Greg Gibson
Vice President, Regulatory Affairs

750 East Pratt Street, Suite 1600
Baltimore, Maryland 21202

UniStar
NUCLEAR ENERGY

10 CFR 50.4
10 CFR 52.79

May 01, 2009

UN#09-227

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

Subject: UniStar Nuclear Energy, NRC Docket No. 52-016
Response to Request for Additional Information for the Calvert Cliffs Nuclear Power Plant, Unit 3,
RAI No. 71, Basic Geologic and Seismic Information
RAI No. 72, Vibratory Ground Motion

References:
1) John Rycyna (NRC) to Robert Poche (UniStar), "RAI No 71 RGS 1928.doc, (PUBLIC)" email dated February 26, 2009
2) John Rycyna (NRC) to Robert Poche (UniStar), "RAI No 72 RGS 2070.doc, (PUBLIC)" email dated February 26, 2009
3) Greg Gibson (UniStar) Letter to Document Control Desk (NRC), Response to Request for Additional Information for the Calvert Cliffs Nuclear Power Plant, Unit 3, RAI No. 71, Basic Geologic and Seismic Information RAI No. 72, Vibratory Ground Motion, dated April 15, 2009

The purpose of this letter is to respond to the requests for additional information (RAIs) identified in the NRC e-mail correspondence to UniStar Nuclear Energy, dated February 26, 2009 (References 1 and 2). These RAIs address Basic Geologic and Seismic Information, as discussed in Section 2.5.1; and Vibratory Ground Motion, as discussed in Section 2.5.2 of the Final Safety Analysis Report (FSAR), as submitted in Part 2 of the Calvert Cliffs Nuclear Power Plant (CCNPP) Unit 3 Combined License Application (COLA), Revision 4.

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Enclosure 1 provides a summary of the questions for RAI 71 & 72 and their status.

Enclosure 2 provides our responses to RAI 71 Questions 02.05.01-2, -3, -5, -13, -14, -15, -19, -20, -25, and -27; and RAI 72 Questions 02.05.02-2, -3, -4, -5, -8, -9, -12, -13 and -14.

COLA impacts associated with these RAI responses are noted with the question response.

A Licensing Basis Document Change Request has been initiated to incorporate these changes into a future revision of the COLA.

Our responses do not include any new regulatory commitments.

If there are any questions regarding this transmittal, please contact me at 410-470-4205, or Mr. Michael J. Yox at (410) 495-2436.

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

Executed on May 01, 2009

Christian Clement
for Greg Gibson

Greg Gibson

Enclosures: 1) Response Summary for Request for Additional Information, RAI No. 71, Basic Geologic and Seismic Information, and RAI No. 72, Vibratory Ground Motion Calvert Cliffs Nuclear Power Plant Unit 3

2) Partial Response to NRC Request for Additional Information, RAI No. 71, Basic Geologic and Seismic Information, and RAI No. 72, Vibratory Ground Motion Calvert Cliffs Nuclear Power Plant Unit 3

3) Enlarged drawings, reference RAI No. 71, Question 02.05.01-5, Figure 1, "Approximate Altitude of the Top of the Piney Point-Nanjemoy Aquifer Showing Cross Section Locations A-A' and B-B', Figure 2, "Hydrogeologic Cross Section A-A' extending near Bristol, Anne Arundel County to Near James, St. Mary's County" and Figure 3, "Hydrogeologic Cross Section B-B' Extending Near La Plata, Charles County to Point Lookout, St. Mary's County"

cc: John Rycyna, NRC Project Manager, U.S. EPR COL Application
Laura Quinn, NRC Environmental Project Manager, U.S. EPR COL Application
Getachew Tesfaye, NRC Project Manager, U.S. EPR DC Application (w/o enclosure)
Loren Plisco, Deputy Regional Administrator, NRC Region II (w/o enclosure)
Silas Kennedy, U.S. NRC Resident Inspector, CCNPP, Units 1 and 2
U.S. NRC Region I Office

Enclosure 1

Response Summary for Request for Additional Information, RAI No. 71, Basic Geologic and Seismic Information, and RAI No. 72, Vibratory Ground Motion Calvert Cliffs Nuclear Power Plant Unit 3

Enclosure 1 of this RAI response provides a summary of the dates for submittal of responses to RAI 71 and 72 questions.

RAI Set 71

Question	Response Status
02.05.01-1	Responded by letter UN#09-152 dated 4/15/09
02.05.01-2	This Letter – see Enclosure 2
02.05.01-3	This Letter – see Enclosure 2
02.05.01-4	Responded by letter UN#09-152 dated 4/15/09
02.05.01-5	This Letter – see Enclosure 2
02.05.01-6	Responded by letter UN#09-152 dated 4/15/09
02.05.01-7	Responded by letter UN#09-152 dated 4/15/09
02.05.01-8	Responded by letter UN#09-152 dated 4/15/09
02.05.01-9	Responded by letter UN#09-152 dated 4/15/09
02.05.01-10	Responded by letter UN#09-152 dated 4/15/09
02.05.01-11	Responded by letter UN#09-152 dated 4/15/09
02.05.01-12	Responded by letter UN#09-152 dated 4/15/09
02.05.01-13	This Letter – see Enclosure 2
02.05.01-14	This Letter – see Enclosure 2
02.05.01-15	This Letter – see Enclosure 2
02.05.01-16	Responded by letter UN#09-152 dated 4/15/09
02.05.01-17	Responded by letter UN#09-152 dated 4/15/09
02.05.01-18	Responded by letter UN#09-152 dated 4/15/09
02.05.01-19	This Letter – see Enclosure 2
02.05.01-20	This Letter – see Enclosure 2
02.05.01-21	Responded by letter UN#09-152 dated 4/15/09
02.05.01-22	Responded by letter UN#09-152 dated 4/15/09
02.05.01-23	Responded by letter UN#09-152 dated 4/15/09
02.05.01-24	Responded by letter UN#09-152 dated 4/15/09
02.05.01-25	This Letter – see Enclosure 2
02.05.01-26	Responded by letter UN#09-152 dated 4/15/09
02.05.01-27	This Letter – see Enclosure 2
02.05.01-28	Responded by letter UN#09-152 dated 4/15/09
02.05.01-29	Responded by letter UN#09-152 dated 4/15/09
02.05.01-30	Responded by letter UN#09-152 dated 4/15/09
02.05.01-31	Responded by letter UN#09-152 dated 4/15/09
02.05.01-32	Responded by letter UN#09-152 dated 4/15/09

RAI Set 72

Question	**Response Status**
02.05.02-1	Responded by letter UN#09-152 dated 4/15/09
02.05.02-2	This Letter – see Enclosure 2
02.05.02-3	This Letter – see Enclosure 2
02.05.02-4	This Letter – see Enclosure 2
02.05.02-5	This Letter – see Enclosure 2
02.05.02-6	Responded by letter UN#09-152 dated 4/15/09
02.05.02-7	Responded by letter UN#09-152 dated 4/15/09
02.05.02-8	This Letter – see Enclosure 2
02.05.02-9	This Letter – see Enclosure 2
02.05.02-10	Not issued
02.05.02-11	Responded by letter UN#09-152 dated 4/15/09
02.05.02-12	This Letter – see Enclosure 2
02.05.02-13	This Letter – see Enclosure 2
02.05.02-14	This Letter – see Enclosure 2

Enclosure 2

Partial Response to NRC Request for Additional Information, RAI No. 71, Basic Geologic and Seismic Information, and RAI No. 72, Vibratory Ground Motion Calvert Cliffs Nuclear Power Plant Unit 3

RAI No 71

Question 02.05.01-2

FSAR Section 2.5.1.1.3.1.4 describes the Plio-Peistocene Upland stratigraphic unit as a, "...sediment sheet whose base slopes toward the southwest (Glaser, 1971) (Hansen, 1996). This erosion might have occurred due to differential uplift during the Pliocene or down cutting in response to lower base levels when sea level was lower during period of Pleistocene glaciation." Additionally, this FSAR Section states "[Quaternary Lowland] deposits occur in only a few places along the eastern shore of Chesapeake Bay". FSAR Section 2.5.1.2.3.3 makes similar statements.

The peninsula the CCNPP site occupies has highly asymmetric topography, steep to the northeast. Schlee (1957, GSA Bull. 68: 1371-1410) discusses the depositional setting of the Upland deposits and possible causes of the southwest dip of their basal contact and the asymmetric topography and concludes neotectonic tilting is strongly suggested. Furthermore, FSAR Figure 2.5-29B shows a progressive southwestward shifting of Quaternary paleochannels within Chesapeake Bay.

Please provide additional discussion with regard to the seismic hazard at the CCNPP site and possible Pliocene or Quaternary neotectonics, Pleistocene glacial effects, and the east-facing monoclines of McCartan (1995).

Response

This question requests a discussion of "Pliocene or Quaternary neotectonics, Pleistocene glacial effects, and the east-facing monoclines of McCartan (1995)." Pleistocene glacial effects are discussed in the response to RAI 71, Question 02.05.01-20, and the east-facing monoclines hypothesized by McCartan et al. (1995) are discussed in the response to RAI 71, Question 02.05.01-32. Therefore, the response to this question focuses on the issues surrounding Pliocene or Quaternary neotectonics raised in this RAI question and observations by Schlee (1957).

Plio-Pleistocene "Upland Gravels" (the topic of this question) represent a regionally extensive coarse-grained fluvial unit with litho- and biostratigraphic corollaries between southeastern Pennsylvania and northeastern Virginia (e.g., Hack, 1955; Hack 1957; Schlee, 1957; Owens and Minard, 1979; Owens and Denny, 1979; Ramsey, 1992; Pazzaglia, 1993; McCartan et al., 1995; Newell et al., 2000). These deposits have been extensively studied for nearly a century (as noted by references provided in Hack [1955] and Schlee [1957], and more recent studies, e.g., Pazzaglia [1993], McCartan et al. [1995]). Schlee (1957) noted that the gravels are gently inclined to the south and southwest and have an asymmetrical drainage pattern (e.g., steep northeast-facing slopes compared to more gently-graded southwest-facing slopes). Schlee (1957) systematically presents and discusses four possible causes for these observations (coriolis force, structural control, offshore bars, and regional tilting) before finally postulating that, "the cause of the tilting is not known unless it might have been related to crustal adjustment due to formation of the Pleistocene ice sheet to the north" (page 1399).

The observations of Schlee (1957), and the potential for them to reflect neotectonic processes were re-evaluated as part of the FSAR efforts for CCNPP Unit 3. Based on a wide-ranging survey of available literature, it is clear that despite the long-standing recognition of the potentially anomalous dip of the gravels, there is no clear consensus within the scientific community for the origin of the numerous depositional (i.e., southerly tilt of Pliocene to Quaternary deposits) and geomorphic oddities in the Salisbury embayment. For example, multiple hypotheses exist that attempt to explain the regional depositional and geomorphologic patterns similar to those described by Schlee (1957), including:

- Regional-scale tilting of the Atlantic coastal margin and independent movement associated with depocenters and intervening arches and structures (Barosh, 1990; Ward, 1992);

- Tertiary displacement along northeast-southwest trending lineaments (e.g. Brandywine and Stafford faults; Mixon et al., 1977; Hansen, 1978; Hack et al., 1989; Mixon et al., 1992);

- Sediment loading and flexural response (Pazzaglia and Gardner, 1993; Poag, 1997);

- Glacial isostatic adjustment (e.g., Gornitz and Seeber, 1990; Pazzaglia and Gardner; 1993; Mitrovica and Davis, 1995; Davis and Mitrovica, 1996; Mitrovica et al., 2001; Douglas and Peltier, 2002; Reusser et al., 2004; Gehrels et al., 2004; Scott, 2006; Pavich et al., 2006);

- Uplift of the northern Appalachians and regional down-to-the-southwest tectonic tilting (Newell and Rader, 1982 as cited in Pazzaglia, 1993 and Ramsey, 1992; Hack et al., 1989); and

- Regional influence of the 35 Ma Chesapeake Bay impact structure (Poag, 1997).

As detailed in the references supporting these ideas, the potential causes of the southerly dip of Pliocene to Quaternary deposits are wide ranging, highly speculative, and potentially interrelated. Despite the uncertainty in the cause of the southerly tilt, none of the proposed geologic processes summarized above, postulates the presence of a capable seismic source (e.g., the northeast-trending Brandywine and Stafford faults are not capable faults; See FSAR Section 2.5.1.1.4.4.4). Therefore, the potentially anomalous geomorphic characteristics of the gravels and unexplained drainage asymmetry do not motivate a revision of the EPRI-SOG seismic source characterizations for CCNPP Unit 3 (NRC Reg. Guide 1.165). Therefore, there is no impact on the seismic hazard assessment at the site inferred from the south to southwest dipping Upland Gravels.

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COLA Impact

None

Question 02.05.01-3

FSAR Section 2.5.1.1.4 quotes Johnston et al (1994) "...global review of earthquakes in [stable continental regions] SCRs shows that areas of Mesozoic and Cenozoic extended crust are positively correlated with large SCR earthquakes. Nearly 70% of SCR earthquakes with [magnitude] M 6 or greater occurred in areas of Mesozoic and Cenozoic extended crust..."

Schulte and Mooney (2005, Geophys. J. Int., 161: 707-721) reassessed whether earthquakes within SCRs are associated with rifted crust. The dataset for that study contained over 1300 magnitude ≥ 4.5 historic and instrumentally recorded crustal earthquakes. CCNPP is located in a SCR region that is also extended crust due to the Mesozoic rifting of Pangaea in the formation of the Atlantic Ocean. There are buried rift basins in the immediate vicinity of CCNPP. The Schulte and Mooney (2005) paper is a significant rework and analysis of the issue of earthquakes in SCRs that post-dates Johnston et al 1994.

Please provide a discussion of the relevance of the Schulte and Mooney paper for the CCNPP site.

Response

In preparing the CCNPP Unit 3 FSAR, the Johnston et al. (1994) report was evaluated to determine whether this body of research constituted new information that should motivate revisions to EPRI-SOG seismic source characterizations (EPRI, 1986) per the guidance provided in NRC Regulatory Guide 1.165 (NRC, 1997). This evaluation resulted in the determination that there was no new information or data within the Johnston et al. (1994) report that required updating of the EPRI-SOG source characterizations. The basis for this conclusion is that the EPRI-SOG earth science teams (ESTs) were aware of the primary conclusion of the Johnston et al. (1994) study that there was a correlation between Mesozoic and Cenozoic extended crust and large stable continental region (SCR) earthquakes and thus already accounted for that observation in their seismic source characterizations.

As described in this question, the Schulte and Mooney (2005) study reassesses the correlation between earthquakes and extended and non-extended SCRs using an updated SCR earthquake catalog. Based on their analysis, Schulte and Mooney (2005) made numerous observations and conclusions that largely support the conclusions of Johnston et al. (1994). In particular, Schulte and Mooney (2005) conclude that:

1. Extended SCR crust only has slightly more earthquakes then non-extended SCR crust, and

2. The largest SCR earthquakes (Mw > 7.0) occur predominately within extended crust.

Schulte and Mooney (2005) state that these conclusions are essentially the same as those of the Johnston et al. (1994) study, and thus the relevance of the Schulte and Mooney (2005) study is that it supports the results of the Johnston et al. (1994) study. Therefore, Schulte and Mooney (2005) do not present any new information with respect to the seismic potential of rifted SCRs that requires specific updates to the EPRI-SOG source characterizations used for the CCNPP site.

The basis for these conclusions is presented below in additional detail.

Johnston et al. (1994) Study

The Johnston et al. (1994) study was conducted from the mid-1980s to the early 1990s under the direction of EPRI with the goal of developing an earthquake database for SCRs worldwide and exploring the possibility of using this database to help constrain characterizations of the potential for large earthquakes within SCRs. To accomplish this goal, the Johnston et al. (1994) study:

(1) Defined SCRs worldwide, subdivided these regions into tectonic domains, and defined descriptor variables for these domains (e.g., crust type, tectonic age, stress regime) (see Chapter 2 of Johnston et al. (1994)).

(2) Compiled a global catalog of earthquakes within SCRs (see Chapter 3 of Johnston et al. (1994)).

(3) Tested for significant statistical correlations between the SCRs subdivided at different levels and the maximum observed earthquake magnitude with these subdivisions to determine if a robust estimator of Mmax values could be developed (see Chapter 5 of Johnston et al. (1994)).

Two of the fundamental assumptions of the Johnston et al. (1994) study are: (1) that for similar tectonic domains within SCRs worldwide (e.g., extended Mesozoic crust), space can be traded for time to allow development of a composite earthquake catalog for that particular style of tectonic domain that is larger than the catalog of earthquakes within just a single occurrence of that domain (e.g., extended Mesozoic crust in North America); and (2) these grouped, similar tectonic domains (e.g., all extended Mesozoic crust worldwide) have the same fundamental seismicity characteristics (i.e., maximum magnitudes (Mmax)).

EPRI's primary motivation for initiating the Johnston et al. (1994) study was twofold: (1) to provide the EPRI-SOG ESTs with guidance on estimating Mmax values for source zones within the central and eastern US (CEUS); and (2) to determine if there is a robust method of estimating Mmax based on historical seismicity. The Johnston et al. (1994) study was conducted in two phases to meet these goals. As part of the first phase, Johnston et al. (1994) developed an initial division of SCRs based on tectonic features and a global catalog of earthquakes within SCRs. These materials were then used to develop first-order conclusions to aid the ESTs in their development of source characterizations for the CEUS. The main conclusion presented to the ESTs was that there is an association between rifts and passive margins of Mesozoic and younger age, where age is defined as the time of the last penetrative deformation (page 2-4) (Johnston et al., 1994), and the largest observed earthquakes in SCR regions (see chapter 1, page 1-2 of Johnston et al. (1994)).

The second phase of the Johnston et al. (1994) study attempted to expand upon this conclusion and determine if there was a robust method for estimating Mmax based on historical earthquakes by following three steps: (1) defining tectonic domains; (2) developing a SCR seismicity catalog; and (3) testing for statistical correlation between the tectonic domains and seismicity.

As part of this effort Johnston et al. (1994) refined their subdivision of tectonic domains and their defining characteristics (see Chapter 2 of Johnston et al. (1994)). The broadest subdivision used by Johnston et al. (1994) to classify SCRs was that between extended and non-extended crust. Extended crust includes regions of rifting, distributed continental extension, and passive margins; non-extended crust includes the remainder of SCR crust. In addition to this subdivision, Johnston et al. (1994) further defined 24 different categories of non-extended crust and 720 categories of extended crust based on what they refer to as descriptor variables characterizing the crust (e.g., stress regime, crustal type, crustal age) (see Chapter 2 and 5 of Johnston et al. (1994)).

These subdivisions, representing different sets of descriptor variables, were examined to determine if there was a statistically significant correlation between the subdivisions and the maximum observed earthquakes in the subdivisions. The conclusion reached by Johnston et al. (1994) from analyzing all of the different subdivisions and descriptor variables was that there is only a slight statistical difference between the mean maximum observed earthquake magnitude in extended crust and the mean maximum observed magnitude in non-extended crust. Additionally, no other descriptor variable was found to have a statistically significant correlation. Johnston et al. (1994) qualify the impact of these conclusions by stating, "we find that there is no strong evidence that any typical extended crust domain has a larger maximum magnitude than a typical non-extended crust domain," (page 5-17) (1994). Johnston et al. (1994) essentially concluded that a robust estimator of Mmax cannot be found using the assumption of space-time equivalence for seismicity and the tectonic descriptions of SCRs defined by Johnston et al. (1994).

Despite the lack of a robust estimator for Mmax, the main conclusion from the first phase of the Johnston et al. (1994) study persisted through the end of the second phase and was refined to say that the maximum observed earthquake in extended SCRs worldwide is greater than the maximum observed earthquake in non-extended SCRs (see Chapter 4 and 5 of Johnston et al. (1994)). As summarized above and outlined in Chapter 1 of Johnston et al. (1994), this main conclusion of the study was presented to the EPRI-SOG ESTs during their evaluations of seismic sources. The information contained within this conclusion was evaluated by the EPRI-SOG ESTs, and thus the information is not new information that requires updating of the EPRI-SOG source characterizations.

Schulte and Mooney (2005) Study

Largely due to the results of the Johnston et al. (1994) study, many in the seismic hazards community have held the opinion that there is a difference in seismicity between extended and non-extended SRCs. The stated purpose of the Schulte and Mooney (2005) study was to reevaluate this hypothesis using an updated earthquake catalog. Unlike the Johnston et al. (1994) study, the goal of the Schulte and Mooney (2005) study was not to investigate SCR Mmax values.

Besides the difference in study motivation, there are three main methodological differences between the Johnston et al. (1994) and Schulte and Mooney (2005) studies:

1. Schulte and Mooney (2005) used an updated seismicity catalog with approximately 58% more earthquakes than in the Johnston et al. (1994) catalog;

2. Schulte and Mooney (2005) divided SCRs into five different classifications of tectonic domains (interior rifts, rifted margins, non-rifted crust, possible interior rifts, and possible rifted margins) as opposed to the hundreds used by Johnston et al. (1994); and

3. Instead of performing statistically robust regressions between domain classifications and earthquakes within the domains, Schulte and Mooney (2005) simply calculated the proportions of SCR earthquakes and seismic moment occurring within the domains for various subsets of the catalog based on earthquake magnitudes, completeness, and measurement type (i.e., historical vs. instrumental) (see Figure 3 of Schulte and Mooney (2005)).

Based on their analysis of the updated seismicity catalog, Schulte and Mooney (2005) present nine specific conclusions (see page 719 of Schulte and Mooney (2005)). Each of these conclusions is discussed below with respect to its relevance for potentially updating the EPRI-SOG source characterizations used for CCNPP.

Conclusions 1-3

- 27% of earthquakes occur within interior rifts, 25% within rifted margins, 36% occur within non-rifted crust, and 12% have an uncertain setting;

- These percentages imply that within interior regions there are slightly more earthquakes within non-rifted crust (36%) than within rifts (25%); and

- These results are relatively stable if only instrumental earthquakes are considered.

Schulte and Mooney (2005) state that these results are similar to the results of Johnston et al. (1994), and thus Schulte and Mooney (2005) provide support to the conclusion that their study presents no new information or data that motivates revisions to the EPRI-SOG source characterizations used for CCNPP.

Conclusion 4

- The above results are relatively stable if only Mw > 6.0 earthquakes are considered, but Mw > 7.0 earthquakes overwhelmingly occur within rifted crust.

This conclusion is essentially the same as that of Johnston et al. (1994) that noted the maximum observed earthquakes in extended SCRs worldwide is greater than the maximum observed earthquakes in non-extended SCRs. Therefore, this conclusion is not considered new information that requires updating the EPRI-SOG source characterizations.

Conclusions 5-6

- Seismicity is spatially inhomogeneous between different interior rifts; and

- Mw > 6.0 earthquakes occur within non-rifted crust.

Both of these conclusions are trivial observations that are also apparent within the earthquake catalog of Johnston et al. (1994). They do not motivate any revisions to the EPRI-SOG source characterizations.

Conclusion 7

- The most seismically active rifts are the Kutch, East China, St. Lawrence, and Reelfoot rifts, and these rifts, with the exception of the Reelfoot, may have additional factors influencing their seismicity.

These regions were also identified as very seismically active within the Johnston et al. (1994) study, and thus this basic observation is not considered new information. The opinion that seismicity within the Kutch and East China rifts may be due to plate boundary process and that seismicity within the St. Lawrence rift may be influenced by the existence of a terrane suture and meteorite impact implies that these regions may be better classified as not SCRs. If these regions are not SCRs, earthquakes within them should not be considered in the analysis of Schulte and Mooney (2005) and Johnston et al. (1994), and the reported relationship between large earthquakes and rifted crust is likely even less robust than presented by Schulte and Mooney (2005) and Johnston et al. (1994). Such a paradigm shift would suggest that there is little significance to the presence of rifted crust surrounding the CCNPP Unit 3 site and thus does not motivate modifying the EPRI-SOG source characterization.

Conclusion 8

- The majority of historically active regions have instrumental records of seismicity that show hardly any greater seismic activity then surrounding regions when only the instrumental record is considered (i.e., many regions with large historical earthquakes have few if any large instrumentally recorded earthquakes).

This conclusion is based on observations of the historical and instrumental seismicity catalog that were also apparent at the time of the EPRI-SOG (EPRI, 1986) and Johnston et al. (1994) studies. As such, this conclusion does not motivate any revisions to the EPRI-SOG source characterizations.

Conclusion 9

- There are few large earthquakes observed within Europe, a region with extensive rifted crust.

While not explicitly stated within the Johnston et al. (1994) study, this observation was apparent in the seismicity catalog used by Johnston et al. (1994) and was therefore accounted for in their domain-earthquake regressions. The impact of the extended SCRs with low levels of seismicity and very few large earthquakes is summarized by Johnston et al. (1994) where they state that "...there is no strong evidence that any typical extended crust domain has a larger maximum magnitude than a typical non-extended crust domain," (page 5-17) (Johnston et al., 1994).

Without referencing any particular studies, Schulte and Mooney (2005) summarize their study by suggesting that "the correlation of seismicity within SCRs and ancient rifts has been overestimated in the past." Again, this conclusion supports the Johnston et al. (1994) observation of only minor differences between the seismicity observed in extended and non-extended SCRs.

Summary

The main conclusions of the Johnston et al. (1994) study with respect to source characterizations are that: (1) there is little statistical difference in the observed seismicity of extended and non-extended SCRs, but (2) the largest magnitude earthquakes tend to occur in extended SCRs. These conclusions were known and evaluated by the EPRI-SOG ESTs during the development of their source characterizations and are thus accounted for in the EPRI-SOG model used for CCNPP (EPRI, 1986). The relevance of the Schulte and Mooney (2005) study to the CCNPP site is that their conclusions largely support the conclusions of Johnston et al. (1994). As reviewed above, several Schulte and Mooney (2005) conclusions directly support the conclusions of Johnston et al. (1994), and none of the Schulte and Mooney (2005) conclusions contradict those of Johnston et al. (1994) or provide new information that motivates revisions of the EPRI-SOG source characterizations used for CCNPP.

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COLA Impact

None

Question 02.05.01-5

FSAR Section 2.5.1.1.4.1.2 states "Northwest-southeast-directed postrift shortening, manifested in Mesozoic basin inversion structures, provides the clearest indication of this change in stress regime (Withjack, 1998)." On FSAR Figure 2.5-13 there is a shallow structural high at borehole CA Gd 60 (Solomons) that dies out with depth that is consistent with typical inverted grabens. Furthermore, the fault proposed by Kidwell (1997) referred to in FSAR Section 2.5.1.1.4.4.4.8 appears to coincide with this high.

Please discuss the potential for this feature to be an inverted Mesozoic fault.

Response

The apparent "shallow structural high" referenced in this question is best explained as a result of a change in orientation of the cross-section line of Achmad and Hansen (1997) with respect to the regional dip of the Coastal Plain sediments and not as an inverted Mesozoic fault. Included with this response are three figures (copies attached and enlarged prints are included in Enclosure 3). Figure 1 depicts the location of the boreholes used to develop cross-sections A-A' (Figure 2) and B-B' (Figure 3) of Achmad and Hansen (1997). Note that Figure 2 is a modified version (color for three geologic formations, labeling of 'Moran Landing', and an added description of the orientation of the cross section with respect to the regional dip of the Chesapeake group) of FSAR Figure 2.5-13 and is presented for this response only. The geologic cross-sections intersect the southeast projection of the hypothesized Kidwell fault and the apparent "shallow structural high" referred to in this question. These regional geologic cross-sections demonstrate that neither the hypothesized Kidwell fault nor the hypothetical inverted Mesozoic fault are apparent in the Chesapeake Group stratigraphy. Both scenarios are discussed below in additional detail.

<u>Shallow Structural High</u>

The regional strike of the Coastal Plain sediments in the region of Figure 2 (FSAR Figure 2.5-13) is northeast to north, and in this area the Coastal Plain deposits dip to the southeast and east at about 1 degree or less (Achmad and Hansen, 1997). In FSAR Figure 2.5-13, the apparent "shallow structural high" referenced in this question is expressed as a minor increase in elevation of the Aquia Aquifer, Nanjemoy Formation, Marlboro Clay, and Chesapeake Group between boreholes Fd-71, Gd-60, and Df-84 (Figures 1 and 2). Northwest of borehole Fd-71, cross-section A-A' (Figure 2) is oriented approximately perpendicular to strike (with the exception of borehole alignment Cc-55 and Db-47, 36) and exhibits a gentle southeast to east dip of the Coastal Plain deposits (Figure 2). In contrast, between boreholes Fd-71 and Df-84, cross-section A-A' trends roughly subparallel to strike and exhibits the noted minor up-dip trend (i.e., a minor increase in elevation of the Aquia Aquifer, Marlboro Clay and Chesapeake Group) between boreholes Fd-71 and Gd-60. As apparent from this discussion, the noted increase in elevation of the Aquia Aquifer, Marlboro Clay and Chesapeake Group is easily explained by the orientation of the cross-section line relative to the regional dip, and not an inverted fault.

Further support for the absence of an inverted Mesozoic fault south of the Patuxent River is provided by an additional northwest-southeast oriented regional geologic cross-section, B-B', that intersects the southeast projection of the anomalous structural high noted in section A-A' (assuming a northeast strike) (see Figures 1 to 3). Cross-section B-B' exhibits similar apparent "shallow structural highs" in regions where the section trends approximately parallel to strike (i.e., apparent dip) and "up-dip" of the Coastal Plain deposits. Removal of these strike-parallel portions (i.e., boreholes Ca-5 to Bb-26, 27 and Fe-31 to Ef-79, 81) shows that the regional geologic dip of the Coastal Plain sediments is gently southeast-dipping consistent with section A-A' and structure contour maps (Figures 1 and 3). This again suggests that the hypothesized "shallow structural highs" reflects the orientation of the cross-section line and apparent dips relative to the regional dip. In addition, a simple southeast projection of the hypothesized structure from section A-A' intersects section B-B' between boreholes Dd-50 and Ef-79, 81, and this section of B-B' exhibits undeformed gently southeast-dipping stratigraphy (Figure 3).

In summary, when the inferred "shallow structural highs" are placed in context with the orientation of the geologic section with respect to bedding strike and dip, the anomalous features can be readily explained by the trend of the cross section line. This explanation is more plausible than a previously unidentified inverted Mesozoic fault.

Kidwell fault

The fault hypothesized by Kidwell (1997) is based on a collection of stratigraphic profiles developed from cliff exposures along the west shore of Chesapeake Bay, where a 230 ft thick section of Pliocene-Miocene Coastal Plain deposits are exposed. Approximately 1.2 miles south of the CCNPP Unit 3 site, Kidwell (1997) interprets an apparent "abrupt" elevation change in Pliocene and Miocene strata and infers the presence of a fault across Moran Landing (Figure 1). Kidwell (1997) postulates that the fault strikes northeast and exhibits a north-side down sense of separation across all the geologic units. The presence of such a fault can be evaluated using the projected intersection of the fault with cross-sections A-A' and B-B' (Figures 2 and 3).

The inferred Kidwell fault intersects cross-section A-A' between boreholes Ed- 45, 22 and Fd-71. The cross-section demonstrates that geologic units stratigraphically below those exposed in Calvert Cliffs and used by Kidwell (1997) to infer the existence of the fault (i.e., Piney Point Formation and older) do not exhibit a north-side down separation. Therefore, cross-section A-A' provides evidence for an absence of significant faulting between boreholes Ed 40, 22 and Fd-71where the Kidwell fault would project.

Cross-section B-B' located to the south of the Patuxent River also provides evidence for the absence of the hypothesized Kidwell (1997) fault. Assuming a simple southwest projection, the hypothesized fault would intersect cross-section B-B' somewhere between boreholes Ca-5, Dd-50, Ef-56, and Ef-79, 81 (Figures 1 and 3). As with cross-section A-A', the Miocene and older stratigraphy along the projection of the hypothesized fault dip gently southeast and do not exhibit a north-side down vertical separation. Therefore, cross-section A-A' provides evidence for an absence of faulting south of the Patuxent River.

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COLA Impact

None

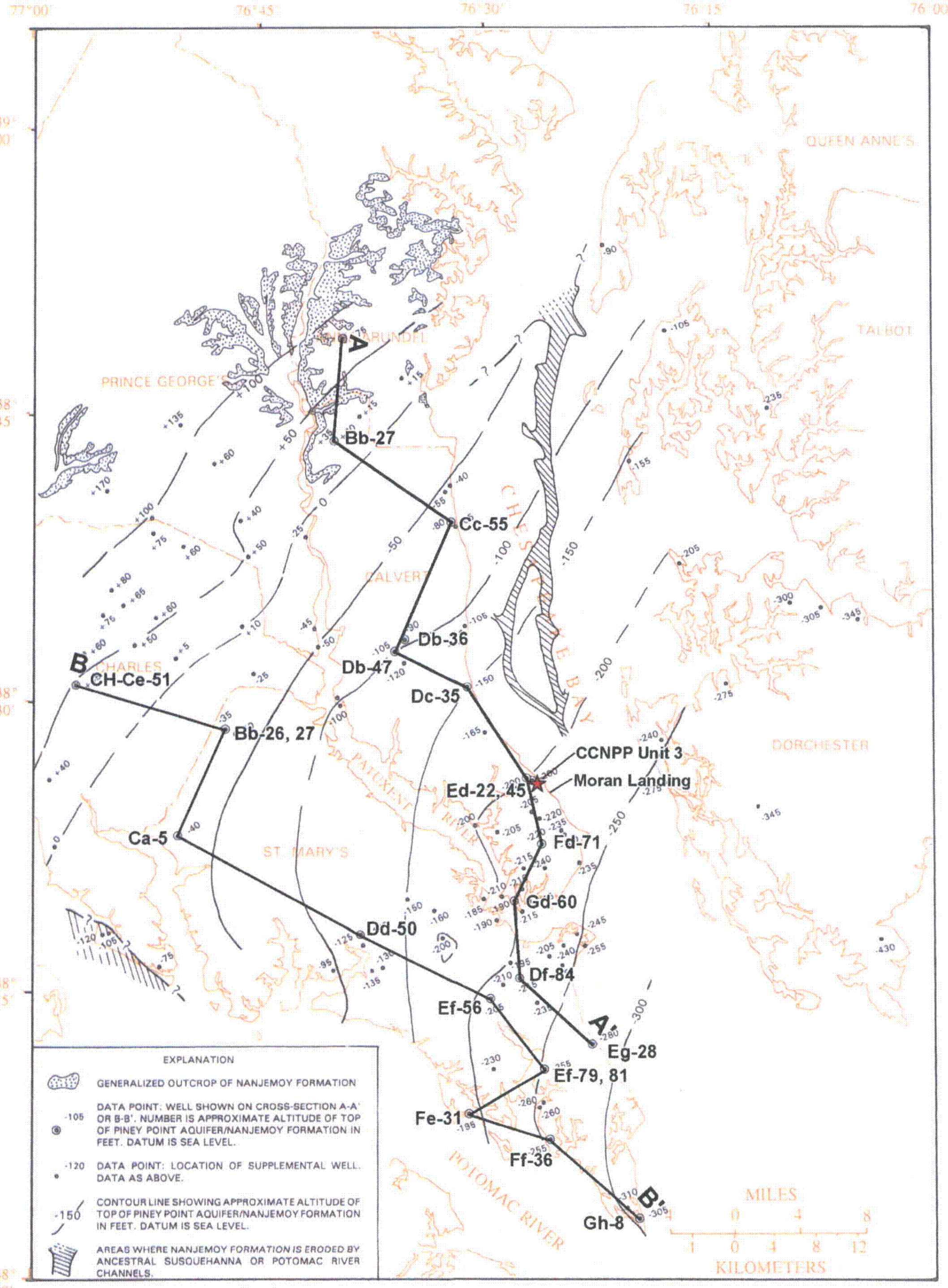

Figure 1. Approximate altitude of the top of the Piney Point-Nanjemoy aquifer showing cross section locations A - A' and B - B' (modified from Achmad and Hansen, 1997).

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Modified 04.08.09

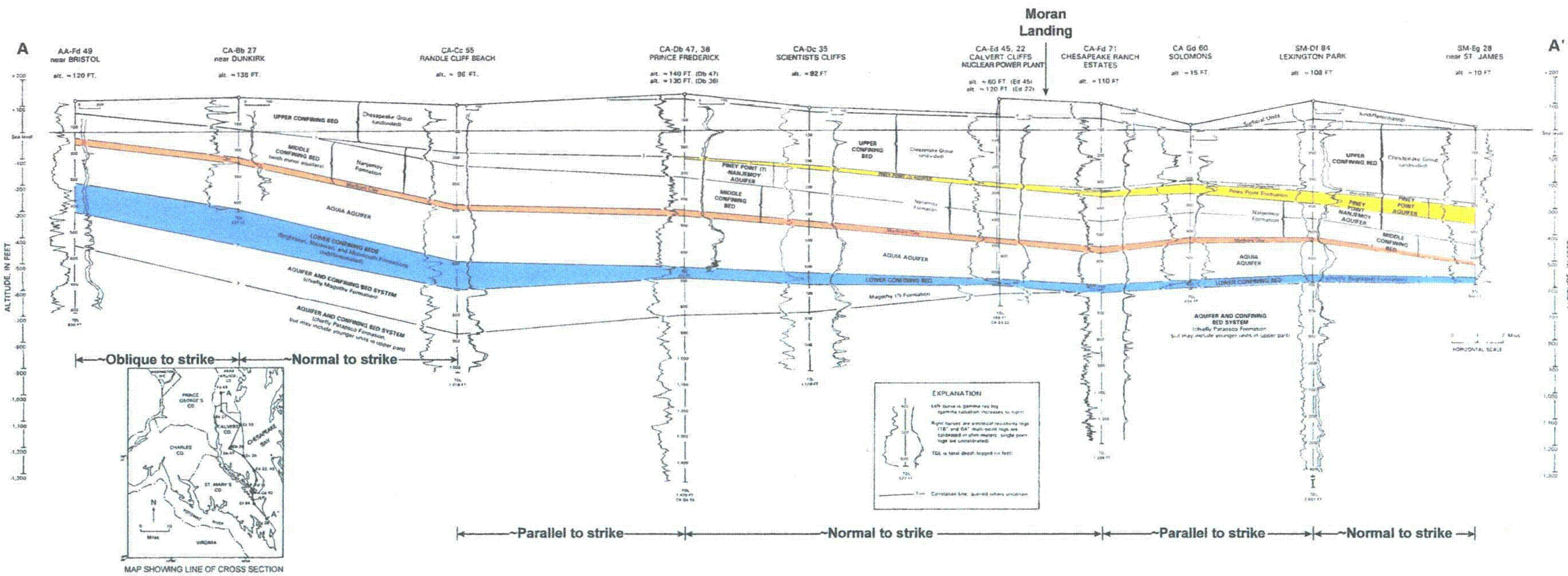

Figure 2. Hydrogeologic cross section A - A' extending near Bristol, Anne Arundel County to near James, St. Mary's County (modified from Achmad and Hansen, 1997).

1782 RAI 02.05.01-5
Modified 04.08.09

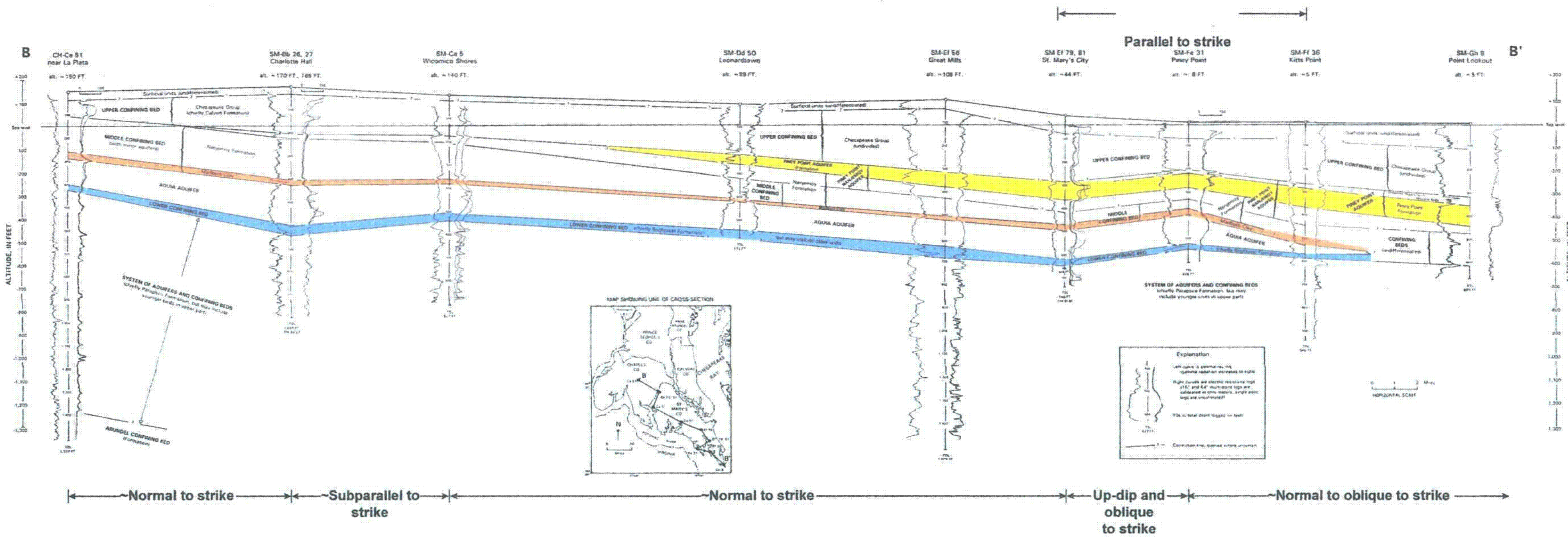

Figure 3. Hydrogeologic cross section B - B' extending near La Plata, Charles County to Point Lookout, St. Mary's County (modified from Achmad and Hansen, 1997).

Question 02.05.01-13

FSAR Sections 2.5.1.1.4.4 and 2.5.1.1.4.4.4 discuss the Eocene Chesapeake Bay Impact Structure (CBIS). FSAR Section 2.5.1.1.4.4 states "Based on the absence of published literature documenting Quaternary tectonic deformation and spatially associated seismicity, we conclude that this feature is not a capable tectonic source (Section 2.5.1.1.4.4.4)."

However, the FSAR does not cite any literature documenting the lack of Quaternary tectonic deformation associated with this feature.

(a) Please explain which, if any, seismograph networks have monitored for seismicity on the CBIS (including time periods of monitoring and minimum magnitude of their earthquake detection threshold).

(b) The spatial association between a normal-faulted passive margin and a large impact crater is also present at the Charlevoix seismic zone, Quebec. In light of this similar spatial association, please provide a discussion of the seismic potential of the Chesapeake Bay impact crater.

(c) FSAR Section 2.5.1.1.4.4.4 states "Primarily middle Miocene to Quaternary sediments thicken and sag into the primary and secondary craters." Please explain how these relations differ from the classic description of a growth fault, in which the faulting would be the same age as the inward-thickening sediments.

Response

a) As part of the review of the EPRI-SOG characterization of potential seismogenic sources, the Eocene Chesapeake Bay Impact Structure (CBIS) was carefully evaluated, as discussed in Part (b) of this response. As part of this evaluation, available geologic, seismologic, and geophysical information and data were reviewed. With regard to the search of seismologic information, no indication was found of the existence of specific monitoring systems designed to evaluate seismicity associated with the CBIS. Available regional seismicity networks that were used in the CCNPP Unit 3 FSAR to characterize seismicity are summarized below.

   Seismic networks that routinely catalog earthquakes in the eastern US were examined to update the ERPI-SOG (1988) earthquake catalog for the CCNPP Unit 3 region. These networks included: Lamont-Doherty Seismic Network, Weston Observatory, ANSS, SEUSSN, Canada, and Ohio Seismic Networks. For the area of, and just to the south of, the site, the SEUSSN was found to have the best coverage. The SEUSSN catalog is compiled by the Virginia Tech Seismological Observatory (VTSO) (see http://www.geol.vt.edu/outreach/vtso/). VTSO operates a digital seismic network with stations in Virginia and southern West Virginia. Along with other southeastern regional seismic networks, VTSO contributes to earthquake monitoring, information dissemination and seismic hazard assessment objectives in the southeastern United States. The southeastern region of the US is covered by several networks operated by different institutions. The list of operators as of 2005 (the latest available SEUSSN bulletin) includes, in addition to VTSO, the Delaware and Maryland Geological Surveys. Data from the Delaware and Maryland Geological Surveys are incorporated into the VTSO compilation.

The search of catalogs for the update of regional seismicity was limited, per the guidelines of Regulatory Guide 1.208, to magnitude 3 or greater or intensity IV or greater. Records of smaller earthquakes were not retained in the catalog for the purposes of the FSAR. However, the SEUSSN, though 2004 – the last date available at the time the FSAR seismicity update was performed - lists locations for earthquakes as small as 0.0 Md from duration or coda length within the broad region 35 - 43 deg north, 71 - 83 deg west. Inclusion of these smaller earthquakes in a plot of epicenters in the area of the CBIS does not suggest either more than background seismicity in this area or a pattern suggesting their association with the CBIS.

Therefore, no evidence was found of any seismometer networks or seismology studies specifically deployed to record or investigate earthquakes associated with the CBIS, nor do the earthquakes routinely cataloged for the region provide strong evidence to support a spatial association of seismicity with existing CBIS structures.

b) As described in FSAR Section 2.5.2, a comprehensive review of available geologic, seismologic, and geophysical information and data was conducted to determine whether or not there was any new information or data developed since the EPRI-SOG study (EPRI, 1986) that would motivate revising the seismic source characterizations used for the CCNPP Unit 3 FSAR. Also, as described in Section 2.5.2, this review was conducted following the guidance of NRC Regulatory Guide 1.165 (NRC, 1997). As part of this review (see FSAR Sections 2.5.1.1.4.4 and 2.5.1.1.4.4.4) the Eocene Chesapeake Bay Impact Structure (CBIS) was identified as a geologic feature that had not been identified at the time of the EPRI-SOG study and should thus be evaluated with respect to its seismogenic potential. The review of available geologic, seismologic, and geophysical information and data conducted as part of the preparation of the CCNPP Unit 3 FSAR led to the conclusion stated in FSAR Section 2.5.1.1.4.4.4 that the CBIS was not a capable seismic source. The primary basis for this conclusion is the lack of any reported evidence of strong ground shaking (i.e., liquefaction) within Maryland, or coincident with the CBIS (see responses to RAI 71, Questions 02.05.01-28 and 02.05.01-30, as well as FSAR Section 2.5.1.2.6.4), and the lack of a spatial association of seismicity with the CBIS (see FSAR Figure 2.5-31 and the discussion in part (a) of this response).

Despite the above observations, this question raises the issue as to whether or not the similarities between the Charlevoix seismic zone (CSZ) and the CBIS motivate revising the EPRI-SOG seismic source characterizations for the region containing the CBIS. The implied assumption of the RAI question is that because the CSZ has had large historical earthquakes (several with Mw > 6.0 and one with Mw ~ 7.0) (Lamontagne et al., 2008), and because the CSZ and CBIS have some similarities, it may be reasonable to assume that the CBIS may be capable of generating similar magnitude earthquakes. Using the guidance of NRC RG 1.165 (NRC, 1997), an evaluation was performed to determine whether this assumption is valid and thus motivates updating the EPRI-SOG source characterizations used for the CCNPP Unit 3 FSAR. The available data do not support a change to the EPRI-SOG source characterization of the CBIS region because:

- The similarities between the CSZ and the CBIS are relatively weak;
- There is a recognized lack of correlation between meteor impact structures and seismicity worldwide; and

- Large earthquakes within the CSZ do not appear to be caused by the Charlevoix impact structure or occur along impact-related faults. Instead, large earthquakes within the CSZ occur along reactivated Iapetan rift faults and are thought to be controlled by several unique features of the CSZ.

Each of these reasons is explained below in additional detail.

Both the CBIS and the CSZ occur within extended crust, but contrary to statements within this question, only the CBIS is on a normal faulted passive margin (the Atlantic margin). The CSZ is within a failed inter-continental rift (e.g., Adams and Basham, 1991; Hasegawa, 1991; Lemieux et al., 2003). Despite the past history of extension in both regions, there are more seismotectonic differences than similarities between them. This observation suggests that the CSZ is not an appropriate analog for the seismic behavior of the CBIS. In contrast to the CBIS, which is underlain primarily by Paleozoic crust extended during the Mesozoic (see FSAR Figure 2.5-17 and discussion in FSAR Section 2.5.1.1.4.1), the CSZ is largely underlain by Grenville age basement rocks first rifted during the opening of the Iapetan ocean and potentially reactivated during the Mesozoic opening of the Atlantic ocean (Adams and Basham, 1991; Hasegawa, 1991; Lemieux et al., 2003). It is worth noting, that it is these reactivated faults that are thought to be the source of large earthquakes within the CSZ (Adams and Basham, 1991; Anglin, 1984; Anglin and Buchbinder, 1981; Bent, 1992; Buchbinder et al., 1988; Hasegawa, 1991; Lamontagne and Ranalli, 1997; Lemieux et al., 2003), and analogous faults have not been identified at the CBIS. Also, in contrast to the CBIS that formed around 35 Ma and well after Mesozoic rifting, the CSZ impact crater formed approximately 350 Ma (Solomon and Duxbury, 1987) after initial Iapetan rifting and before the Mesozoic reactivation of rift faults. The exact relevance of the differences in the impact and tectonic history between the CSZ and the CBIS are uncertain with respect to seismic potential of either region, but the longer history of fault reactivation in the CSZ, alternate impact timing, and the different tectonic settings indicate that the CSZ is not an appropriate analog for crust surrounding the CBIS.

The most distinct difference between the CBIS and the CSZ is the dramatic difference in historical and instrumental seismicity between the two areas. The CSZ is one of the most seismically active areas of eastern North America with several historical and instrumental earthquakes with Mw > 6.0 and hundreds of small earthquakes per year (e.g., Bent, 1992; Hasegawa, 1991; Lamontagne, 1999; Lamontagne et al., 2008; Lamontagne et al., 2003; Lamontagne and Ranalli, 1997). In contrast the region surrounding the CBIS is seismically very quiet (e.g., FSAR Figure 2.5-31) (see part (a) of this response). This difference in seismicity suggests a fundamental contrast between the seismic potential of the regions surrounding the two impact structures and further suggests that the CSZ is not an appropriate analog of the seismic behavior of the CBIS.

Further support against using the CSZ as an analog for the seismic potential of the CBIS is the observation that worldwide there is no consistent correlation between impact craters and seismicity (Solomon and Duxbury, 1987). Solomon and Duxbury (1987) analyzed seismicity rates surrounding 30 impact structures within stable continental crust, three of which are either within or immediately adjacent to Paleozoic and younger extended crust as defined by Johnston et al. (1994), to determine if there are higher seismicity rates surrounding impact craters.

The CSZ was the only crater found to have an increased level of tectonically induced seismicity, suggesting that the CSZ is unique and is not a good analog for the seismic behavior of impact structures. As such, the study of Solomon and Duxbury (1987) does not support using the CSZ to define the seismic potential of the CBIS.

Finally, additional support for not using the CSZ as an analog for the seismic potential of the CBIS comes from the opinion of several experts that large earthquakes within the CSZ are not caused or controlled by impact related structures. CSZ earthquakes occur within a northeast striking alignment dipping to the south. This band of earthquakes is bound on the north and the south by lapetan normal faults potentially reactivated during the Mesozoic opening of the Atlantic Ocean; between these bounding faults are numerous supra-crustal faults related to the meteor impact. Since the 1970s there have been various opinions with respect to whether CSZ seismicity was occurring along lapetan normal faults or impact related faults (e.g., Adams and Basham, 1991; Anglin, 1984; Anglin and Buchbinder, 1981; Bent, 1992; Buchbinder et al., 1988; Hasegawa, 1991; Leblanc and Buchbinder, 1977). If large earthquakes are associated with the impact related faults, their occurrence potentially supports the idea that impact related faults in the CBIS could be the source of large earthquakes. More recently as the accuracy of determining the hypocenter locations have improved and the magnitude detection threshold has decreased within the CSZ, it has become apparent that small earthquakes occur on impact related faults and the large earthquakes occur on lapetan normal faults (Lamontagne, 1999; Lamontagne and Ranalli, 1997; Lemieux et al., 2003; Vlahovic et al., 2003; Wheeler, 1995). This observation suggests that the impact crater is not the source for large earthquakes within the CSZ, and therefore the CSZ is not a good analog for the potential of large earthquakes on CBIS related faults. Furthermore, several researchers have proposed that site-specific conditions within the CSZ (e.g., glacial rebound stresses, high pore-fluid pressures) (e.g., Lamontagne, 1999; Vlahovic et al., 2003; Wu, 1997; Wu and Hasegawa, 1996) preferentially allow for the occurrence of earthquakes within the CSZ, and there is no prior reason to expect these same conditions to occur in the CBIS.

In summary, a review of available data and information regarding the CBIS and the CSZ demonstrates that: (1) there is no evidence to support Quaternary seismic activity on any faults related to the CBIS, and (2) there is no evidence to suggest that the CSZ is an appropriate analog of the seismic behavior of the CBIS (i.e., large magnitude events like those observed in the CSZ are not expected in the CBIS). Based on these conclusions, and the observation that some of EPRI-SOG source characterizations for the region surrounding the CBIS have maximum magnitude values as large as the magnitudes of the largest CSZ earthquakes, there are no new data, or information, that justifies updating the EPRI-SOG source characterizations to account for the discovery of the CBIS.

c) The statement quoted in this question from FSAR Section 2.5.1.1.4.4.4 is based on Poag et al. (2004) which provides extensive structural and stratigraphic descriptions of the CBIS and its related features. Poag et al. (2004) describes in several places that post-impact sediments (i.e., those referred to in the FSAR quotation) are thickest in the center of the crater (e.g., see sections 2.2.3, 4.1.1.1, and 5.2 of Poag et al. (2004)). Poag et al. (2004) and Poag (1997) attribute this thickening to subsidence driven by compaction of syn- and post-impact sediments preferentially occurring in the deepest portions of the crater (i.e., in the thickest deposits). Poag et al. (2004) describes that some of this subsidence was syndepositional and was accommodated along growth faults.

Evidence for syndepositional growth faulting comes from seismic reflection data that shows thickened sedimentary sections on the down-thrown sides of faults (Poag et al., 2004). Therefore, the relations referred to in this question do not necessarily differ from the typical definition of a growth fault.

It should be noted that the existence of growth faults within the CBIS does not have any impact on the seismic source characterization used in the CCNPP Unit 3 FSAR because if these faults are still active, they are not capable of generating earthquakes with magnitudes greater than mb 5.0 (the lower-bound magnitude used in the PSHA for CCNPP Unit 3, see FSAR Section 2.5.2). This conclusion is based on the following facts:

- Similar growth faults in marine depositional settings (e.g., Gulf of Mexico) are not considered seismogenic (e.g., Bernreuter et al., 1989a, b; Crone and Wheeler, 2000; EPRI, 1986; Hanson et al., 1999; NRC, 2007; Petersen et al., 2008; Wheeler, 2005);

- No earthquakes have been attributed to the faults; and

- The growth faults generally extend to depths no greater than 0.5 km from the surface of the seafloor and are not laterally continuous (Poag et al., 2004). Given standard relationships between rupture area and magnitude (Wells and Coppersmith, 1994) and basic observations that most earthquakes initiate at depths deeper than the base of the growth faults (Scholz, 2002), the growth faults are too shallow to produce significant seismogenic rupture (i.e., earthquakes with magnitudes greater than mb 5.0).

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COLA Impact

None

Question 02.05.01-14

FSAR Section 2.5.1.1.4.4.1 states "Extended crust of the Iapetan passive margin extends eastward beneath the Appalachian thrust front approximately to the eastern edge of Mesozoic extended crust...." The FSAR concludes the Grenville crust that was extended by Iapetan rifting is no closer to the site than about 113 km (70 mi).

However, the interpreted eastern limit of extended Grenville crust is actually only the eastern limit of largely intact Grenville crust, which has undergone only slight extension by Iapetan faulting (Wheeler, 1996, Fig. 2). Wheeler (1996) cites interpretations of published seismic-reflection profiles. The interpretations indicate that more intensely extended and thinned Grenville crust extends at least another 40-80 km eastward.

Please discuss how this may impact hazard assessment at the site.

Response

As the above quoted FSAR text summarizes, the extent of largely intact and slightly extended Iapetan crust extends east beneath the Appalachian thrust front to the edge of Paleozoic crust extended during Mesozoic time (See revised FSAR Figure 2.5-15 and response to RAI 71, Question 02.05.01-25). As discussed in CCNPP Unit 3 FSAR Section 2.5.1.1.4.4.2 and the response to RAI 71, Question 02.05.01-15, the North America Basement complex (Grenville Crust) is thought to underlie the Appalachian fold belt and extend beneath Taconic and younger accreted terranes (e.g. Goochland, Sussex, and Carolina/Chopawamsic) as shown in CCNPP Unit 3 FSAR Figure 2.5-17 (Glover and Klitgord, 1995). The existing CCNPP Unit 3 FSAR Figure 2.5-17 illustrates the salient point in the above RAI Question 02.05.02-14, showing extended and thinned Grenville crust may be closer to the CCNPP Unit 3 site than stated above. To avoid confusion the CCNPP Unit 3 FSAR text will be modified as noted in the COLA Impact section below.

As described in FSAR Section 2.5.2, a comprehensive review of available geologic, seismologic, and geophysical information and data was conducted to determine whether or not there was any new information or data developed since the EPRI-SOG study (EPRI, 1986) that would motivate revising the seismic source characterizations used for the CCNPP Unit 3 FSAR. Also, as described in Section 2.5.1 and 2.5.2, this review was conducted following the guidance of NRC Regulatory Guide 1.165 (NRC, 1997). As part of this review, seismogenic potential of Iapetan normal faulted crust was evaluated and was known at the time of the EPRI-SOG study (see CCNPP Unit 3 FSAR Sections 2.5.1.1.4.4.2). The review of available geologic, seismologic, and geophysical information and data conducted as part of the preparation of the CCNPP Unit 3 FSAR led to the conclusion stated in FSAR Section 2.5.1.1.4.4.1 that no data have been published since 1986 on any Late Proterozoic features with in the site region (200-mile radius) that would cause a significant change in the EPRI seismic source model. Thus, there is no impact on the hazard assessment at the site.

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COLA Impact

The first paragraph, last sentence of the CCNPP Unit 3 FSAR Subsection 2.5.1.1.4.4.1 will be revised in a future COL revision as shown below:

> At its closest approach, the area of <u>largely intact and slightly</u> extended Iapetan crust is located about 70 mi (113 km) northwest of the CCNPP site (Figure 2.5-23).

Question 02.05.01-15

FSAR Section 2.5.1.1.4.4.2 states "The majority of these structures dip eastward and sole into one or more levels of low angle, basal Appalachian decollement (Figure 2.5-17). Below the decollement are rocks that form the North American basement complex (Grenville or Laurentian crust)."

(a) There are several levels of detachment but only one basal decollement. Please clarify the quoted sentence.

(b) Iapetan (Rodinia rifting) normal faults are expected in this basement complex, and the figure shows them schematically. Please include these probable structures in the discussion.

Response

a) The apparent confusion noted by NRC staff will be clarified revising the CCNPP Unit 3 FSAR Section 2.5.1.1.4.4.2 first paragraph, second to last sentence as follows:

"The majority of these structures dip eastward and sole into either a low angle thrust or the low angle basal Appalachian decollement (Figure 2.5-17)."

b) As summarized in FSAR Section 2.5.1.1.4.4.2, the basal Appalachian decollement represents a major tectonic boundary separating the North American basement complex (Grenville or Laurentian) in the footwall from Taconic and younger accreted terranes (e.g. Goochland, Sussex, and Carolina/Chopawamsic) in the hanging wall. The North American basement complex is thought to underlie the Appalachian fold belt beneath much of the Piedmont Province (Hatcher, 1987; Glover and Kitgord, 1995; Wheeler, 1996) (See CCNPP Unit 3 FSAR Section 2.5.1.1.4.1.1, Figure 2.5-8, and Figure 2.5-17). Early Cambrian rifting associated with the break up of Rodinia and the development of the Iapetus Ocean formed east-dipping normal faults through Laurentian crust (See CCNPP Unit 3 FSAR Section 2.5.1.1.4.4.1). Many of these Iapetan normal faults were likely truncated by the basal Appalachian decollement during later Paleozoic collisional events (Harris et al., 1984; Glover and Kitgord, 1995) (CCNPP Unit 3 FSAR Figure 2.5-17). For example, Harris et al. (1982) interpret a deep seismic line along I-64 and interpret Iapetan normal faults truncated by the overlying basal Appalachian decollement.

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COLA Impact

The CCNPP Unit 3 FSAR Section 2.5.1.1.4.4.2 first paragraph, second to last sentence will be revised as follows in a future revision of the COLA:

> The majority of these structures dip eastward and sole into either a low angle thrust or ~~one~~ ~~more levels of~~ the low angle~~,~~ basal Appalachian decollement (Figure 2.5-17).

Question 02.05.01-19

FSAR Section 2.5.1.1.4.4.4.6 (Unnamed fault beneath northern Chesapeake Bay, Cecil County, Maryland) cites the unnamed fault as having its southwest side up, but near the mouth of the Susquehanna River the west side is downthrown. The unnamed fault is mapped in FSAR Figure 2.5-25 as submarine. The east coast of the Chesapeake Bay along the southern projection of the unnamed fault is very straight in FSAR Figure 2.5-25.

(a) Please explain the apparent contradiction between the two senses of displacement.

(b) Is there any new submarine information about this possible fault?

(c) Please evaluate the hypothesis that the straight eastern coast line of the Chesapeake Bay might be a result of young faulting, and present the evidence and reasoning for your evaluation.

Response

a) The referenced CCNPP Unit 3 FSAR Section 2.5.1.1.4.4.4.6 cites the unnamed fault as having its southwest side up. This is a typographical error. The inferred fault, as defined by Pazzaglia (1993), would exhibit northwest-side down and southeast-side up displacement. The first paragraph of the CCNPP Unit 3 FSAR Section 2.5.1.1.4.4.4.6 will be corrected to read as noted in the proposed COLA Impact section below.

b) There is no new submarine information about the inferred fault. The fault was first inferred by Higgins et al. (1974) from aeromagnetic data. Higgins et al. (1974) interpret a steep aeromagnetic anomaly coincident with a low gradient along the west side of Turkey Point and infer a normal or high-angle reverse fault. Subsequent mapping by Higgins and Conant (1986 and 1990) does not support the existence of the original fault interpretation (see (c)).

c) The RAI appears to be referring to the northeast-trending coastline of Chesapeake Bay located southeast and along projection of the hypothesized Pazzaglia (1993) fault (see CCNPP Unit 3 FSAR Figure 2.5-25). Based on available geologic information that supports a non-tectonic process for the presence of the "straight shoreline" (e.g., bathymetric data, position of ancient Susquehanna paleochannels), bedrock mapping (Cleaves et al., 1968; Higgins and Conant, 1986; Higgins and Conant, 1990; Benson, 2006), and the absence of geologic observations supporting faulting as causing the shoreline, we believe that the "straight shoreline" can be explained by a non-tectonic process.

   First, there are strong geologic observations that there is not a Quaternary fault near the unnamed fault. A geologic map of Cecil County, prepared by Higgins and Conant (1986 and 1990), that encompasses the inferred aeromagnetic lineament of Higgins et al. (1974), does not show any on-land northeast-striking fault. In particular, Higgins and Conant (1986) map (Higgins was the original author of the inferred submarine fault) unfaulted Cretaceous deposits along the projection of the inferred northeast-striking fault and state: "No irregularities such as local steepening, flattening, or reversal of the dip of the Coastal Plain strata have been found in Cecil County which would indicate that there has been significant post-depositional tectonic movements."

Also, both the eastern and western coastlines of Chesapeake Bay along the southwest projection of the unnamed fault are mapped as Quaternary Lowland deposits (Cleaves et al., 1968). A cross-section developed by Benson (2006; cross-section I-I') that intersects the inferred submarine fault between Turkey Point (on the east) and Spesutie Island (on the west) shows flat-lying, undeformed Cretaceous stratigraphy and the absence of faulting.

Second, the "straight shoreline" is actually sinuous and not representative of the expected morphology of a "young" fault-controlled shoreline. The shoreline only appears straight on small-scale maps (e.g., CCNPP Unit 3 FSAR Figure 2.5-25), and large-scale representations i.e., Google Earth) depict an eastern shoreline that is considerably scalloped with inlets. Throughout the Pleistocene interglacial and glacial periods, the area now occupied by Chesapeake Bay alternated between a valley incised by the paleo-Susquehanna River (sea-level low stands) and estuarine conditions (sea-level high stands) (Hack, 1957; Colman et al., 1990; Pazzaglia, 1993). As a result of the melting of the Laurentide ice sheets and the subsequent rise in sea-level during the Holocene, the former fluvial valley of the Susquehanna River became drowned and formed Chesapeake Bay (Hack, 1957). The Susquehanna River transported glacial outwash deposits derived from the northeast and over time developed a series of submerged and exposed fluvial surfaces that have been poorly correlated across the region (Hack, 1957; Colman et al., 1990; Pazzaglia, 1993; McCartan et al., 1995).

The "straight" and partially eroded coastline also could have been carved by these ancient paleochannels of the Susquehanna River. For instance, submarine studies of Susquehanna River paleo-channels south of the "straight" coastline (between the Chesapeake Bay Bridge and the mouth of the Chesapeake Bay) indicate that significant lengths of the submerged ancient paleochannels are linear and form submerged and shallow, fairly straight east-bounding terrace margins, not unlike the exposed feature referred to in the RAI question (Colman and Halka, 1989; Colman et al., 1990; Chen et al., 1994; Bratton et al., 2003). Similar observations have been made of the submerged portions of the paleo-Susquehanna River in the northern part of the bay (Newell et al., 2004).

Based on the absence of geologic evidence demonstrating Cretaceous and younger faulting, coupled with the fluvial-like erosional scars of the "straight" coastline, and somewhat linear submerged paleochannels of the Susquehanna River within Chesapeake Bay, we find that there is no conclusive evidence to demonstrate the presence of faulting along the eastern shoreline of Chesapeake Bay near Turkey Point, Maryland. There also is no pre-EPRI or post-EPRI seismicity spatially associated with the northeast-trending part of Chesapeake Bay (CCNPP Unit 3 FSAR Figure 2.5-25).

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COLA Impact

The second sentence of the first paragraph of CCNPP Unit 3 FSAR Section 2.5.1.1.4.4.4.6 will be revised as shown below in a future revision of the COL:

> "On the basis of geologic data and assuming that the bay is structurally controlled, Pazzaglia (1993) infers a 14 mi (23 km) long, northeast-striking fault with a ~~southwest-side~~ southeast-side up sense of displacement."

Question 02.05.01-20

FSAR Section 2.5.1.1.4.4.4.7 states "The observation that the west side of Chesapeake Bay is elevated and dissected, and that approximately 37 ka estuarine deposits are approximately 6 feet above sea level is compelling evidence for recent (late Quaternary) uplift. Similar elevated, dissected topography and approximately 37 ka estuarine deposits are observed over broad portions of the Coastal Plain along the eastern seaboard east and west of Chesapeake Bay. These surfaces of apparent anomalous elevations have recently been attributed to the presence of a glacial fore-bulge developed outboard of the Laurentide ice sheet (Scott, 2006)." Scott (2006) is a thesis and, therefore, not readily available to all reviewers.

It is not clear if the glacial forebulge referred to is associated with the last Wisconsin glacial advance circa 20 ka and if the said forebulge has not collapsed completely enough to let 37 ka-old estuarine deposits back down to their original elevation. Please elaborate on this issue and alternative tectonic explanations and the implications of de-glacial and tectonic epeirogeny to seismic potential.

Response

There are three issues identified within this RAI question:

1. Please elaborate on this issue and alternative tectonic explanations and the implications of de-glacial and tectonic epeirogeny to seismic potential;

2. It is not clear if the glacial forebulge referred to is associated with the last Wisconsin glacial advance circa 20 ka; and

3. It is not clear if the said forebulge has not collapsed completely enough to let 37 ka-old estuarine deposits back down to their original elevation.

Each of these issues is discussed below in detail.

<u>Issue 1</u>

The above-quoted paragraph from CCNPP Unit 3 FSAR Section 2.5.1.1.4.4.4.7 is in reference to the occurrence of 37 ka old estuarine deposits over broad regions of Chesapeake Bay that lie above their expected elevations based on established glacial-eustatic sea-level curves. McCartan et al. (1995) argue that the presence of the elevated estuarine deposits provide evidence for a hypothetical structure (e.g., north-trending monocline) beneath Chesapeake Bay. As detailed in the response to RAI 71, Question 02.05.01-32, undeflected Eocene structure contours (Achmad and Hansen, 1997) and the absence of vertically displaced Miocene Choptank Formation demonstrate that: (1) the inferred monoclines of McCartan et al. (1995) along the western margin of Chesapeake Bay likely do not deform Eocene and younger Coastal Plain sediments, and thus do not represent a surface-fault rupture hazard or a capable tectonic source; and (2) the geologic data used by McCartan et al. (1995) do not support the existence of the inferred monoclines.

Furthermore, as part of the CCNPP Unit 3 FSAR preparation, detailed studies were conducted to determine if there was evidence for any Quaternary tectonic deformation within the site region. These efforts included: (1) compilation and review of existing published and unpublished literature; (2) telephone and in-person interviews of regional and local experts; (3) field and aerial reconnaissance, (4) review of aerial photography (5-mile-radius), digital elevation maps, and LiDAR coverage; (5) analysis of any potential association between historical seismicity and known geologic structures; and (6) a search for paleoliquefaction evidence. All of these efforts indicated that there are no potential Quaternary faults or tectonic-related features within the site vicinity. Therefore, these efforts demonstrate that given the current information available, the increased elevation of the 37 ka deposits is not due to a tectonic nor seismogenic process. The estuarine deposits must have been elevated by an alternative (non-tectonic) geologic process.

Glacial isostatic adjustment has been proposed as a probable mechanism to explain several anomalous geologic events and observations (e.g., rapid down-cutting of the Potomac and Susquehanna Rivers; elevated Quaternary estuarine and shoreline deposits; a general southerly dip of Quaternary surfaces) along the eastern seaboard, as well as in the Chesapeake Bay region (e.g., Gornitz and Seeber, 1990; Pazzaglia; 1993; Mitrovica and Davis, 1995; Davis and Mitrovica, 1996; Mitrovica et al., 2001; Douglas and Peltier, 2002; Reusser et al., 2004; Gehrels et al., 2004; Scott, 2006; Pavich et al., 2006). Based on these wide ranging observations, uplift by glacial forebulge processes is a reasonable alternative interpretation for explaining the elevated 37 ka deposits. The glacial forebulge process is characterized as a regional non-tectonic phenomenon that extends from at least northern Chesapeake Bay to Florida, and is not recognized as a seismic source (Davis and Mitrovica, 1996; Gehrels et al., 2004).

Issue 2

During an evaluation of long-term relative sea level changes Clark et al., (1978), Gornitz and Seeber, (1990), Davis and Mitrovica (1996), Mitrovica and Davis (2001); Douglas and Peltier (2002), Gehrels et al. (2004), Scott (2006), and Pavich et al. (2006) identify a regional pattern of broad, non-tectonic warping along the eastern U.S. seaboard. The regional warping is interpreted as flexure of the lithosphere caused by differential loading from the previous existence and recession of the Laurentide ice sheet. The broad warping is interpreted as a glacial forebulge that extends from the former maximum extent of the Laurentide ice sheet to as far south as Florida (Mitrovica and Davis, 1995; Davis and Mitrovica, 1996; Douglas and Peltier, 2002). As the Laurentide ice sheet melted, the unbalanced gravitational forces from the forebulge and depressed regions beneath the ice sheet induced a return flow of mantle material that caused crustal rebound in the formerly ice-covered regions and subsidence in the forebulge (Douglas and Peltier, 2002).

The results of multiple studies on relative sea-level rise (e.g., Gornitz and Seeber, 1990; Davis and Mitrovica, 1996; Mitrovica et al., 2001; Douglas and Peltier, 2002; Gehrels et al., 2004; Scott, 2006; Pavich et al., 2006) indicate that rates of sea-level rise are extremely high (between 2 and 4 mm/yr) in the Chesapeake Bay region relative to other locations along the eastern seaboard. These high rates are best explained by post-glacial isostatic adjustment occurring in the collapsing forebulge region and are not a result of tectonic processes (Davis and Mitrovica, 1996; Gornitz and Seeber, 1990).

Glacial isostatic adjustment is a slow process that decays exponentially at a rate dependent upon the mantle viscosity and was initiated after the last glacial maximum of about 20,000 yr BP (Douglas and Peltier, 2002).

Although the original elevation of the 37 ka estuarine deposits is poorly known, a review of Pavich et al. (2006) and global eustatic sea level curves suggest that this deposit should be submerged in regions of zero uplift. Based on established glacial-eustatic sea-level curves, Pavich et al. (2006) argue that the 37 ka deposit that is aerially exposed between 1 and 10 m above present-day sea level has been broadly uplifted as much as 40 m since deposition. This uplift was regionally coincident with the glacial forebulge that was created by loading of the Laurentide ice sheet during oxygen isotope stage 2 (approximately 20 to 18 ka; Pavich et al., 2006). Because these deposits are still above sea level, it is likely that the regions containing the deposits are not yet in isostatic equilibrium (i.e., the effects of the glacial forebulge have not yet completely passed) (Gornitz and Seeber, 1990; Scott, 2006; Davis and Mitrovica, 1996; Mitrovica et al., 2001; Douglas and Peltier, 2002; and Gehrels et al., 2004).

Issue 3

The results of multiple studies on relative sea-level rise (Gornitz and Seeber, 1990; Scott, 2006; Davis and Mitrovica, 1996; Mitrovica et al., 2001; Douglas and Peltier, 2002; and Gehrels et al., 2004) indicate that forebulge collapse is ongoing in the Chesapeake Bay region. Although the original elevation of the 37 ka deposit is poorly constrained, and the characterization of the forebulge dimensions are complicated, it appears that much of the deposit has not been lowered to its original depositional elevation (Pavich et al., 2006).

Summary

During the NRC site audit at CCNPP in February 2009, the NRC review panel acknowledged that the topic of this question and the discussion in the FSAR of the glacial forebulge is potentially confusing. Upon further consideration, UniStar agrees with the NRC reviewers that the discussion of the forebulge is potentially confusing and is irrelevant to the discussion of the potential McCartan et al. (1995) monocline because: (1) there is conclusive evidence supporting the conclusion that the monocline, if it exists, is not a capable tectonic feature (see response to RAI 71, Question 02.05.01-32), and (2) the glacial forebulge hypothesis speculates on the regional origin of an elevated estuarine deposit that does not provide evidence for or against a local structure beneath Chesapeake Bay (e.g., the McCartan et al. (1995) monocline). As a result, CCNPP Unit 3 FSAR Section 2.5.1.1.4.4.4.7 will be modified accordingly (see COLA Impact).

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Scott, T.W., Correlating Late Pleistocene Deposits on the Coastal Plain of Virginia with the Glacial-Eustatic Sea-Level Curve [MS Thesis], Old Dominion University, p. 112, May 2006.

COLA Impact

The fifth paragraph of CCNPP Unit 3 FSAR Section 2.5.1.1.4.4.4.7 that describes the forebulge hypothesis will be deleted as shown below in a future revision of the COL.

> ~~Field reconnaissance along much of the western shoreline shows that the north- to northeast-trending linear coastline could be controlled locally, in part, by a weak, poorly-developed, sub-vertical joint set oriented subparallel to the coast (Section 2.5.1.2.4). The observation that the west side of Chesapeake Bay is elevated and dissected, and that~~

~~approximately 37 ka estuarine deposits are approximately 6 feet above sea level is compelling evidence for recent (late Quaternary) uplift. Similar elevated, dissected topography and approximately 37 ka estuarine deposits are observed over broad portions of the Coastal Plain along the eastern seaboard east and west of Chesapeake Bay. These surfaces of apparent anomalous elevations have recently been attributed to the presence of a glacial fore-bulge developed outboard of the Laurentide ice sheet (Scott, 2006).~~

Question 02.05.01-25

FSAR Section 2.5.1.2.4 states "Although the basement beneath the site has not been penetrated with drill holes, regional geologic cross sections developed from geophysical, gravity and aeromagnetic, as well as limited deep borehole data from outside of the CCNPP site area, suggest that Precambrian and Paleozoic crystalline rocks and, less likely, Mesozoic rift-basin deposits are present at about 2,500 ft (762 m) msl (Section 2.5.1.2.2)."

This statement summarizes a change in tone midway through the application such that the argued age of the crust under the site changes from Mesozoic to Paleozoic. For example, FSAR Figures 2.5-10, 2.5-11, 2.5-12, 2.5-15, and 2.5-16b indicate Mesozoic crust at or near the site. Please provide further explanation and revise text and/or figures as necessary.

Response

As the above-quoted CCNPP Unit 3 FSAR text summarizes, the age of the crust beneath site area is unknown because approximately 2500 ft (762 m) of Coastal Plain deposits bury basement rocks and no geologic borings penetrate basement in the site area (5-mile radius)(Figure 2.5-11)(see Section 2.5.1.1.3.1.1) (Hansen and Wilson, 1984; Hansen and Edwards, 1986). However, geologic, geophysical, and tectonic models suggest that crust under the site area is composed of Precambrian and Paleozoic crystalline rocks with the possibility that a Mesozoic basin, containing rift-basin deposits, formed within this pre-Mesozoic crust (Horton, 1991; Benson, 1992; Glover and Klitgord, 1995; Klitgord et al., 1995). The delineation of Mesozoic basins beneath the site is equivocal with little data to confirm or deny the presence of a basin (see CCNPP Unit 3 FSAR Section 2.5.1.1.3.1.1 and responses to RAI 71, Questions 02.05.01-7 and 02.05.01-26 for more details). This uncertainty is captured in discussions of the various basin geometries in CCNPP Unit 3 FSAR Section 2.5.1.1.4.4.3 and shown on five CCNPP Unit 3 FSAR figures (Figures 2.5-5, 2.5-10, 2.5-12, 2.5-16, and 2.5-22). No new data are available that definitively answer whether a Mesozoic basin underlies the site.

The 'age of crust' in the CCNPP Unit 3 FSAR text is considered the age of formation of crystalline basement, not 'tectonic age' as used by Johnston et al. (1994) (see response to RAI 71, Question 02.05.01-29). Johnston et al. (1994) considered the 'tectonic age' of crust as the last penetrative event to affect the region. Thus, CCNPP Unit 3 FSAR Figure 2.5-15, reproduced directly from Johnston et al. (1994), illustrates areas of Mesozoic extension within the CCNPP Unit 3 site region (200-mile radius) (e.g. Mesozoic extension of Paleozoic crust). Note this figure has been modified for clarification in the CCNPP Unit 3 FSAR text (see response to RAI 71, Question 02.05.01-29). In addition, the presence of a basin under the site area does not mean the age of crust under the site is Mesozoic, because the amount of Mesozoic basin sediments is very small compared to the extended Paleozoic crystalline basement. For example, CCNPP Unit 3 FSAR Figure 2.5-17 illustrates a possible geometry of buried and exposed Mesozoic basins in the site region (Glover and Klitgord, 1995). The basins are thin (< 5 km thick) compared to the thick (30-40 km thick) rifted continental crust.

To avoid further confusion, the CCNPP Unit 3 FSAR text will be modified to clearly delineate the age of crust beneath the CCNPP Unit 3 site area.

References

Benson, R. N. Map of Exposed and Buried Early Mesozoic Rift Basins/Synrift Rocks of the U.S. Middle Atlantic Continental Margin, Delaware Geological Survey Miscellaneous Map Series No. 5, 1992.

Glover, L., III, and K. D. Klitgord. E-3 Southwestern Pennsylvania to Baltimore Canyon Trough, Geological Society of America Centennial Continent/Ocean Transect #19, 1995.

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Horton, J. W., Drake, A. A., Rankin, D. W., and Dallmeyer, R. D., Preliminary Tectonostratigraphic Terrane Map of the Central and Southern Appalachians, U.S. Geological Survey Miscellaneous Investigations Series Map I-2163, 1991.

Johnston, A.C., Coppersmith, K.J., Kanter, L.R., and Cornell, C.A., The Earthquakes of Stable Continental Regions, Volume 1: Assessment of Large Earthquake Potential, Final Report TR-102261-V1, prepared for Electric Power Research Institute (EPRI), 1994.

Klitgord, K.D., Poag, C.W., Glover, L., Sheridan, R.E., Hutchinson, D.R., Mixon, R.D., and Benson, R.N., Mid-Atlantic Continental Margin: The Mesozoic-Cenozoic Continent-Ocean Boundary, in L. Glover III, and K. D. Klitgord, Chief Compilers, E-3 Southwestern Pennsylvania to Baltimore Canyon Trough, Geological Society of America Continent/Ocean Transect #19, Explanatory Pamphlet, 1995.

COLA Impact

The CCNPP Unit 3 FSAR will be revised in a future revision of the COLA as folllows:

1. The fourth sentence in the third paragraph of FSAR subsection 2.5.1.1.4 will be revised as shown:

   Paleozoic and <u>older crust extended during the </u>Mesozoic ~~extended crust~~ underlies the entire 200 mi (322 km) CCNPP site region (Figure 2.5-15).

2. The fifth sentence in the first paragraph of FSAR subsection 2.5.1.1.4.4.1 will be revised as shown:

   Within the eastern Piedmont physiographic province, extended crust of the Iapetan passive margin extends eastward beneath the Appalachian thrust front approximately to the eastern edge of Paleozoic crust extended during the Mesozoic ~~extended crust within the eastern Piedmont physiographic province~~ (Johnston, 1994)(Wheeler, 1996) (Figure 2.5-15).

3. The second sentence in the first paragraph of FSAR Subsection 2.5.1.1.4.4.3. Will be revised as shown:

   A series of elongate rift basins of early Mesozoic age are exposed in a belt extending from Nova Scotia to South Carolina and define ~~the~~ an area of crust extended during the Mesozoic ~~crust~~ (Figure 2.5-10).

Question 02.05.01-27

FSAR Section 2.5.1.2.4 refers to elevation differences across a postulated fault within 2 km of the site (Kidwell, 1997). The applicant stated: "...these can be readily explained by channeling and highly irregular erosional surfaces. Field and aerial reconnaissance, coupled with interpretation of aerial photography and LiDAR data (Section 2.5.3.1 for additional information regarding the general methodology) conducted as part of this CCNPP Unit 3 study revealed no features suggestive of tectonic deformation developed in the surrounding Pliocene and Quaternary surfaces."

Kidwell (1997) describes the details of sedimentary facies at Calvert Cliffs. Many channel deposits are defined in the paper, and it seems unlikely that overlooked channels can account for the multiple stratigraphic contacts that are offset. Furthermore, on FSAR Figure 2.5-26 Moran Landing is at the northeast end of a fairly linear stream valley trending northeast that may be a fault or fracture zone trace.

Please provide additional surface and subsurface data across this feature to show that each of the geologic contacts that are down-dropped at the proposed fault contain channel deposits in the lows.

Response

The statement regarding the erosional unconformities and channel deposits was meant to refer only to Kidwell's inferred elevation changes in the "probable Pleistocene cliff-top gravels" (p. 324) (Kidwell, 1997). Field investigations conducted as part of preparing the FSAR confirm that the basal contact of these cliff-top gravels is an erosional unconformity, and any potential variation in the elevation of this contact or thickness of the gravels cannot be used to infer stratigraphic offsets. The undulatory nature of the contact is highly variable as demonstrated in numerous profiles prepared by Kidwell (1997). Therefore, it is not appropriate or relevant to discuss the presence or absence of channel deposits within the Miocene units because the CCNPP Unit 3 FSAR text was not meant to describe channel deposits within these units. The paragraph within FSAR Section 2.5.1.2.4 with reference to this channeling has been revised to clarify the original intent of the statement.

As described in CCNPP Unit 3 FSAR Section 2.5.1.2.4 and in Kidwell (1997), the presence of the hypothesized fault at Moran Landing is based on a change in elevation between stratigraphic contacts of multiple units within the Miocene St. Mary's Formation on either side of Moran Landing, a distance of approximately 1 km (see figures 4 and 5 of Kidwell (1997)). Based on cross sections presented within Kidwell (1997), the difference in elevation within the St. Mary's Formation across Moran Landing is at most 2 to 3.7 meters. Given the small differences in elevation of the St. Mary's Formation (on the order of meters) relative to the distance over which those observations are extrapolated (on the order of hundreds of meters), the differences in elevation are at best weak evidence of faulting within the Miocene St. Mary's Formation. Because the proposed Pleistocene gravels overlying the Miocene units are deposited on an erosional unconformity, the extrapolated elevation differences of these gravels cannot be used to constrain the presence of Quaternary faulting.

The presence of similar warped discontinuities preserved in the St Mary's Formation are mapped by Kidwell (1997) south of Moran Landing at Little Cove Point (Figure 2.5.1-30).

At Cove Point the elevation changes are preserved in nearly a continuous exposure and are interpreted as "small" monoclinal warps rather than faulting by Kidwell (1997). The monoclines have kilometer long wavelengths and amplitudes of several meters similar to the inferred feature across Moran Landing. Geometric similarities and the association of St. Marys deposits at Little Cove Point with those north and south of Moran Landing, where there is an absence of continuous exposure, strongly suggest that the elevation change of Miocene strata across Moran Landing should be characterized as a subtle warp and not a fault. Broad subtle warps such as those interpreted by Kidwell (1997) could also be developed by non-tectonic processes such as differential compaction and loading (Prothero and Schwab, 1996).

Also, this question raises the casual observation that Moran Landing, and the area of Kidwell's hypothesized fault Kidwell (1997), coincides with a "fairly linear stream valley trending northeast" and seems to suggest that this may be supporting evidence for a fault zone at Moran Landing. CCNPP Unit 3 FSAR Figure 2.5-26 shows there are numerous fairly linear stream valleys trending northeasterly within the greater site area and thus demonstrating that the trend of the valley near Moran Landing is not unique or anomalous in the area. Cliff exposures along Chesapeake Bay contain northeast-striking joints in the St. Mary's Formation that trend perpendicular to the cliff face and likely promote accelerated erosion along such drainages rather than the presence of a fault zone. As discussed in FSAR Section 2.5.3.1, an extensive search for evidence of surface faulting within the site area, including near Moran Landing, uncovered no evidence of faulting. Combined, these observations support the conclusions that the linear valley associated with Moran Landing is not related to the presence of a capable fault.

Regional geologic data southwest of Moran Landing, such as geologic cross sections and seismic reflection data, also provide evidence for the absence of the hypothesized Kidwell (1997) fault. Kidwell (1997) postulates that the fault strikes northeast and exhibits a north-side down sense of separation across Miocene through Quaternary stratigraphy. The presence of such a fault can be evaluated using the projected intersection of the fault with cross-sections A-A' and B-B' of Achmad and Hansen (1997) (see Figures 1 through 3 for the response to RAI 71, Question 02.05.01-5). These cross-sections demonstrate the absence of a large structure at depth coincident with the Kidwell (1997) fault. In addition, Hansen (1978) does not describe faulting in seismic reflection line St. M-2 that would intersect the southwest projection of the inferred fault (see Figure 2 of the response to RAI 71, Question 02.05.01-18).

These observations provide evidence to conclude that the inferred fault proposed by Kidwell (1997) at Moran Landing is most likely not a capable fault or does not exist. However, there is extensive additional evidence presented within the CCNPP Unit 3 FSAR, other RAI 71 question responses, and analysis supporting the definitive conclusion that the inferred fault is not a capable fault, including:

- The absence of any fault-related lineaments observed in the analysis of LiDAR data near Moran landing (see FSAR Section 2.5.3.1; the LiDAR data are provided with the response to RAI 71,Question 02.05.01-18);

- The absence of any fault-related lineaments observed during an office-based terrace mapping exercise using LiDAR data of multiple fluvial terraces along the Patuxent and Potomac Rivers;

- The absence of any fault related features found during analysis of aerial photographs and reconnaissance (CCNPP Unit 3 FSAR Section 2.5.3.1); and
- The lack of any evidence for Quaternary faulting found during field reconnaissance activities and review of fluvial surfaces south of Moran Landing (CCNPP Unit 3 FSAR Section 2.5.3.1).

References

Achmad, G. and Hansen, H.J., Hydrogeology, Model Simulation, and Water-Supply Potential of the Aquia and Piney Point-Nanjemoy Aquifers in Calvert and St. Mary's Counties, Maryland, Department of Natural Resources Maryland Geological Survey Report of Investigations No. 64, 197 p., 1997.

Hansen, H.J., Upper Cretaceous (Senonian) and Paleocene (Danian) Pinchouts on the South Flank of the Salisbury Embayment, Maryland and Their Relationship to Antecedent Basement Structures, Department of Natural Resources Maryland Geological Survey Report of Investigations No. 29, 36 p., 1978.

Kidwell, S. M., Anatomy of Extremely Thin Marine Sequences Landward of a Passive-Margin Hinge Zone: Neogene Calvert Cliffs Succession, Maryland, U.S.A., Journal of Sedimentary Research, v. 67, No 2, p. 322-340, 1997.

Prothero, D.R., and Schwab, F., Sedimentary Geology: An Introduction to Sedimentary Rocks and Stratigraphy, published by W.H. Freeman and Company, New York, p. 575, 1996.

COLA Impact

The CCNPP Unit 3 FSAR Section 2.5.1.2.4, ninth paragraph will be revised in a future COLA revision as shown below and a new paragraph will be added following the revised paragraph:

> ~~Near Moran Landing, a~~About 1.2 mi (1.9 km) south of the site, Kidwell (Kidwell, 1997) interprets an apparent 6 to 10 ft (2 to 3 m) elevation change in Miocene strata by extrapolating unit contacts across the approximately 0.6 mile wide (1 km) gap at Moran Landing (Figure 2.5-25 and Figure 2.5-30). Kidwell (Kidwell, 1997) also interprets~~, and~~ a 3 to 12 (0.9 to 3.7 m) ft elevation change in younger (Quaternary (?))~~Pliocene and Quaternary (?)~~ fluvial material across this same gap. Because of the lack of cliff exposures at Moran Landing (only the valley margins), no direct observations of these elevation changes can be made. ~~(Figure 2.5-25 and Figure 2.5-30).~~ Kidwell (Kidwell, 1997) ~~infers the presence of a fault to~~ explains the differences in elevation ~~of strata across~~ of the Miocene-Quaternary stratigraphy by hypothesizing the existence of a fault at Moran Landing that strikes northeast and accommodates a north-side down sense of separation. However, ~~T~~the postulated fault of Kidwell (Kidwell, 1997) is not shown on any of Kidwell's (Kidwell, 1997) cross-sections, or any published geologic map (e.g., Glaser, 2003b and 2003c). In addition, Hansen (1978) does not describe faulting in seismic reflection line St. M-2 that intersects the inferred southwest projection of the hypothesized Kidwell (1997) fault (FSAR Figure 2.5-27).~~, however the inferred location is approximately 1.2 mi (1.9 m) south of the CCNPP site.~~

~~The hypothesized fault is not exposed in the cliff face, but Kidwell (Kidwell, 1997) postulates the presence of a fault, and is based entirely on a change in elevation and bedding dip of Miocene stratigraphic boundaries projected across the fluvial valley of Moran Landing. Kidwell (Kidwell, 1997) postulates that the fault strikes northeast and exhibits a north-side down sense of separation across all the geologic units (Miocene through Quaternary). With regard to the apparent elevation changes for the Pliocene and Quaternary unconformities, these can be readily explained by channeling and highly irregular erosional surfaces. Field and aerial reconnaissance, coupled with interpretation of aerial photography and LiDAR data (Section 2.5.3.1 for additional information regarding the general methodology) conducted as part of this CCNPP Unit 3 study revealed no features suggestive of tectonic deformation developed in the surrounding Pliocene and Quaternary surfaces.~~

The observations of offset younger gravels do not provide any evidence for the existence of a fault because the surface on which the gravels are deposited is an erosional unconformity with extensive variable relief (Kidwell, 1997). Observations made during field reconnaissance, as part of the FSAR preparation, confirmed that this contact was an erosional unconformity with significant topography north and south of Moran Landing consistent with stratigraphic representations in Kidwell (1997) profiles. The observations of several feet of elevation change in the Miocene units over several thousands of feet of horizontal distance is at best weak evidence for faulting within the Miocene deposits. For example, subtle elevation variations in Miocene strata characterized along a near-continuous exposure south of Moran Landing contain similar vertical and lateral dimensions as to the inferred elevation change across Moran Landing; however, the features are interpreted as subtle warps and not faults by Kidwell (1997). On the basis of association with similar features to the south and the lack of a continuous exposure, there is little to no evidence to support a fault across Moran Landing. The lack of evidence for Quaternary faulting within the observations made by Kidwell (Kidwell, 1997), and the results of the studies undertaken as part of the CCNPP Unit 3 COLA effort (field and aerial reconnaissance, air photo and LiDAR analysis) (see FSAR Section 2.5.3.1), collectively support the conclusion that the hypothesized fault of Kidwell (Kidwell, 1997) is not a capable fault.

The CCNPP Unit 3 FSAR Section 2.5.3.2.3, second paragraph will be revised in a future COLA revision as shown below and a new paragraph will be added following the revised paragraph:

~~Near Moran Landing, a~~About 1.2 mi (1.9 km) south of the CCNPP site, Kidwell (Kidwell, 1997) interprets an apparent 6 to 10 ft (1.8 to 3 m) elevation change in Miocene strata by extrapolating unit contacts across the approximately 0.6 mile wide (1 km) gap at Moran Landing (Figure 2.5-25 and Figure 2.5-30). Kidwell (Kidwell, 1997) also interprets~~, and~~ a 3 to 12 (0.9 to 3.7 m) ft elevation change in younger (Quaternary (?))~~Pliocene and Quaternary (?)~~ fluvial material ~~deposits has been interpreted (Kidwell, 1997) as shown in Figure 2.5-30~~ across this same gap. Because of the lack of cliff exposures at Moran Landing (only the valley margins), no direct observations of these elevation changes can be made. ~~(Figure 2.5-25 and Figure 2.5-30).~~ Kidwell (1997) ~~The presence of a fault to~~ explains the differences in elevation~~ of similar strata across~~ of the Miocene-Quaternary stratigraphy by hypothesizing the existence of a fault at Moran Landing that strikes northeast and accommodates a north-side down sense of separation.~~ has been inferred (Kidwell, 1997).~~

However, ~~T~~the postulated fault of Kidwell (Kidwell, 1997) is not shown on ~~the Section~~ any of Kidwell's (Kidwell, 1997) cross-sections, or any published geologic map (e.g., Glaser, 2003b and 2003c). In addition, Hansen (1978) does not describe faulting in seismic reflection line St. M-2 that intersects the inferred southwest projection of the hypothesized Kidwell (1997) fault (Figure 2.5-27).~~; however, the inferred location is approximately 1.2 mi (1.9 m) south of the CCNPP site. The hypothesized fault is not exposed in the cliff face and is based entirely on the change in elevation and bedding dip of Miocene stratigraphic boundaries across Moran Landing as shown in Figure 2.5-30. It is postulated (Kidwell, 1997) that the fault strikes northeast and exhibits a down-to-the-north sense of separation. The apparent elevation change of the Pliocene and Quaternary contacts, however, can be explained by fluvial processes (channeling and irregular erosional and depositional surfaces).~~

The observations of offset younger gravels do not provide any evidence for the existence of a fault because the surface on which the gravels are deposited is an erosional unconformity with extensive variable relief (Kidwell, 1997). Observations made during field reconnaissance, as part of the FSAR preparation, confirmed that this contact was an erosional unconformity with significant topography north and south of Moran Landing consistent with stratigraphic representations in Kidwell (1997) profiles. The observations of several feet of elevation change in the Miocene units over several thousands of feet of horizontal distance is at best weak evidence for faulting within the Miocene deposits. For example, subtle elevation variations in Miocene strata characterized along a near-continuous exposure south of Moran Landing contain similar vertical and lateral dimensions as to the inferred elevation change across Moran Landing; however, the features are interpreted as subtle warps and not faults by Kidwell (1997). On the basis of association with similar features to the south and the lack of a continuous exposure, there is little to no evidence to support a fault across Moran Landing.

RAI No 72

Question 02.05.02-2

Page 2.5-98 of the FSAR states that the magnitudes given in the catalogs were converted to EPRI best or expected estimate values of m_b based on FSAR Equations 2.5.2-1 and 2.5.2-2. Please justify the use of these formulas, which are based on magnitude data acquired more than 20 years ago.

Also, in FSAR Equation 2.5.2-3, the applicant assumes b=1.0. Explain whether or not this b-value is supported by the regional seismicity data.

Response

In the development of the EPRI methodology (EPRI, 1988) and database an effort was made to develop a uniform characterization of body-wave magnitude (m_b) for each earthquake in the EPRI seismicity catalog in order to develop a robust database from which rigorous assessments of magnitude-frequency recurrence and maximum magnitudes could be made for subsequent input to probabilistic seismic hazard analyses (PSHA). The EPRI (EPRI, 1988) methodology documentation discusses the statistical analyses that were applied to the EPRI seismicity catalog to develop the magnitude conversion relations, referenced in the CCNPP Unit 3 FSAR as Equations 2.5.2-1 and 2.5.2-2. The earthquake database from which these relationships were derived – including assessment of various magnitude and intensity measures for each earthquake serving as input to the regressions for magnitude conversion relationships – was developed under an equivalent Senior Seismic Hazards Analysis Committee (SSHAC) Level 4 process (NRC, 1997b). Both the EPRI seismicity catalog and the magnitude conversion relations developed from that database are considered to be an adequate characterization of seismicity in the central and eastern United States through 1984.

As detailed in CCNPP Unit 3 FSAR 2.5.2.1, four catalogs were used to update the EPRI seismicity catalog:

- Southeastern US Seismic Network (SEUSSN) Catalog
- Advanced National Seismic System (ANSS) Catalog
- Canada On-line Bulletin (Canada)
- Ohio Seismic Network Catalog (Ohio)

Of these four catalogs, only the SEUSSN presents multiple magnitude type measures for each event – up to three magnitudes and one intensity estimate -- allowing comparison between different type sizes of the events. Of the 12,787 events in the SEUSSN catalog, only 125 have m_b and Md co-evaluations; only 81 of these are within the CCNPP Unit 3 seismicity update region, and only 47 of these occurred after 1984. Only 17 SEUSSN events with Md-m_b co-evaluations are finally listed in CCNPP Unit 3 FSAR Table 2.5-2. All four Md-m_b subsets of the SEUSSN catalog cluster about the EPRI Md-m_b conversion relation, suggesting only a marginally higher estimated trend of m_b from Md – a maximum of ~0.1 magnitude units at an Md value of 5.0.

In the full SEUSSN catalog only 45 events have m_b and ML co-evaluations – none are in the CCNPP Unit 3 site region. There are, therefore, no ML-m_b pairs in the site region to consider revising the EPRI conversion relationship.

From these observations, the EPRI conversion relations are still valid and the Emb values adopted for the EPRI catalog update of the CCNPP Unit 3 FSAR are reasonable.

In EPRI (EPRI, 1988) a b-value of 1.0 was used to determine m_b^* in the EPRI seismicity catalog. Again for consistency in methodology, b=1.0 was used in the CCNPP Unit 3 FSAR for the updated seismicity when using Equation 2.5.2-3. CCNPP Unit 3 FSAR Figure 2.5-63 shows b-values of about 0.95 to 1.0, demonstrating that b=1.0 is a reasonable global b-value for the purposes of evaluating m_b^* in the CCNPP Unit 3 study region.

References

EPRI, 1988. Seismic Hazard Methodology for the Central and Eastern United States, Electric Power Research Institute, Report NP-4726-A, Revision 1, Volume 1, Part 2, 1988.

NRC, 1997b. Recommendations for Probabilistic Seismic Hazard Analysis: Guidance on Uncertainty and Use of Experts, Prepared by Senior Seismic Hazard Analysis Committee (SSHAC), U.S. Nuclear Regulatory Commission, NUREG/CR-6372, 1997.

COLA Impact

None

Question 02.05.02-3

FSAR Tables 2.5-4 through 2.5-9 summarize each of the six EPRI team's seismic source models. The tables list probability of activity (Pa) for each source.

(a) Please explain the meaning "probability of activity" in these tables and also discuss the impacts on the seismic hazard.

(b) For the Central Virginia seismic zone (CVSZ), Tables 2.5-4 through 2.5-9 list the following values probability values specified by each team: Bechtel (0.35), Dames and Moore (1.0), Rondout (1.0), Law (0.43). Given the seismogenic nature of the CVSZ (i.e. continued seismic activity in the CVSZ since the EPRI 1986 study and the occurrence of the 9 December 2003 M4.3 central Virginia earthquake (Kim and Chapman, 2005, BSSA), please explain why the CVSZ probability of activity values have not been adjusted to 1.0.

(c) In FSAR Table 2.5-5, the Dames and Moore source characterization parameters are presented for Zones 41 (Southern Cratonic Margin) 53 (Southern Appalachian Mobile Belt), 47 (Connecticut Basin), and 4 (Appalachian Fold Belts). Relatively low probabilities of activity were assigned to these zones by the Dames and Moore team. Please justify the source characterization parameters used by the Dames and Moore team for Zones 41, 53, 47, and 4 to assess seismic hazard of the region surrounding the Calvert Cliffs site. Considering the low probability values selected by the Dames and Moore team, please also justify the conclusion that the source characterization for Zones 41, 53, 47, and 4 still falls within the range for seismic hazard in the Central and Eastern U.S (CEUS) that is accepted by the scientific peer community.

Response

a) In Tables 2.5-4 through 2.5-9, Pa is the probability of activity, which was defined in EPRI methodology as the probability that the source (often representing a tectonic feature) is capable of generating earthquakes. In regions of historical seismicity such as the Central Virginia seismic zone (CVSZ), the EPRI Earth Science Teams (teams) often developed alternative sources representing alternative explanations of historical seismicity, each with its own Pa. These alternatives captured the teams' uncertainties in characterizing the sources that explain earthquake occurrences. Some teams (e.g., the Dames & Moore team) evaluated Pa as the probability that the source (often representing a tectonic feature) is capable of generating moderate-to-large earthquakes.

   For each source, the seismic hazard (frequency of exceedance of ground motion amplitudes) is directly proportional to Pa. For regions with multiple alternative seismic sources, each with its own Pa, the hazard from each source is (in effect) weighted by the Pa value for that source, and the total mean hazard is the weighted sum of hazards from each source.

b) The Bechtel team assigned a Pa value of 0.35 to its source E, which is its Central Virginia source. In logic-tree branches for which source E is not active (which have a probability 0.65), the seismicity is explained by background source BZ5. Thus the seismicity in the CVSZ is represented with probability 1. In seismic hazard calculations, source BZ5 was assigned a Pa of 1, rather than 0.65, so in the region of the CVSZ there was a conservative representation of seismic activity.

This was done because source BZ5 is the host source for the Calvert Cliffs site. The amount of conservatism is small since, for the Bechtel team, the CVSZ contributes only a small fraction of the hazard. (See the response to RAI 72, Question 02.05.02-9)

Dames & Moore assigned a Pa value of 1 to its source 40, which is its Central Virginia source, so this seismicity is represented by a single source. Rondout assigned a Pa value of 1 to its source 29, which is its Central Virginia source, so this seismicity is represented by a single source.

Law assigned a Pa value of 0.43 to its Mafic pluton sources (M22 through M30), several of which are in central Virginia and could be explanations of the seismicity there. In addition, source 107, Law's Eastern Piedmont source, covers the eastern part of the CVSZ and is active with Pa=1. The western part of the CVSZ is represented, in addition to the Mafic pluton sources, by source 17, Law's Eastern Basement source, which is active with Pa=0.62. In addition, the region of source 17 is represented by Law background source 217, which is active with Pa=1. Thus the seismicity in the CVSZ is represented with probability 1.

c) In the coastal plain region, Dames & Moore used three types of seismic sources to explain earthquakes with $m_b>5$:

	Assigned Pa
Buried Triassic basins (sources 47, 48, 49, 50, 51, 65):	0.28
Charleston Mesozoic rift (source 52):	0.46
Southern Appalachian Mobile Belt (default source 53):	0.26
Total Pa:	1.00

In the Piedmont region, Dames & Moore used four seismic sources to explain earthquakes with $m_b>5$:

	Assigned Pa
Newark-Gettysburg basin (source 42):	0.40
Ramapo Fault (source 43):	0.20
Dan River basin (source 46):	0.28
Southern Cratonic Margin (default source 41):	0.12
Total Pa:	1.00

Similarly, in the Appalachian region, Dames & Moore used two seismic sources to explain earthquakes with $m_b>5$:

	Assigned Pa
Kinks in Fold Belt (sources 4A, 4B, 4C, and 4D):	0.65
Appalachian Fold Belt (source 4):	0.35
Total Pa:	1.00

These source characterization parameters are justified as follows. In each region, Dames & Moore adopted the position that only one tectonic explanation of earthquakes in the region could be correct, the probability of each explanation being correct is represented by Pa, and the last interpretation in each list represented the position that none of the others were correct, i.e. the last interpretation was the default source. In all cases, Pa values summed to 1.

The Pa values derived by the Dames & Moore team reflect the view that there are certain parts of the earth's crust that are relatively stable and that will not generate moderate-to-large earthquakes. The various source interpretations listed above indicate that Dames & Moore was uncertain about which parts of each region could and could not generate moderate-to-large earthquakes, and represented that uncertainty with alternative source interpretations. This is a common concept in seismic hazard analysis. In the EPRI-SOG project, the Law team had a similar position with respect to a number of their sources including their Eastern Basement Background (source 217). The Law team expressed their uncertainty in where earthquakes with $m_b>5$ could occur using a background probability P_B, which is the fraction of area within a source that can produce $m_b>5$. The concept is the same: not all areas of the earth's crust can produce moderate-to-large earthquakes, and the Law team was uncertain where those regions were.

For example, in Europe, where the SESAME project[1] defined seismic sources for seismic hazard analysis in the Mediterranean Basin[2], it can be seen that not all of Europe was covered by seismic sources (e.g., central Spain and the bootheel of Italy). This means that some parts of the earth's crust were considered stable and incapable of producing magnitudes large enough to be considered in the seismic hazard analysis. In Australia, Gaull et al. (1990) defined a background zone covering much of western Australia (west of longitude 129° E) that could not produce earthquakes with $M_L>5$. Thus the concept that Dames & Moore expressed with its Pa values is not unique, has been used in other seismic hazard efforts, and has been accepted by the scientific peer community.

References

Gaull, B.A., M.G. Miclael-Leiba, and J.M.W.Rynn (1990). Probabilistic Earthquake Risk Maps of Australia, Australian Journal of Earth Sciences, 37, 169-187.

COLA Impact

None

[1] www.seismo.ethz.ch/gshap/sesame
[2] See map at www.seismo.ethz.ch/gshap/sesame/fig3.gif

Question 02.05.02-4

In FSAR Sections 2.5.2.2.1.7 (page 2.5-113) and 2.5.1.1.4.5.1. (page 2.5-66) the applicant stated that Chapman and Krimgold (1994) used an Mmax of m_b 7.25 for the Central Virginia seismic zone (CVSZ). The applicant also noted that Chapman and Krimgold's estimate is "similar to" those of the EPRI teams. However, FSAR Tables 2.5-3 through 2.5.9 show that the weighted mean of the Mmax (m_b) values of the EPRI teams for the source zones is m_b 6.2. Please explain how the Mmax values summarized by these weighted means are "similar to" the value provided by Chapman and Krimgold.

Response

The statements noted in this question of whether the maximum magnitude (Mmax) of mb 7.25 for the Central Virginia seismic zone (CVSZ) from Chapman and Krimgold (1994) is within the range of Mmax values defined by EPRI-SOG (EPRI, 1986) for the CVSZ (mb 6.6 to mb 7.2) are misleading because of: (1) a typographical error in the equivalent mb magnitude used by Chapman and Krimgold (1994) for the CVSZ, and (2) several details regarding the Chapman and Krimgold (1994) study that were unintentionally excluded from the CCNPP Unit 3 FSAR text.

Chapman and Krimgold (1994) state that "... maximum magnitude is impossible to define objectively...", and therefore they use the estimated magnitude of Mw 7.53 from Johnston (1992) (as cited in Chapman and Krimgold, 1994) for the 1886 Charleston earthquake as the Mmax for the CVSZ. Using the Mw to mb conversion described in CCNPP Unit 3 FSAR Section 2.5.2.1.2, the equivalent mb Mmax for the CVSZ is 7.22 (see CCNPP Unit 3 FSAR Table 2.5-12). The mb 7.25 value reported in CCNPP Unit 3 FSAR text is a typographical error that occurred while transcribing the value from Table 2.5-12. This error has no effect on downstream analyses performed for the CCNPP Unit 3 COLA.

Shortly after the Chapman and Krimgold (1994) study, Johnston (1996) revised his previous estimate of the magnitude of the 1886 Charleston earthquake from Mw 7.53 (Johnston, 1992) downward to Mw 7.3. More recently Bakun and Hopper (2004) have estimated the magnitude of the 1886 earthquake to be Mw 6.9. The equivalent mb magnitudes for these estimates are 7.1 and 6.9, respectively. Based on Chapman and Krimgold's (1994) reliance on the magnitude of the 1886 Charleston earthquake as the basis for their CVSZ Mmax value, it is reasonable and appropriate to assume that the Mmax for the CVSZ previously described in Chapman and Krimgold (1994) should be lowered to account for the updated magnitudes for the 1886 earthquake.

Therefore, the conclusion stated in the CCNPP Unit 3 FSAR that the Mmax of Chapman and Krimgold's (1994) CVSZ is similar to the Mmax values used in EPRI-SOG study is based on:

1. The original Mmax of Chapman and Krimgold (1994) CVSZ is only 0.02 Mw magnitude units above the EPRI-SOG Mmax range; and

2. Revised Mmax values of Chapman and Krimgold (1994) for the CVSZ (derived from newer magnitude estimates of the 1886 earthquake (mb 7.1 and 6.9)) are within the range of EPRI-SOG Mmax values for the CVSZ (mb 6.6 to 7.2).

References

Bakun, W.H., and Hopper, M.G., Magnitudes and Locations of the 1811-1812 New Madrid, Missouri and the 1886 Charleston, South Carolina, Earthquakes: Bulletin of the Seismological Society of America, v. 94, p. 64-75, 2004.

Chapman, M.C., and Krimgold, F., Seismic Hazard Assessment for Virginia, Virginia Tech Seismological Observatory, Department of Geological Sciences, 1994,

EPRI, 1986 Seismic hazard Methodology for the Central and Eastern United States (NP-4726), Vol. 5-10, Electric Power Research Institute (EPRI), 1986.

Johnston, A.C., The Stable Continental Region Earthquake Data Base, in Coppersmith, K.J., Johnston, A.C., Kanter, L.R., Youngs, R., and Metzger, A.G., eds., Methods for Assessing Maximum Earthquakes in the Central and Eastern U.S., Project Report RP-2556-12, prepared for Electric Power Research Institute (EPRI), 1992.

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

COLA Impact

The CCNPP Unit 3 FSAR Section 2.5.1.1.4.5.1, last paragraph starting with the fifth sentence will be revised in a future COLA revision as shown below:

> Also,Chapman and Krimgold (Chapman, 1994) have used a Mmax of Mw 7.53 (mb 7.25) for the Central Virginia seismic source zone based on the estimated magnitude of the 1886 Charleston earthquake.~~and most other sources in their seismic hazard analysis of Virginia.~~ ~~This m~~More recent estimates of the 1886 earthquake magnitude are lower (Bakun and Hopper, 2004; Johnston, 1996) indicating that the Mmax of Chapman and Krimgold (Chapman, 1994) should also be lowered.~~Mmax is similar to the Mmax values used in the 1986 EPRI studies~~. These more recent estimates of Mmax for the Central Virginia seismic zone are within the range of the Mmax values used in the 1986 EPRI studies (Section 2.5.2.2.1.7).~~Similarly~~ Also, the distribution and rate of seismicity in the Central Virginia seismic source have not changed since the 1986 EPRI study (Section 2.5.2.2.8). Thus, there is no new information or data that motivates modifying ~~change to~~ the source geometry, ~~or~~ rate of seismicity~~.~~, or Mmax values for the Central Virginia seismic zone in the EPRI-SOG model. ~~In 2005, the NRC agreed with the findings of the North Anna ESP application's assessment of the Central Virginia seismic zone (NRC, 2005). Therefore, the conclusion is that no new information has been developed since 1986 that would require a significant revision to the EPRI seismic source model.~~ The same conclusion was reached in the North Anna ESP application, and in 2005 the NRC agreed with this conclusion (NRC, 2005).

The CCNPP Unit 3 FSAR Section 2.5.2.2.1.7, last paragraph will be revised in a future COLA revision as shown below and a new paragraph will be added following the revised paragraph:

> The 1986 EPRI source model (EPRI, 1986) includes various source geometries and parameters to capture the seismicity of the Central Virginia seismic zone (Figure 2.5-51). Subsequent hazard studies have used maximum magnitude (Mmax) values that are within the range of maximum magnitudes used by the six EPRI models. Collectively, upper-bound ~~maximum values of~~ Mmax values used by the EPRI teams range from mb 6.6 to 7.2 (M 6.5 to 7.5) (Table 2.5-10). More recently, Bollinger (USGS, 1992) has estimated a Mmax of M 6.2 (mb 6.4)~~mb 6.4 (M 6.2)~~ for the Central Virginia seismic source, and Chapman and Krimgold (Chapman, 1994) ~~has~~ have used a Mmax of M 7.53 (mb 7.22) ~~mb 7.25 (M 7.6)~~ for the Central Virginia seismic source ~~and most other sources in their seismic hazard analysis of Virginia.~~ based on the estimated magnitude of the 1886 Charleston earthquake from Johnston (1992) (as cited in Chapman and Krimgold (Chapman, 1994)). However, more recent estimates of the 1886 earthquake magnitude made by Johnston (1996) and Bakun and Hopper (2004) are lower, M 7.3 (mb 7.1) and M 6.9 (mb 6.9), respectively. ~~This more recent estimate of Mmax is similar to the Mmax values used in the 1986 EPRI studies (EPRI, 1986). Similarly, the distribution and rate of seismicity in the Central Virginia seismic source has not changed since the 1986 EPRI study (EPRI, 1986). Thus, there is no change to the source geometry or rate of seismicity. In addition the NRC agreed with these findings as part of a review of Dominion Nuclear North Anna LLC's ESP application and assessment of the Central Virginia seismic zone as documented in NUREG-1835, Safety Evaluation Report for an Early Site Permit (ESP) at the North Anna ESP Site, (NRC, 2005). This supports the conclusion that no new information has been developed since 1986 that would require a significant revision to the EPRI seismic source model (EPRI, 1986).~~
>
> Based on Chapman and Krimgold's (1994) reliance on the magnitude of the 1886 Charleston earthquake as the basis for their Central Virginia seismic zone Mmax value, it is reasonable and appropriate to assume that the Mmax for the Central Virginia seismic zone described in Chapman and Krimgold (1994) should be lowered to account for the updated magnitude (i.e., Johnston, 1996; Bakun and Hopper, 2004) estimate of the 1886 earthquake. It is concluded that the more recent estimates of Mmax for the Central Virginia seismic zone are within the range of Mmax values used in the 1986 EPRI studies (EPRI, 1986) because (1) the original Mmax of the Chapman and Krimgold (1994) Central Virginia seismic zone is only 0.02 Mw magnitude units above the EPRI-SOG range, and (2) the revised Mmax values for the Chapman and Krimgold (1994) Central Virginia seismic zone that are derived from newer estimates of the magnitude of the 1886 earthquake lie within the range of EPRI-SOG Mmax values for the Central Virginia seismic zone. Also, the distribution and rate of seismicity in the Central Virginia seismic source has not changed since the 1986 EPRI study (EPRI, 1986). Thus, there is no new information or data that motivates modifying the source geometry, rate of seismicity, or Mmax values for the Central Virginia seismic zone in the EPRI-SOG model. The same conclusion was reached in the North Anna ESP application, and the NRC agreed with these findings as part of a review of Dominion Nuclear North Anna LLC's ESP application and assessment of the Central Virginia seismic zone as documented in NUREG-1835, Safety Evaluation Report for an Early Site Permit (ESP) at the North Anna ESP Site, (NRC, 2005).

This supports the conclusion that no new information has been developed since 1986 that would require a significant revision to the EPRI seismic source model (EPRI, 1986).**Question 02.05.02-5**

FSAR Section 2.5.2.2.2.3 discusses post-EPRI seismic source characterization studies including the USGS (2002) model. The recurrence of New Madrid Seismic Zone (NMSZ) Mmax earthquakes is recognized as having changed (USGS, 2002) since the EPRI (1986) study. However, there is no calculation of the contribution of the NMSZ to the hazard at the CCNPP site. Intensity observations due to the Dec. 16, 1811 earthquake rank MMI IV in the site region. Shake Map MMI IV suggests a PGA between 3.9 and 9.2% g. This is close to the 0.1g PGA associated with the GMRS (refer to FSAR page 2.5-143). Please discuss the significance of the NMSZ at the CCNPP site and provide justification for not including this source zone in the seismic hazard analysis in light of the above intensity observations and recent revisions to the national seismic hazard maps (USGS, 2002, 2008).

Response

The New Madrid seismic zone (NMSZ) is about 1200 km from the CCNPP Unit 3 site. The NMSZ was not included in the seismic hazard analysis for the CCNPP Unit 3 site for the following reasons:

(1) The EPRI (2004) ground motion equations are only defined to a distance of 1000 km. They likely do not produce reliable estimates of ground motion at distances beyond 1000 km, and probably are conservative for distances beyond 500 km, because some of the equations apparently do not include crustal Q, leading to conservative estimates at long distances.

(2) The definition of Modified Mercalli Intensity (MMI IV) does not include damage to buildings under the Modified Mercalli scale. Damage to buildings begins with MMI VI, and only then for "poorly built buildings." Thus the occurrence of MMI IV in the site region would not imply damage to an engineered facility.

(3) A recent correlation of ground motion values with MMI levels (Atkinson and Kaka, 2007) indicates that the mean peak ground acceleration (PGA) level associated with MMI IV is about 8 cm/sec^2, or about 0.008g. Further, it is likely that high frequency characteristics of ground motion (such as PGA) are attenuated at long distances from earthquakes because of crustal Q (among other effects), and that MMI effects at those long distances are elevated (relative to the low PGA levels) and are caused by lower-frequency motions and long durations. This effect is seen in Figure 10 of Atkinson and Kaka, 2007, which is a plot of residuals defined as [observed MMI – predicted MMI] vs. distance. (Figure 10 of Atkinson and Kaka, 2007 is for 3.3 Hz spectral acceleration; an equivalent plot for PGA is not presented). At distances larger than 100 km the residuals in Figure 10 are positive for central United States earthquakes, indicating that larger-than-predicted MMI levels were observed at long distances. This was likely the case for the inferred MMI IV level from the 1811 earthquake, implying that the appropriate PGA level would be lower than predicted from the average MMI-PGA relationship.

References

Atkinson, G.M., and S.I. Kaka (2007). "Relationships between felt intensity and instrumental ground motion in the central United States and California," Bull. Seism. Soc. Am., 97, 2, 497-510, April.

EPRI, 2004. CEUS Ground Motion Project Final Report, Electric Power Research Institute, TR-1009684 2004, December 2004.

COLA Impact

None

Question 02.05.02-8

FSAR Section 2.5.2.4.1 (page 2.5-129) states: "For amplitudes corresponding to annual exceedance frequencies in the range 10^{-4} to 10^{-6}, the 2006 calculations replicate the 1989 EPRI results (EPRI, 1989a) to an accuracy that is in the range of 3 percent to 12 percent, with the 2006 calculations indicating slightly higher hazard. This is acceptable agreement, given that independent software was used to perform these calculations."

(a) Provide the basis for concluding that a 12% disagreement just due to software is acceptable.

(b) Discuss the possible sources of this 3 to 12% difference due to the use of independent software to perform the hazard calculations.

Response

a) The replication of 1989 EPRI hazard results was re-examined and an error was found in the EPRI team's input. This error did not propagate to subsequent hazard calculations with updated models, but only affected the comparison with the 1989 EPRI hazard results. Table 02.05.02-8A (below) shows an updated comparison of current hazard results and EPRI-SOG hazard results. The maximum difference is 3.8% in hazard. This is considered acceptable, because the corresponding difference in ground motion amplitude for a fixed annual frequency of exceedance would be about 1%, which is the same order as the precision with which spectral amplitudes are usually reported (three significant figures). CCNPP Unit 3 FSAR Table 2.5-20 {Comparison of EPRI-SOG Seismic Hazard Results and Replication Calculated in 2006, for PGA, 10 Hz, and 1 Hz Spectral Velocity} will be updated with the values shown below.

Table 02.05.02-8A

PGA comparison			
Ampl, cm/s^2	2006 mean	EPRI-SOG mean	% difference
50	4.43E-04	4.30E-04	3.1%
100	1.07E-04	1.03E-04	3.8%
250	1.17E-05	1.13E-05	3.5%
500	1.42E-06	1.37E-06	3.7%
10 Hz comparison			
Ampl, cm/s	2006 mean	EPRI-SOG mean	% difference
1	7.92E-04	7.74E-04	2.3%
5	2.39E-05	2.32E-05	2.9%
10	3.41E-06	3.33E-06	2.5%
20	3.32E-07	3.26E-07	1.7%
1 Hz comparison			
Ampl, cm/s	2006 mean	EPRI-SOG mean	% difference
1	1.59E-03	1.56E-03	1.9%
5	1.35E-04	1.33E-04	1.3%
10	3.64E-05	3.58E-05	1.6%
20	7.68E-06	7.53E-06	1.9%

b) Possible sources of difference in hazard caused by using different software are differences in algorithms to integrate over spatial geometries representing area sources, differences in numerical integration step sizes, differences in computer precision (hazards are calculated as the sum of numerous small quantities), and unstated approximations in EPRI-SOG software that are not made in current software.

References

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

COLA Impact

The CCNPP Unit 3 FSAR Table 2.5-20 will be revised in a future COL revision as shown below:

Table 2.5-20 – {Comparison of EPRI-SOG Seismic Hazard Results and Replication Calculated in 2006, for PGA, 10 Hz, and 1 Hz Spectral Velocity}

	PGA comparison		
Ampl, cm/s^2	**2006 mean**	**EPRI-SOG mean**	**% difference**
50	~~4.57~~4.43E-04	4.30E-04	~~6.3~~3.1%
100	~~1.12~~1.07E-04	1.03E-04	~~8.43~~3.8%
250	~~1.25~~1.17E-05	1.13E-05	~~10.4~~3.5%
500	~~1.54~~1.42E-06	1.37E-06	~~12.4~~3.7%
	10 Hz comparison		
Ampl, cm/s	**2006 mean**	**EPRI-SOG mean**	**% difference**
1	~~8.11~~7.92E-04	7.74E-04	~~4.8~~2.3%
5	~~2.52~~2.39E-05	2.32E-05	~~8.7~~2.9%
10	~~3.67~~3.41E-06	3.33E-06	~~10.3~~2.5%
20	3.32E-07	3.26E-07	1.7%
	1 Hz comparison		
Ampl, cm/s	**2006 mean**	**EPRI-SOG mean**	**% difference**
1	~~1.61~~1.59E-03	1.56E-03	~~3.3~~1.9%
5	~~1.38~~1.35E-04	1.33E-04	~~3.9~~1.3%
10	~~3.77~~3.64E-05	3.58E-05	~~5.2~~1.6%
20	7.68E-06	7.53E-06	1.9%

Question 02.05.02-9

FSAR Section 2.5.2.4.6 (page 2.5-133) states the following:

"Use of all distances in the calculation of mean magnitude and distance controlling earthquake values of M = 5.5 and R =97 for the 10^{-4} event. It is clear from the total deaggregation results (see Figure 2.5-67 of the FSAR) that this is not the distance of the earthquake controlling high frequency motions. Use of the alternative method leads to the same mean magnitude but to the closer distance, R, of 35 km, in better agreement with the deaggregation results (again, as shown in the figure)."

FSAR Figure 2.5-91 shows that the mean seismic hazard (at 10^{-4}) by source for the Rondout team at 10Hz is dominated by the Central Virginia seismic zone (CVSZ), which is denoted RND-29. This Rondout source zone is 89km from the CCNPP site.

(a) Using the procedure specified in Appendix D to RG 1.208, the applicant obtained values of M=5.5 and R=97, which fit well with a source in the CVSZ. Given that FSAR Figure 2.5-91 shows the CVSZ clearly controls high frequency motions, please justify the use of the alternative method.

(b) On page 2.5-134 of the FSAR, in reference to Figure 2.5-9, the applicant stated that "... local sources, particularly the central Virginia seismic zone, tend to dominate the hazard, particularly for high frequency ground motions (10 Hz)". However, FSAR Figure 2.5-67 does not show a dominant contribution to high frequency motions from earthquakes in the distance range of the CVSZ (i.e 76-100km). Please reconcile this apparent conflict.

(c) Which source zone (from which team) actually dominates the large contribution to the hazard at M 5.0-5.5 and R 10-20km shown in FSAR Figure 2.5-67? Please provide a figure like FSAR Figure 2.5-91, which shows the relative contribution to the hazard of the sources from that team.

Response

a) CCNPP Unit 3 FSAR Figure 2.5-91 shows the hazard curves for 10 Hz spectral acceleration by source for the Rondout Earth Science Team (team). For this team and this spectral frequency, the Central Virginia seismic zone (CVSZ) dominates the hazard. This is also evident in Figure 02.05.02-9A, (see below) which is a deaggregation of 10 Hz seismic hazard for the Rondout team only, calculated at a 10 Hz amplitude of 0.15 g (which is the 10^{-4} spectral amplitude for 10 Hz for all teams). The contribution to seismic hazard in Figure 02.05.02-9A from about 80 to 160 km shows the importance of the CVSZ for the Rondout team.

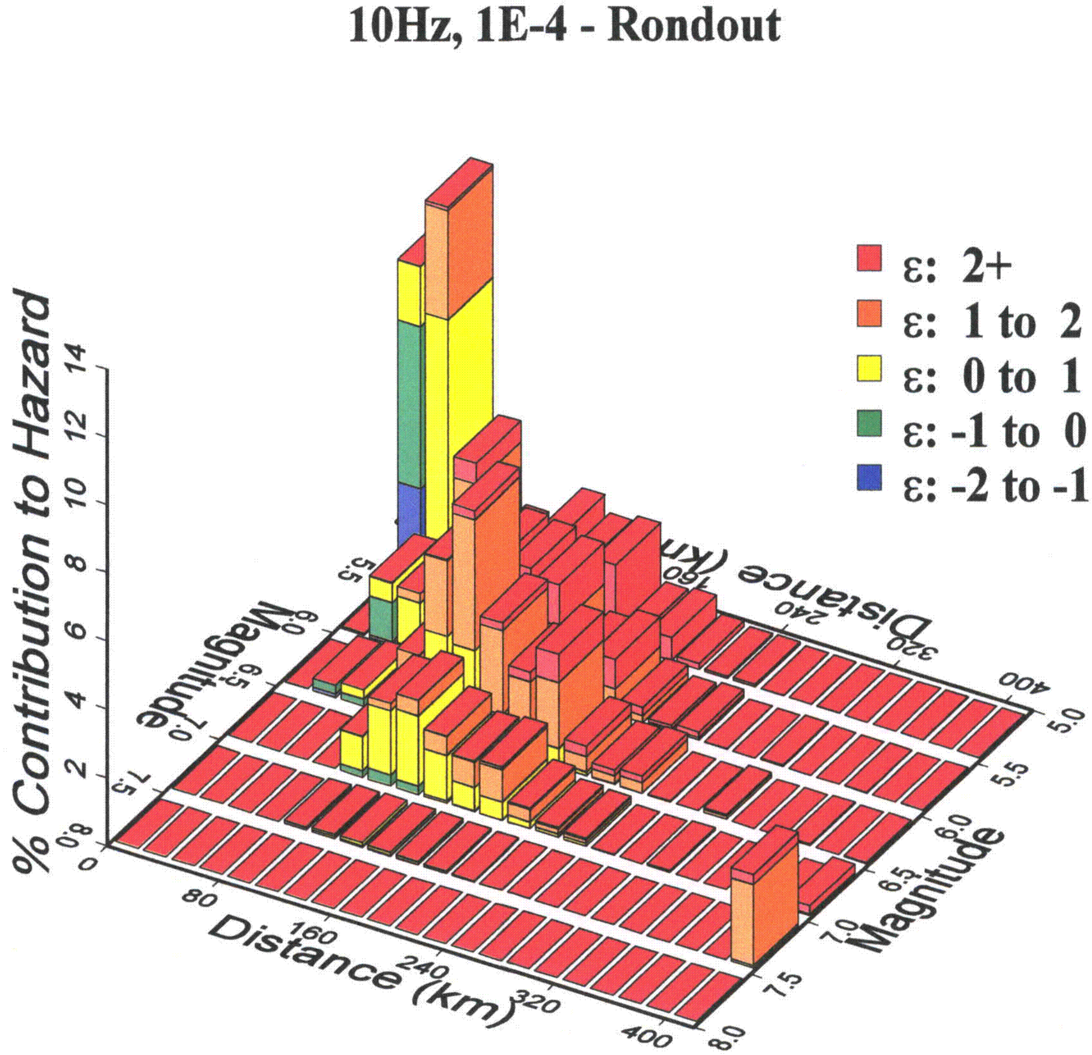

Figure 02.05.02-9A. Deaggregation of 10 Hz spectral acceleration at 10^{-4} for the Rondout team.

For comparison, Figure 02.05.02-9B (see below) shows a similar 10 Hz deaggregation for the Bechtel team. For this team the contribution of the CVSZ to 10 Hz hazard is much less important, and the host source (which for the Bechtel team is BZ5) is dominant. This source has an important contribution from 0 to 40 km.

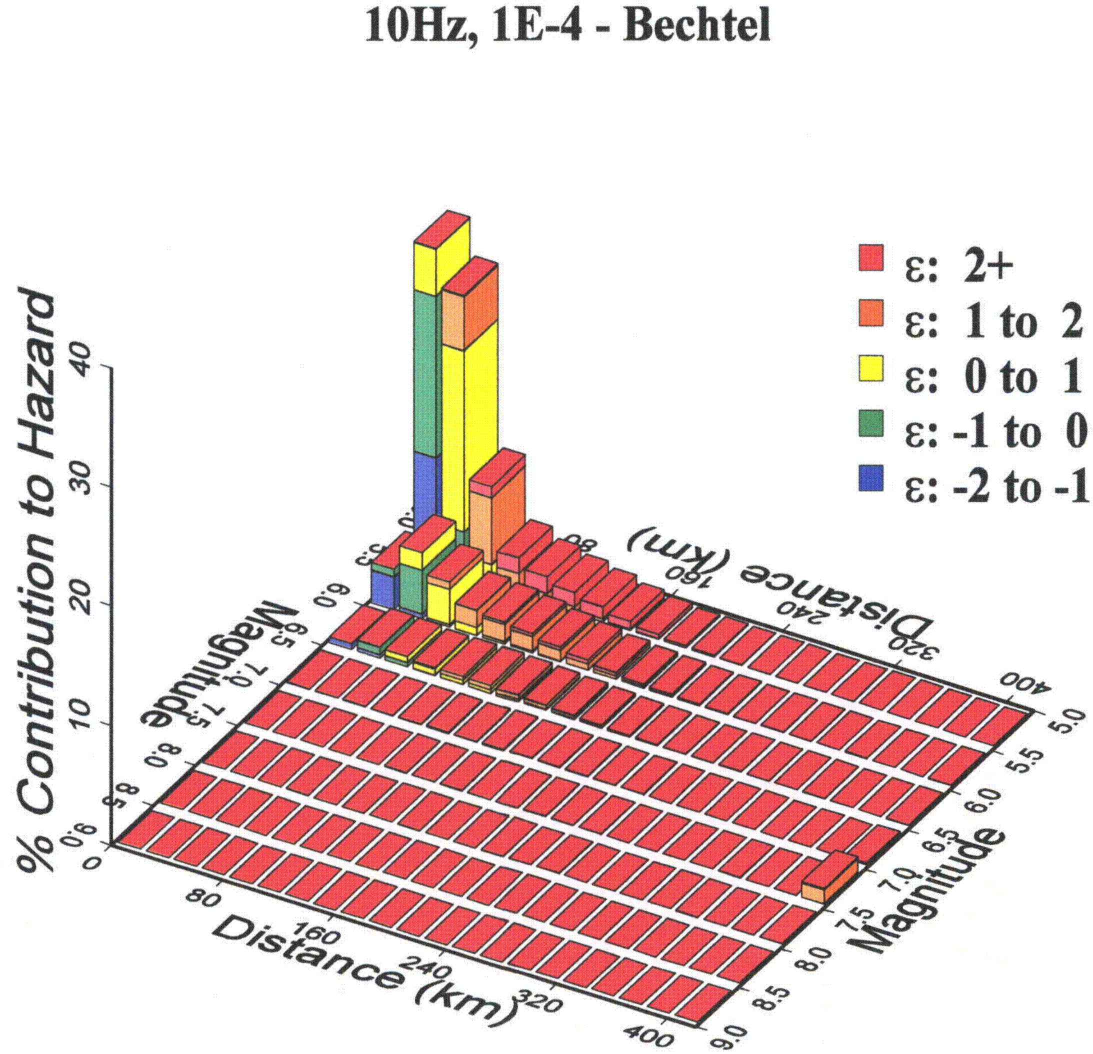

Figure 02.05.02-9B. Deaggregation of 10 Hz spectral acceleration at 10^{-4} for the Rondout team.

The dominance of source BZ5 is also evident in Figure 02.05.02-9C (see below), which shows mean 10 Hz seismic hazard by source for the Bechtel team.

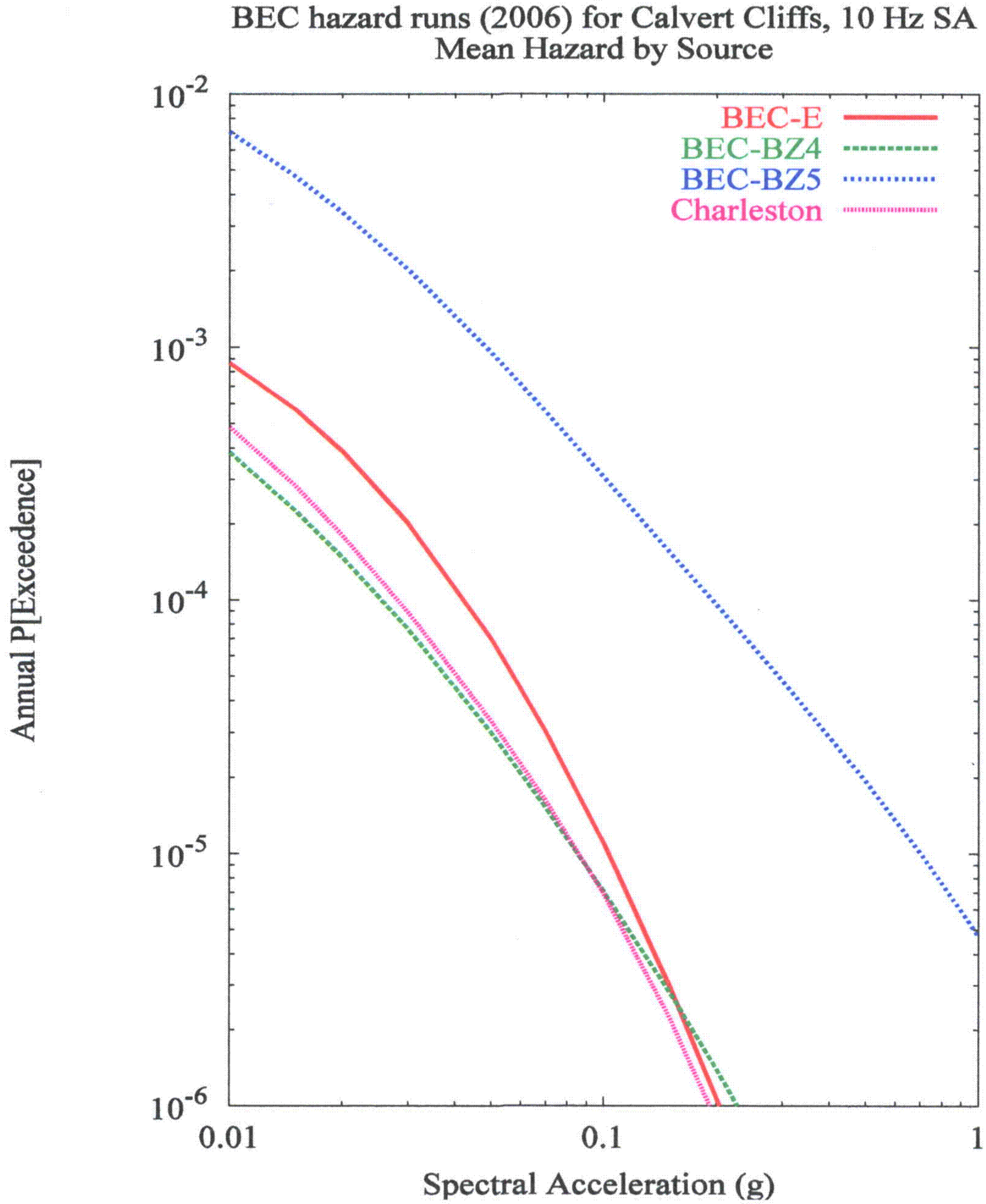

Figure 02.05.02-9C. Mean seismic hazard by source for Bechtel team, 10 Hz spectral acceleration.

The Rondout team hazard curves were plotted in CCNPP Unit 3 FSAR Figures 2.5-91 and 2.5-92 (for 10 Hz and 1 Hz spectral accelerations, respectively) because the Rondout team had a simple seismic source model for the central and eastern United States (CEUS). However, other teams do not show this strong dominance of the CVSZ for 10 Hz hazard, with the host source being dominant for those teams As a result, CCNPP Unit 3 FSAR Figure 2.5-67 (the mean 10^{-4} deaggregation for 5 and 10 Hz combined), showing a strong contribution to hazard at short distances, is representative of the overall, nearby earthquake could be accurately represented with a distance of 35 km, rather hazard results. This is the reason that the alternative method was used, so that the high frequency, nearby earthquake could be accurately represented with a distance of 35 km, rather than a generic earthquake with a distance of 97 km.

b) The following statement was made on page 2-1143 of Rev. 4 of the CCNPP Unit 3 FSAR "...local sources, particularly the central Virginia seismic zone, tend to dominate the hazard, particularly for high frequency ground motions (10 Hz)." This statement was made in reference to CCNPP Unit 3 FSAR Figure 2.5-91 which shows mean hazard curves by source for the Rondout team. For the Rondout team, Figure 02.05.02-9A (see above) confirms that this statement is accurate. For other teams, it is accurate that local sources dominate the 10 Hz seismic hazard, but the role of the CVSZ is less important for those teams. Figure 02.05.02-9B demonstrates this for the Bechtel team, and CCNPP Unit 3 FSAR Figure 2.5-67 shows that local sources dominate the high-frequency hazard for the six teams combined. Thus CCNPP Unit 3 FSAR Figure 2.5-67 is an accurate summary of the deaggregation of high-frequency hazard for all six teams.

c) Figure 02.05.02-9C (see above) shows that host source BZ5 dominates the 10 Hz seismic hazard for the Bechtel team. This plot is like CCNPP Unit 3 Figure 2.5-91 and is representative of the Dames & Moore, Law, Weston, and Woodward-Clyde teams, showing that the host source dominates the seismic hazard for high frequencies.

COLA Impact

None

Question 02.05.02-12

In FSAR Section 2.5.2.5.1.5 (page 2.5-139), the applicant stated that it used a stress drop of 120 bars. Please justify this choice of stress drop. For example, the current update of the USGS National Seismic Hazard Maps for sources in the central and eastern US considers equal weighting of 140 and 200 bar stress drops for the Atkinson and Boore (2006) ground motion model.

Response

In the USGS National Seismic Hazard Map project, the Toro et al. (1997) ground motion model was also used (with a stress drop of 120 bars), and was given a weight equal to the Atkinson and Boore (2006) ground motion model. Thus an earthquake stress drop of 120 bars is a credible estimate for the central and eastern United States (CEUS).

To evaluate the sensitivity of site amplification factors to stress drop, three factors are important. First, when random vibration theory (RVT) is used to calculate site response, the input rock motion spectrum is fixed. Given this input, the only effect of stress drop is on the duration of shaking. Duration varies as the inverse of the corner frequency of the rock motion, and the corner frequency varies as the cube root of stress drop. Thus increasing the stress drop from 120 bars to 200 bars would change the corner frequency (and duration) by less than 20%. Second, spectral amplitudes (the peak response of linear oscillators) are only weakly dependent on duration of shaking. Third, changing stress drop would change the duration of the rock motion and soil motion equally, so the (small) effect on spectral amplitudes of rock and soil motion would be similar. Given these three factors, the effect on response spectrum ratios (soil/rock amplification factors) of an increased stress drop would be minimal.

<u>References</u>

Toro, G.R., N.A. Abrahamson, and J.F. Schneider (1997). Model of Strong Ground Motions from Earthquakes in Central and Eastern North America: Best Estimates and Uncertainties, Seism. Res. Ltrs. Jan.-Feb.

Atkinson, G. M., and Boore, D. M. (2006). Earthquake Ground-Motion Prediction Equations for Eastern North America. Bulletin of the Seismological Society of America, 96(6), 2181–2205.

COLA Impact

None

Question 02.05.02-13

In order for the staff to verify the adequacy of the GMRS, please provide electronic values for the total mean (soil) hazard curves for 1, 2.5, 5, 10, 25, and 100 Hz structural frequencies (i.e. soil hazard curves corresponding to the GMRS location or the soil column that did not contain any soil above the base of the nuclear island) for annual exceedance frequencies ranging from 10^{-3} to 10^{-6} (including a range of values between 10^{-4}, 10^{-5}, and 10^{-6}).

Response

The soil spectra at CCNPP Unit 3 were calculated using NUREG/CR-6728 Approach 2A, which amplifies rock uniform hazard response spectra (UHRS) to calculate soil UHRS. Approach 2A has been used for ESP and COL applications at other nuclear plant sites in the central and eastern United States. This approach follows Section 4.3 of Reg. Guide 1.208, which recommends multiplying rock UHRS by site-specific amplification factors to calculate site-specific soil-based UHRS. Reg. Guide 1.208 recommends that mean UHRS should be determined for annual exceedance frequencies of 10^{-4}, 10^{-5}, and 10^{-6} (Section 3.4) and that mean probabilistic hazard characterization be deaggregated for these annual frequencies (Section 3.5). Furthermore, the basis for the performance-based site ground motion response spectra (GMRS) is the surface site-specific 10^{-4} and 10^{-5} UHRS values, so that only these points on the soil hazard curves are calculated. Soil hazard curve values for other annual frequencies have not been calculated for the CCNPP Unit 3 site and therefore are not available.

References

NRC, 2007, Reg. Guide 1.208: A Performance-Based Approach to Define the Site-Specific Earthquake Ground Motion, US NRC, p. 53.

NRC, 2001. Technical Basis for Revision of Regulatory Guidance on Design Ground Motions, Hazard- and Risk-Consistent Ground Motion Spectra Guidelines, NUREG/CR-6728, U. S. Nuclear Regulatory Commission, 2001.

COLA Impact

None

Question 02.05.02-14

FSAR Section 2.5.2.6 (page 2.5-142) states, "A vertical SSE spectrum was calculated by deriving vertical-to-horizontal (V:H) ratios and applying them to the horizontal SSE." using three different methods. Please justify not considering the approach described in Appendix J of NUREG/CR-6728, which presents a methodology to estimate V/H for CEUS soil and rock sites.

In addition, recent data show that the 14 June 2008 M 6.9 Iwate-Miyagi earthquake in Japan produced a vertical ground motion of greater than 3.8 g at the surface and 0.68 g at 260 m depth (Aoi, S. and others, 2008, Trampoline effect in extreme ground motion: Science, v.322, p. 727). This vertical ground motion is much higher than its horizontal components at the surface and about equal at depth of the basement rock over a wide range of frequencies. How do these documented observations affect the modeled ground motions at the CCNPP3 site?

Response

Appendix J of NUREG/CR-6728 recommends using multiple, well-validated models to estimate vertical-to-horizontal (V/H) ratios for central and eastern United States (CEUS) ground motions at soil sites. The application of these models would require assumptions on the damping and stiffness characteristics of soil layers for vertical motions caused by (P) and (SV) waves. These characteristics have not been well-studied, particularly for CEUS sites, and would be important for sites with high design ground motions where soil response may become nonlinear, both in the horizontal and vertical directions. Additionally, high V/H ratios for both rock and soil sites are associated with ground motions recorded in the near-source region of M~6.5 and larger earthquakes. Neither of these conditions applies to the CCNPP Unit 3 site.

Rather, an approach was taken that compared the recommended rock V/H ratios for CEUS sites (from NUREG/CR-6728, NRC, 2001 for PGA≤0.2g) with empirical estimates for soil sites in the western United States (WUS) with frequencies shifted to represent CEUS ground motions. This comparison is presented in CCNPP Unit 3 FSAR Figure 2.5-88, where none of the approaches showed V/H ratios exceeding 0.9 at high frequencies, or exceeding 0.67 at frequencies below 8 Hz. This trend is reinforced by the V/H ratios shown in NUREG/CR-6728, NRC, 2001 Figure J-27 (lower figure) for a WUS soil site, where the V/H ratio for M 5.5 at 20 km (which is the magnitude and approximate distance of the high-frequency controlling earthquake in FSAR Table 2.5-21 for 10^{-5}) does not exceed a value of 0.85. For a CEUS soil site, the frequency of the peak in the V/H ratio is expected to be higher than for a WUS soil site, but the peak itself is expected to be similar. For the 10^{-4} motions, a mean distance of 35 km was calculated (CCNPP Unit 3 FSAR Figure 2.5-21), implying a lower V/H ratio.

The V/H ratio recommended to calculate vertical spectra has a value of unity above 25 Hz, a value of 0.75 below 5 Hz, and a log-linear interpolation between 5 and 25 Hz. Given the empirical ratios available from the WUS and the model calculations for rock in the CEUS, this recommended ratio is accurate to estimate vertical motions from the controlling earthquakes that define the design earthquake ground motion.

The 14 June 2008 Iwate-Miyagi (M 6.9) earthquake produced high recorded vertical motions in the near-source region, compared to the horizontal motions at those sites.

High vertical motions have been recorded elsewhere, that is in the near-source region of earthquakes with M greater than about 6.5 (e.g. the Lucerne record from the 1992 Landers earthquake, M 7.2, and the Arleta record from the 1994 Northridge earthquake, M 6.7). These conditions would not apply to the CCNPP Unit 3 site, where the controlling earthquake for high frequencies is M 5.5 at distances from 18 to 35 km (for 10^{-5} and 10^{-4} ground motions, respectively). Further, the high vertical ground motion during the Iwate-Miyagi earthquake was recorded above the rupture plane of a reverse-faulting earthquake, which is not a design event for the CCNPP Unit 3 site.

Even if a V/H ratio similar to that of the Iwate-Miyagi earthquake were recorded at a magnitude-distance combination relevant for the CCNPP Unit 3, one observation would not necessarily invalidate the assumed V/H ratio of 1.0 for peak acceleration. This V/H ratio is intended to represent a ratio of median values. Both the vertical and horizontal peak amplitudes at any given site and during any given earthquake are expected to deviate from their respective median values, and these deviations are only moderately correlated.

References

NRC, 2001. Technical Basis for Revision of Regulatory Guidance on Design Ground Motions, Hazard- and Risk-Consistent Ground Motion Spectra Guidelines, NUREG/CR-6728, U. S. Nuclear Regulatory Commission, 2001.

COLA Impact

None

Enclosure 3

Enlarged drawings, reference RAI No. 71, Question 02.05.01-5, Figure 1,"Approximate Altitude of the Top of the Piney Point-Nanjemoy Aquifer ShowingCross Section Locations A-A' and B-B', Figure 2, "Hydrogeologic CrossSection A-A' extending near Bristol, Anne Arundel County to Near James,St. Mary's County" and Figure 3, "Hydrogeologic Cross Section B-B' Extending Near La Plata, Charles County to Point Lookout, St. Mary's County"

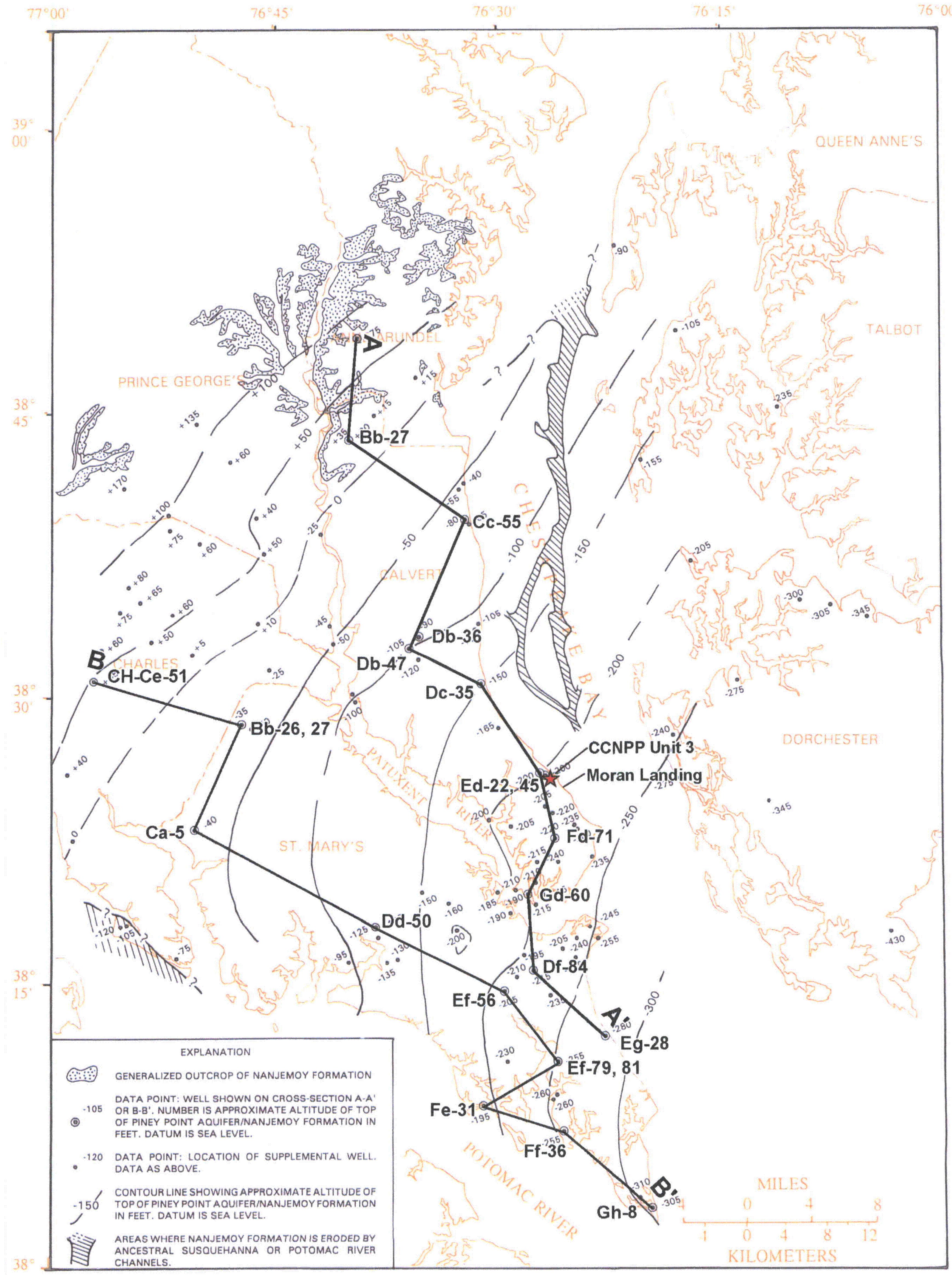

Figure 1. Approximate altitude of the top of the Piney Point-Nanjemoy aquifer showing cross section locations A - A' and B - B' (modified from Achmad and Hansen, 1997).

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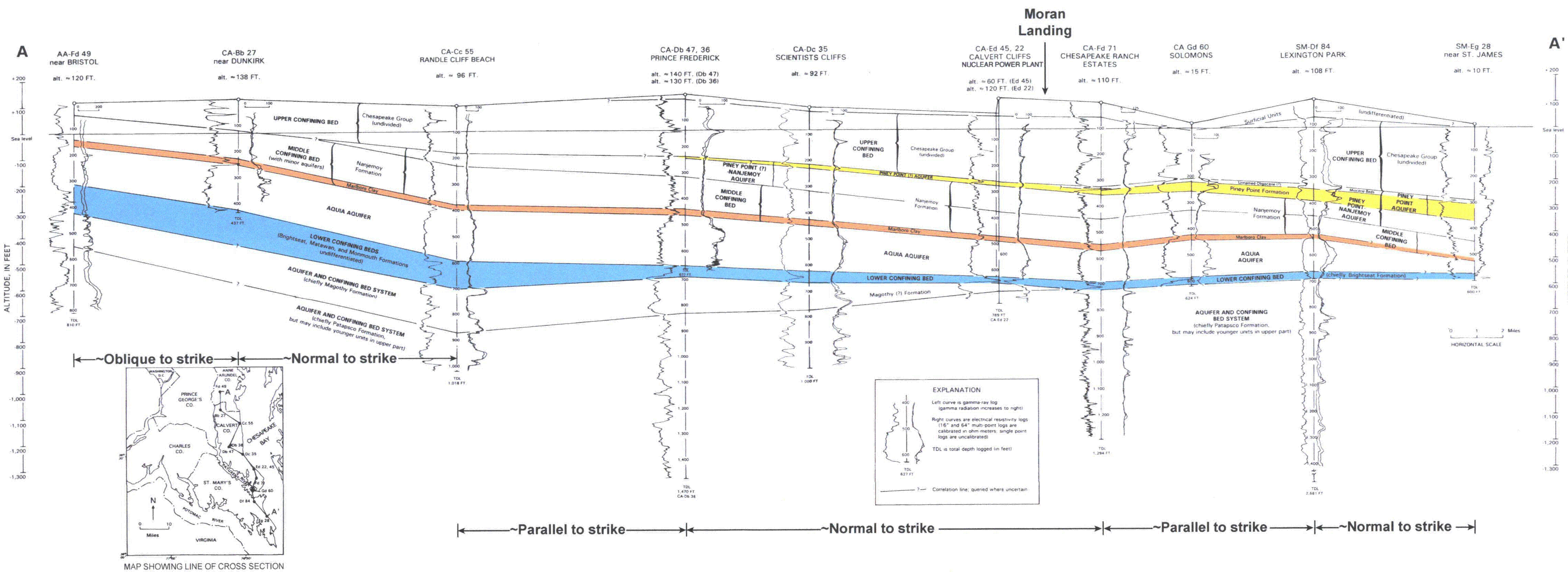

Figure 2. Hydrogeologic cross section A - A' extending near Bristol, Anne Arundel County to near James, St. Mary's County (modified from Achmad and Hansen, 1997).

1782 RAI 02.05.01-5
Modified 04.08.09

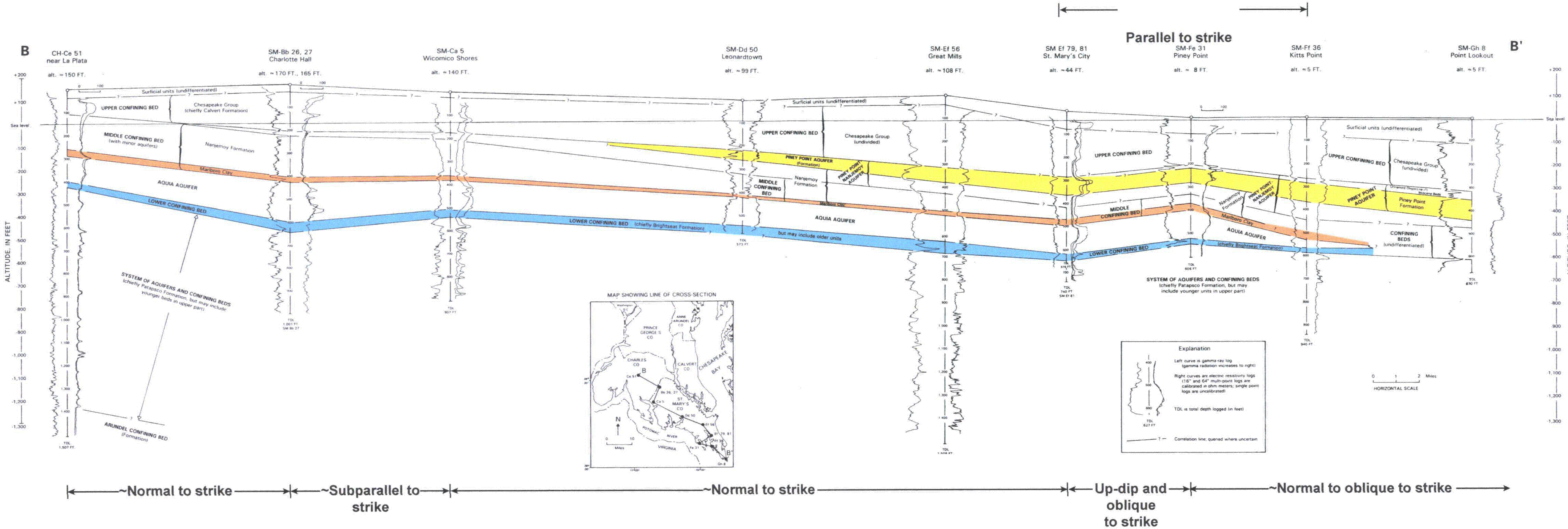

Figure 3. Hydrogeologic cross section B - B' extending near La Plata, Charles County to Point Lookout, St. Mary's County (modified from Achmad and Hansen, 1997).

1782 RAI 02.05.01-5
Modified 04.08.09