June 23, 2011

BELOW IS THE USGS TRIP REPORT SITE AUDIT OF CALVERT CLIFFS

WHICH WAS TAKEN PLACE JULY 8, 2009

JCN No. Q–4151
Task Order No. 6, Review of the Calvert Cliffs Application for Combined Operating License in the Areas Relating to Geology and Seismology
TAC No. RX0105
UniStar Nuclear

USGS Trip Report on Site Audit of Calvert Cliffs, Maryland site, Submitted July 8, 2009

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This letter report summarizes participation of the U.S. Geological Survey (USGS) in the Calvert Cliffs, Maryland site audit on February 23–26, 2009. USGS participants were staff of its Geologic Hazards Team (GHT) and of USGS's subcontractor, the University of Memphis. UniStar Nuclear has applied to the U.S. Nuclear Regulatory Commission (NRC) for authorization to add one new nuclear power reactor (Unit 3) to the two operating reactors (Units 1 and 2) at the site. The site is on the southwest shore of Chesapeake Bay. Discussions covered USGS and NRC Requests for Additional Information (RAIs) and possible responses by the applicant for the application's sections 2.5.1 (Basic Geologic and Seismic Information), 2.5.2 (Vibratory Ground Motion), 2.5.3 (Surface Faulting), and 2.5.4 (Stability of Subsurface Materials and Foundations). NRC does not ask the GHT or its subcontractor to review section 2.5.4. Accordingly, only minimal mention will be made of section 2.5.4, and its geotechnical specialists are not included in the "Selected List of Attendees" that follows.

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Summary

Discussions clarified several RAIs for the applicant and strengthened the planned responses to other RAIs. Tuesday, February 24, was spent examining field relations around a suggested young fault 2 km southeast of the planned site of Unit 3. Wednesday was devoted to indoor discussions.

Selected List of Attendees

UniStar Nuclear:
- **William Lettis & Associates:** J. Baldwin, R. Givler (geology)
- **Bechtel Power Corporation:** D. Fenster (geology)

Risk Engineering: R. McGuire, G. Toro (seismology)
Nuclear Regulatory Commission: S. Gonzalez (seismology), R. Karas (branch chief), J. Rycyna (project manager), A. Stieve (geology)
U.S. Geological Survey: O. Boyd (seismology), R. Wheeler (geology)
University of Memphis: R. Cox (geology), S. Horton (seismology)

Simplified Agenda with Notes

Tuesday, February 24, 2009:

Morning:

<u>Suggested faulting at Moran Landing:</u>

Kidwell (1997) measured 98 stratigraphic sections along approximately 40 km of the coastal Calvert Cliffs. The cliffs are nearly vertical, 25–40 m high, and dissected by several gaps where streams enter Chesapeake Bay. The cliffs expose Early to Middle Miocene marine strata that are overlain by the shallow marine and coastal Late Miocene St. Marys Formation. Nearly all of these Miocene strata are made of sands, silts, and clays. The Miocene units are bounded and divided by unconformities that Kidwell was able to correlate throughout the length of the Calvert Cliffs. The tops of the cliffs crosscut and expose post-Miocene, probably Pleistocene channels that are filled with coarse fluvial and tidal sediments, including some gravels (Kidwell, 1997).

Kidwell reported that dips of the exposed Miocene Calvert, Choptank, and St. Marys Formations are less than 1° to the southeast. Kidwell's figures 2 and 4 show that throughout the Calvert Cliffs the unconformities and the strata that they bound are gently folded. Fold amplitudes are generally less than 10 m and fold wavelengths generally exceed 1 km. Two kilometers south of the planned site of Unit 3, the cliffs are interrupted by a stream valley about one-half kilometer wide that forms a gap in the cliffs at Moran Landing. Most of the stratigraphic section that is exposed on both sides of the gap is the St. Marys Formation. Kidwell's figures 2 and 4 show that the general southeastern dip is reversed across the gap. The basal unconformity of the St. Marys Formation and the three higher unconformities within the St. Marys are all 1–2 m lower on the north side of the gap than on the south side, as measured on an enlarged version of Kidwell's figure 4. The northward lowering and its persistence throughout the St. Marys Formation led Kidwell (p. 324) to suggest the existence of post-Miocene faulting at the gap.

<u>RAI on the possible faulting:</u>

The application (Final Safety Analysis Report, or FSAR) attributed the northward lowering to channeling and irregular erosion surfaces. RAI 02.05.01–27 questions this explanation as follows.

"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."

Field observations and interpretations — kinks and joints:

We spent the first part of the morning examining the cliffs north and south of Moran Landing and walking along the straight stream mentioned in the RAI. Most of the materials exposed in the cliffs are soft, but at least one bed partway up the cliffs is hard, cemented sand about one-half meter thick. We saw few, if any, erosional surfaces that are irregular enough, or channels that are large enough, to explain the 1–2 m northward lowering that occurs across the gap at Moran Landing.

Kidwell's figure 4 suggests an alternative explanation for the lowering that does not involve faulting. The figure is a detailed drawing of bed dips, unconformities, and correlated beds along a 6–7 km stretch of the coast that is centered on Moran Landing. (The horizontal scale bar in figure 4 is erroneously short. Horizontal distances given later were estimated from figure 2.) Figure 4 shows two south-facing monoclines that are exposed in the cliffs roughly 1 and 2 km south of the Moran Landing gap. The monoclines are better termed kinks because their hinges are narrow and their steep limbs are planar. The two kinks affect the lower part of the St. Marys Formation and its lowest three unconformities. The kinks are about half as wide as the gap at Moran Landing, and their structural relief is 2–3 m, similar to the northward lowering across the Moran Landing gap. Note that the lowering across the gap need not occupy the entire width of the gap. Thus, if the lowering across the gap is the result of an unexposed third kink that occupies only part of the gap, the main difference between it and the two exposed kinks would be that the unexposed one faces north instead of south.

The cliffs near the gap expose two approximately perpendicular sets of vertical systematic joints. The larger joints strike northwest, parallel to the cliff faces. One especially well-exposed joint face shows twist hackle (Kulander and others, 1990), which demonstrates that the joint formed in extension with negligible shear, as a Mode I crack (Neuendorf and others, 2005). The joints are up to 10 m tall and several times as long. They appear to be a mechanism by which the cliffs collapse as they are undercut by waves. We concluded that the larger joints are probably release joints that are surficial in origin. In contrast, the smaller joints strike northeast, approximately perpendicular to the larger joints and the cliff faces. Because of the high angle between the northeast-striking joints and the cliff faces, we could not tell whether the northeast-striking joints bear twist hackle or other indications of a Mode I origin. However, the sizes, parallelism, and spacings of the northeast-striking joints and their confinement to individual beds in some parts of the cliff together are more reminiscent of Mode I cracks than of faults. In one area the cliff face consists of a single large cliff-parallel joint that is intersected by several northeast-striking joints. At one of the intersections, the cliff-parallel joint abuts against the northeast-striking joint. If the northeast-striking joints are Mode I cracks, then the abutting relation demonstrates that the cliff-parallel joint is the younger (Kulander and others, 1979, especially figure 49). These limited observations suggest that the northeast-striking joints may have formed first, perhaps before the cliff face had been eroded back to its present location.

The northeast-striking joints are most abundant in a stiff clay bed 2–4 m thick. The joints span the clay bed and have spacings similar to the thickness of the clay bed. The northeast-striking joints appear to be more closely spaced near the Moran Landing gap than away from it, although we did not measure any spacings to test this impression.

If there is an unexposed kink within the Moran Landing gap, kinking would have involved rotation of the steep limb from the original, nearly zero dip to a slightly greater dip of several degrees. The steep limb would have been extended slightly parallel to bedding, perhaps forming northeast-striking joints as Mode I cracks. The local stress field produced by the kinking would have extended outside the kink itself, perhaps producing additional northeast-striking joints that are more closely spaced near the kink. The kinking would have preceded erosional exposure of the present-day cliff faces and formation of the observed cliff-parallel joints. However, others have described joint spacings that decrease toward faults. Therefore, early formation of the northeast-striking joints and smaller joint spacings near the Moran Landing gap could also result from faulting within the gap.

Field observations and interpretations — the straight stream:

The straight stream is the southeastern of two tributaries that merge to form the stream that flows into the gap at Moran Landing (FSAR figure 2.5–32). The stream is about one kilometer long and trends northeast, toward and approximately parallel to the northeast-striking joints that we saw on the north side of the Moran Landing gap. As we walked up the straight stream through an open forest, we noticed that the stream flows in a small valley about a meter deep and about 10 m wide, with a flat floor into which the stream is slightly incised. At one place we found two loose blocks of cemented sand. The blocks are 0.5–1.0 m wide and roughly half that thick. We saw no other large float or outcrops along the straight stream and there are no steep slopes close to the stream. Thus, the two blocks are unlikely to have moved more than a few meters from their source in bedrock.

Perhaps the northeast striking joints continue into the cliffs as far inland as the straight stream extends, and perhaps the two large float blocks are the hard cemented sand that we saw in the cliff face or another similar bed. We speculate that a resistant cemented sand bed close to the ground surface slows downward erosion, except where northeast-striking joints are closely-spaced enough to concentrate erosional removal of the resistant bed. If so, then perhaps a zone of northeast-striking joints produced the straight stream valley. As noted earlier, such a joint zone could be produced by either an unexposed kink or an unexposed fault within the gap at Moran Landing.

Conclusions:

Properties of the joints, presence of large blocks of cemented sand in the straight stream valley, and detailed geomorphology of the valley are all consistent with either an unexposed kink or an unexposed fault in the gap at Moran Landing. Either structure could have produced the northward lowering of the St. Marys Formation across the gap. Kidwell's observations of two nearby kinks and her and our lack of observations of any nearby faults makes a kink the more likely cause of the lowering.

Afternoon:

We visited a water-monitoring well at the center of the planned reactor for Unit 3. The applicant explained the geotechnical drilling and monitoring program whose results will be used in construction.

The applicant led us out along the boat dock east of Units 1 and 2. From there we obtained a synoptic view of approximately 1 km of cliff face, the stratigraphy of the exposed units, and gentle folds and unconformities. From the base of the boat dock, we walked up a deep, narrow stream incision that exposed aspects of the stratigraphic sequence. From bottom to top, we were shown (1) a distinctively shell-rich marker horizon immediately beneath the St. Marys Formation, (2) three cemented sands a few feet apart stratigraphically within the St. Marys Formation, and, atop a hill, (3) sand with some gravel of the post-Miocene deposits.

Wednesday, February 25, 2009:

Before the site audit NRC and USGS submitted 32 geology RAIs and 14 seismology RAIs to the applicant. Most of the RAIs were straightforward or required little or no clarification during the audit. These were discussed briefly or not at all.

This report deals with RAIs that were discussed at some length. Most of the fieldwork on Tuesday had been devoted to RAI 2.5.1–27. RAIs for section 2.5.3 had been moved into the end of section 2.5.1 before submittal to the applicant. Below, unindented paragraphs in quotation marks are parts of RAIs, whereas indented paragraphs without quotation marks are our notes.

Selected geology RAIs and notes on them:

02.05.01–18:

“FSAR Section 2.5.1.1.4.4.4.5 states, ‘Based on seismic reflection data, collected about 9 mi (15 km) west-southwest of the site, the [Hillville] fault zone consists of a narrow zone of discontinuities that vertically separate basement by as much as 250 ft (76 m) (Hansen, 1978).’ In FSAR figure 2.5–27 seismic line St M–1 is located across the Hillville fault. Please provide the seismic line St M–1 for inspection and the Hansen (1978) profile, if different. Was the Hillville fault seen in any Chesapeake Bay marine data?”

We examined a paper plot of St M–1. The applicant explained that St M–1 and the profile of Hansen are the same. Collection of the seismic-reflection data was designed to image the top of basement at approximately 0.7s two-way travel time. The resolution of the printed plot is too poor to determine whether the offset continues upward into the Tertiary section. If the data are in digital form or can be digitized, then reprocessing may clarify reflectors in the Tertiary section. As far as the applicant knows, Hansen’s data have not been located and reprocessed. The applicant reported that the Hillville fault projects into an exposed cliff within the study area of Kidwell (1997) approximately 1 km southeast of Governor Run (FSAR figure 2.5–26; Kidwell’s figure 2). Kidwell showed the same degree of detail in the measured sections there as near the site of Unit 3. She was aware of the possibility of faults, but she did not mention any faults near the projection of the Hillville fault.

02.05.01–26:

“FSAR Section 2.5.1.2.4 suggests that no basin-related fault or faulting is known directly beneath the site area. FSAR figure 2.5–10 summarizes mapping that indicates that a border fault on the northwestern side of the Taylorsville basin crops out about 50 km northwest of the site, and that the border fault on the northwestern side of the postulated Queen Anne basin crops out 10–15 km northwest of the site. Both faults dip southeastward under their basins. Such master faults are generally assumed to flatten downward. Furthermore, the normal faulting that formed the basins requires that the entire hanging-wall block and all upper crust southeast of it must slip southeastward on a Mesozoic detachment fault. Please evaluate whether or not the border fault of either basin is likely to extend beneath the site and what the implications for hazard might be. Please provide further discussion about the presence of a Mesozoic basin directly beneath the site.”

The applicant explained that the FSAR uses two maps of Mesozoic basins, one published by Benson in 1992 and the other by Withjack and others in 1998. Both maps show basin-bounding faults. Benson inferred the presence of a basin from aeromagnetic, gravity, well, and seismic-reflection data. His map shows faults on at least one border of most basins. Withjack and others mentioned outcrop, well, and especially seismic-reflection data, together with other kinds of information that constrain ages instead of the presence of faults. Their maps show faults on at least one border of nearly all basins. Benson interpreted a Mesozoic basin under the site; Withjack and others did not. The applicant observed that there does not appear to be a consensus on how to combine the different data types to determine whether or not a Mesozoic basin is present. Some

EPRI–SOG teams interpreted a basin near or under the site. Thus, there is uncertainty as to whether there is a Mesozoic basin or a basin-bounding fault under the site.

<u>02.05.01–32:</u>

“FSAR Section 2.5.3.2.2 refers to an east-facing monocline 3.2 km east of the site reported by McCartan et al. (1995) and states ‘If the feature does exist, the Miocene St. Marys Formation is not depicted (USGS, 1995) to be deformed. Therefore, the inferred monoclines (USGS, 1995) are older than Late Miocene in age and do not represent a surface-fault rupture or deformation hazard at the CCNPP site.’ FSAR figure 2.5–40 shows that the St. Marys Formation has been removed by erosion at the location of the monocline, so that it is not continuous enough to determine it is unfolded. Please reconcile the quotation with what USGS (1995) does and does not show. Explain the hazard consequences if the monocline were to be younger than Miocene.”

The applicant explained that the undeformed unit was erroneously stated to be the St. Marys Formation, but that it is the underlying Choptank Formation. However, figure 2.5–40 shows that the Choptank is also not preserved widely enough to constrain the age of the monoclines.

McCartan and others (1995) show five cross sections, of which their section A–A' is shown in FSAR figure 2.5–40. Section A–A' was drawn to show two east-facing monoclines. Farther southeast, section E–E' was drawn to show one monocline, which may be the southward continuation of the eastern monocline on A–A'. Control of the cross sections by well logs is sparse, particularly near the inferred monoclines. No logged wells are shown to penetrate the monoclines themselves. The applicant explained that the data from the two wells can also be honored with an alternative interpretation that omits the monoclines and shows all units thickening smoothly seaward. The alternative interpretation is consistent with our examination of the five cross sections. The monoclines appear to be an interpretation that is allowed by the well data but not required by them.

McCartan and others (p. 4 and p. 8–9) noted that geomorphology and subsurface thickness changes around Chesapeake Bay indicate alternating uplifts and downwarps of the west side of the bay with respect to the east side. They conclude that these changes “require significant episodic tectonic movement” (p. 9). However, no evidence is provided as to why these vertical relative movements would have been restricted to such narrow zones as the monoclines.

Additionally, USGS pointed out that the structure contour map of FSAR figure 2.5–14 rules out the presence of monoclines with significant structural relief. The structure contour map is from a publication two years more recent than that of McCartan and others (1995). The structure contour map is drawn atop the Early Eocene Nanjemoy Formation. The map uses a contour interval of 50 ft. Although the suggested monoclines are in the easternmost part of the contoured area, well control there is sufficient to require the structure contours to trend northeast approximately 6–12 km apart much as they do in the rest of the map area. In contrast, the monoclines as drawn by McCartan and others are 2–4 km wide and have structural relief at the Nanjemoy level of approximately 100 m. The expressions of the monoclines on the structure contour map would be a closely spaced group of about six parallel contours. The well data of the contour map do not allow such a pattern. Thus, if the monoclines exist at all, they have structural relief less than 50 ft.

In conclusion, apparently the monoclines are much smaller than drawn by McCartan and others, and they may not exist at all. We know of no data that require their existence. Accordingly, questions of their age are moot.

Selected seismology RAIs and notes on them:

<u>02.05.02–5:</u>

"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)."

The applicant explained that the New Madrid Seismic Zone is approximately 1,300 km from the site but EPRI ground-motion equations extend out to distances of only 1,000 km. The applicant also stated that at large distances intensities are produced less by high frequencies and more by low frequencies. Therefore, peak ground acceleration (PGA) would be lower than the 3.9–9.2 percent suggested in the RAI. The USGS requested that the applicant provide a reference for the work on which the statement was based.

USGS pointed out that the intensity was still IV, even if the frequency were 1 Hz instead of 10 Hz. Doesn't this mean that the New Madrid Seismic Zone should be included in the source model for the site?

The applicant responded that, for most of the ground-motion equations that were used in the analysis of the FSAR, the 1–Hz ground motion predicted at 1,000 km is less than 0.01 g. Two of the EPRI equations that predict larger ground motions were discounted by the applicant because they lack a Q term. The applicant pointed out that the two equations are unrealistic at large distances because Q becomes significant at distances of approximately 1,000 km and greater.

02.05.02–7

"In FSAR Section 2.5.2.2.2.7 (page 2.5–123), the applicant discussed the 2–sigma analysis of event ages performed for the updated Charleston seismic source model and stated the following: 'Event ages have then been defined by selecting the age range common to each of the samples. For example, an event defined by overlapping 2–sigma sample ages of 100–200 cal. yr. BP (before present) and 50–150 cal. yr. BP would have an event age of 50–150 cal. yr. BP.' Please clarify if the resulting event age of 50–150 cal. yr. BP is an error and instead should be 100–150 cal. yr. BP. Please also explain whether or not this error has been propagated through subsequent analyses."

The applicant confirmed that this was a typographical error and had not propagated into the analysis.

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."

The applicant stated that calculated hazard was greater than that calculated with the original EPRI codes and that the difference was due to unstated assumptions in the original code. The applicant felt that significant effort would be required to reconcile the difference.

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' produces '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."

The applicant stated that figure 2.5–91 does not well represent the range of models used in the PSHA. Further, the Bechtel model has a source zone very near the CCNPP site. The applicant showed a figure of the mean seismic hazard for the Bechtel model to support their deaggregation result.

02.05.02–10

"FSAR figures 2.5–78, 2.5–80, 2.5–82, and 2.5–84 show amplification functions resulting from the applicant's site response analysis. In each case, the amplification functions decrease with frequency from about 10Hz to about 20Hz, bottom out, then increase with frequency above about 50Hz. (a) Please provide a physical mechanism to explain this increase at high frequency for the amplification function. (b) If the increase reflects a numerical artifact rather than a physical process, state the nature of the numerical artifact and explain why or why not the artifact should be removed and results recomputed."

The applicant stated the increasing values of the site response function at high frequencies above 50Hz result from the use of pseudo-response spectra instead of Fourier spectra. Specifically the pseudo-response spectra saturate for frequencies beyond fmax (acceleration spectra fall off beyond fmax) because of lack of energy. The use of the pseudo-response spectra is a standard engineering practice. The increased site response function at high frequencies is a very conservative estimate.

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."

The applicant provided additional information about the choice of stress drop in other attenuation models, for example, 120 bars for Toro and others (1997). They went on to explain that the hazard results are relatively insensitive to the choice of stress drop.

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