutbush Creek fault is unknown. No geomorphic expression of the fault was observed during aerial reconnaissance. (see Subsection 2.5.1.2.4.3) Additionally, there are no anomalies or expression of faulting in a stream profile along Middle Creek, just south of the Parker locality (Profile QQ', Figure 2.5.1-220).

In summary analysis of the two fall lines (DFL and NFL) within the site vicinity suggests that where the fall lines do coincide with changes in stream gradient, the changes are more likely the result of fluvial stream adjustments related to differential erosion of bedrock varying in hardness. Additionally, although the fall lines locally correspond with changes in stream gradient, profiles derived using 6 m (20 ft.)-resolution topographic data from LIDAR indicate that in some cases there are no marked changes where the fall lines cross the streams, and changes in stream gradient of similar magnitude to the fall lines also exist where no fall lines are mapped (Figure 2.5.1-220).

The overall conclusion from this analysis is that although anomalies in the longitudinal stream profiles at the fall lines coincide locally with Mesozoic or Paleozoic tectonic features, the fall lines are not as well defined or continuous as suggested by Weems (Reference 2.5.1-273) and there is no clear indication of localized neotectonic deformation or reactivation of structures along the length of the fall lines in the site vicinity. These conclusions are consistent with the observations and results of the Dominion North Anna ESP analysis (Reference RAI 02.05.01-12 01 and Reference 2.5.1-274)."

<u>References</u>

Reference RAI 02.05.01-12 01

Weems, Email communication December 15, 2006

Reference RAI 02.05.01-12 02

Bain, G.L and B.W. Harvey, "Field Guide to the Geology of the Durham Triassic Basin," Carolina Geological Society Fortieth Anniversary Meeting, October 7-9, 1977

Reference RAI 02.05.01-12 03

Dominion Nuclear North Anna, LLC , July 8, 2004, Letter from Eugene S. Grecheck, Dominion Nuclear North Anna, LLC, to NRC, Subject: Dominion Nuclear North Anna, LLC North Anna Early Site Permit Application Response to Request for Additional Information No. 3. (Responses to 2.5.1-1, 2.5.1-2, 2.5.1-3, 2.5.1-4, 2.5.2-2, 2.5.2-3, 2.5.2-4, 2.5.3-1).

Reference RAI 02.05.01-12 04

Bradley, P.J, Gay, N.K., Bechtel, R, and Clark, T.W., Geologic Map of the Farrington 7.5-Minute Quadrangle, Chatham, Orange AND Durham Counties, North Carolina, North Carolina Geological Survey Open-File Report 2007-03, 2007.

Reference RAI 02.05.01-12 05

Blake, D.E, and Clark, T.W, Geologic Map of the Farrington 7.5-Minute Quadrangle, Chatham, Orange AND Durham Counties, North Carolina, North Carolina Geological Survey Unpublished Geologic Map drafted October 28, 2008.

Attachments/Enclosures:

Attachment 02.05.01-14A:	Revised Figure 2.5.1-219
Attachment 02.05.01-11C1-C4:	Revised Figure 2.5.1-220 (Sheets 1 through 4)
Attachment 02.05.01-12A:	RAI 02.05.01-12 Figure 1
Attachment 02.05.01-12B:	RAI 02.05.01-12 Figure 2
Attachment 02.05.01-12C:	RAI 02.05.01-12 Figure 3
Attachment 02.05.01-12D:	RAI 02.05.01-12 Figure 4
Attachment 02.05.01-12E:	RAI 02.05.01-12 Figure 5

NRC Letter No.: HAR-RAI-LTR-030

NRC Letter Date: October 14, 2008

NRC Review of Final Safety Analysis Report

NRC RAI #: 02.05.01-16

Text of NRC RAI:

FSAR Section 2.5.1.1.4.3 (p. 2.5-51) concludes:

"Based on our independent evaluation of the geomorphic, seismic reflection, and seismicity data, our confidence in the existence and activity of the ECFS is low to moderate. In our judgment, all of the geomorphic "anomalies" have credible nontectonic (i.e., fluvial geomorphic) explanations. Our three-dimensional (3-D) analysis of microseismicity in the vicinity of the ECFS does not clearly define a discrete structure (Figure 5) [Figure 2.5.1-225]. Available seismic reflection data do not unambiguously delineate a through-going structure in the vicinity of the ECFS."

a) This conclusion about the ECFS is not supported by the analysis provided in the text. More details about specifically what data was examined and how it supports or refutes previous investigator's conclusions needs to be provided. Specifically, more details on the analysis of the seismic reflection data and the 3-D analysis of microseismicity. Figure 2.5.2-225 does not present a 3-D analysis of microseismicity, it only provides the x, y 2-D expression of seismicity.

b) In the section for the Adams Run fault, (p 2.5-52) reference is made to a 3-D microseismicity analysis. Please explain the 3-D microseismcity analysis.

c) In the section for the Sawmill Branch Fault, (p 2.5-52) please define the 3 features that Talwani and Katuna used in their paper. Please explain the 3-D microseismcity analysis and how the applicant reached the conclusion that the Ashley river fault and the Sawmill Branch fault are the same fault. Please discuss the errors associated with earthquake locations in the Ashley River area and provide figures of cross-sectional views of the microseismicity in relation to the local faults.

d) In the discussion of the Helena Banks fault zone, (p 2.5-53) there is no explanation why Crone and Wheeler, 2000 classified the zone as C. Please clarify. Why did Wheeler 2005 eliminate the zone? It has been 6 years since the earthquake. No references are provided. Have any papers been published?

PGN RAI ID #: H-0153

PGN Response to NRC RAI:

a) This text is a direct quote from the Southern Nuclear Company (SNC) report summarizing the updated characterization of the Charleston seismic source (Reference 2.5.1-263). Additional descriptions of previous assessments of the East Coast fault system conducted as part of other ESP and COL applications (i.e., the SNC Vogtle ESP, the North Anna ESP) that were incorporated into the assessment of the ECFS for the HAR FSAR is provided in the response to RAI 02.05.01-10. More recent analyses of microseismicity in the Middleton Place-Summerville seismic zone (MPSSZ) (Reference RAI 02.05.01-16 01; Reference RAI

02.05.01-16 02; Reference RAI 02.05.01-16 03); and reprocessing of a seismic profile line near Summerville (Reference RAI 02.05.01-16 04) have been conducted subsequent to the SNC Charleston source update. The results of these studies provide improved data to evaluate subsurface structures and the shallow crust in the epicentral area of the 1886 Charleston earthquake. These data provide more definitive evidence to suggest that seismicity in MPSSZ is associated with different faults and different mechanisms. These data will be used to update text in FSAR Section 2.5.1.1.4.2.5.2.2 that describe possible fault sources in the meizoseismal region of the Charleston earthquake.

Talwani and Durá-Gómez (Reference RAI 02.05.01-16 03) observe that a portion (at least 30 km [10 mi.]) of the 'zone of river anomalies' (ZRA) (subsequently referred to as the ECFS) north of the Ashley River shows an excellent spatial correlation with the northern segment of the Woodstock fault, but that to the south, parts of the ZRA appear to have been eroded away by the streams in the swamp, leaving behind some scarps and isolated high grounds. There is no additional new subsurface or other information presented in this manuscript, however, to support the continuation of the Woodstock fault further to the north along the entire ECFS-S.

The statement in the Vogtle ESP report (Reference 2.5.1-263) that the available seismic reflection data do not unambiguously delineate a through-going structure in the vicinity of the ECFS-S was not meant to imply that potential faults are not recognized in Charleston-Summerville area seismic lines. Rather, connecting specific features observed in individual lines to define a potential through-going structure is not straight-forward (Ross Hartleb, William Lettis & Associates, Inc., personal communication, December 17, 2008 [Reference RAI 02.05.01-16 05]). As noted by Chapman and Beale (Reference RAI 02.05.01-16 04), the evidence for faulting near the intersection of the inferred Woodstock and Sawmill Branch faults that is well imaged in reprocessed line VT-3b is suggested by features on other lines, but only reprocessed line VT-3b has sufficient resolution to unequivocally image significant offset of reflectors. The existing reflection data thus do not constrain the strike of the faulting or permit correlation with specific structures described by Durá-Gómez and Talwani (Reference RAI 02.05.01-16 02).

The 3-D analysis of seismicity performed for the Vogtle ESP evaluation involved viewing the SEUSSN catalog into ArcGIS 3D Spatial Analyst and rotating it manually on the computer screen to view the seismicity cloud (and surrounding structures) in more detail. The basic conclusion from this effort was that there were no obvious planar trends in the data to suggest obvious fault sources. There is no written documentation available for this analysis. They did not perform any double-difference algorithms such as HypoDD or other methodology to relocate the earthquakes. (Reference RAI 02.05.01-16 06; Reference RAI 02.05.01-16 05). The more detailed analysis completed by Durá-Gómez and Talwani (Reference RAI 02.05.01-16 03), which employed the double-difference algorithm HypoDD (Reference RAI 02.05.01-16 06) and association of revised hypocentral locations with different faults based on the first motions recorded at different locations indicates that seismicity in the MPSSZ is associated with a major strike-slip fault system consisting of two en echelon segments (WF[N] and WF[S]) and with an antidialational compressional left step between the two segments at Middleton Place. Three short NW-SE trending faults (Sawmill Branch, Lincolnville and Charleston faults) lie within this left step, and together with WF (N) and WF (S) are the location of a localized stressed volume and the observed seismicity. Durá-Gómez and Talwani (Reference 02.05.01-16 02) infer that the mainshock of the 1886 Charleston earthquake was probably associated with the N30°E oriented, oblique right-lateral strike-slip Woodstock fault.

The overall results of the more recent studies support the preference given in the SNC Vogtle ESP updated Charleston seismic source model for Zone A (faults in the Charleston area) (weight of 0.7) as the location of the source of repeated large magnitude Charleston earthquakes.

b) This text regarding the 3-D microseismicity analysis is a direct quote from the SNC report of the characterization of the updated Charleston seismic source (Reference 2.5.1-264). Figure 2.5.1-225 is the only figure presented in SNC (Figure 5 of Reference 2.5.1-263) showing microseismicity in the area of the Adams Run fault; they do not provide a figure showing their 3-D analysis of microseismicity. As noted above, the 3-D analysis of seismicity performed for the SNC report involved loading earthquake data into ArcGIS 3D Spatial Analyst and rotating it manually on the computer screen to view the seismicity cloud (and surrounding structures) in more detail. They did not perform any double-difference or other methodology to relocate the earthquakes and did not prepare a calculation (Reference RAI 02.05.01-16 06).

Talwani and Durá-Gómez (Reference RAI 02.05.01-16 03) attribute seismicity in the Adams Run seismic zone to the Woodstock fault.

c) The three features discussed by Talwani and Katuna (Reference 2.5.1-290) are the Woodstock fault, Sawmill Branch fault, and the Ashley River fault (Figure 2.5.1-225 and RAI 02.05.01-16 Figure 1). The approximately N30°E trending (and southwest-dipping) Woodstock fault consists of two en echelon segments offset along the N30°W trending (and SW dipping) Sawmill Branch fault. The Ashley River fault, which was initially defined as a single structure, has subsequently been divided into two parts, the seismogenic Sawmill Branch fault (SBF) striking N30°W with approximately 67°SW dip and the essentially aseismic Ashley River fault (ARF), which dips to the southwest and is associated with reverse faulting (Reference RAI 02.05.01-16 15).

At the time of the SNC Vogtle ESP assessment, the Ashley River and Sawmill Branch fault were differentiated primarily by the association of seismicity with the Sawmill Branch fault and lack of seismicity on the Ashley River fault. Both faults were assigned a southwest dip. It is assumed that the conclusion in the Vogtle ESP application that the Ashley river fault and the Sawmill Branch fault are the same fault is based on the apparent along strike continuity of the two structures as shown on RAI 02.05.01-16 Figures 1 and 2.

A recent analysis of seismicity by Durá-Gómez and Talwani (Reference RAI 02.05.01-16 01) using a double-difference algorithm shows that most of the seismicity within an approximately 6 km (3.6 mi.) long antidilational compressional left step in the right-lateral-oblique Woodstock fault is occurring on the approximately 3 km (1.8 mi.) wide Sawmill Branch fault zone (RAI 02.05.01-16 Figure 3). A preferred dip direction of the Sawmill Branch fault zone to the northeast is opposite to the earlier interpretation of a southwest dip. Durá-Gómez and Talwani (Reference RAI 02.05.01-16 02) state that the approximately N55W trending Ashley River fault lying between Middleton Place and the Magnolia Plantation appears to be currently inactive.

Durá-Gómez and Talwani (Reference RAI 02.05.01-16 02) discuss the location accuracy of earthquakes located in the Middleton Place-Summerville seismic source zone. For the period 1974-2004, 294 earthquakes were located using HYPOELLIPSE and testing of the velocity model used to evaluate the locations indicates that the "absolute" locations obtained by using HYPOELLIPSE are considered robust and reliable. Of these, 217 earthquakes were located with quality A and B, with a mean RMS residual of 0.08 s; these correspond to horizontal and vertical location errors of <1.3 km and <2.0 km respectively. To further improve the relative locations for tectonic interpretation, Durá-Gómez and Talwani input these 217 events in the double difference (DD) location algorithm HypoDD (Reference 02.05.01-16 07).

Cross sections showing alternative interpretations of the Sawmill Branch fault zone are presented on RAI 02.05.01-16 Figures 4 and 5. No cross-sectional views of microseismicity across the seismically inactive Ashley River fault are available in either the Vogtle ESP report (Reference 2.5.1-263) or the Durá-Gómez and Talwani paper (Reference RAI 02.05.01-16 02).

d) The most recent published paper that discusses the Helena Banks fault zone is the summary by Wheeler (Reference RAI 02.05.01-16 08), which does not contain any new information, and is based on studies by Behrendt et al. (Reference 2.5.1-292) and Behrendt and Yaun (Reference 2.5.1-293). The shallowest offset reflectors in seismic reflection profiles analyzed by Behrendt et al. (Reference 2.5.1-292) are probably Miocene in age. Overlying, apparently undeformed material may be younger, but it is acoustically transparent and any deformation that might be present in it would not be recognizable in seismic-reflection profiles (Reference 2.5.1-292). Onshore adjacent to the fault zone, 5 to 25 meters (15 to 75 ft) of Pleistocene to Holocene unconsolidated sands have been mapped overlying Tertiary deposits. If similar deposits are present offshore, they would likely not be recognizable (Reference 2.5.1-258). Behrendt and Yuan (Reference 2.5.1-293) speculate that the youngest deformation could be Pleistocene, but provide no evidence. Because there is no reported evidence for slip younger than Miocene on the Helena Banks fault zone, it was assigned to class C by Crone and Wheeler (Reference 2.5.1-258). Wheeler (Reference 2.5.1-259) likely did not include the Helena Banks fault because there is no evidence of Quaternary activity.

Associated HAR COL Application Revisions:

The following changes will be made to HAR FSAR Chapter 2 in a future revision:

Revise FSAR Section 2.5.1.1.4.3 from:

"2.5.1.1.4.3 Significant Seismic Sources at Distance Greater than 320 km (200 mi.)

The EPRI-SOG evaluation indicated that the seismic sources in the Charleston, South Carolina, region were significant contributors to the hazard at the HNP site (Reference 2.5.1-203). Several investigations that post-date the EPRI-SOG evaluation indicate that parameters related to location, maximum magnitude, and recurrence of possible seismic sources in the Charleston region should be updated (Reference 2.5.1-203). In support of the Southern Nuclear Company ALWR ESP Application, a thorough review and analysis of the new data were completed (Reference 2.5.1-263, Reference 2.5.1-264). The updated source model is discussed in Subsection 2.5.2.

The following excerpt from the Southern Nuclear Company report summarizes new (post-EPRI) information pertaining to the characterization of these parameters (Reference 2.5.1-263, Reference 2.5.1-203).

Geometry

Several recent studies provide direct or indirect evidence regarding the geometry of the Charleston seismic source. Studies that provide direct evidence are those that identify or hypothesize specific tectonic features that may have produced the 1886 Charleston earthquake. The geometries of these tectonic features, therefore, directly reflect the possible geometry of the Charleston seismic source. These tectonic features are summarized in Table 1 [Table 2.5.1-203] and shown in Figures 1 and 2 [Figures 2.5.1-221 and 2.5.1-222]. Uncertainty in the location and existence of these tectonic features and their hypothesized relationship to the 1886 Charleston earthquake is described below.

Studies that provide indirect evidence are those that present information on the geographic distribution of phenomena that may be related to the Charleston seismic source. These phenomena include liquefaction features and strong motion data from the 1886 Charleston earthquake, paleoliquefaction features from prehistoric earthquakes in the region, historical and instrumental seismicity data, and use of global intraplate seismicity to associate large-magnitude intraplate earthquakes within specific tectonic environments.

Direct Evidence

A compilation of local and regional tectonic features is shown in Figures 1 and 2 [Figures 2.5.1-221 and 2.5.1-222]. These features are differentiated to show both pre- and post-1986 EPRI information. Recent post-EPRI studies that have identified tectonic features in the 1886 Charleston meizoseismal area include those by Marple and Talwani [Reference 2.5.1-262, Reference 2.5.1-243, Reference 2.5.1-287]; Weems et al. [Reference 2.5.1-288]; Weems and Lewis [Reference 2.5.1-289]; and Talwani and Katuna [Reference 2.5.1-290]. In particular, five postulated faults have been identified in the Charleston area since 1986 (Table 1 and Figure 1) [Table 2.5.1-203 and Figure 2.5.1-221] and additional information has been developed on the offshore Helena Banks fault zone. These are described below:

East Coast fault system. The East Coast fault system (ECFS, the southern section of which is also known as the 'zone of river anomalies' or ZRA, is a northeast-trending, ~600 km (375 mi.) long fault system extending from west of Charleston, South Carolina to southeastern Virginia [Reference 2.5.1-243]. The ECFS consists of three, ~200 km (125 mi.) long, right-stepping sections (southern, central, and northern; Figures 2 and 3) [Figures 2.5.1-222 and 2.5.1-223]. Evidence for the southern section is strongest, with evidence becoming successively weaker northward [Reference 2.5.1-259]. Marple and Talwani [Reference 2.5.1-262] identified a series of geomorphic anomalies (i.e., ZRA) located along and northeast of the Woodstock fault, and attributed these to a buried fault much longer than the Woodstock fault. Marple and Talwani [Reference 2.5.1-262, Reference 2.5.1-243, Reference 2.5.1-287] suggested that this structure, the southern section of the ECFS, may have been the source of the 1886 Charleston earthquake.

Marple and Talwani [Reference 2.5.1-243] provided additional evidence for the existence of the southern section of the ECFS, including seismic reflection data, linear aeromagnetic anomalies, exposed Plio-Pleistocene faults, local breccias, and upwarped strata. Since most of the geomorphic anomalies associated with the southern section of the ECFS are in late Pleistocene sediments, Marple and Talwani [Reference 2.5.1-243] speculated that the fault was active 130 – 10 ka, and perhaps remains active. Wildermuth and Talwani [Reference 2.5.1-291] subsequently used gravity and topographic data to postulate the existence of a right-stepping pull-apart basin between the southern and central sections of the ECFS. Existence of the pull-apart basin suggests a component of right-lateral slip on the northeast-trending ECFS, which is consistent with the inferred sense of slip based on the orientation of the fault in the regional stress field.

Wheeler [Reference 2.5.1-259] classified the ECFS as a class C feature; that is, one for which "geologic evidence is insufficient to demonstrate (1) the existence of tectonic faulting, or (2) Quaternary slip or deformation associated with the feature."

Based on our independent evaluation of the geomorphic, seismic reflection, and seismicity data, our confidence in the existence and activity of the ECFS is low to moderate. In our judgment, all of the geomorphic "anomalies" have credible nontectonic (i.e., fluvial geomorphic) explanations. Our three-dimensional (3-D) analysis of microseismicity in the vicinity of the ECFS does not clearly define a discrete structure (Figure 5) [Figure 2.5.1-225]. Available seismic reflection data do not unambiguously delineate a through-going structure in the vicinity of the ECFS.

Adams Run Fault. Weems and Lewis [Reference 2.5.1-289] postulated the existence of the Adams Run fault on the basis of microseismicity and borehole data (Figures 1 and 4) [Figures 2.5.1-219, 2.5.1-220, and 2.5.1-224]. Their interpretation of borehole data suggests the presence of areas of Cenozoic uplift and subsidence separated by the inferred fault (Figure 4) [Figure 2.5.1-224]. However, our review of these data shows that the pattern of uplift and subsidence (1) do not appear to persist through time (i.e., successive stratigraphic layers) in the same locations and (2) that the intervening structural lows between the proposed uplifts are highly suggestive of erosion along ancient river channels. In addition, there is no geomorphic evidence for the existence of the Adams Run fault, and our 3-D analysis of microseismicity in the vicinity of the proposed Adams Run fault does not clearly define a discrete structure (Figure 5) [Figure 2.5.1-225]. Thus, our confidence in the existence and activity of this fault is low.

Sawmill Branch Fault. Talwani and Katuna [Reference 2.5.1-290] postulated the existence of the Sawmill Branch fault on the basis of microseismicity and further speculated that this feature experienced surface rupture in the 1886 earthquake. According to Talwani and Katuna [Reference 2.5.1-290], this ~5 km (3 mi.) long, northwest-trending fault, which is a segment of the larger Ashley River fault, offsets the Woodstock fault in a left-lateral sense (Figure 1) [Figure 2.5.1-221]. Earthquake damage at three localities was used to infer that surface rupture occurred in 1886. However, our field review of these features along the banks of the Ashley River (small, discontinuous cracks in a tomb that dates to 1671 A.D. and displacements (<10 centimeters [cm] [4 inches (in.)]) in the walls of colonial Fort Dorchester) are almost certainly the product of shaking effects as opposed to fault rupture. Moreover, our 3-D assessment of microseismicity in the vicinity of the proposed Sawmill Branch fault does not clearly define a discrete structure distinct or separate from the larger Ashley River fault, which was defined based on seismicity (Figure 5) [Figure 2.5.1-225]. Thus, our confidence in the existence and activity of this fault is low.

Summerville Fault. Weems et al. [Reference 2.5.1-288] postulated the existence of the Summerville fault on the basis of microseismicity (Figure 1) [Figure 2.5.1-221]. However, there is no geomorphic or borehole evidence for the existence of the Summerville fault, and our 3-D analysis of microseismicity in the vicinity of the proposed Summerville fault does not clearly define a discrete structure (Figure 5) [Figure 2.5.1-225]. Thus, our confidence in the existence and activity of this fault is low.

Helena Banks Fault Zone. The Helena Banks fault zone is clearly imaged on seismic reflection lines offshore of South Carolina [Reference 2.5.1-292, Reference 2.5.1-293] and was known to the six EPRI earth science teams (ESTs) at the time of the 1986 EPRI study as a possible Cenozoic-active fault zone. Some ESTs recognized the offshore fault zone as a candidate tectonic feature for producing the 1886 event and included it in their Charleston seismic source zones. However, since 1986 three additional sources of information have become available:

- In 2002, two magnitude $m_b \geq 3.5$ earthquakes (m_b 3.5 and 4.4) occurred offshore of South Carolina in the vicinity of the Helena Banks fault zone in an area previously devoid of seismicity (Figures 1 and 2) [Figures 2.5.1-221 and 2.5.1-222].
- Bakun and Hopper [Reference 2.5.1-294] reinterpreted intensity data from the 1886 Charleston earthquake and show that the calculated intensity center is located over 150 km (93 mi.) offshore from Charleston, suggesting that the source of the 1886 earthquake may lie offshore of South Carolina. Bakun and Hopper [Reference 2.5.1-294] ultimately conclude, however, that the epicentral location most likely lies onshore in the Middleton Place-Summerville area (Figures 2 and 6) [Figures 2.5.1-222 and 2.5.1-226] based on the concentrated seismicity in this area.
- Crone and Wheeler [Reference 2.5.1-258] described the Helena Banks fault zone as a potential Quaternary tectonic feature, but classified the fault zone as a Class C feature that lacks sufficient evidence to demonstrate Quaternary activity.

In our review of available information, we assign a high confidence to the existence of this fault zone and a low to moderate confidence that the fault may be active and the source of the 1886 earthquake. Seismic reflection data clearly show the existence of the Helena Banks fault zone (as opposed to a deep-seated landslide) extending to a depth of >1 km (>0.6 mi.). Furthermore, the occurrence of 2002 earthquakes and location of the Bakun and Hopper [Reference 2.5.1-294] intensity center offshore suggest, at a low probability, that the fault zone could be considered a potentially active fault. If the Helena Banks fault zone is an active source, its length and orientation could possibly explain the distribution of paleoliquefaction features along the South Carolina coast. Therefore, we include the Helena Banks fault zone as a possible source for the 1886 Charleston earthquake in our update of the Charleston seismic source geometry in order to capture the uncertainty associated with this fault.

Indirect Evidence

Indirect evidence relating to the geometry of the Charleston seismic source includes:

(1) The relationship of large intraplate earthquakes worldwide to specific tectonic environments,

(2) The geographic distribution, density, and size of liquefaction features produced by the 1886 and prehistoric earthquakes in the Charleston region,

(3) Earthquake intensity data from the 1886 Charleston earthquake, and

(4) Instrumental seismicity.

Johnston et al. [Reference 2.5.1-295] evaluated the correlation of large-magnitude intraplate earthquakes to specific tectonic environments throughout the world. They concluded that large-magnitude earthquakes generally occur in tectonic environments characterized by Mesozoic and younger rifted crust. The Charleston meizoseismal region occurs in a region of Mesozoic extended crust along the southeastern margin of the North American craton [Reference 2.5.1-295]. Several Mesozoic basins are defined in the region. In our assessment of Charleston geometry, we considered the location, structural orientation (i.e., NE-SW), and spatial correlation of possible Mesozoic basins and structures to characterize alternative models of the source zone geometry.

The 1886 Charleston earthquake produced widespread significant liquefaction. The distribution and density of this liquefaction was documented by Dutton [Reference 2.5.1-296] and provides useful information on the epicentral location of the earthquake. Additional studies by Obermeier et al. [Reference 2.5.1-297, Reference 2.5.1-298], Amick [Reference 2.5.1-299], Amick et al. [Reference 2.5.1-270, Reference 2.5.1-300], Talwani and Schaeffer [Reference 2.5.1-301], and others evaluated the distribution of 1886 liquefaction and earlier paleoliquefaction features to assess the geometry as well as the stationarity or non-stationarity of the Charleston seismic source.

Several researchers have performed searches for paleoliquefaction features both in the 1886 Charleston epicentral area and in the southeastern U.S. coastal region to better define the location and geometry of the Charleston seismic source. Obermeier et al. [Reference 2.5.1-297, Reference 2.5.1-298, Reference 2.5.1-302] investigated the spatial distribution, size, and abundance of paleoliquefaction features in the Charleston region and beyond. Obermeier et al. [Reference 2.5.1-297, Reference 2.5.1-298] observed that both the abundance and diameters of pre-1886 Holocene sandblow craters are greatest within the meizoseismal zone of the 1886 Charleston earthquake. No features were found beyond 100 km (60 mi.) from Charleston [Reference 2.5.1-302].

Amick et al. [Reference 2.5.1-270] searched for paleoliquefaction features in late Quaternary beach and near-shore deposits (i.e., deposits susceptible to liquefaction) in Virginia, North Carolina, South Carolina, Georgia, and in the Wilmington, Delaware, area. Their search identified liquefaction features almost exclusively in South Carolina. Liquefaction features were not found in susceptible deposits outside of South Carolina (the lone exception being a liquefaction feature discovered directly north of the South Carolina-North Carolina state line). The negative evidence provided by Obermeier et al. [Reference 2.5.1-302] and Amick et al. [Reference 2.5.1-300] (i.e., the dearth of features outside of the Charleston area) strongly suggest that the seismic source that produced the 1886 Charleston earthquake and earlier large-magnitude earthquakes is localized in the Charleston meizoseismal area.

Based on the geographic and temporal distribution of paleoliquefaction features in coastal South Carolina, Talwani and Schaeffer [Reference 2.5.1-301] proposed two scenarios for the occurrence in time and space of Charleston-area earthquakes. In their first scenario, three seismic sources are inferred to occur within the coastal plain of South Carolina: a Charleston source that has produced earthquakes with magnitudes ≥ ~7, and a source in each of the Georgetown and Bluffton areas that have produced more moderate earthquakes with magnitudes ~6. In Talwani and Schaeffer's [Reference 2.5.1-301] second scenario, all events recorded in the paleoliquefaction record were centered at Charleston with magnitudes ≥ ~7.

Intensity data for the 1886 Charleston earthquake reported by Dutton [Reference 2.5.1-296] and reinterpreted by Bollinger [Reference 2.5.1-303] indicate a meizoseismal area centered on Charleston (Figures 1 and 2) [Figures 2.5.1-221 and 2.5.1-222]. Bakun and Hopper [Reference 2.5.1-294] calculated an intensity center for the 1886 Charleston earthquake that is located offshore about 200 km east of Charleston (Figure 6) [Figure 2.5.1-226]. The offshore location for the intensity center may be a function of the spatial distribution of the input data, all of which lie onshore [Reference 2.5.1-294]. Bakun and Hopper's [Reference 2.5.1-294] preferred intensity center for the 1886 Charleston earthquake is onshore within the Middleton Place-Summerville seismic zone.

The Middleton Place-Summerville seismic zone (MPSSZ) is an area of elevated microseismic activity located ~20 km (13 mi.) northwest of Charleston [Reference 2.5.1-304, Reference 2.5.1-305, Reference 2.5.1-306, Reference 2.5.1-290]. Between 1980 and 1991, 58 events with duration magnitude (Md) 0.8 – 3.3 were recorded in an 11 x 14 km^2 area, with hypocentral depths ranging from 2 to 11 km (1 to 7 mi.) [Reference 2.5.1-306]. The elevated seismic activity of the MPSSZ has been attributed to stress concentrations associated with the intersection of the Ashley River and Woodstock faults [Reference 2.5.1-307, Reference 2.5.1-306, Reference 2.5.1-290, Reference 2.5.1-308]. Persistent foreshock activity was reported in the MPSSZ area [Reference 2.5.1-296], and it has been speculated that the 1886 Charleston earthquake occurred within the MPSSZ [e.g., Reference 2.5.1-307, Reference 2.5.1-304, Reference 2.5.1-294].

Given the direct and indirect data described previously, significant revision to the Charleston geometry provided in the EPRI seismic source model is warranted. New information published since 1986 strongly indicate that the Charleston earthquake is localized in the 1886 Charleston meizoseismal area or in the region of coastal South Carolina constrained by the paleoliquefaction data.

Maximum Magnitude (M_{max})

Multiple methods and types of data have been used to characterize the maximum magnitude (M_{max}) of the Charleston seismic source. These approaches include using the worldwide data set to constrain the minimum and maximum range of M_{max} for regions of Mesozoic and younger extensional crust [Reference 2.5.1-295] and evaluating the size of the 1886 Charleston earthquake as a proxy for the maximum earthquake that may be produced by the Charleston seismic source (Table 2) [Table 2.5.1-204]. The latter approach has used both intensity data [Reference 2.5.1-309, Reference 2.5.1-294] and the size and geographic distribution of the liquefaction fields [Reference 2.5.1-297, Reference 2.5.1-298, Reference 2.5.1-302, Reference 2.5.1-309] to estimate the magnitude of the 1886 event. Because the causative fault for the 1886 event is unknown, we consider estimates of M_{max} based on the 1886 earthquake magnitude and worldwide database more reliable than using postulated fault dimensions to estimate M_{max} for the Charleston seismic source. Johnston et al. [Reference 2.5.1-295] compiled a worldwide database of earthquakes in stable continental regions (SCRs) to evaluate the correlation of large-magnitude SCR earthquakes to specific tectonic environments, if any. The database showed that the largest SCR earthquakes (>**M** 7) are confined to regions of Mesozoic and younger extended crust. The maximum observed magnitude for Mesozoic extended crust along passive cratonic margins similar to the southeastern United States is **M** 7.7 ± 0.2 [Reference 2.5.1-295]. Based on an analysis of intensity data, Johnston et al. [Reference 2.5.1-295] estimated the 1886 Charleston earthquake to be **M** 7.56 ± 0.35. Using Bayesian statistics, Johnston et al. [Reference 2.5.1-295] indicated that the M_{max} for the Charleston seismic source should not be much larger than the 1886 event. This conclusion supports the idea that an M_{max} developed for the Charleston seismic source should be primarily based on the estimate of the size of the 1886 Charleston event.

Martin and Clough [Reference 2.5.1-310] used a geotechnical approach to back-calculate ground motions for the 1886 Charleston earthquake based on soil properties of 1886 paleoliquefaction features. The threshold peak ground acceleration required to cause ground deformation was estimated based on the intersection of the layer curve effect of Ishihara [Reference 2.5.1-311] and the cyclic stress method [e.g.,Reference 2.5.1-312]. Martin and Clough [Reference 2.5.1-310] concluded that the liquefaction evidence was consistent with an earthquake no larger than **M** 7.5, and possibly as small as **M** 7.0 (Table 2) [Table 2.5.1-204].

Johnston [Reference 2.5.1-309] developed specific eastern North America regressions of seismic moment based on isoseismal area and averaged these with global stable continental regions relations to estimate the magnitude of the 1886 Charleston earthquake. After considering multiple regressions, options for best-weighted values, and a correction for wedge effects of Coastal Plain sediments on isoseismals, a preferred best estimate of **M** 7.3 ± 0.26 (**M** 7.04 – 7.56) was obtained (Table 2) [Table 2.5.1-204]. The Johnston study [Reference 2.5.1-309] also estimated a magnitude of **M** 7.4 ± 0.35 (**M** 7.05 – 7.77) using the extent and severity of liquefaction and the Liquefaction Severity Index (LSI). These estimates of M_{max} reflect a slight downward revision from the estimate from the estimate of M_{max} provided in Johnston et al. [Reference 2.5.1-295] of **M** 7.56 ± 0.35. Johnston [Reference 2.5.1-309] concluded that while uncertainties in magnitude are reported, "the final results of this study are best stated in general terms." For the 1886 Charleston earthquake, Johnston [Reference 2.5.1-309] concluded that the best estimate of magnitude is "in the low- to mid-**M** 7 range." We consider this estimate as a credible magnitude and it is incorporated into our assessment of M_{max} for the UCSS.

In comparing intensity attenuation with epicentral distance for different stable continental regions, Bakun and McGarr [Reference 2.5.1-313] showed that eastern North America exhibits lower attenuation of seismic energy than other worldwide stable continental regions. Johnston [Reference 2.5.1-309] also recognized this difference and developed eastern North America relations, which were averaged with global stable continental regions relations, to arrive at a best estimate of **M** 7.3 for the 1886 Charleston earthquake. Based on this observation, Bakun and McGarr [Reference 2.5.1-313] concluded that the Johnston [Reference 2.5.1-309] magnitude estimates for 1811 – 1812 New Madrid earthquakes, derived solely on a global stable continental regions attenuation model, are overestimated. Bakun and McGarr [Reference 2.5.1-313] also state that magnitude estimates based on averaging intensity attenuation relations from eastern North America and other stable continental regions may be overestimated. This suggests that Johnston [Reference 2.5.1-309] may have overestimated the magnitude of the 1886 Charleston earthquake.

Bakun and Hopper [Reference 2.5.1-294] estimated the magnitude and location of the 1886 Charleston earthquake using eastern North America intensity models that relate intensity and epicentral distance [Reference 2.5.1-314]. Assuming that the 1886 event was centered in the Middleton Place-Summerville cluster of seismicity (and not offshore at their estimated intensity center), Bakun and Hopper [Reference 2.5.1-294] estimated a magnitude range of **M** 6.4 – 7.2 at the 95 percent confidence interval. Bakun and Hopper [Reference 2.5.1-294] preferred magnitude estimate for the Charleston earthquake is M_I 6.9 (M_I is considered equivalent to **M**). The Bakun and Hopper [Reference 2.5.1-294] magnitude estimate suggests that the 1886 event may have been smaller than the Johnston [Reference 2.5.1-309] estimate. We consider that both of these studies represent the most credible estimates of the 1886 Charleston earthquake.

Obermeier et al. [Reference 2.5.1-297, Reference 2.5.1-298, Reference 2.5.1-302] investigated the spatial distribution, size, and abundance of paleoliquefaction features in the Charleston coastal region and beyond. Based on the widespread distribution of sand blow craters in coastal South Carolina, Obermeier et al. [Reference 2.5.1-298] stated that these features were likely the result of earthquakes with magnitudes of at least m_b 5.5, and probably much stronger. Based on the observation that the limits of prehistoric liquefaction extend at least as far from Charleston as those formed during the 1886 earthquake (and the liquefaction susceptibility of deposits subjected to prehistoric earthquakes was likely as high as the liquefaction susceptibility of those subjected to the 1886 earthquake), Obermeier et al. [Reference 2.5.1-302] suggested that prehistoric Charleston area earthquakes were probably at least as strong as the 1886 Charleston earthquake.

For paleoearthquakes, Talwani and Schaeffer [Reference 2.5.1-301] estimated the magnitudes of past Charleston area events based on the spatial distribution and areal extent of paleoliquefaction sites (Figure 7) [Figure 2.5.1-227]. Talwani and Schaeffer [Reference 2.5.1-301] did not use a rigorous empirical method in their estimation of the magnitudes of past events. Instead they used a simple approach by which all past liquefaction episodes interpreted as having spanned a region comparable in size to the 1886 liquefaction field were assigned **M** 7+, and all past liquefaction episodes interpreted as having spanned a smaller areal extent were assigned **M** 6+.

Hu et al. [Reference 2.5.1-315, Reference 2.5.1-316] used the event chronology as interpreted by Talwani and Schaeffer [Reference 2.5.1-301] and the energy-stress method to estimate magnitudes of past Charleston area earthquakes. For earthquakes that produced liquefaction features over extended areas centered near Charleston, Hu et al. [Reference 2.5.1-316] estimated magnitudes of **M** 6.8 – 7.8, and they estimated magnitudes of **M** 5.5 – 7.0 for earthquakes that produced liquefaction over more limited areas.

Leon [Reference 2.5.1-317] and Leon et al. [Reference 2.5.1-318] also estimated the magnitudes of past Charleston area earthquakes using the event chronology as interpreted by Talwani and Schaeffer; [Reference 2.5.1-301], but the Leon [Reference 2.5.1-317] and Leon et al. [Reference 2.5.1-318] method takes into account the effects of sediment age on the liquefaction potential of those sediments. Using the magnitude-bound method, Leon et al. [Reference 2.5.1-318] estimated magnitudes of **M** 6.9 – 7.1 for earthquakes that produced liquefaction features over extended areas, and **M** 5.7 – 6.3 for earthquakes that produced liquefaction over more limited areas. Using the energy-stress method, Leon et al. [Reference 2.5.1-318] estimated magnitudes of **M** 5.6 – 7.2 for earthquakes that produced liquefaction features over extended areas, and **M** 4.3 – 6.4 for earthquakes that produced liquefaction over more limited areas.

The magnitude ranges estimated for earthquakes that produced liquefaction over extended areas [Reference 2.5.1-315, Reference 2.5.1-316, Reference 2.5.1-318] have significant overlap with magnitude estimates of the 1886 earthquake by Johnston [Reference 2.5.1-309] and Bakun and Hopper [Reference 2.5.1-294]. However, given the large uncertainties in working with the paleoliquefaction record and methods for estimating magnitudes from these data, we consider that the best representation of the M_{max} for the Charleston seismic source should be based on estimates of the size of the 1886 earthquake (Table 2) [Table 2.5.1-204].

It is important to note that the magnitudes estimated from the paleoliquefaction record for earthquakes that produced liquefaction over limited areas may have been less than **M** 6.3 [Reference 2.5.1-318]. This implies that some events in the paleoliquefaction record may not represent large, 1886-type characteristic earthquakes. Therefore, the inclusion of any smaller paleoearthquakes in the recurrence model described below may bias the recurrence toward moderate-sized earthquakes and may overestimate the frequency of large events.

Taken together, these new data suggest that M_{max} for the 1886 Charleston earthquake is on the order of **M** 6 ¾ to 7 ½ ([Reference 2.5.1-310, Reference 2.5.1-309, Reference 2.5.1-294]; Table 2 [Table 2.5.1-204]). The 95 percent confidence interval of Bakun and Hopper [Reference 2.5.1-294] implies the magnitude could have been as low as **M** 6.4; however, the preponderance of the data and evaluations indicate that the low end of this estimate likely underestimates the size of the 1886 earthquake.

Recurrence

Recent studies of paleoliquefaction features in the southeast United States provide new insight into the recurrence interval for Charleston area earthquakes [e.g., Reference 2.5.1-299, Reference 2.5.1-270, Reference 2.5.1-300, Reference 2.5.1-301]. The post-1986 EPRI studies of paleoliquefaction features suggest that recurrence of large earthquakes on the Charleston seismic source is on the order of hundreds of years. This is significantly less than the EPRI model recurrence of several thousand years predicted by historical seismicity.

Earthquakes recorded in the paleoliquefaction record may include events significantly less than M_{max} because the minimum threshold magnitude for earthquakes to cause liquefaction is estimated as m_b>5.5 [Reference 2.5.1-298] or **M** 4.3 – 6.4 [Reference 2.5.1-318]. Therefore, estimates of M_{max} recurrence intervals based upon the paleoliquefaction record may include events smaller than M_{max} and overestimate the frequency of M_{max} recurrence. Simply because the age determinations for paleoliquefaction features at widely distributed sites overlap, does not necessitate that the features were the result of a single, large earthquake. The possibility that paleoliquefaction features of similar age (i.e., within the uncertainty in age determination) resulted from smaller earthquakes that occurred over a wide area, closely spaced in time is an inherent uncertainty in the paleoliquefaction record. Recent (post-1986) EPRI studies that characterized the recurrence of prehistoric earthquakes from the paleoseismic record are described below:

- Amick [Reference 2.5.1-299] and Amick et al. [Reference 2.5.1-270, Reference 2.5.1-300] described the spatial distribution and dating of paleoliquefaction features on the Atlantic Seaboard, including the coastal regions of the Carolinas and Georgia, as well as central Virginia and Wilmington, Delaware. Amick [Reference 2.5.1-299] and Amick et al. [Reference 2.5.1-300, Reference 2.5.1-270] used the liquefaction data to suggest that large earthquakes occur every 500 to 600 years in Coastal South Carolina, and that paleoliquefaction evidence for earthquakes located outside of South Carolina is lacking.
- Talwani and Schaeffer [Reference 2.5.1-301] combined previously published data with their own studies of liquefaction features in the South Carolina coastal region (Figure 7) [Figure 2.5.1-227]. Talwani and Schaeffer [Reference 2.5.1-301] used the spatial distribution of paleoliquefaction features in combination with estimates on the timing of the formation of the

liquefaction features in order to derive possible earthquake recurrence histories for the region. Talwani and Schaeffer's [Reference 2.5.1-301] scenario 1 allows for the possibility that some events in the paleoliquefaction record are smaller in magnitude (~**M** 6+), and these more moderate events occurred to the northeast (Georgetown) and southwest (Bluffton) of Charleston. In scenario 2 [Reference 2.5.1-301], all earthquakes in the record are large shocks (~**M** 7+) located near Charleston. Talwani and Schaeffer's [Reference 2.5.1-301] preferred estimate for the recurrence of large earthquakes in coastal South Carolina is 500 to 600 years.

In summary, post-1986 EPRI studies suggest that Charleston M_{max} recurrence is on the order of hundreds of years, significantly less than the EPRI model recurrence of several thousand years predicted by historical seismicity."

To read:

"2.5.1.1.4.3 Charleston Seismic Source

The 1886 Charleston, South Carolina, earthquake was the largest earthquake occurring in historical time in the eastern U.S. The event produced Modified Mercalli Intensity (MMI) X shaking in the epicentral area (Reference 2.5.1-309). Based on the felt intensity reports defining the meizoseismal area (area of maximum damage) and the occurrence of continuing seismic activity (the Middleton Place Summerville seismic zone), the epicentral region of the 1886 earthquake is considered to be centered northwest of Charleston, but there remains uncertainty in the causative structure on which the earthquake occurred.

The EPRI-SOG evaluation indicated that the seismic sources in the Charleston, South Carolina, region were significant contributors to the hazard at the HNP site (Reference 2.5.1-203). Several investigations that post-date the EPRI-SOG evaluation (Reference 2.5.1-203) indicate that parameters related to location, maximum magnitude, and recurrence of possible seismic sources in the Charleston region should be updated. In support of the Southern Nuclear Company Vogtle ESP Application, a thorough review and analysis of the new data were completed (Reference 2.5.1-264). The updated Charleston seismic source (UCSS) model for the Vogtle ESP Application, which was adopted for this study, is further discussed in Subsection 2.5.2.

Recent published and unpublished studies for information on the potential location and extent of the Charleston source and the maximum earthquake and recurrence of repeated large magnitude events expected to occur on it are described as follows.

2.5.1.1.4.3.1 Location and Geometry

Several recent studies provide direct or indirect evidence regarding the location and geometry of the Charleston seismic source. The source of the earthquake is inferred based on the geology, geomorphology, and instrumental seismicity of the region. Local and regional tectonic features that may be related to the Charleston seismic source are shown in Figures 2.5.1-221 and 2.5.1-222. Features are differentiated to show both pre- and post-1986 EPRI information. Recent post-EPRI studies that have identified tectonic features in the 1886 Charleston meizoseismal area include those by Marple and Talwani (Reference 2.5.1-262, Reference 2.5.1-243, Reference 2.5.1-287); Weems et al. (Reference 2.5.1-288); Weems and Lewis (Reference 2.5.1-289); Talwani and Katuna (Reference 2.5.1-290) and Talwani and Durá-Gómez (References RAI 02.05.01-16 01; RAI 02.05.01-16 02; RAI 02.05.01-16 03). In particular, five postulated faults have been identified in the Charleston area since 1986 (Table 2.5.1-203 -and Figure 2.5.1-221) and additional information has been developed on the offshore Helena Banks fault zone. A description of the East Coast fault system is provided in Subsection 2.5.1.1.4.2.5.2.2. Descriptions of the other faults or postulated faults in the Charleston area are as follows.

Adams Run Fault. Weems and Lewis [Reference 2.5.1-289] postulated the existence of the Adams Run fault on the basis of microseismicity and borehole data [Figures 2.5.1-221 and 2.5.1-224]. Weems and Lewis's interpretation of borehole data suggests the presence of areas of Cenozoic uplift and subsidence separated by the inferred fault [Figure 2.5.1-224]. Based on a review and analysis of these data for the Southern Nuclear Company Vogtle ESP Application (Reference 2.5.1-264), it was concluded that the pattern of uplift and subsidence (1) do not appear to persist through time (i.e., successive stratigraphic layers) in the same locations and (2) that the intervening structural lows between the proposed uplifts are highly suggestive of erosion along ancient river channels. It was also noted that there is no geomorphic evidence for the existence of the Adams Run fault, and a 3-D analysis of microseismicity in the vicinity of the proposed Adams Run fault completed for that study did not clearly define a discrete structure.

Talwani (1982 Reference 2.5.1-307) associates seismicity observed in the Adams Run seismic zone with the Woodstock fault, and this fault is not shown as a structure on the current seismotectonic framework map of the Charleston area Durá-Gómez and Talwani (Reference RAI 02.05.01-16 02) (RAI 02.05.01-16 Figure 3).

Ashley River Fault. Talwani (1982) (Reference 2.5.1-307), identifies the Ashley River fault in the meizoseismal area of the 1886 Charleston earthquake on the basis of a northwest-oriented, linear zone of seismicity located about 9.6 km (6 mi.) west of Woodstock, South Carolina. The postulated fault was judged to be a southwest-side-up reverse fault that appeared to offset the north-northeast-striking Woodstock fault about 4.8 to 6.4 km (3 to 4 mi.) to the northwest near Summerville (Reference 2.5.1-307; Reference 2.5.1-289; Reference RAI 02.05.01-16 09). The Ashley River fault subsequently was subdivided into two structures, the seismogenic Sawmill Branch fault (SBF) striking N30°W with a strong reverse component and dip of about 70 degrees to the southwest and the approximately 50 to 60 degree west-striking, essentially aseismic Ashley River fault (ARF) between Middleton Palace and Magnolia Plantation, for which the name Ashley River fault was retained. (Reference RAI 02.05.01-16 03).

Charleston Fault. Lennon (Reference RAI 02.05.01-16 10) proposes the Charleston fault on the basis of geologic map relations and subsurface borehole data. Weems and Lewis (Reference 2.5.1-289) suggest that the Charleston fault is a major, high-angle reverse fault that has been active at least intermittently in Holocene to modern times. It was noted by SNC Vogtle ESP that the Charleston fault as mapped by Weems and Lewis has no clear geomorphic expression, nor is it clearly defined by microseismicity (Reference 2.5.1-264) (Figure 2.5.1-225)

Talwani and Durá-Gómez (Reference RAI 02.05.01-16 03) state that the interpretation of Weems and Lewis is inconsistent with fault kinematics, and that a more plausible explanation is that the Charleston fault is not a steep dipping (and northeast-dipping), but rather its surface projection is approximately 7 km (4.4 mi.) to the northeast along the northwest axis of the Mt. Holly dome with the southwest side upthrown (RAI 02.05.01-16 Figure 3). Based on interpretation of relocated earthquake hypocenters Durá-Gómez and Talwani (Reference RAI 02.05.01-16 03) associate some of the current seismicity occurring in the antidilational compressional left step at Middleton Place with the Charleston fault and infer a southwest dip of approximately 40 degrees for the fault.

Cooke Fault. Behrendt et al. (Reference RAI 02.05.01-16 11) and Hamilton et al. (Reference RAI 02.05.01-16 12) identify the Cooke fault based on seismic reflection profiles in the meizoseismal area of the 1886 Charleston earthquake. This east-northeast-striking, steeply northwest-dipping fault has a total length of about 9.6 km (6 mi.) (Reference 2.5.1-262 and Reference 2.5.1-243). Marple and Talwani (References 2.5.1-243 and Reference 2.5.1-262) reinterpret these data to suggest that the Cooke fault may be part of a longer, more northerly striking fault (i.e., the ZRA of Marple and Talwani (Reference 2.5.1-262) and the ECFS of Marple and Talwani (Reference 2.5.1-243). Crone and Wheeler (Reference 2.5.1-258) classify the Cooke fault as a Class C feature based on lack of evidence for faulting younger than Eocene.

Helena Banks Fault Zone. The Helena Banks fault zone is clearly imaged on seismic reflection lines offshore of South Carolina (Reference 2.5.1-292, Reference 2.5.1-293) and was known to the six EPRI earth science teams (ESTs) at the time of the 1986 EPRI study as a possible Cenozoic-active fault zone. Some ESTs recognized the offshore fault zone as a candidate tectonic feature for producing the 1886 event and included it in their Charleston seismic source zones. However, since 1986 three additional sources of information have become available as outlined in the SNC Vogtle ESP study (Reference 2.5.1-264):

- In 2002, two magnitude $m_b \geq 3.5$ earthquakes (m_b 3.5 and 4.4) occurred offshore of South Carolina in the vicinity of the Helena Banks fault zone in an area previously devoid of seismicity (Figures 2.5.1-221 and 2.5.1-222).
- Bakun and Hopper [Reference 2.5.1-294] reinterpreted intensity data from the 1886 Charleston earthquake and show that the calculated intensity center is located over 150 km (93 mi.) offshore from Charleston, suggesting that the source of the 1886 earthquake may lie offshore of South Carolina. Bakun and Hopper (Reference 2.5.1-294) ultimately conclude, however, that the epicentral location most likely lies onshore in the Middleton Place-Summerville area (Figures 2.5.1-222 and 2.5.1-226] based on the concentrated seismicity in this area.

Crone and Wheeler (Reference 2.5.1-258) described the Helena Banks fault zone as a potential Quaternary tectonic feature, but classified the fault zone as a Class C feature that lacks sufficient evidence to demonstrate Quaternary activity. There is no reported evidence for slip younger than Miocene on the Helena Banks fault zone. The youngest deformation could be as old as Miocene, depending on whether the deformed Miocene clay dates from the early or late Miocene. Accordingly, the Helena Banks fault zone is assigned to class C for lack of evidence of faulting younger than Miocene.

In the Vogtle ESP Application (Reference 2.5.1-264) a high confidence was assigned to the existence of this fault zone and a low to moderate confidence was assigned that the fault may be active and the source of the 1886 earthquake. Seismic reflection data clearly show the existence of the Helena Banks fault zone (as opposed to a deep-seated landslide) extending to a depth of >1 km (>0.6 mi.). Furthermore, the occurrence of 2002 earthquakes and location of the Bakun and Hopper [Reference 2.5.1-294] intensity center offshore suggest, at a low probability, that the fault zone could be considered a potentially active fault. If the Helena Banks fault zone is an active source, its length and orientation could possibly explain the distribution of paleoliquefaction features along the South Carolina coast. Therefore, the Helena Banks fault zone was included as a possible source for the 1886 Charleston earthquake in the SNC Vogtle ESP update of the Charleston seismic source geometry in order to capture the uncertainty associated with this fault.

The current USGS seismic source characterization model for the National Hazards Mapping Project also includes a revised geometry for the large Charleston zone, extending it farther offshore to include the Helena Banks fault (Peterson et al. 2008 Reference 02.05.01-16 13)

Lincolnville Fault. This fault is defined by Durá-Gómez and Talwani (Reference 02.05.01-16 02) as one of three northwest-southeast striking reverse faults recognized within an approximately 6 km (3.7 mi.) long antidilational compressional left step of the Woodstock fault near Middleton Place. The Lincolnville fault dips steeply to the northeast. Minor earthquake activity is associated with this fault.

Sawmill Branch Fault. The Sawmill Branch fault, which was speculated to have experienced surface rupture in the 1886 earthquake, was initially differentiated from the southeastern part of the Ashley River fault based on analysis microseismicity (Reference 2.5.1-290). According to Talwani and Katuna (Reference 2.5.1-290), this approximately 5 km (3 mi.) long, northwest-trending fault, which is a segment of the larger Ashley River fault, offsets the Woodstock fault in a left-lateral sense (Figure 2.5.1-221). Earthquake damage at three localities (along the banks of the Ashley River, small, discontinuous cracks in a tomb that dates to 1671 A.D., and displacements (<10 centimeters [cm] [4 inches (in.)]) in the walls of colonial Fort Dorchester) was used to infer that surface rupture occurred in 1886.

Field investigations and a review of the postulated evidence for surface rupture in 1886 and seismicity were conducted in support of the Southern Nuclear Company Vogtle ESP Application (Reference 2.5.1-264). The general conclusions from this study were: (1) the features are almost certainly the product of shaking effects as opposed to fault rupture (Reference 2.5.1-264).

Durá-Gómez and Talwani (Reference RAI 02.05.01-16 01) present an updated seismogenic framework for the Charleston area based on relocated earthquake hypocenters. Their analysis of the recorded seismicity between 1974 and 2004 suggests that most of the seismicity within an approximately 6 km (3.6 mi.) long antidilational compressional left step in the right-lateral-oblique Woodstock fault is occurring on the approximately 3 km (1.8 mi.) wide Sawmill Branch fault zone. The inferred dip direction of the Sawmill Branch fault zone to the northeast is opposite to the earlier interpretation of a southwest dip or the inferred dip of the essentially aseismic Ashley River fault. Fault plane solutions suggest that the Sawmill Branch fault behaves as a left-lateral fracture but displays a significant reverse component (Reference RAI 02.05.01-16 02).

Summerville Fault. Weems et al. (Reference 2.5.1-288) postulated the existence of the Summerville fault on the basis of microseismicity (Figure 2.5.1-221). Based on a review and analysis of these data for the Southern Nuclear Company Vogtle ESP Application (Reference 2.5.1-264), it was concluded that there is no geomorphic or borehole evidence for the existence of the Summerville fault, and microseismicity in the vicinity of the proposed Summerville fault does not clearly define a discrete structure (Figure 2.5.1-225).

Woodstock Fault. Talwani (Reference 2.5.1-288) identifies the Woodstock fault, a postulated north-northeast-trending, dextral strike-slip fault, on the basis of a linear zone of seismicity located approximately 9.6 km (0.6 mi.) west of Woodstock, South Carolina, in the meizoseismal area of the 1886 Charleston earthquake.

In a recent revised seismotectonic framework for the Charleston earthquakes, the Woodstock fault is defined by Talwani and Durá-Gómez (Reference RAI 02.05.01-16 01) as an approximately 50 km (31 mi.) long, approximately N30°E striking, northwest-dipping fault characterized by right-lateral-oblique strike-slip motion, with an associated approximately 6 km (3.7 mi.) long antidilational compressional left step near Middleton Place that divides the fault zone into Woodstock North and Woodstock South faults (RAI 02.05.01-16 Figure 3). The Woodstock North fault lies along the southeast boundary of a buried Triassic basin, and the current seismicity is inferred to be due to its reactivation (Reference RAI 02.05.01-16 03). Based on a review of available geomorphological, geodetic, shallow stratigraphic, seismic reflection, refraction and potential field data, Talwani and Durá-Gómez (Reference RAI 02.05.01-16 03) conclude the ongoing tectonic activity has resulted in breaking the overlying basalt along the Woodstock fault and warping of the overlying sediments. The current seismicity in the Charleston area is reportedly due to the reactivation of the Woodstock North fault (Reference RAI 02.05.01-16 03). Talwani and Durá-Gómez (Reference RAI 02.05.01-16 03) integrated their revised seismogenic framework with the observed effects of the 1886 earthquake and conclude that the most intense shaking occurred on the Woodstock fault (North and South) and the northwest-southeast-trending Charleston and Lincolnville faults and comparatively less on the Sawmill Branch fault. That comparison suggests that most of the built up stress along the Woodstock and the faults was released in 1886, leaving only the Sawmill Branch fault currently seismic. Durá-Gómez and Talwani (Reference 02.05.01-16 02) infer that the mainshock of the 1886 Charleston earthquake was probably associated with the N30°E oriented, oblique right-lateral strike-slip Woodstock fault.

Chapman and Beale (Reference RAI 02.05.01-16 04) present additional evidence for reactivation of faulting near the intersection of the inferred Woodstock and Sawmill Branch faults. Reprocessing of seismic reflection profile VT-3b, originally collected in 1981, provides an improved image of the shallow crust in the epicentral area of the 1886 Charleston earthquake. There is clear evidence in the reprocessed line of a down-to-the-east steeply dipping fault with approximately 200 m (61 m) of vertical offset that displaces lower Mesozoic sedimentary and volcanic rocks. The overlying Cretaceous and Tertiary sedimentary section shows approximately 10 m (33 ft.) of reverse up-to-the-east displacement that can be resolved to within 100 m (30 m) of the ground surface. Two other near-vertical faults with down-to-the-east offset of lower Mesozoic units are inferred to be located to the northwest of the major fault. The faulting is considered to be a likely candidate structure for the 1886 Charleston earthquake. The existing reflection data (which includes several other seismic lines), although suggestive of extensions of the faulting to the north and south, do not have sufficient resolution to constrain the strike of the faulting imaged on VT-3b.

Association with Mesozoic Basins

Johnston et al. (Reference 2.5.1-295) evaluated the correlation of large-magnitude intraplate earthquakes to specific tectonic environments throughout the world. They concluded that large-magnitude earthquakes generally occur in tectonic environments characterized by Mesozoic and younger rifted crust. The Charleston meizoseismal region occurs in a region of Mesozoic extended crust along the southeastern margin of the North American craton (Reference 2.5.1-295). Several Mesozoic basins are defined in the region. The location, structural orientation (i.e., northeast-southwest), and spatial correlation of possible Mesozoic basins and structures was used by Southern Nuclear Company in the Vogtle ESP assessment of the updated Charleston seismic source to characterize alternative models of the source zone geometry (Reference 2.5.1-264). The spatial correlation of the northern segment of the Woodstock fault to the southeast margin fault of the Mesozoic Jedberg basin, which shows reactivation as an oblique right-lateral-slip fault with up to the northwest displacement (Reference 02.05.01-16 03).

Paleoliquefaction Features

Based on the geographic and temporal distribution of paleoliquefaction features in coastal South Carolina, Talwani and Schaeffer [Reference 2.5.1-301] proposed two scenarios for the occurrence in time and space of Charleston-area earthquakes. In their first scenario, three seismic sources are inferred to occur within the coastal plain of South Carolina: a

Charleston source that has produced earthquakes with magnitudes ≥ approximately 7, and a source in each of the Georgetown and Bluffton areas that have produced more moderate earthquakes with magnitudes approximately 6. In Talwani and Schaeffer's (Reference 2.5.1-301) second scenario, all events recorded in the paleoliquefaction record were centered at Charleston with magnitudes ≥ approximately 7.

Intensity Data

Intensity data for the 1886 Charleston earthquake reported by Dutton (Reference 2.5.1-296) and reinterpreted by Bollinger (Reference 2.5.1-303) indicate a meizoseismal area centered on Charleston (Figures 2.5.1-221 and 2.5.1-222). Bakun and Hopper (Reference 2.5.1-294) calculated an intensity center for the 1886 Charleston earthquake that is located offshore about 200 km (125 mi.) east of Charleston (Figure 2.5.1-226). The offshore location for the intensity center may be a function of the spatial distribution of the input data, all of which lie onshore (Reference 2.5.1-294). Bakun and Hopper's (Reference 2.5.1-294) preferred intensity center for the 1886 Charleston earthquake is onshore within the Middleton Place-Summerville seismic zone.

2.5.1.1.4.3.2 Maximum Magnitude (M_{max})

As outlined in the Southern Nuclear Company Vogtle ESP Application (Reference 2.5.1-264), multiple methods and types of data have been used to characterize the maximum magnitude (M_{max}) of the Charleston seismic source. These approaches include using the worldwide data set to constrain the minimum and maximum range of M_{max} for regions of Mesozoic and younger extensional crust (Reference 2.5.1-295) and evaluating the size of the 1886 Charleston earthquake as a proxy for the maximum earthquake that may be produced by the Charleston seismic source (Table 2.5.1-204). The latter approach has used both intensity data (Reference 2.5.1-309, Reference 2.5.1-294) and the size and geographic distribution of the liquefaction fields (Reference 2.5.1-297, Reference 2.5.1-298, Reference 2.5.1-302, and Reference 2.5.1-309) to estimate the magnitude of the 1886 event.

Because the causative fault for the 1886 event is unknown, the Southern Nuclear Company Vogtle ESP Application (Reference 2.5.1-264) update of the Charleston seismic source model considered estimates of M_{max} based on the 1886 earthquake magnitude and worldwide database more reliable than using postulated fault dimensions to estimate M_{max} for the Charleston seismic source. Johnston et al. (Reference 2.5.1-295) compiled a worldwide database of earthquakes in stable continental regions (SCRs) to evaluate the correlation of large-magnitude SCR earthquakes to specific tectonic environments, if any. The database showed that the largest SCR earthquakes (>**M** 7) are confined to regions of Mesozoic and younger extended crust. The maximum observed magnitude for Mesozoic extended crust along passive cratonic margins similar to the southeastern United States is **M** 7.7 ± 0.2 [Reference 2.5.1-295]. Based on an analysis of intensity data, Johnston et al. [Reference 2.5.1-295] estimated the 1886 Charleston earthquake to be **M** 7.56 ± 0.35. Using Bayesian statistics, Johnston et al. [Reference 2.5.1-295] indicated that the M_{max} for the Charleston seismic source should not be much larger than the 1886 event. This conclusion supports the idea that a M_{max} developed for the Charleston seismic source should be primarily based on the estimate of the size of the 1886 Charleston event.

Martin and Clough (Reference 2.5.1-310) used a geotechnical approach to back-calculate ground motions for the 1886 Charleston earthquake based on soil properties of 1886 paleoliquefaction features. The threshold peak ground acceleration required to cause ground deformation was estimated based on the intersection of the layer curve effect of Ishihara (Reference 2.5.1-311) and the cyclic stress method (e.g., Reference 2.5.1-312).

Martin and Clough (Reference 2.5.1-310) concluded that the liquefaction evidence was consistent with an earthquake no larger than **M** 7.5, and possibly as small as **M** 7.0 (Table 2.5.1-204).

Johnston (Reference 2.5.1-309) developed specific eastern North America regressions of seismic moment based on isoseismal area and averaged these with global stable continental regions relations to estimate the magnitude of the 1886 Charleston earthquake. After considering multiple regressions, options for best-weighted values, and a correction for wedge effects of Coastal Plain sediments on isoseismals, a preferred best estimate of **M** 7.3 ± 0.26 (**M** 7.04 – 7.56) was obtained (Table 2.5.1-204). The Johnston study (Reference 2.5.1-309) also estimated a magnitude of **M** 7.4 ± 0.35 (**M** 7.05 – 7.77) using the extent and severity of liquefaction and the Liquefaction Severity Index (LSI). These estimates of M_{max} reflect a slight downward revision from the estimate from the estimate of M_{max} provided in Johnston et al. (Reference 2.5.1-295) of **M** 7.56 ± 0.35. Johnston (Reference 2.5.1-309) concluded that while uncertainties in magnitude are reported, "the final results of this study are best stated in general terms." For the 1886 Charleston earthquake, Johnston (Reference 2.5.1-309) concluded that the best estimate of magnitude is "in the low- to mid-**M** 7 range." The Southern Nuclear Company Vogtle ESP analysis considered this estimate as a credible magnitude and incorporated it into the assessment of M_{max} for the UCSS.

In comparing intensity attenuation with epicentral distance for different stable continental regions, Bakun and McGarr (Reference 2.5.1-313) showed that eastern North America exhibits lower attenuation of seismic energy than other worldwide stable continental regions. Bakun and McGarr (Reference 2.5.1-313) noted that magnitude estimates based on averaging intensity attenuation relations from eastern North America and other stable continental regions may be overestimated. This suggests that Johnston (Reference 2.5.1-309) may have overestimated the magnitude of the 1886 Charleston earthquake.

Bakun and Hopper (Reference 2.5.1-294) estimated the magnitude and location of the 1886 Charleston earthquake using eastern North America intensity models that relate intensity and epicentral distance (Reference 2.5.1-314) Assuming that the 1886 event was centered in the Middleton Place-Summerville cluster of seismicity (and not offshore at their estimated intensity center), Bakun and Hopper (Reference 2.5.1-294) estimated a magnitude range of **M** 6.4 – 7.2 at the 95 percent confidence interval. Bakun and Hopper (Reference 2.5.1-294) preferred magnitude estimate for the Charleston earthquake is M_I 6.9 (M_I is considered equivalent to **M**). The Bakun and Hopper (Reference 2.5.1-294) magnitude estimate suggests that the 1886 event may have been smaller than the Johnston (Reference 2.5.1-309) estimate. Both estimates are considered as credible and are included in the UCSS model (Reference 2.5.1-264).

Obermeier et al. (Reference 2.5.1-297, Reference 2.5.1-298, Reference 2.5.1-302) investigated the spatial distribution, size, and abundance of paleoliquefaction features in the Charleston coastal region and beyond. Based on the widespread distribution of sand blow craters in coastal South Carolina, Obermeier et al. (Reference 2.5.1-298) stated that these features were likely the result of earthquakes with magnitudes of at least m_b 5.5, and probably much stronger. Based on the observation that the limits of prehistoric liquefaction extend at least as far from Charleston as those formed during the 1886 earthquake (and the liquefaction susceptibility of deposits subjected to prehistoric earthquakes was likely as high as the liquefaction susceptibility of those subjected to the 1886 earthquake), Obermeier et al. (Reference 2.5.1-302) suggested that prehistoric Charleston area earthquakes were probably at least as strong as the 1886 Charleston earthquake.

For paleoearthquakes, Talwani and Schaeffer (Reference 2.5.1-301) estimated the magnitudes of past Charleston area events based on the spatial distribution and areal extent of paleoliquefaction sites (Figure 2.5.1-227). Talwani and Schaeffer (Reference 2.5.1-301) did not use a rigorous empirical method in their estimation of the magnitudes of past events. Instead they used a simple approach by which all past liquefaction episodes interpreted as having spanned a region comparable in size to the 1886 liquefaction field were assigned **M** 7+, and all past liquefaction episodes interpreted as having spanned a smaller areal extent were assigned **M** 6+.

Hu et al. (Reference 2.5.1-315, Reference 2.5.1-316) used the event chronology as interpreted by Talwani and Schaeffer (Reference 2.5.1-301) and the energy-stress method to estimate magnitudes of past Charleston area earthquakes. For earthquakes that produced liquefaction features over extended areas centered near Charleston, Hu et al. (Reference 2.5.1-316) estimated magnitudes of **M** 6.8 – 7.8, and they estimated magnitudes of **M** 5.5 – 7.0 for earthquakes that produced liquefaction over more limited areas.

Leon (Reference 2.5.1-317) and Leon et al. (Reference 2.5.1-318) also estimated the magnitudes of past Charleston area earthquakes using the event chronology as interpreted by Talwani and Schaeffer; (Reference 2.5.1-301), but the Leon (Reference 2.5.1-317) and Leon et al. (Reference 2.5.1-318) method takes into account the effects of sediment age on the liquefaction potential of those sediments. Using the magnitude-bound method, Leon et al. (Reference 2.5.1-318) estimated magnitudes of **M** 6.9 – 7.1 for earthquakes that produced liquefaction features over extended areas, and **M** 5.7 – 6.3 for earthquakes that produced liquefaction over more limited areas. Using the energy-stress method, Leon et al. (Reference 2.5.1-318) estimated magnitudes of **M** 5.6 – 7.2 for earthquakes that produced liquefaction features over extended areas, and **M** 4.3 – 6.4 for earthquakes that produced liquefaction over more limited areas.

Based on review of these published observations and analyses, the Southern Nuclear Company Vogtle ESP Application (Reference 2.5.1-263, Reference 2.5.1-264) concluded the following:

- The magnitude ranges estimated for earthquakes that produced liquefaction over extended areas (Reference 2.5.1-315, Reference 2.5.1-316, Reference 2.5.1-318) have significant overlap with magnitude estimates of the 1886 earthquake by Johnston (Reference 2.5.1-309) and Bakun and Hopper (Reference 2.5.1-294). However, given the large uncertainties in working with the paleoliquefaction record and methods for estimating magnitudes from these data, the best representation of the M_{max} for the Charleston seismic source should be based on estimates of the size of the 1886 earthquake (Table 2.5.1-204).
- The magnitudes estimated from the paleoliquefaction record for earthquakes that produced liquefaction over limited areas may have been less than **M** 6.3 (Reference 2.5.1-318). This implies that some events in the paleoliquefaction record may not represent large, 1886-type characteristic earthquakes. Therefore, the inclusion of any smaller paleoearthquakes in the recurrence model may bias the recurrence toward moderate-sized earthquakes and may overestimate the frequency of large events.
- Taken together, these new data suggest that M_{max} for the 1886 Charleston earthquake is on the order of **M** 6 ¾ to 7 ½ (Reference 2.5.1-310, Reference 2.5.1-309, Reference 2.5.1-294; Table 2.5.1-204). The 95 percent-confidence interval of Bakun and Hopper (Reference 2.5.1-294) implies the magnitude could have been as low as **M** 6.4; however, the preponderance of the

data and evaluations indicate that the low end of this estimate likely underestimates the size of the 1886 earthquake.

2.5.1.1.4.3.3 Recurrence

Post-1986 EPRI studies of paleoliquefaction features (e.g., Reference 2.5.1-299, Reference 2.5.1-270, Reference 2.5.1-300, Reference 2.5.1-301] suggest that recurrence of large earthquakes on the Charleston seismic source is on the order of hundreds of years. This is significantly less than the EPRI model recurrence of several thousand years predicted by historical seismicity.

Earthquakes recorded in the paleoliquefaction record may include events significantly less than M_{max} because the minimum threshold magnitude for earthquakes to cause liquefaction is estimated as m_b>5.5 (Reference 2.5.1-298) or **M** 4.3 – 6.4 (Reference 2.5.1-318). It was noted in the Southern Nuclear Company Vogtle ESP Application (Reference 2.5.1-264) that estimates of M_{max} recurrence intervals based upon the paleoliquefaction record may include events smaller than M_{max} and overestimate the frequency of M_{max} recurrence. Simply because the age determinations for paleoliquefaction features at widely distributed sites overlap, does not necessitate that the features were the result of a single, large earthquake. The possibility that paleoliquefaction features of similar age (i.e., within the uncertainty in age determination) resulted from smaller earthquakes that occurred over a wide area, closely spaced in time is an inherent uncertainty in the paleoliquefaction record. Recent (post-1986) EPRI studies that characterized the recurrence of prehistoric earthquakes from the paleoseismic record are described below:

- Amick (Reference 2.5.1-299) and Amick et al. (Reference 2.5.1-300, Reference 2.5.1-270) used liquefaction data collected from South Carolina and their more regional reconnaissance investigations along the North Carolina and Virginia coastlines to suggest that large earthquakes occur every 500 to 600 years in Coastal South Carolina, and that paleoliquefaction evidence for earthquakes located outside of South Carolina is lacking.

- Talwani and Schaeffer (Reference 2.5.1-301) combined previously published data with their own studies of liquefaction features in the South Carolina coastal region (Figure 2.5.1-227). Talwani and Schaeffer (Reference 2.5.1-301) used the spatial distribution of paleoliquefaction features in combination with estimates on the timing of the formation of the liquefaction features in order to derive possible earthquake recurrence histories for the region. Talwani and Schaeffer's (Reference 2.5.1-301) scenario 1 allows for the possibility that some events in the paleoliquefaction record are smaller in magnitude (approximately **M** 6+), and these more moderate events occurred to the northeast (Georgetown) and southwest (Bluffton) of Charleston. In scenario 2 (Reference 2.5.1-301), all earthquakes in the record are large shocks (approximately **M** 7+) located near Charleston. Talwani and Schaeffer's (Reference 2.5.1-301) preferred estimate for the recurrence of large earthquakes in coastal South Carolina is 500 to 600 years.

- For the SNC Vogtle ESP study, the radiocarbon ages used by Talwani and Schaeffer (Reference 2.5.1-301) were analyzed and recalibrated to report the ages with 2-sigma error bands that give broader age ranges for paleoliquefaction events in the Charleston area (Reference RAI 02.05.01-16 14). (The 1-sigma error bands used by Talwani and Schaeffer (Reference 2.5.1-301) are considered by many to be too narrow and thus leading to potential over-interpretation such that more episodes of paleoliquefaction are interpreted than actually occurred.) The 2-sigma analysis identified six earthquakes (including the 1886 event) in which event ages were defined and considered to represent the 95 percent- confidence interval based on grouping paleoliquefaction features that have overlapping calibrated radiocarbon ages. This analysis indicated that each of the six earthquakes represent large, Mmax events, in contrast to the Talwani and Schaeffer (Reference 2.5.1-301) scenario in which some smaller, moderate-magnitude events are recognized."

<u>References</u>

Reference RAI 02.05.01-16 01

Talwani, P., and I. Durá-Gómez, I., 2008, "A revised seismotectonic framework for the Charleston, South Carolina earthquake," (abstract) 2008 AGU Fall Meeting, SF, CA, S42A-06.

Reference RAI 02.05.01-16 02

Durá-Gómez, I., and P. Talwani, "Finding faults in the Charleston area, South Carolina: 1. Seismological Data", unpublished manuscript submitted to Seismological Research Letters (in review), 54 p.

Reference RAI 02.05.01-16 03

Talwani, P., and I. Durá-Gómez, I., "Finding faults in the Charleston area, South Carolina: 2. Corroborative Data", unpublished manuscript submitted to Seismological Research Letters (in review), 62 p.

Reference RAI 02.05.01-16 04

Chapman, M.C. and Beale, J.N., "Mesozoic and Cenozoic faulting imaged at the epicenter of the 1886 Charleston, South Carolina, earthquake", Bulletin of the Seismological Society of America, vol. 98, No. 5, 2008, p. 2533-2542.

Reference RAI 02.05.01-16 05

Electronic communication from Ross Hartleb, William Lettis & Associates, Inc., December 17, 2008.

Reference RAI 02.05.01-16 06

Electronic communication from Scott Lindvall, William Lettis & Associates, Inc., December 10, 2008.

Reference RAI 02.05.01-16 07

Waldhauser, F., "HypoDD: a program to compute double-difference hypocenter locations", U. S. Geological Survey Open-File Report 01-113.

Reference RAI 02.05.01-16 08

Wheeler, R.L., 2006, "Quaternary tectonic faulting in the Eastern United States", Engineering Geology, Vol. 82, p. 165-186.

Reference RAI 02.05.01-16 09

Talwani, P., "Macroscopic effects of the 1885 Charleston earthquake," Field trip #1, 2000, 6 pp.

Reference RAI 02.05.01-16 10

Lennon, G., 1986,"Identification of a northwest trending seismogenic graben near Charleston, South Carolina," U. S. Nuclear Regulatory Commission Report, NUREG/CR-4075, 43p..

Reference RAI 02.05.01-16 11

Behrendt, J.C., Hamilton, R. M. Ackermann, H.D., Henry, V.J., "Cenozoic faulting in the vicinity of the Charleston, South Carolina, 1886 earthquake", Geology, v. 9, 1981,p. 117-122.

Reference RAI 02.05.01-16 12

Hamilton, R. M., J.C. Behrendt, and H.D. Ackermann, "Land multichannel seismic reflection evidence for tectonic features near Charleston, South Carolina," *in* Gohn, G. S., ed., Studies related to the Charleston, South Carolina, earthquake of 1886—Tectonics and seismicity: U.S. Geological Survey Professional Paper 1313, 1983. p. I1–I18.

Reference RAI 02.05.01-16 13

Peterson, M. D., A. D. Frankel, S. C. Harmsen, C. S. Mueller, K. M. Haller, R. L. Wheeler, R.L. Wessonk Y. Zeng, O.S. Boyd, D.M.Perkins, N. Luco, E.H. Field, C.J. Wills, and K.S. Rukstales, 2008, "Documentation for the 2008 Update of the United States National Seismic Hazard Maps," U.G. Geological Survey Open-File Report 2008-1128.127 p.

Reference RAI 02.05.01-16 14

Southern Nuclear Operating Company (SNC), 2007, "Response to March 15, 2007 RAI Letter No. 6 for the Vogtle ESP Application Involving Geology, Seismology and Geotechnical Engineering, AR-07-0801, Enclosure 1," submitted April 16, 2007.

Reference RAI 02.05.01-16 15

Talwani, P., "Paleoseismological Studies in the Charleston, South Carolina Region", Annual Project Summary 04HQGR0053, 2004, 5 pp.

Attachments/Enclosures:

Attachment 02.05.01-16A:	RAI 02.05.01-16 Figure 1
Attachment 02.05.01-16B:	RAI 02.05.01-16 Figure 2
Attachment 02.05.01-16C:	RAI 02.05.01-16 Figure 3
Attachment 02.05.01-16D:	RAI 02.05.01-16 Figure 4
Attachment 02.05.01-16E:	RAI 02.05.01-16 Figure 5

List of Files included on Attached CD:

Attachment 02.05.01-10A.pdf
Attachment 02.05.01-10B.pdf
Attachment 02.05.01-10C.pdf
Attachment 02.05.01-10D.pdf
Attachment 02.05.01-10E.pdf
Attachment 02.05.01-10F.pdf
Attachment 02.05.01-10G.pdf
Attachment 02.05.01-10H.pdf
Attachment 02.05.01-10I.pdf
Attachment 02.05.01-10J.pdf
Attachment 02.05.01-10K.pdf
Attachment 02.05.01-10L.pdf
Attachment 02.05.01-10M.pdf
Attachment 02.05.01-10N.pdf
Attachment 02.05.01-10O.pdf
Attachment 02.05.01-10P.pdf
Attachment 02.05.01-10Q.pdf
Attachment 02.05.01-10R.pdf
Attachment 02.05.01-11A1.pdf
Attachment 02.05.01-11A2.pdf
Attachment 02.05.01-11A3.pdf
Attachment 02.05.01-11A4.pdf
Attachment 02.05.01-11A5.pdf
Attachment 02.05.01-11A6.pdf
Attachment 02.05.01-11B.pdf
Attachment 02.05.01-11C1.pdf
Attachment 02.05.01-11C2.pdf
Attachment 02.05.01-11C3.pdf
Attachment 02.05.01-11C4.pdf
Attachment 02.05.01-12A.pdf
Attachment 02.05.01-12B.pdf
Attachment 02.05.01-12C.pdf
Attachment 02.05.01-12D.pdf
Attachment 02.05.01-12E.pdf
Attachment 02.05.01-16A.pdf
Attachment 02.05.01-16B.pdf
Attachment 02.05.01-16C.pdf
Attachment 02.05.01-16D.pdf
Attachment 02.05.01-16E.pdf

Pre-Flight Report for Files Included on Attached CD

This document serves as a pre-flight report for the attachments to responses specific to NRC RAI LTR-030, Supplement 2, in support of the Harris COLA. All files passed pre-flight, therefore they comply with the NRC electronic submittal checklist.