Progress Energy

Serial: NPD-NRC-2010-083 10CFR52.79
November 30, 2010

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

LEVY NUCLEAR PLANT, UNITS 1 AND 2
DOCKET NOS. 52-029 AND 52-030
RESPONSE TO REQUEST FOR ADDITIONAL INFORMATION LETTER NO. 094 RELATED TO PROBABLE MAXIMUM TSUNAMI FLOODING

Reference: Letter from Brian C. Anderson (NRC) to John Elnitsky (PEF), dated October 4, 2010, "Request for Additional Information Letter No. 094 Related to SRP Section 2.4.6 for the Levy County Nuclear Plant, Units 1 and 2 Combined License Application"

Ladies and Gentlemen:

Progress Energy Florida, Inc. (PEF) hereby submits our response to the Nuclear Regulatory Commission's (NRC) request for additional information provided in the referenced letter. A response to the NRC request is addressed in the enclosure. The enclosure also identifies changes that will be made in a future revision of the Levy Nuclear Plant Units 1 and 2 (LNP) application.

As part of this response, a native file supporting the probable maximum tsunami analysis is provided on the attached CD. The supplemental information contained in the file on the attached CD is provided to support the NRC's review of the LNP COL application but does not comply with the requirements for electronic submission. The NRC staff requested the file be submitted in its native format, required for utilization in the software employed to support the COL application development. PEF understands that converting the information to a PDF output file would not serve the underlying purpose of the submittal; i.e., to provide the raw, unprocessed data to enable reviewers to evaluate software used in the LNP application.

If you have any further questions, or need additional information, please contact Bob Kitchen at (919) 546-6992, or me at (727) 820-4481.

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

Executed on November 30, 2010.

Sincerely,

John Elnitsky
Vice President
New Generation Programs & Projects

Progress Energy Florida, Inc.
P.O. Box 14042
St. Petersburg, FL 33733

D094
NRO

Enclosure/Attachments

cc : U.S. NRC Region II, Regional Administrator (without attached CD)
Mr. Brian C. Anderson, U.S. NRC Project Manager (with 3 copies of attached CD)

Levy Nuclear Plant Units 1 and 2
Response to NRC Request for Additional Information Letter No. 094 Related to SRP Section 2.4.6 for the Combined License Application, dated October 4, 2010

NRC RAI #	Progress Energy RAI #	Progress Energy Response
02.04.06-16	L-0867	Response enclosed – see following pages

NRC Letter No.: LNP-RAI-LTR-094

NRC Letter Date: October 4, 2010

NRC Review of Final Safety Analysis Report

NRC RAI NUMBER: 02.04.06-16

Text of NRC RAI:

In RAI 2.4.6-02 (RAI ID 2162, Question 8855), the staff requested the applicant to provide a discussion in the updated FSAR of the hill-slope failures near the Levy County site with reference to the findings in Section 2.5 of the FSAR.

The applicant's response, dated 22 July 2009, provided a description of hill-slope stability in the RAI response that is reasonable, but did not appear to indicate that the FSAR will be changed to include this description Section 2.4.6.3. In their response, the applicant indicates a change in FSAR Section 2.5.5 that is unrelated to this RAI.

In RAI 2.4.6-03 (RAI ID 2162, Question 8856), the staff requested the applicant to provide a clarification in the updated FSAR of the meaning of the descriptor "impact" as used on pg. 2.4-45 of the FSAR: "...historically no Caribbean tsunami has impacted the United States Gulf Coast."

The applicant's response, dated 22 July 2009, provided a description of what is meant by "impact", but does not appear to indicate that the FSAR will be changed to include this description in Section 2.4.6.2. In RAI 2.4.6-08 (RAI ID 2162, Question 8862), the staff requested the applicant to provide the theoretical basis, assumptions (e.g., source parameterization), and applicability to the Levy County site for the tsunami attenuation function discussed on pg. 2.4-53 (Equation 2.4.6-1) and make available the details of the Monte Carlo analysis used to estimate the maximum wave height and where the maximum wave height estimate is geographically located. For this and other methods of tsunami analysis indicated in the FSAR, provide the procedure use to calculate tsunami propagation, runup, and inundation (i.e., tsunami water levels) at the Levy County site from offshore tsunami amplitude.

The applicant's response, dated 22 July 2009, provided substantial new effort regarding analysis for tsunami generation, propagation, and runup. NRC staff requests additional documentation of the formulas for source amplitude. The water depths listed in Table 1 seem arbitrary (300-800 m for East Breaks). In addition, the response does not appear to describe source "diameter" is determined. The numbers for the Veracruz and Venezuela source diameters (Table 4) appear to have typographic errors. The assumption that "wave amplitude onshore cannot exceed its estimated runup height at shore" does not appear to utilize standard tsunami terminology. Further, variable Co in equations 17 and 18 does not appear to be defined.

In RAI 2.4.6-015 (RAI ID 4217, Question 16353), the staff requested the applicant to provide additional details regarding new methodology for tsunami analysis described in response to RAI 2.4.6-08. This discussion should specifically include (1) the basis for source amplitude formulae (they are not contain in Silver et al., 2009); (2) clarify what is meant by "wave amplitude onshore cannot exceed its estimated runup height at shore" (statement is incorrect using standard tsunami terminology); (3) definition of variable Co in equations 17 and 18.

The applicant's response, dated 25 March 2010 (using their revised method), provided a maximum "runup" of 22.5 m which does not appear to be reasonably consistent with a "run-in" distance of 2.07 km that is estimated by the applicant. In the staff's 2HD analysis using conservative friction values, an attenuated 3 m runup is associated with a18 km inundation distance. Using similar scaling for the applicant's 22.5 m runup would result in tsunami that would impact the site.

To meet the requirements of GDC 2, 10 CFR 52.17, and 10 CFR Part 100, the staff requests the following:

1) Please provide an FSAR update to include information contained in applicant's response to RAI 2.4.6-02 (RAI ID 2162, Question 8855)

2) Please provide an FSAR update to include information contained in applicant's response to RAI 2.4.6-03 (RAI ID 2162, Question 8856)

3) In reference to Progress Energy's response to RAI 02.04.06-15 (25 March 2010, NPD-NRC-2010-025, L0696), the PMT runup (21.4 m) given in Table 1 appears to be inconsistent with the accompanying inundation distance. It is noted that runup is defined as the ground elevation at the location of maximum tsunami inundation, which is consistent with the depiction given in Figure ATTACHMENT 02.04.06-15A. As can be found from topographic maps, the ground elevation at a distance of 1.2 miles from the shoreline in the direction of the Levy County site is approximately 1m. The 21 m topographic elevation is well inland of the Levy County site. It would not be expected that two separate equations are needed to find the runup and the inundation distance; calculation of either one, used in conjunction with topographic maps, provides the other value.

Please provide clarification on these values (eta and X in Table 1), including which of the two values should be used to define the PMT, and if the variable definitions as given in Figure ATTACHMENT 02.04.06-15A are correct. In Table 1 provided in the response, please provide the geographic location (lat, long) corresponding to the location at the given distance R from the source, as well as the depth at that location, since it is needed to determine the runup elevation. Please present all equations used, including a discussion of assumptions inherent in these equations and the associated conservatism, and the procedure to calculate the provided values. Please provide all input data sources, calculation packages, and associated modeling input files.

PGN RAI ID #: L-0867

PGN Response to NRC RAI:

The PMT analysis has been re-conducted and the FSAR will be modified to reflect the changes. The issues identified in this RAI have been addressed in the FSAR revisions and supporting calculations as described below in the same order as the questions are presented above.

(1) Provide an FSAR update to include information contained in applicant's response to RAI 2.4.6-02

RAI 2.4.6-02 requested that the FSAR include discussion of the generation of tsunami-like waves from hill-slope failures, specifically: "Please discuss the hill-slope failures near the Levy County site with reference to the findings in Section 2.5 of the FSAR, or explain why such a discussion is not necessary." We explained why an analysis was not necessary in the RAI response, and we will now include a similar explanation in the next revision of the FSAR in Section 2.4.6.3.1. The proposed revisions are shown in Attachment RAI 02.04.06-16C.

(2) Provide an FSAR update to include information contained in applicant's response to RAI 2.4.6-03

RAI 2.4.6-03 requested the PMT assessment of the LNP site and include reference to historical tsunami-like waves affecting the region, including: "Please provide a clarification of the meaning of the descriptor "impact" as used on pg. 2.4-45 of the FSAR: '...historically no Caribbean tsunami has impacted the United States Gulf Coast.'" We explained the context of the use of the word *impact* in the above sentence in the RAI response, and we will now include this clarification in the next revision of the FSAR in Section 2.4.6.2. The proposed revisions are shown in Attachment RAI 02.04.06-16C.

(3a) In reference to Progress Energy's response to RAI 02.04.06-15 (25 March 2010, NPD-NRC-2010-025, L-0696), the PMT runup (21.4 m) given in Table 1 appears to be inconsistent with the accompanying inundation distance...

We agree that the response to RAI 02.04.06-15 could have been stated differently. We used the term run-up and the wave height at the shoreline synonymously which was confusing. The terms shown in Attachment 02.04.06-15A submitted with our RAI 02.04.06-15 response are correct and these terms will continue to be used in the future revision of the FSAR 2.4.6.6. This subsection of the analysis was extensively edited to ensure consistency in the use of terms and the proposed FSAR revision is shown in Attachment RAI 02.04.06-16C.

(3b) In Table 1 provided in the response, please provide the geographic location (lat, long) corresponding to the location at the given distance R from the source, as well as the depth at that location, since it is needed to determine the runup elevation.

For some of the regions that may experience landslides there is a broad area where they could occur. For example, the Florida Escarpment stretches from the southern tip of Florida to the panhandle. Distance measured from tsunami source is approximately along a straight line from the base of the slide to the LNP site. To be conservative in estimating the attenuation of the wave (conservative in this context means to predict a higher tsunami wave), the distance should not be overestimated. So for the Florida Escarpment, the distance was more or less the most perpendicular path to the LNP site. Furthermore, the distance is from the expected source to a point about <1 to 20 km offshore (depending on the size of tsunami generated) because that is the point where shoaling begins (input distance into the equation). The depth where shoaling begins is approximately equal to the height of the propagated wave at that location, and estimates of the shoaled depth ranged from 0.11 to 7.17 meters (m) in height.

The distance from landslides is from the end of the slide event which is where the initial amplitude of the maximum tsunami wave originates and also would be the most conservative input into the calculation as it would be the deepest point. Some slides are expected to travel further than others. The distance that a slide from the Slope above the Florida Escarpment is a little further from LNP than the Florida Escarpment because a landslide from the upper Slope would travel further and the ultimate origination will be located further away than a slide from the main Escarpment.

The approximate latitude and longitudes listed in Table 1 were taken from Google Earth and are likely to be misleading as they imply more precision than is warranted considering that they are taken from small scale maps. These values will not be presented in the FSAR. Rather the Brink et al. (2008) (Reference RAI 02.04.06-16 01) report is the primary reference for the location of source tsunamis from landslides. As an example, for the East Breaks landslide, the location of the Breaks is a distance of about 1,200 km from the LNP coast. The literature reported a slump distance of about 160 km. The depth when shoaling begins is about 7 meters, which is about 18 to 20 km from shore. So the distance used in the attenuation computation was taken as 1,000 km because a slightly closer tsunami would conservatively have lower attenuation resulting in a higher offshore wave reaching the shoaling depth.

RAI 02.04.06-16 Table 1 Approximate Latitude and Longitude of Landslide Sources of Tsunamis in the Gulf of Mexico Region

Landslide	**Approximate Latitude of Slide Zone**	**Approximate Longitude of Region**
East Breaks Region	27° 30' N	95° 0' to 30' W range
Mississippi Canyon Region	27° 45' N	89° 0' to 20' W range
Florida Escarpment near LNP	27° 50' N	85° 40' to 55' W range
Slope above the Florida Escarpment near LNP	27° 50' N	85° 20' to 50' W range

Figure 3-2 in Brink et al. (2008) (Reference RAI 02.04.06-16 01) indicates that the depth of the Slope above the Florida Escarpment ranges from 200 to 1000 m, resulting in an average depth of 600 m. Based upon Figure 4 from USGS (2001) (Reference RAI 02.04.06-16 02), the east-west lateral dimension of the West Florida Slope is approximately 50 km from the 200 m water depth shelf break off the west coast of Florida to the 1,500 m water depth at the top of the Florida Escarpment, resulting in a slope of 1.5 degrees. Figure 3-2 of Brink et al. (2008) (Reference RAI 02.04.06-16 01) indicates that the depth of the top of the Florida Escarpment is between 1500 and 2500 m, resulting in an average depth of 2000 m. The average land slope of the Florida Escarpment is at least 20 degrees. Figure 3-1b of Brink et al. (2008) (Reference RAI 02.04.06-16 01) indicates that depth of the bottom of the East Breaks slide is between 1,500 and 2,000 m, so an average depth of 1,750 m was used. Similarly, the depth of the Mississippi Canyon was taken from Figures 3-1b and 3-12 of Brink et al. (2008) (Reference RAI 02.04.06-16 01) which shows the depths to be about 1,700 m near the downstream end of the slide. An average value of 1,689 m was used based on an average of several locations around this area.

(3c) Please present all equations used, including a discussion of assumptions inherent in these equations and the associated conservatism, and the procedure to calculate the provided values. Please provide all input data sources, calculation packages, and associated modeling input files.

The PMT analysis has been re-conducted and the FSAR modified to reflect the changes. The proposed revisions are presented in Attachment RAI 02.04.06-16C. The calculation package is available in the project's reading rooms. There is no separate computer simulation of the tsunamis, such as a 2-D or 3-D numeric model. All computations were conducted utilizing Excel and that file is provided as a requested native file in the attached CD (Attachment RAI 02.04.06-16B).

Note that the procedure for estimating run-in distance has been modified to eliminate the use of an average slope (SINΘ) in the equation. The new approach uses an average slope determined directly from the more detailed landscape profile, shown in Attachment RAI 02.04.06-16A. For tsunamis with different run-in distances, the average slope for that particular scenario is applied and that can only be determined by using an iterative procedure. This will be clear by reviewing the proposed revisions to FSAR Subsection 2.4.6.6.3.5 provided in Attachment RAI 02.04.06-16C.

References:

RAI 02.04.06-16 01 Brink, U.T, Twichell, D., Geist, E., Chaytor, J., Locat, J., Lee, H., Buczkowski, B., Barkan, R., Andrews, B., Parsons, P., Lynett, P., Lin, J., and Sansoucy, M. (2008). Evaluation of Tsunami Sources with the Potential to Impact the U.S. Atlantic and Gulf Coasts: An Updated Report to the Nuclear Regulatory Commission, Atlantic and Gulf of Mexico Tsunami Hazard Assessment Group, USGS.

RAI 02.04.06-16 02 USGS (2001). A Summary of Findings of the West Central Florida Coastal Studies Project. Available at http://pubs.usgs.gov/of/2001/of01-303/process.html . Accessed February 23, 2010.

Associated LNP COL Application Revisions:

The following changes will be made to the LNP FSAR in a future revision:

Text for FSAR Subsections 2.4.6.2 and 2.4.6.3.1 will be revised in a future revision of the FSAR as presented in Attachment RAI 02.04.06-16C.

Text, tables, and a new figure added for FSAR Subsection 2.4.6.6.3 will be revised in a future revision as presented in Attachment RAI 02.04.06-16C.

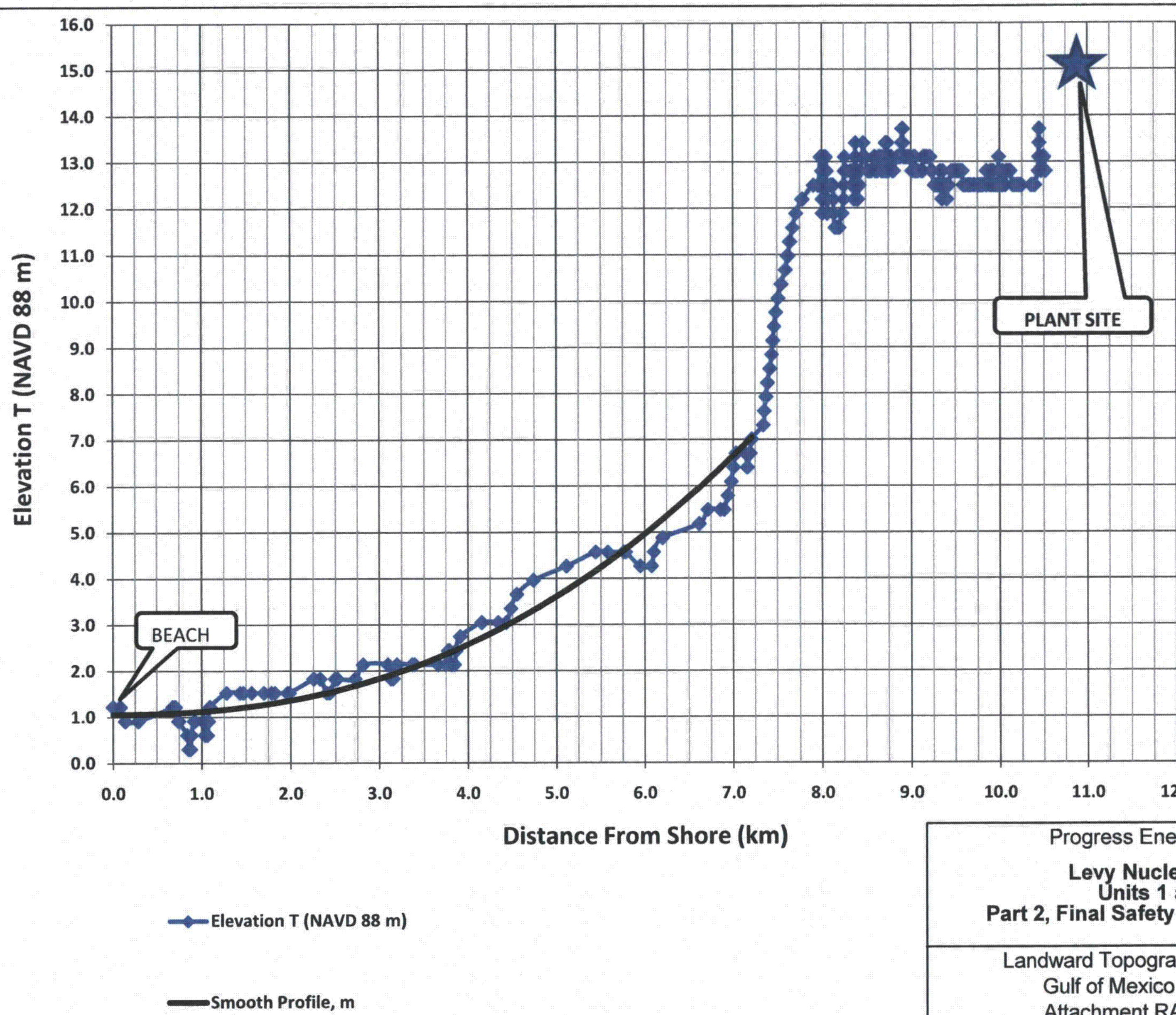
- Tables 2.4.6-206 through 2.4.6-211 are fully replaced with those shown in Attachment RAI 02.04.06-16C.
- RAI 2.4.6-16 Figure 1 will be added as shown in Attachment RAI 02.04.06-16A. All other figures in Subsection 2.4.6 remain unchanged.

Attachments/Enclosures:

Attachment RAI 02.04.06-16A, Landward Topographic Profile from Gulf of Mexico to LNP Site [1 page]

Attachment RAI 02.04.06-16B, CD with one Excel file entitled: New Approach Tsunami Cal_FINAL.xlsx

Attachment RAI 02.04.06-16C, Associated LNP FSAR Revisions [22 pages]



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Landward Topographic Profile from Gulf of Mexico to LNP Site
Attachment RAI 2.4.6-16A
FIGURE 2.4.6-230

Rev 3

FSAR Revisions associated with Response Item (1)

LNP FSAR Subsection 2.4.6.3.1 will be revised to read:

2.4.6.3.1 Tsunamigenic Source Mechanisms

Historically, 71 percent of tsunamis striking the United States have been induced by earthquakes (Reference 2.4.6-201). Considering all source mechanisms, the most destructive tsunamis are the result of large, shallow earthquakes with an epicenter or fault line near the ocean floor. Large earthquakes can tilt, offset, or otherwise displace large areas of ocean floor for distances ranging from a few kilometers to 1000 km (621 mi.) or more. When large vertical offsets occur, these earthquakes also displace water and produce destructive tsunami waves. Tsunami waves can travel large distances from their source. For example, in 1960, there was an earthquake off the coast of Chile with a magnitude of $M_W = 9.5$ ($M_S = 8.6$) and a rupture zone of 1000 km (621 mi.). This earthquake produced the Great 1960 Chilean tsunami, as well as destructive waves that hit Hawaii, Japan, and other locations in the Pacific (Reference 2.4.6-205).

Though less common, tsunami events can also result from rock falls, icefalls, and sudden submarine translational landslides or rotational slumps (Reference 2.4.6-205). Historically, 23 percent of tsunamis striking the United States have been the result of landslides (Reference 2.4.6-201). These events are caused by sudden failures of submarine slopes, which are often triggered by earthquakes. In the 1980s, construction work along the coast of Southern France triggered an underwater landslide that produced destructive tsunami waves in the harbor of Thebes (Reference 2.4.6-205). It is also thought that a 1998 earthquake triggered a large underwater slump of sediments, which produced a tsunami that destroyed coastal villages and killed thousand of people along the northern coast of Papua, New Guinea.

A description of historical tsunami records is presented in Subsection 2.4.6.1. Based on an extensive literature search and site-specific borings at LNP (Section 2.5), no geologic evidence of paleo-tsunami or tsunami-like deposits or geologically conducive locations for deposition were found in the vicinity of the Levy County site or in nearby coastal regions. There are no permanent slopes or hill slopes present on the LNP site (Section 2.5.5) nor within the coastal areas near the site that could adversely affect safety-related structures from local landslides. Potential tsunamis from offshore landslides are evaluated later in this section.

Volcano-induced tsunamis are rare, and account for only about 2 percent of tsunami events impacting the United States (Reference 2.4.6-201). However, like landslides, volcanic eruptions are impulsive disturbances, and they are capable of displacing large volumes of water and producing extremely destructive tsunami waves in the area in close proximity to their source. Volcanoes can produce tsunamis by one of three methods. According to the International Tsunami Information Center, "waves may be generated by the sudden displacement of water caused by a volcanic explosion, by a volcano's slope failure, or more likely by a phreatomagmatic explosion and collapse/engulfment of the volcanic magmatic chambers." The 1883 explosion and collapse of the Indonesian volcano Krakatoa produced one of the largest and most destructive tsunamis ever recorded. The resulting tsunami waves reached a height of 41.15 m (135 ft.), and resulted in significant damage to property and loss of human life. A similar explosion and collapse of the volcano Santorin in the Aegean Sea may have produced a tsunami that destroyed Greece's Minoan civilization in 1490 B.C. (Reference 2.4.6-205).

Most meteorites burn up within the atmosphere and no asteroid has fallen during recorded history. However, large craters are evidence that large meteorites have struck the Earth's surface in ancient history, and it is possible that a large asteroid fell on Earth sometime during the Cretaceous period, 65 million years ago. Given that water covers four-fifths of the planet's surface, falling asteroids and meteorites have a good chance of impacting oceans and seas. According to the International Tsunami Information Center, "The fall of meteorites or asteroids in the earth's oceans has the potential of generating tsunamis of cataclysmic proportions." The impact of a moderately sized asteroid, 5 to 6 km (3.1 to 3.7 mi.) in diameter, in the Atlantic Ocean could produce a tsunami that would destroy Atlantic Coast cities and travel to the Appalachian Mountains in the northern two-thirds of the United States (Reference 2.4.6-205). Meteorites and asteroids are potential tsunamigenic sources; however, the occurrence of such an event is highly unlikely.

It is believed that a large nuclear explosion could also serve as a tsunamigenic source. However, no significant tsunami has been reported as the result of nuclear testing, which is currently banned by international treaty (Reference 2.4.6-205).

FSAR Revisions associated with Response Item (2)

LNP FSAR Subsection 2.4.6.2 will be revised to read:

2.4.6.2 Observed Historic Tsunami Events Impacting the Caribbean

Reference 2.4.6-209 gives an overview of the tsunami history from 1498 to 1997 in the Caribbean Sea in terms of source events and runup elevations illustrating future expected geologic hazards. Based on this document, tsunamis are a relatively minor hazard in the Caribbean. The record for the last hundred years lists 33 possible tsunamis or 1 about every 3 years. It was observed that the typical recurrence interval for the destructive tsunamis in the Caribbean is about 21 years. The last destructive tsunami in the Caribbean occurred in August 1946, more than 60 years ago. Wave heights of 2.5 m (8.2 ft.) at Matancitas and 4 to 5 m (13.1 to 16.4 ft.) at Julia Molina were reported (Reference 2.4.6-209). This tsunami was generated by an $M_s = 7.8$, $M_w = 8.1$ earthquake that occurred about 65 km (40.4-mi.) off the northeast coast of the Dominican Republic. The waves produced by this tsunami were recorded at Daytona Beach, Florida, at Atlantic City, New Jersey, and at Bermuda. The travel time from the earthquake epicenter to Atlantic City was 4.8 hours, and 4.0 hours for Daytona Beach. An aftershock that occurred 4 days later produced a small tsunami that impacted the same areas (Reference 2.4.6-210).

In the Caribbean, there are four source mechanisms that have produced tsunamis in the past: tsunamis from remote sources (teletsunamis), tsunamis generated by mass movements (landslide tsunamis), tsunamis generated by volcanic processes (volcanic tsunamis), and tsunamis produced by earthquakes (tectonic tsunamis) (Reference 2.4.6-209). Table 2.4.6-201 lists verified historic Caribbean tsunamis from 1498 to 2000 in terms of their origin and impacted locations (Reference 2.4.6-209). Based on this data, it can be stated that historically no Caribbean tsunami has ~~impacted~~ resulted in significant danger to the United States Gulf Coast. Thus, it is unlikely that any particularly dangerous tsunami generated in the Caribbean Sea will impact the Gulf Coast of northern-central Florida where the LNP site is located.

FSAR Revisions associated with Response Item (3a), (3b), (3c)

LNP FSAR Subsections 2.4.6.6.3, 2.4.6.7, 2.4.6.8, and 2.4.6.9 will be revised to read:

2.4.6.6.3 Water Levels Due to Worst Case Tsunamigenic Events Using a Simplified Formula-Based Approach

~~A simplified "formula- based approach" of tsunami analysis was derived from many computer simulations of tsunamis based on the linear dispersive water wave theory (Reference 2.4.6-229).~~ The application of the tsunami simulation approaches to earthquake and landslide tsunamis have been thoroughly presented by Ward (Reference 2.4.6-232), Ward and Asphaug (Reference 2.4.6-233), and Ward and Day (Reference 2.4.6-234). Simpler formula-based approaches of tsunami analysis were derived from many computer simulations of tsunamis based on the linear dispersive water wave theory (Reference 2.4.6-229). Theis simulation approach is mode and ray-based and includes landslide evolution, geometrical spreading, dispersive spreading, frequency dependent shoaling, and diffractive corrections. The complex computer simulation results have been reduced to formula form by their authors for common applications so the analysis can be duplicated without the actual computer model (Reference 2.4.6-230). ~~Like many tsunami simulations, this approach takes the waves to a shallow water location near the site of interest.~~

~~The formula -based approach does not require detailed computer modeling, and it but does makes many simplifications compared towith the simulation- based approach (Reference 2.4.6-230). Due to these simplifications, the formula -based approach in many situations overestimates the magnitude of wave runup in many situations. In addition, T~~the formula--based approach ~~attempts to~~ embodiesy the same processes (generation, spreading, shoaling, run-up) as the simulation-based approach but uses simplified approximations of the processes instead of more rigorous computer calculations. These simplifications were compensated for by the use of conservative input parameter assumptions which are expected to overestimate the magnitude of wave run-up.

Certain parameters in the formula-based approach were obtained by fitting output created by many runs from a full simulation; so in thatis sense, the ~~formula- and simulation- based~~ two approaches are linked and physics-based.

In general, according to the formula-based approach, the wave run-up, ~~η~~ η, can be represented as a product of the following components:

$$\eta = A_0 PSB \qquad \text{Equation 2.4.6-2}$$

where A_0 is the source amplitude, P is the propagation loss (less than 1.0), S is the shoaling correction in shallow near-shore water (usually more than 1.0), and B is the amplification due to beaching (that is, as the waves move onto land). The procedure to calculate these components is explained below.

2.4.6.6.3.1 Determination of Source Amplitude A_0

In the case of a landslide, A_0 is given as:

$$A_0 = 3.5T\left(\frac{V_s}{\sqrt{gH_0}}\right)^{1.8}$$ Equation 2.4.6-3

where T is the thickness of the landslide unit, V_s is the landslide speed, g = 9.8 m/s^2 (32.2 ft/s^2), and H_0 is the water depth at the slide. Faster moving slides tend to produce bigger waves. Equation 2.4.6-3 is applicable for all landslide velocities satisfying $0<V_s<\sqrt{gH_0}$.

Whereas, the initial tsunami amplitude for fast slides can be approximated by ~~Silver et al.~~ (Reference 2.4.6-230) ~~is~~:

$$A_0 = T$$ Equation 2.4.6-4

It is clear from these two expressions (Equations 2.4.6-3 and 2.4.6-4) that, for the initial tsunami amplitude, Equation 2.4.6-3 is more complicated than Equation 2.4.6-4 (Reference 2.4.6-230), as the former tries to account for the effect of landslide velocity whereas the latter does not. Equation 2.4.6-3 was derived by fitting the results from many numerical landslide tsunami experiments ~~in~~by Ward~~'s equation~~ (Reference 2.4.6-236). It can be noted that for nominal landslide speeds (V_s~$0.5\sqrt{gH_0}$), both approximations (Equations 2.4.6-3 and 2.4.6-4) for the initial tsunami amplitude give nearly equal results. The range of V_s values used in Equation 2.4.6-3 can be estimated from the "terminal velocity" of low basal friction slides $V_{term} = \sqrt{\frac{g \sin \Theta}{C_d}}$ where Θ is slope of the surface, and C_d the coefficient of dynamic friction. For underwater landslides, Ward and Day (References 2.4.6-238 and 2.4.6-239) used values C_d = (2 to 20)x10^{-4}/m ([6.6 to 66]x10^{-4}/ft.). Regardless of the value of C_d selected, the important feature is that the plausible range of V_s used in Equation 2.4.6-3 be lower for slides on shallow slopes and larger for slides on steep slopes.

In case of an earthquake, A_0 is given as:

$$A_0 = \alpha \Delta u.$$ Equation 2.4.6-5

where Δu is earthquake slip and α is a fraction of slip that transforms into uplift. This factor depends upon the style of the fault. Mathematically, α can be determined using the following relationship:

$$\alpha = (1-\phi/180)Sin(\phi)|Sin(\rho)|$$ Equation 2.4.6-6

where ϕ and ρ are the dip and rake angles, respectively, in degrees. Combining Equations 2.4.6-5 and 2.4.6-6, A_0 for an earthquake is given as:

$$A_0 = (1-\phi/180)\,Sin(\phi)|Sin(\rho)|\,\Delta u$$ Equation 2.4.6-7

The most efficient mechanism for tsunami generation have ϕ near 45 degrees and ρ = ± 90 degrees. ~~Our test~~The LNP PMT analysis earthquakes employed these values.

2.4.6.6.3.2 Determination of Propagation Loss P

Propagating tsunami waves go through significant transformations such as modification in wave shape, duration, and attenuation in amplitude. The attenuation in tsunami wave amplitude is roughly proportional to inverse distance traveled due to geometrical spreading and frequency dispersion (Reference 2.4.6-228). For a constant depth ocean, Ward and Asphaug (Reference 2.4.6-233) fit the peak tsunami amplitude by the following relationship:

$$P = \left(1 + \frac{2R}{D}\right)^{-\varphi}$$ Equation 2.4.6-8

where R is the distance of measurement point from the source, D is the dimension of the tsunami source, and φ is an exponent defined as:

$$\varphi = 0.5 + 0.575\exp\left(-0.0175\frac{D}{H_0}\right)$$ Equation 2.4.6-9

The first term in Equation 2.4.6-9 accounts for geometrical spreading. The second term in Equation 2.4.6-9 accounts for additional wave height losses due to frequency dispersion. Generally larger dimensioned sources decay slower with distance on this account. Typically the value of φ from Equation 2.4.6-9 varies between 0.7 and 1.0. Combining Equations 2.4.6-7, 2.4.6-8, and 2.4.6-9, the peak wave amplitude at a distance R from the source A(R) can be determined by the following equations:

For ~~E~~earthquakes:

$$A(R) = A_0 P = \left(1 - \frac{\phi}{180}\right) Sin(\phi) |Sin(\rho)| \Delta u \left(1 + \frac{2R}{D}\right)^{-\left[0.5+0.575\exp\left(-0.0175\frac{D}{H_0}\right)\right]}$$

Equation 2.4.6-10

For ~~L~~landslides:

$$A(R) = A_0 P = 3.5T\left(\frac{V_s}{\sqrt{gH_0}}\right)^{1.8}\left(1 + \frac{2R}{D}\right)^{-\left[0.5+0.575\exp\left(-0.0175\frac{D}{H_0}\right)\right]}$$

Equation 2.4.6-11

2.4.6.6.3.3 Determination of Shoaling Correction S

Equation 2.4.6-8, which led to Equations 2.4.6-10 and 2.4.6-11, assumes oceans of constant depth H_0. Toward shore, however, oceans shallow until the amplitude of the propagated wave is approximately the same as the depth of the ocean, defined as H_S. When a tsunami group reaches water shallower than H_S they slow and grow in height to conserve energy flux, and this is called shoaling.Toward shore, however, real oceans become shallow to depth H_S. When tsunamis reach shallow water, they slow and grow to conserve energy flux. -For the peak waves of interest, deep water amplitude A(R) given by Equations 2.4.6-10 and 2.4.6-11 needs to be corrected to account for shoaling. According to linear theory, the shoaling correction, S, is given by the following relationship (Reference 2.4.6-228):

$$S = \left[\frac{V_G(\omega_{\max}, H_0)}{V_G(\omega_{\max}, H_S)} \right]^{\frac{1}{2}}$$ Equation 2.4.6-12

where- $V_G(\omega_{\max}, H_0)$ and $V_G(\omega_{\max}, H_S)$ are the tsunami wave group (grouped by their frequency, ω) velocities at ocean depths H_0 and H_S, respectively. It is clear from Equation 2.4.6-12 that the shoaling amplification depends on the ratio of group velocity at the source site and the coast site evaluated at the frequency associated with the peak tsunami height. As we are interested in a simplified formula versus full simulation, Equation 2.4.6-12 can be approximated using a long wave assumption (Reference 2.4.6-228) as:

$$S = \left(\frac{H_0}{H_S} \right)^{\frac{1}{4}}$$ Equation 2.4.6-13

Using Equation 2.4.6-13, the shoaled amplitude A(S) is defined as a function of the peak wave amplitude A(R) at distance R from the source as:

$$A(S) = A(R) \left(\frac{H_0}{H_S} \right)^{\frac{1}{4}}$$ Equation 2.4.6-14

2.4.6.6.3.4 Applying Beaching Correction

To be clear in terminology as the tsunami wave moves onto the landscape, the following terms, symbols, and their definitions are presented:

Shoreline Wave Height, h, shoaled wave height located at the beach and ocean interface. Note that the terms "shoreline wave height" and "flow depth at the shoreline" are sometimes used synonymously.

Run-up Elevation, η, is the maximum inland elevation that a tsunami reaches.

Run-in Distance, X_{max}, is the maximum distance inland that a tsunami reaches. The topographic elevation at the run-in distance X_{max} equals η.

Flow Depth, $F_d(X)$, is the depth of the tsunami wave at various places located at distance X from shoreline. Under normal conditions flow depth goes from its maximum value at the shoreline, $F_d(0) = h$, to $F_d(X_{max}) = 0$ at the run-in distance X_{max}.

The shoaled shoreline wave height, h, is estimated using the following empirical formula given by (Reference 2.4.6-228):

$h = A(S)^{4/5} H_S^{1/5}$ Equation 2.4.15

Using Equation 2.4.15, one can estimate shoreline wave height from offshore shoaled wave height. This establishes part of the "beaching correction," B, in Equation 2.4.6-2. Many formulas for this correction exist that include parameters like beach slope, wave period, and so forth. However, a simpler formula can be derived by combining Equations 2.4.6-14 and 2.4.6-15 to yield the estimated shoreline wave height as:

$h = A(R)^{4/5} H_0^{1/5}$ Equation 2.4.16

Using Equation 2.4.16, one can estimate shoreline wave height completely using only the terms of offshore wave height, A(R), and source water depth, H_0.

Runup height η_{est} is estimated using the following empirical formula (Reference 2.4.6-228):

$\eta_{est} = A(S)^{4/5} H_S^{1/5}$ Equation 2.4.6-15

Using Equation 2.4.6-15, one can estimate wave runup from offshore shoaled wave height. Combining Equations 2.4.6-14 and 2.4.6-15, the estimated runup can be calculated using the following relationship:

$\eta_{est} = A(R)^{4/5} H_0^{1/5}$ Equation 2.4.6-16

Using Equation 2.4.6-16, one can estimate runup using offshore wave height A(R) and source water depth H_0. In order to be clear in terminology, the following terms are defined:

Runup height, η, is the maximum elevation that a tsunami reaches. Runup height can be either an actual observed value η_{obs} or an estimated value η_{est}.

Run-in distance, X, is the maximum distance inland that a tsunami reaches. Run-in distance can be either an actual observed value X_{obs} or an estimated value X_{est}. The topographic elevation at the run-in distance X_{obs} equals the runup height η_{obs}.

Flow Depth, $F_d(X)$, is the depth of the flowing water at various places X onshore. Flow depth goes from its maximum value $F_d(0)$ at the shoreline to $F_d(X_{obs}) = 0$ at the run-in distance X_{obs}.

2.4.6.6.3.5 Determination Estimation of Run-up Elevation andof Run-in Distance

Run-in distance is the maximum distance inland that a tsunami reaches. Hills and Mader (References 2.4.6-231 and 2.4.6-240) estimated run-in distance asusing the following expression:

$$X_{est} = 0.06 F_d(0)^{1.33} n^{-2} \quad \text{Equation 2.4.6-17}$$

where X_{est} is the estimated run-in distance in meters, $F_d(0)$ is the flow depth at the shoreline in meters, and n is Manning's roughness coefficient. Equation 2.4.6-17 accounts for the loss in flow depth due to friction as the wave travels inland. A value of n = 0 corresponds to no friction. Larger n corresponds to higher friction.

Equation 2.4.6-18 was modified to include the increase in topography landward:

$$\frac{dF_d(X)}{dX} = -\left[\frac{16.7n^2}{F_d(0)^{0.33}} + \frac{dT(X)}{dX} \right]$$ Equation 2.4.6-18

where $dF_d(X)/dX$ is the loss in flow depth per meter of run-in distance and T(X) is the landward topographic height in meters. The second right hand term in Equation 2.4.6-18 accounts for the loss in flow depth as the wave climbs up from the beach. Integrating Equation 2.4.6-18 yields:

$$F_d(X) = F_d(X_0) - \left[\frac{16.7n^2}{F_d(X_0)^{0.33}}(X - X_0) + (T(X) - T(X_0)) \right]$$ Equation 2.4.6-19

where X_0 is the beach position (X=0). Elevation $T(X_0)$ at the beach position is usually small (i.e., essentially sea level). At run-in distance $X = X_{max}$, $F_d(X_{max}) = 0$. By substituting these boundary conditions yields the final equation used to estimate run-in distance, X_{max}:

$$[T(X_{max}) - T(X_0)] + \frac{16.7n^2}{F_d(X_0)^{0.33}}(X_{max} - X_0) = F_d(X_0)$$ Equation 2.4.6-20

Because the landscape slope profile can be nonlinear, an iterative solution is required to solve for the run-in distance. To use Equation 2.4.6-20, start at $X_{max}=X_0$ and move inland using the local land profile to evaluate the left hand side until it first equals the right hand side. That X_{max} would be the run-in distance and $T(X_{max})$ would be the run-in elevation.

Note that if there were no wave height losses resulting from friction during the run-in, then n=0 in Equation 2.4.6-20, the run-up elevation, $T(X_{max})$, would be approximately equal to the flow depth at the beach, $F_d(X_0)$. In the presence of friction however, overland flow attenuates and Equation 2.4.6-20 predicts run-up elevations lower than the flow depth at the beach.

Flow depths are difficult to measure after the fact. One needs a surviving telephone pole, post, tree, or building with water marks to fix flow depths and on open beaches these are in short supply. To use Equation 2.4.6-20, the flow depth at the shoreline, h from Equation 2.4.6-16 is set equal to the flow depth at the shoreline, $F_d(0)$ in Equation 2.4.6-20 under normal conditions.

Run-in and run-up were adjusted to account for the 10 percent exceedance astronomical high tide, sea level anomaly, and expected sea level rise correction factors to obtain a high extreme event (see FSAR Section 6.4.6.6.3.9 for the basis). The worst case run-in distance, X_{max}, and run-up elevation, η [= $T(X_{max})$] estimates were obtained by solving Equation 2.4.6-20 using the topographic profile starting at a higher water level, which moved the shoreline tsunami wave inland somewhat.

~~This equation was modified by McSaveney and Rattenbury (Reference 2.4.6-240) to include a slope factor:~~

$$\frac{dF_d(X)}{dX} = \left[\frac{16.7n^2}{F_d(0)^{0.33}} + 5Sin(\theta)\right]$$ Equation 2.4.6-18

where $dF_d(X)/dX$ is the loss in flow depth per meter of run-in distance and θ is the beach slope. Integrating Equation 2.4.6-18 provides:

$$F_d(X) = F_d(0) - \left[\frac{16.7n^2}{F_d(0)^{0.33}} + 5Sin(\theta)\right]X$$ Equation 2.4.6-19

The maximum run-in distance can be estimated from Equation 2.4.6-19 by substituting $F_d(X) = 0$, as:

$$X_{est} = \frac{F_d(0)^{1.33}}{16.7n^2 + 5F_d(0)^{0.33}Sin(\theta)}$$ Equation 2.4.6-20

Flow depths are difficult to measure after a tsunami event has occurred. In order to determine actual flow depths, water marks need to be measured on surviving telephone poles, posts, trees, or buildings. Generally on open beaches, these features do not exist and hence flow depth information is not readily available. Moreover, to use Equation 2.4.6-20, flow depth at the shoreline must be known. For applications here, the estimated runup height, η_{est}, from Equation 2.4.6-16 is substituted for flow depth at the shoreline, $F_d(0)$, in Equation 2.4.6-20 to get the following result:

$$X_{est} = \frac{\eta_{est}^{1.33}}{16.7n^2 + 5\eta_{est}^{0.33}Sin(\theta)}$$ Equation 2.4.6-21

In most cases the estimated runup height, η_{est}, is larger than $F_d(0)$, so the substitution $F_d(0) = \eta_{est}$ in Equation 2.4.6-21 is conservative.

2.4.6.6.3.6 Example Determination of Tsunami Hazard

Consider a facility located at elevation E_{site} and distance D_{site} from the coast. For the facility to be located in an estimated tsunami hazard zone, the following two conditions must be met:

- Condition 1: The site must have an elevation less than the estimated tsunami runup, η_{est}, ($E_{Site} < \eta_{est}$).
- Condition 2: The site must be closer to the beach than the estimated run-in distance, X_{est}, ($D_{Site} < X_{est}$).

Both of the above conditions ($E_{Site} < \eta_{est}$ and $D_{Site} < X_{est}$) must be satisfied for the site to be considered within the estimated tsunami hazard zone. If one of the conditions is not met, then the site is considered outside of the estimated tsunami hazard zone.
For numerical purposes, the actual topography data was represented by a fitted regular function:

$$T(X) = a + bX^c$$ Equation 2.4.6-21

where X= 0 kilometer (km) is the normal beach position, and a, b, and c are curve fitting parameters. Using the topography of the Gulf coast between the water and the LNP site, a profile was obtained and a profile equation for the plant site was estimated as shown in Figure 2.4.6-230.The curve parameters are: a = 3.4748, b = 1.1529E-09, and c = 2.3392 for Equation 2.4.6-21 where X is expressed in feet, and the regression equation is valid through an inland elevation of 7 m (23 ft.) which exceeds the predicted tsunami run-up elevation. This profile was used in conjunction with Equation 2.4.6-20 to estimate the run-in and run-up results found in this analysis.

For the normal case [Without considering correction factors for the 10 percent exceedance astronomical high tide, sea level anomaly, and expected long-term sea level rise]:

Take X_0=0 as the normal beach position. At X_0=0, the elevation on the fitted smooth topographic profile is $T(X_0=0)$ =1.06 meters (m).

The highest predicted landslide tsunami, the Mississippi Canyon Landslide, resulted in an estimated shoreline wave height of $h = F_d(X_0) = 21.37$ m (70.1 ft.). To solve, find the X_{max} that satisfies Equation 2.4.6-20 expressed as:

$$[T(X_{max}) - 1.06] + \frac{16.7 x 0.03^2}{21.37^{0.33}}(X_{max} - 0) = 21.37$$

To solve the above equation, one has to use an iterative procedure along with the topographic profile function, Equation 2.4.6-21. The solution X_{max}= 3.68 km (2.3 miles) and $T(X_{max})$= 2.3 m (7.5 ft.) NAVD88 satisfies the above equation. To confirm this:

(2.3 - 1.06) + (0.00547) x (3,680) = 21.37, which is the right hand side of the above equation.

For the high Gulf water level case [Considering correction factors for the 10 percent exceedance astronomical high tide, sea level anomaly, and expected long-term sea level rise]:

Continuing with the Mississippi Canyon Landslide for the extreme high water case, it is assumed that sea level will be 1.12 m higher than in the normal case. This higher water will cause the tsunami wave to shift inland during this event, so a new shoreline position, X_0 must be established. The new shoreline position is found from:

$[T(X_0) - 1.06] = 1.12$ m (3.7 ft.), which from the LNP land profile yields X_0 =3.52 km (2.2 miles) for $T(X_0)$=2.18 m (7.2 ft.).

The next step for estimating the extreme run-up and run-in values is to solve Equation 2.4.6-20 again with the new X_0 and $T(X_0)$, but keeping the same flow depth at the shoreline as in the normal case shifted to the new beach position. That is, $F_d(3{,}520) = 21.37$ m and T(3,520) = 2.18 m.

$$[T(X_{\max}) - 2.18] + \frac{16.7\text{x}0.03^2}{21.37^{0.33}}(X_{\max} - 3{,}520) = 21.37$$

Again the above equation is solved by iterating X_{max} and $T(X_{max})$ from the topographic profile and selecting the solution that makes the left hand side equal to the right hand side. The final results were X_{max}= 6.71 km (4.2 miles) and $T(X_{max})$= 6.12 m (20.1 ft.) NAVD88. To confirm this:

(6.12 - 2.18) + (0.00547) x (3,185.79) = 21.37, which is the right hand side of the above equation.

Consequently, the extreme high Gulf water levels increase the run-up elevation and run-in distance significantly.

2.4.6.6.3.7 Water Levels at the LNP Site Due to the Worst Case Submarine Landslides in the Gulf of Mexico

FSAR Subsection 2.4.6.3.2.2 provides a detailed discussion of the potential tsunami generators in the Gulf of Mexico, including submarine landslides. In order to conduct a tsunami hazard evaluation for the LNP site, a range of worst case potential tsunami generators were considered in the Gulf of Mexico, including the following submarine landslides:

- East Breaks
- Mississippi Canyon Landslide
- Landslides along the Florida Escarpment
- Along the Sslope above the Florida Escarpment

The geometrical parameters of the potential tsunami generators listed above were taken from the USGS Report to NRC (Reference 2.4.6-212). These landslides were termed the "Maximum Credible Submarine Landslides" in the USGS Report. Landslide speed can strongly affect tsunami size; generally faster moving slides generate larger waves and slower moving slides generate smaller waves (FSAR Subsection 2.4.6.6.3.1). Landslide speed can vary considerably depending upon the properties of the slide material and the slope and distance over which the slide moves. While conducting tsunami hazard evaluation for a given slide, a range of possible slide speeds from 25 to 50 m/s were considered.

Figure 2.4.6-228 (References 2.4.6-212 and 2.4.6-235) indicates that the depth of the Sslope above the Florida Escarpment ranges from 200 to 1000 m (656.2 to 3280.8 ft.), resulting in an average depth of 600 m (1968.5 ft.). Based upon Figure 2.4.6-229 (Reference 2.4.6-241), the east-west lateral dimension of the West Florida Slope (that is, the entire Sslope above the Florida Escarpment) is approximately 50 km (31.1 mi.) from the 200 m (656.2 ft.) water depth shelf break off the west coast of Florida to the 1,500 m (4921.2 ft.) water depth at the top of the Florida Escarpment, resulting in a slope of 1.5 degrees.

Figure 2.4.6-228 (References 2.4.6-212 and 2.4.6-235) indicates that the depth of the top of the Florida Escarpment is between 1500 and 2500 m (4921.2 and 8202.1 ft.), resulting in an average depth of 2000 m (6561.7 ft.). The average gradient of the Florida Escarpment is at least 20 degrees.

As described above, ~~the slope of~~ the S~~s~~lope above the Florida Escarpment is far less steep than the slope of the Florida Escarpment. As such, it would be expected that the speed of slides on the S~~s~~lope above the Florida Escarpment would be considerably less than the speed of slides on the Florida Escarpment. Based on the description presented in FSAR Subsection 2.4.6.6.3.1, the terminal landslide velocity, V_{term}, is proportional to the square root of sin of gradient as given below:

$$V_{term} \propto \sqrt{\sin \Theta} \qquad \text{Equation 2.4.6-22}$$

Using Equation 2.4.6-22, a relationship can be established between landslide velocities of the slope above the Florida Escarpment and the Florida Escarpment as given below:

$$\frac{V_{term}(Slope)}{V_{term}(Escarpment)} = \sqrt{\frac{\sin \Theta_{Slope}}{\sin \Theta_{Escarpment}}} \approx 0.28 \qquad \text{Equation 2.4.6-23}$$

If a velocity of 25 to 50 m/s (82 to 164 ft./sec) is used for slides on the Florida Escarpment, then a velocity of 7 to 14 m/s (23 to 45.9 ft./sec) can be ~~estimated~~ expected for slides on the S~~s~~lope above the Florida Escarpment which was used in the computations. ~~. Assumption of a larger gradient for the Florida Escarpment results in smaller, less conservative, velocities.~~

~~Using t~~The methodology presented in FSAR Subsections 2.4.6.6.3 through 2.4.6.6.4 and the landslide input parameters presented in Table 2.4.6-206 were used to estimate the potential tsnuamis from the four source locations. ~~, landslide analyses were conducted~~. Table 2.4.6-207 presents ~~impacts~~ the shoreline wave heights of worst case tsunamis ~~at the LNP site~~ generated due to potential submarine landslides in the Gulf of Mexico under normal water levels. ~~in terms of runup.~~

~~In order to determine run-in distances for various runup values tabulated in Table 2.4.6-207, beach slope and surface roughness are required. The nominal plant grade elevation for the footprints of LNP 1 and LNP 2 is 15.2 m (50 ft.) NAVD88 (FSAR Subsection 2.4.1.1) and the elevation of the Cedar Key datum is 4.06 ft. NAVD88 (Table 2.4.5-204). Further, the coast line of the Gulf of Mexico is about 12.8 km (7.9 mi.) from the LNP site (FSAR Subsection 2.4.1.1). Using this information, the beach slope θ is about 0.06 degree.~~ According to Gerardi et al. (Reference 2.4.6-231), the roughness of the land surface is represented by Manning's coefficient, n, that is 0.015 for smooth topography, 0.03 for urbanized/built land, and 0.07 for densely forested landscape. The landscape between the shoreline and the LNP site falls between urbanized/built land and densely forested category. However, to be conservative, the value of Manning's roughness coefficient, n, was assumed to be 0.03 for the tsunami inundation analysis for the LNP site.

Using the beaching ~~slope and surface roughness parameters~~ procedure described in Subsection 2.4.6.6.3.6, run-in distances and the corresponding ~~to various~~ run-up elevation values were determined as tabulated in Table 2.4.6-20~~7~~8.

2.4.6.6.3.8 Water Levels at the LNP Site Due to the Worst Case Earthquake Tsunamis

Using the formula-based approach in FSAR Subsection 2.4.6.6.3, the following worst case earthquake tsunamis were analyzed to determine the flooding impact at the LNP site:

- Mid-Gulf Tsunamigenic Earthquake
- Veracruz Tsunamigenic Earthquake
- Venezuela Tsunamigenic Earthquake

Table 2.4.6-2098 presents parameters associated with the worst case earthquakes that were used to determine the impacts of generated tsunamis at the LNP site. Table 2.4.6--2109 presents the offshore wave heights and the shoreline wave heights , runup heights, and run-in distances corresponding to these earthquake tsunamis under normal water levels. -Using the beaching procedure described in Subsection 2.4.6.6.3.6, run-in distances and their corresponding run-up elevation values were determined as tabulated in Table 2.4.6-211.

2.4.6.6.3.9 PMT Water Levels Coincident with Tides, Wind Waves, and Sea Level Anomalies

In FSAR Subsections 2.4.6.6.3.76 and 2.4.6.6.3.87, the run-up heights and run-in values were determined without considering tides, wind waves, sea level anomalies, or the effect of long-term climate change. NRC Regulatory Guide 1.59, however, requires that the 10 percent exceedance astronomical high spring tide be used as the antecedent water level for the storm surge due to a PMH event. The same antecedent water level condition is also used to obtain the PMT maximum water level. The 10 percent exceedance antecedent high spring tide at the Crystal River coastline near the LNP site is taken as 1.3 m (4.3 ft.) MLW, which is equivalent to 0.82 m (2.68 ft.) NAVD88.

As presented in FSAR Subsection 2.4.5.2.2, and according to Regulatory Guide 1.59, the sea level anomaly for Crystal River is 0.18 m (0.6 ft.). Further, the expected sea level rise is 0.12 m (0.39 ft.) for a design period of 60 years for the LNP site.

Combining the 10 percent exceedance high spring tide (2.68 ft. NAVD88), sea level anomaly (0.6 ft.), and the long-term sea level rise (0.39 ft.) with the postulated conservative tsunami run-up values at the Florida Gulf Coast shoreline near the LNP site presented in FSAR Subsections 2.4.6.6.3.6 and 2.4.6.6.3.7 results in an increase of 3.67 ft. (1.12 m) NAVD88 (2.68+0.6+0.39 = 3.67 ft.). The associated coincident PMT wave run-up and run-in are also presented in Tables 2.4.6-20810 and 2.4.6-211 for worst case landslides and earthquake tsunamis, respectively. The concurrent occurrence of the astronomical high tide, sea level anomaly, and sea-level rise is considered the extreme high water levels that may occur in the Gulf of Mexico. Combined with the very high tsunamis estimated for the LNP project and the lack of any historical evidence of tsunamis of this magnitude, these estimated potential tsunami run-up elevations are considered very conservative.

~~As shown in Tables 2.4.6-210 and 2.4.6-211, the maximum runup height estimates after applying the 10 percent exceedance high spring tide, sea level anomaly, and long-term sea level rise corrections are 22.5 m (73.8 ft) NAVD88 and 6.8 m (22.3 ft) NAVD88 for the worst-case landslide and earthquake, respectively. The corresponding maximum run-in~~

~~distances are 2.07 km (1.29 mi) and 0.5 km (0.31 mi), respectively. Therefore, the actual runup height will be much smaller than the estimated runup height.~~

2.4.6.6.3.10 Determination of Tsunami Hazard at the LNP Site

As shown in Tables 2.4.6-208 and 2.4.6-211, the maximum run-up elevation estimates after applying the 10 percent exceedance high spring tide, sea level anomaly, and long-term sea level rise corrections are 6.12 m (20.1 ft) NAVD88 and 2.96 m (9.7 ft) NAVD88 for the worst-case landslide and earthquake, respectively. However, for highest PMT, the Mississippi Canyon Landslide, the extreme Gulf water levels run-in distance results are far from the LNP site (about 6.1 km in this case) and much lower (about 9 m lower) than the LNP plant which is at elevation 15.5 m (51 ft.) NAVD88.
~~In order to determine whether the LNP site would be impacted by these worst case tsunamis, tsunami hazard criteria described in FSAR Subsection 2.4.6.6.3.6 was used. In Tables 2.4.6-210 and 2.4.6-211, values of η_{est} and X_{est} have been assembled for all plausible scenarios for both cases of with and without tides, wind waves, sea level anomalies, and the effect of longterm climate change for the worst case tsunamis generated by landslides and earthquakes. It is clear that in no case do both conditions ($E_{Site} < \eta_{est}$ and $D_{Site} < X_{est}$) apply to the LNP site. Therefore, tsunamis generated by worst case submarine landslides or earthquakes are not expected to impact the LNP site.~~

2.4.6.7 Summary and Conclusions

The most common tsunamigenic mechanisms are earthquakes, landslides, and volcanic eruptions. Although meteorites, asteroids, and nuclear explosions are also potential tsunamigenic sources, their occurrence is rare. Based on the literature review of various source mechanisms, the most destructive tsunamis are the result of large, shallow earthquakes with an epicenter or fault line near the ocean floor and a magnitude $M_W \geq 6.5$.

There are no significant near-field tsunamigenic sources threatening the Gulf Coast. The Gulf of Mexico does not have the tectonic conditions that can generate destructive tsunamis. However, the Gulf of Mexico has produced some notable earthquakes in the recent past. The most recent and largest event occurred in September of 2006 and had a magnitude of $M_W = 5.8$. However, given the lack of sliding tectonic plates (subduction of one plate over the other, specifically) and the infrequent occurrence and modest magnitude of these "midplate" earthquakes, there is little likelihood that a seismic event in the Gulf of Mexico would produce a tsunami. Furthermore, there are no permanent slopes or hill slopes present on the LNP site (Section 2.5.5) nor within the coastal areas near the site that could adversely affect safety-related structures from local landslides.

~~The tsunamigenic threat of near-field and far-field landslides within the Gulf of Mexico is more difficult to characterize.~~ Though the Gulf of Mexico ~~is characterized by~~ has evidence of frequent landslide events, they have not been a source of any tsunami that has been documented instrumentally or in the geologic record for the Gulf Coast. The potential worst-case scenario may be represented by review of the East Breaks slump — a landslide that likely occurred 5000 to 20,000 years ago. Preliminary analysis of this event suggests that such a landslide would have produced a tsunami with a maximum offshore height of 7.6 m (25 ft.). This calculation has not been supported by subsequent publication, and there is no documented geologic evidence of the impact of such a wave along the Gulf Coast. However, the inland distance and elevation of the LNP site when coupled with the site's distance from the East Breaks slump source suggest that a tsunami with a maximum initial wave height of 7.6 m (25 ft.) would not likely impact the LNP site.

Far-field seismic tsunamigenic sources for the Gulf of Mexico include the Aleutian Trench in Alaska, the Azores - Gibraltar fracture zone, and various locations within the Caribbean Sea. The Caribbean region in particular has several active subduction zones as the result of the movement of the Caribbean plate. Far-field landslides (e.g., the Canary Islands) and volcanoes (e.g., the Lesser Antilles) are also a potential source, but are unlikely to produce tsunamis that will be destructive to the Gulf Coast.

Historical records of tsunami waves along the Gulf Coast indicate an infrequent occurrence and magnitudes too small to cause any significant damage. Three historical tsunami events have been documented for the Gulf Coast in the available tsunami databases and literature. On October 24, 1918, a small wave was recorded at a Galveston, Texas, tide gauge, and was likely generated by an earthquake aftershock originating in the Mona Passage, just northwest of Puerto Rico. On May 2, 1922, a 0.6-m (2-ft.) wave was recorded on a tide gauge in Galveston, Texas, as a result of an earthquake originating near Isla de Vieques, Puerto Rico. Most recently, on March 27, 1964, standing wave activity was recorded throughout the Gulf Coast as a result of an earthquake in Prince William Sound, Alaska. All historical tsunami waves recorded along the Gulf Coast have been less than 1 m (3.28 ft.).

In addition to the recorded events in the Gulf of Mexico, numerical simulations indicate that the 1755 Lisbon earthquake may have also produced a tsunami that impacted the Gulf Coast. If so, the deep-water amplitude of the resulting tsunami would have been reduced to less than 1 m (3.28 ft.) once within the Gulf of Mexico.

NOAA's West Coast and Alaska Tsunami Warning Center evaluated four seismic tsunamigenic sources that could potentially produce "worst-case" impacts for the Gulf Coast. These sources include Puerto Rico Trench, Swan fault, North Panama Deformed Belt, and a hypothetical source just North of Veracruz, Mexico. This study concluded that sources outside of the Gulf of Mexico will not likely produce a tsunami capable of damaging the Gulf Coast, because bottom friction will result in significant energy losses for a tsunami traveling through the Straits of Florida or the Caribbean Sea. In 2007, the USGS conducted a complimentary study on a similar set of seismic sources within the Caribbean region. The results of this study were limited to deep-water (250 m [820.2 ft.]) amplitudes, but were generally consistent with the NOAA report.

The tsunamigenic threat for the LNP site is negligible. Maximum historic observed tsunami waves have been less than 1 m (3.28 ft.) along the Gulf Coast. No significant near-field threats exist, and the region is effectively shielded from far-field earthquake tsunami events by the narrow, shallow waters of the Straits of Florida and Caribbean Sea. Regions of high seismicity in the Caribbean Sea, such as the Puerto Rico Trench, Swan fault, and North Panama Deformed Belt pose the most significant tsunamigenic threat. ~~Simulations suggest that the maximum likely tsunami runup from one of these sources will be less than 2 m (6 ft.). Because the LNP safety-related facilities are at a higher elevation (nominal plant grade elevation of 15.2 m [50 ft.] NAVD88) and well inland from the Levy County coastline, it is not expected to be impacted by the probable maximum tsunami event.~~

Based on run-up and run-in calculations due to potential worst case tsunamigenic submarine landslide and earthquake events using the ~~Simplified Formula Approach as~~approach described in FSAR Subsection 2.4.6.6.3~~.10~~, the LNP site will not be impacted.

2.4.6.8 Hydrography and Harbor or Breakwater Influences on Tsunami

Routing of the controlling tsunami, which includes breaking wave formation, bore formation, and resonance effects, is expected to be minor and limited to shorelines. As the LNP site is approximately 12.8 km (7.9 mi.) from the Gulf of Mexico, hydrography and harbor or breakwater influences are not expected to be severe enough under any circumstances to jeopardize the operation of the safety-related structures.

2.4.6.9 Effects on Safety-Related Facilities

As concluded~~discussed~~ in FSAR Subsection 2.4.6.7~~5.3~~, the LNP site is not expected to be impacted by PMT. Thus, effects of the controlling tsunami are not expected to ~~be severe enough under any circumstances to~~ jeopardize the operation of the safety-related structures. Therefore, measures to protect the LNP site against the effects of a tsunami are not included in the design criteria.

LNP FSAR TABLES 2.4.6-206 through 2.4.6-211 will be replaced as follows:

Table 2.4.6-206
Parameters for Worst Case Landslide Tsunamis

Landslide	Area, A (Km^2)	Volume, V (Km^3)	Thickness of the Unit, T (m)	Slide Speed, Vs (m/s)	Initial Wave Amplitude, A_0 (m)	Water Depth of the Slide Event, H_0 (m)	Dimension of Tsunami Source, D (Km)	Distance of the measurement point from the Source, R (Km)
East Breaks	520	22	42	25	7	1,750	25,719	1000
	520	22	42	50	26	1,750	25,719	1000
Mississippi Canyon	3,720	428	115	25	21	1,689	68,822	640
	3,720	428	115	50	73	1,689	68,822	640
Florida Escarpment	648	16.2	25	25	4	2,000	28,724	275
	648	16.2	25	50	14	2,000	28,724	275
Slope above the Florida Escarpment	648	16.2	25	7	1.2	600	28,724	325
	648	16.2	25	14	4.1	600	28,724	325

Notes:

km = kilometer
km^2 = square kilometer
km^3 = cubic kilometer
m = meter
m/s = meters per second
Vs = slide velocity (speed)

Table 2.4.6-207
Shoreline Wave Height for Selected Worst Case Landslide Tsunamis

Landslide	Exponent, φ (unitless)	Offshore Wave Height at a distance R from the source, A(R) (m)	Shoreline Wave Height h (m)
East Breaks	0.94	0.12	0.8
	0.94	0.42	2.2
Mississippi Canyon	0.78	2.06	7.9
	0.78	7.17	21.4
Florida Escarpment	0.95	0.23	1.4
	0.95	0.80	3.8
Slope above the Florida Escarpment	0.75	0.11	0.6
	0.75	0.38	1.7

Notes:

m = meter

Table 2.4.6-208
Coincident Run-up and Run-in for the Worst Case Landslide Tsunamis

Name	Without Considering Tides, Wind Waves, and Sea Level Anomalies Corrections		Considering Tides, and Wind Waves, and Sea Level Anomalies Corrections	
	Run-in Distance X_{max} Km (mi)	Run-up $\eta = T(X_{max})$ m (ft) NAVD88	Run-in Distance X_{max} Km (mi)	Run-up $\eta = T(X_{max})$ m (ft) NAVD88
East Breaks (Vs = 25 m/s)	0.15 (0.09)	1.06 (3.48)	3.65 (2.28)	2.28 (7.48)
East Breaks (Vs = 50 m/s)	0.41 (0.25)	1.07 (3.5)	3.88 (2.42)	2.46 (8.08)
Mississippi Canyon (Vs = 25 m/s)	1.42 (0.88)	1.19 (3.91)	4.75 (2.97)	3.32 (10.89)
Mississippi Canyon (Vs = 50 m/s)	3.68 (2.3)	2.3 (7.55)	6.71 (4.19)	6.12 (20.07)
Florida Escarpment (Vs = 25 m/s)	0.26 (0.16)	1.06 (3.48)	3.75 (2.34)	2.36 (7.73)
Florida Escarpment (Vs = 50 m/s)	0.69 (0.43)	1.08 (3.56)	4.13 (2.58)	2.68 (8.8)
Slope above the Florida Escarpment (Vs = 7 m/s)	0.11 (0.07)	1.06 (3.48)	3.62 (2.26)	2.26 (7.4)
Slope above the Florida Escarpment (Vs = 14 m/s)	0.3 (0.19)	1.06 (3.49)	3.79 (2.37)	2.39 (7.84)
Maximum	**3.68 (2.3)**	**2.3 (7.55)**	**6.71 (4.19)**	**6.12 (20.07)**

Note:

Km = kilometer
Mi = mile
m = meter
ft = feet
NAVD88 = North American Vertical Datum of 1988

Table 2.4.6-209
Parameters for Worst Case Earthquake Tsunamis

Earthquake Location	Rigidity, μ (Pa)	Fault Length, L (Km)	Fault Width, W (Km)	Fault Area, A (Km^2)	Average Fault Slip, Δu (m)	Dip Angle, ϕ (degree)	Rake Angle, ρ (degree)	α	Magnitude, Mw (Nm)	Water Depth at the Source, H_0 (m)	Diameter or Physical size of uplift, D (Km)	Distance of the measurement point from the Source, R (Km)
Mid Gulf	3.0E+10	50	23	1,150	1	45	90	0.530	7.0	3,121	36.500	450
Vera Cruz	3.0E+10	199	93	18,507	4	45	90	0.530	8.2	2,836	146.000	1,500
Venezuela	3.0E+10	550	100	55,000	21.5	17	90	0.265	9.0	1,847	325.000	2,400

Notes:

Pa = Pascal
km = kilometer
km^2 = square kilometer
m = meter
degree = degree angle
Nm = Newton meter

Table 2.4.6-210
Shoreline Wave Height for Selected Worst Case Earthquake Tsunamis

Earthquake Location	Exponent, φ (unitless)	Offshore Wave Height at a distance R from the source, A(R) (m)	Shoreline Wave Height h (m)
Mid Gulf	0.96	0.02	0.25
Vera Cruz	0.73	0.22	1.48
Venezuela	0.53	1.33	5.67

Note:

m = meter

Table 2.4.6-211
Coincident Run-up and Run-in for the Worst Case Earthquake Tsunamis

Name	Without Considering Tides, Wind Waves, and Sea Level Anomalies Corrections		Considering Tides, and Wind Waves, and Sea Level Anomalies Corrections	
	Run-in Distance X_{max} Km (mi)	Run-up $\eta = T(X_{max})$ m (ft) NAVD88	Run-in Distance X_{max} Km (mi)	Run-up $\eta = T(X_{max})$ m (ft) NAVD88
Mid Gulf	0.05 (0.03)	1.06 (3.47)	3.56 (2.23)	2.21 (7.25)
Vera Cruz	0.27 (0.17)	1.06 (3.48)	3.76 (2.35)	2.36 (7.76)
Venezuela	1.02 (0.64)	1.12 (3.68)	4.42 (2.76)	2.96 (9.71)
Maximum	**1.02 (0.64)**	**1.12 (3.68)**	**4.42 (2.76)**	**2.96 (9.71)**

Note:

Km = kilometer
Mi = mile
m = meter
ft = feet
NAVD88 = North American Vertical Datum of 1988