Tsunami Safety Criteria and Current Site Reviews in the United States

By

Goutam Bagchi, Hosung Ahn, Henry Jones, Annie Kammerer,
Richard Raione and Nilesh Chokshi

United States Nuclear Regulatory Commission

Abstract

The U.S. Nuclear Regulatory Commission (NRC) has promulgated an alternate licensing framework for early site permits (ESPs), certified reactor designs, and combined construction permits and operating licenses (COLs) as described in 10 Code of Federal Regulations (CFR) Part 52. New applicants have been using the Part 52 framework in submittals since 2003. The reactor site criteria are addressed in 10 CFR Part 100. Guidance for the public on approaches that meet NRC requirements is outlined in NRC regulatory guides. Factors to be considered when selecting the site include physical characteristics of the site including seismology, meteorology, geology, and hydrology. The NRC staff review guidance and acceptance criteria are provided in a document, "Review of Safety Analysis Reports for Nuclear Power Plants, NUREG 0800, Revised March 2007." Section 2.4 of the staff guidance in NUREG 0800 relates to hydrology and flooding design basis for a nuclear power plant.

The objective of this paper is to describe several initiatives undertaken in the U.S. to capture the lessons learned from the 2004 Indian Ocean tsunami; to describe revision of the staff guidance documented in NUREG 0800 Section 2.4.6, "Probable Maximum Tsunami Hazards" and some essential elements from Section 2.4.5, "Probable Maximum Surge and Seiche Flooding;" and to describe efforts related to the revision of the regulatory guide 1.59, "Design Basis Floods for Nuclear Power Plants." This document also describes the efforts to use the lessons and insights learned from the current site reviews.

Several coastal sites are currently under review for assessment of flood parameters associated with tsunami and hurricane (e.g. maximum and minimum surge levels, residence time, recession rate, erosion and sedimentation effects, etc.). Modeling of wave propagation and overland runup is important for these efforts. Also, tsunami and hurricane surge estimates, including consideration of site-specific long term climate change and sea level rise effects are important aspects of the assessment. At coastal sites, the effects of tsunami and hurricane should be carefully examined to determine which effect governs the site flooding hazard.

Introduction

The Code of Federal Regulation Title 10, Part 100 (10 CFR Part 100) relates to Reactor Site Criteria, and Subpart A applies to applications prior to 1997 and Subpart applies to applications after 1997. The site factors that are required to be considered include geological, seismological, hydrological, meteorological and other factors. In order to expedite site selection and certification of standard reactor designs a decoupled process was incorporated in 10 CFR Part 52 of the NRC regulation. This decoupled process allows for early site permit (ESP) applications to be separate from the standard reactor certification. The ESP needs to establish site characteristics that can accommodate an envelope of plant parameters. An applicant seeking to license a nuclear power plant can then use an ESP and a certified reactor design to submit an application for a combined operating license. Although the option exists for an applicant to use a new reactor design at a brand new site or use an ESP with a new reactor design.

NRC regulation 10 CFR Part 100.20 requires adherence to a set of siting factors. Assessment activities related to these factors include the following:

- The nature and proximity of man-related hazards (e.g., airports, dams, transportation routes, military and chemical facilities) must be evaluated to establish site parameters for use in determining whether a plant design can accommodate commonly occurring hazards, and whether the risk of other hazards is very low.
- Physical characteristics of the site, including seismology, meteorology, geology, and hydrology must be identified, characterized and assessed.
- Meteorological characteristics of the site that are necessary for safety analysis or that may have an impact upon plant design (such as maximum probable wind speed and precipitation) must be identified and characterized.
- Factors important to hydrological radionuclide transport (such as soil, sediment, and rock characteristics, adsorption and retention coefficients, ground water velocity, and distances to the nearest surface body of water) must be obtained from on-site measurements. The maximum probable flood along with the potential for seismically induced floods must be estimated using historical data.

In addition to the consideration of the siting factors above, a proposed facility must include the principal design criteria. The principal design criteria establish the necessary design, fabrication, construction, testing, and performance requirements for structures, systems, and components important to safety; that is, structures, systems, and components that provide reasonable assurance that the facility can be operated without undue risk to the health and safety of the public. Appendix A to 10 CFR Part 50 specifies these general design criteria (GDC) to establish minimum requirements for the principal design criteria for water-cooled nuclear power plants similar in design and location to plants for which construction permits have been issued by the Commission. The General Design Criteria are also considered to be generally applicable to other types of nuclear power units and are intended to provide guidance in establishing the principal design criteria for such other units. GDC 2 requires appropriate consideration of the most severe of the natural phenomena that have been historically reported for the site and surrounding area, with sufficient margin for the limited accuracy, quantity, and period of time in which the historical data have been accumulated. Appropriate combinations of the effects of normal and accident conditions with the effects of the natural phenomena are also required.

Regulatory Guidance on Flood Hazard Determination

Regulatory Guide (RG) 1.59, "Design Basis Floods for Nuclear Power Plants" provides guidance for one acceptable method of establishing the design basis floods at a specific site and NUREG 0800, "Standard Review Plan (SRP)" provides guidance to the NRC staff on details of conducting the review and the determination of safety findings. RG 1.59 is currently being revised, and the SRP was revised on March 31, 2007.

NRC has adopted the concept of a "probable maximum event," for estimating design bases. The probable maximum event, which is determined by accounting for the physical limits of the natural phenomenon, is the event that is considered to be the most severe reasonably possible at the location of interest and is thought to exceed the severity of all historically observed events. For example, dam failures, a probable maximum flood (PMF) is the hypothetical flood generated in the drainage area by a probable maximum precipitation (PMP) event. The probable maximum storm surge is generated by the probable maximum hurricane (PMH) or the probable maximum windstorm (PMWS). These events are defined by the American National Standards Institute (ANSI) and ANS in ANSI/ANS-2.8-1992 (ANS, 1992). Similar concepts exist for a probable maximum tsunami, which is not covered in the ANSI standard. Because the PMP is a deterministic concept with no associated probability distribution, estimating the PMF also is a deterministic process.

In order to assess the design basis flood, first, for the selected site of a nuclear power plant, the causal phenomena or mechanisms that could lead to flooding should be identified. Flooding causal mechanisms refer to the set of those hydro-meteorological, geo-seismic, or structural failure phenomena (embankment, near by water control structures) that may produce a flood at or near the site. The geographical area that is relevant when determining floods at or near the site for each flooding causal mechanism should be identified. This geographical area, generally termed the vicinity of the site or site region (or just "the vicinity"), depends on the nature of the flood causal mechanism being considered. Floods generated in the vicinity because of the hydro-meteorological, geo-seismic, or structural failure may propagate to the site. For example, a PMF in a river that flows by a site may consist of the entire watershed of the river upstream of the site. For a site located near coastal regions, an ocean, or a large lake may also be subjected to tsunamis or storm surges that might propagate to the site.

An inspection of historical data may reveal the flooding causal mechanisms that should be considered for a site. For example, an inspection of air temperature data may suggest potential for formation of ice jams or dams, the subsequent collapse of which may generate a flood. More important is the need to inspect the hydrology, topography, morphology, and geology and the presence of any water control structures in the vicinity of the site (e.g., a site located on the banks of a river should be investigated for the PMF in the river; a site that has several upstream dams should be analyzed for floods from single and cascading dam failures). Typically, flooding causal mechanisms that should be considered include local intense precipitation, flooding in rivers and streams, flooding from upstream dam breaches or failures, flooding from storm surges or seiches, flooding from tsunamis, flooding from ice-induced events, and flooding from channel diversions towards the site. A hierarchical hazard assessment starts with the most conservative simplifying assumptions that maximize the hazards from the probable maximum event for each natural flooding causal phenomenon expected to occur in the vicinity of a proposed site. If the site is not inundated by floods from any of the phenomena, a conclusion that the site is not susceptible to flooding would be valid (ANS, 1992), and no further flood hazard assessment is needed. For these reasons, the SRP emphasizes the need to apply a hierarchical approach for establishing the design basis flood.

U. S. Tsunami Initiatives Post-2004 Indian Ocean Tsunami

In response to the 2004 Indian Ocean tsunami, in 2005 the NRC coordinated a tsunami safety study with the National Tsunami Safety initiative conducted by the National Oceanic and Atmospheric Administration (NOAA). The NRC tsunami hazard study was conducted by the Pacific Northwest National Laboratory and the Pacific Marine and Environmental Laboratory which is a part of NOAA. This early effort resulted in the publication of two documents. They were NUREG-CR 6966, "Tsunami Hazard Assessment at Nuclear Power Plant Sites in the Untied States of America", which was published in final form in March 2009, and NOAA Technical Memorandum OAR PMEL-136, "Scientific and Technical Issues in Tsunami Hazard Assessment of Nuclear Power Plant Sites,", which was published in 2007. These documents form the basis of the 2007 tsunami-related updates to NUREG 0800.

In 2006, the NRC also initiated a long-term research tsunami research program. This program, which includes cooperative work with the United States Geological Survey (USGS) and the National Oceanic and Atmospheric Administration (NOAA), was designed both to support activities associated with the licensing of new nuclear power plants in the U.S and to support development of new regulatory guidance. This research program has resulted in several publication and made important contributions to tsunami modeling approach and standards, as summarized in conference papers by Kammerer (2008)

Necessarily, the US NRC research program includes assessment of both seismic- and landslide-based tsunamigenic sources in both the near and the far fields. The inclusion of tsunamigenic landslides, an important category of sources that impact tsunami hazard levels for the Atlantic and Gulf Coasts, is a key difference between this program and most other tsunami hazard assessment programs that existed at the time. The initial phase of work undertaken by the USGS as part of the research program consisted of collection, interpretation, and analysis of available offshore data, with significant effort focused on characterizing offshore near-field landslides and analyzing their tsunamigenic potential and properties. This work is summarized in ten Brink et al (2008). In addition, eight papers have been published in a special edition of Marine Geology Marine Geology Special Issue: Tsunami Hazard Along the U.S. Atlantic Coast, Volume 264, Issues 1-2, (2009) dedicated in whole to the results of the NRC research program. These papers are listed in the reference section of this document.

In the current phase of research, additional field investigations are being conducted in key locations of interest and additional analysis of the data is being undertaken. Simultaneously, the MOST tsunami generation and propagation model used by NOAA has been enhanced to include landslide-based initiation mechanisms and is being used to investigate the impact of the tsunamigenic sources identified and characterized by the USGS. The potential for probabilistic tsunami hazard assessment will also be explored in the final phases of the program.

Regulatory Guide 1.59 (1977) briefly discussed tsunami as a source of flooding. This regulatory guide is currently being updated. However, the update of this guide will not include tsunami-induced flooding. NRC staff is currently preparing a new regulatory guide focused on tsunami hazard assessment and risk.

U. S. Storm Surge Initiatives Post-2005 Hurricane Katrina

At the end of August 2005, Hurricane Katrina made landfall near the Louisiana/ Mississippi border. Less than one month later, Hurricane Rita struck near the Louisiana/Texas border. Both of these storms produced catastrophic damage, and areas of the Louisiana and Mississippi coasts were devastated. NRC tasked the U.S. Army Corps of Engineers (USACE) to review the NOAA Technical Report NWS 23, "Meteorological Criteria for Standard Project Hurricane and Probable Maximum Hurricane Wind Fields, Gulf and East Coasts of the United States" and the NRC Regulatory Guide 1.59, "Design Basis Floods for Nuclear Power Plants". Regulatory Guide 1.59 and its supporting documents provide a methodology for estimating the probable maximum surge (PMS) for open coast locations of the Atlantic and Gulf of Mexico. The PMS estimates are determined by use of the probable maximum hurricane (PMH) parameters applied as input to a quasi-two-dimensional numerical storm surge model developed in the early 1970s. The PMH is a hypothetical hurricane having a combination of characteristics that give the highest sustained wind speed that can probably occur at a specified location.

In 2009, the Engineer Research and Development Center, Corps of Engineers Coastal and Hydraulics Laboratory (ERDC CHL) recommended that both the NWS Report 23 and Regulatory Guide 1.59 be updated. The meteorological criteria for the PMH wind fields are developed in the NOAA Technical Report NWS 23 published in September 1979. However, additional information from the many sources which were unavailable at the time of that study, along with data from many well-documented storms since 1979, have shown some potentially important inconsistencies between the PMH derived in that study and current understanding of the characteristics of intense hurricanes. Similarly, the two-dimensional storm surge model developed in 1971 is extremely limited by restrictions and simplifications made in order to make the problem computationally tractable given the computer resources available in the early to mid 1970's. The model assumptions and simplifications reduce the applicability and accuracy of the model.

Based on new theoretical concepts and data, NRC has continued its strong collaboration with NOAA and USACE with the ultimate objective to transition storm surge regulatory guidance to a more risk-informed methodology (1) by accounting for annual probabilities of exceedance of joint wind speed/storm surge events, and (2) by considering the effects of topography and bathymetry at the sites of interest, as the storm surge at any specific location is highly dependent upon these factors. In general, the methodology involves the simulation and selection of a stochastic set of storm tracks (synthetic approach), integration of the selected storm tracks into a hydrodynamic simulation model to generate time histories of wind speeds and corresponding time histories of storm surge heights at a site, and the application of probabilistic methods to develop joint probabilities of exceedance and mean recurrence intervals for wind speed/storm surge height events.

Limited observed data and the scale and extent of coastal storm surges have defeated attempts to characterize them by a statistical analysis of direct measurements. Thus, it is necessary to perform simulation studies using knowledge of the local climatology combined with numerical models capable of accurately simulating storm surges throughout the coastal zone. The current state-of-the-art uses the Empirical Simulation Technique (EST) and Joint Probability Method (JPM). The EST method utilizes historic data to generate a large number of multi-year simulations of possible future storm events for a specific location. The approach is based on resampling and interpolation of data contained in a database of events derived from historic events. The ensemble of simulations is consistent with the statistics and correlations of past storm activity at the site, but allows for random deviations in behavior that are likely to occur in the future. The JPM method considers all possible combinations of storm characteristics at landfall, calculates the surge effects for each combination, and then combines these results considering the combinations' associated probabilities. The result is the annual probability of exceeding any desired storm stage. Both the EST and JPM methods have become the standard approach for the evaluation of surge inundation from tropical cyclones.

EST and JPM schemes have been developed and applied in recent probabilistic hurricane-studies performed by teams led by NOAA and by USACE for the central Gulf of Mexico coast. An empirical simulation technique for modeling the entire tracks of tropical cyclones was first published by Vickery, et al. (2000a) and used to determine hurricane wind speeds and storm surge for the Gulf of Mexico and Atlantic coasts for the NRC. The surge model used in the Vickery study was the NOAA standard storm surge model SLOSH (Sea, Lake and Overland Surges from Hurricanes). The USACE has an ongoing study for the Gulf of Mexico coast using the JPM method and ADCIRC (Advanced Circulation) storm surge model to refine the physics of the processes that contribute to storm surge (Resio and Westerink, 2008).

The Great Lakes and climate change remain challenges. Although the EST method is applicable to extratropical storms, more research will be required to update guidance for future NRC nuclear power plant sites located on the Great Lakes. Current guidance for extratropical storm surge is defined by the American National Standards Institute (ANSI) and ANS in ANSI/ANS-2.8-1992 (ANS, 1992). Similar to tropical cyclones, PMS estimates are determined by use of the probable maximum storm (PMS) parameters applied as input to a quasi-two-dimensional numerical storm surge model developed in the early 1970s. Site-specific flooding analyses from PMS is carried out by using qualified and benchmarked wave run models based on detailed flow channel cross sections and contours. In regard to climate change, since the statistics, and thus the risks of certain surge heights, depend on the storms, any change in storm intensities will lead to a change in storm surge heights. While mean sea level is expected to rise, storms may become in some regions more frequent and violent, while in others less so. This remains an area of intense scientific scrutiny. When any significant change becomes evident, the NRC has regulatory measures available to implement changes, if necessary for adequate protection of public health and safety.

Current Reviews for Coastal Sites

There are several coastal sites that are currently in review. Section 2.4.6 of the Final Safety Analysis Report (FSAR) for COL applications includes the description of PMT, historical tsunami record, source generator characteristics, tsunami analysis, tsunami water levels, hydrography and harbor or breakwater influences on tsunami, and effects on safety-related facilities. FSAR are produced by each licensee and submitted to the US NRC.

The NRC staff bases the PMT for the costal sites on the historical record of tsunamis and previously published tsunami assessments for the Gulf of Mexico or the Atlantic Ocean. Wave heights from offshore landslide sources were considered in the establishment of the PMT.

The NRC staff then establishes a maximum water level at the site of interest, by applying a runup amplification factor and taking into account 10% exceedance spring high tide and global sea-level rise within the next century. The staff determines whether the estimated PMT will not affect safety-related facilities at the proposed site or not based on the maximum on-site surge level. If affected, the staff proposes flood protection measures in FSAR Section 2.4.10. If the tsunami forces or erosion is of concern, the staff recommends sea walls or wave break structures. If the site flooding is of concern, then external flood protections\measures are necessary for plant safety.

Historical and/or Paleo Tsunami

The staff examines published information to determine the source characteristics for several different types of potential tsunamis sources: seismogenic, volcanogenic, and landslide generated. Both far-field seismogenic sources and near-field submarine and above ground landslide sources as potential generators for the PMT are considered. After reviewing published and internet-based tsunami catalogs, databases, and historical accounts, the staff identifies historical tsunami events for the site of interest.

The application should address any evidence of paleo-tsunami deposits in the FSAR. For example for South Texas site in the USA, a deposit located in Falls County, Texas near the Brazos River was originally interpreted as caused by a paleo-tsunami. The common interpretation of this deposit is that it was emplaced by a tsunami generated from Chicxulub asteroid impact, owing to its date and the existence of impact ejecta at the Brazos site. Researchers suggested that a tsunami wave 50-100 m high was necessary to explain this deposit. It appears that the wave that created these deposits was not likely to be generated by any landslide source that would be of relevance to the present-day PMT determination. Waves emanating from such a source would not have the needed extreme wave heights and long periods to be able to propagate significant wave energy far inland to a potential NPP site. The common interpretation of this deposit is that it was emplaced by a tsunami generated by the Chicxulub impact. It is unlikely, however, that the wave heights inferred from the deposit are relevant to determination of the present-day PMT at a proposed site.

Potential Tsunamigenic Sources

Potential tsunami sources that are likely to determine the PMT at the U.S. costal sites are submarine landslides, subaerial landslides, volcanogenic sources, near-field intra-plate earthquakes and inter-plate earthquakes. These sources are identified as following:. .

> *Subaerial Landslides:* With regard to subaerial landslides, the staff looks for major coastal cliffs near the site that would produce tsunami-like waves that exceed the amplitude of those generated by other sources.
>
> *Volcanogenic Sources:* The staff relies on the databases developed by either USGS, NOAA, or other government agencies (e.g. the Global Volcanism Program of the Smithsonian Institution, from*http://www.volcano.si.edu/*). Catastrophic failures associated with volcanoes along the U.S. Coasts are considered as potential tsunami sources that generate significant wave activity near the sites of interests.
>
> *Intra-Plate Earthquakes*: The staff relies on the tectonic plate boundary maps in the Gulf of Mexico and Atlantic regions. Also looking are the maximum magnitude and slip of earthquakes. The staff reviews the maximum slip, and consequently the maximum sea floor displacement, associated with an earthquake scales with its magnitude to determine the initial tsunami wave amplitude associated with an intra-plate earthquake..
>
> *Inter-Plate Earthquakes*: In the far-field, description of major plate boundary faults, specific source parameters, and offshore tsunami amplitudes from oceanic inter-plate earthquakes are estimated.
>
> *Local Submarine Landslides*: Submarine landslides in the U.S. Coasts are considered a potential tsunami hazard for the reactor sites for two reasons: (1)

some dated landslides in the region have post-glacial ages, suggesting that triggering conditions for these landslides are still present and (2) analysis of recent seismicity suggest the presence of small-scale energetic landslides in the region.

The primary landslide parameters that are used in the tsunami wave generation models include the excavation depth, volume and slide width, which can be directly measured from sea floor mapping of the largest observed slide in the four geologic provinces. The other necessary parameter is down slope landslide length, interpreted from the runout distance. The runout distance measured from sea floor mapping is a combination of fast plug flow (low viscosity, non-turbulent), creeping plug flow (high viscosity/viscoplastic, non-turbulent) and turbidity currents (turbulent boundary layer fluid). The latter two likely have little to no tsunami-generating potential. The amplitude of the initial negative wave above the excavation region is linked to the maximum excavation depth. The amplitude of the initial positive wave above the deposition region is determined from a conservation of landslide volume. The excavation volume can be well determined using GIS techniques (see below). Setting the deposition volume equal to the excavation volume, the positive amplitude is determined for a given landslide length. For a fixed volume, increasing the landslide length decreases the initial positive amplitude of the tsunami.

Landslide volume calculations are based on measuring the volume of material excavated from the landslide source area using a technique similar to that of ten Brink and others (2006) and Chaytor and others (2009). Briefly stated, the approach involves using multibeam bathymetry to outline the extent of the excavation area, interpolating a smooth surface through the polygons that define the edges of the slide to provide an estimate of the pre-slide slope surface, and subtracting this surface from the present seafloor surface.

The maximum observed landslide from multibeam surveys is taken as the maximum landslide for a given region. It may be possible that larger landslides could occur in a given region; however this determination of the maximum landslide is consistent with the overall definition of PMT as "the most severe of the natural phenomena that have been historically reported or determined from geological and physical data for the site and surrounding area". In this case, the maximum landslide is taken from geologic observations spanning tens of thousands of years.

Seismic Seiches

Rather than being impulsively generated by displacement of the sea floor, seismic seiches occur from resonance of seismic surface waves within enclosed or semi-enclosed bodies of water. The harmonic periods of the oscillation are dependent on the dimensions and geometry of the body of water. For instance in 1964, seiches were set up along the Gulf Coast from seismic surface waves emanating from the M=9.2 Gulf of Alaska earthquake, owing in part to amplification of seismic waves from the thick sedimentary section along the Gulf Coast. Because the propagation path from Alaska to the Gulf Coast is almost completely continental and because the magnitude of the 1964 earthquake is close to the maximum possible for that subduction zone, it is likely that the historical observations of 1964 seiche wave heights are the maximum possible and less than the PMT amplitudes from landslide sources.

Tsunami Propagation Modeling

Tsunami propagation, runup, and inundation have been computed using COULWAVE model which is a 2-dimentional non-linear wave model. At the beginning of the wave simulation, the staff used to make an initial simulation using a one-dimension wave model. The purpose of these initial simulations is to provide an upper limit of the tsunami wave height that could be generated by different landslide scenarios.

Source parameters for the simulation include landslide width, length, and excavation depth. Although landslide volume is not a direct parameter used in the model, the volumes of excavation and deposition are conserved and are used in determining the amplitude of the initial positive wave. Note that these limiting simulations use physical assumptions that are arguably unreasonable; the results of these simulations are useful to filter out tsunami sources under even the most conservative assumptions. Specifically, these assumptions are:

1. Time scale of submarine landslide motion is very small (i.e., instantaneous) compared the period of the generated tsunami
2. Bottom roughness, and the associated energy dissipation, is negligible in locations that are initially wet (i.e. locations with negative bottom elevation, offshore)

With Assumption 1, the free water surface response matches the change in the seafloor profile exactly. The landslide time evolution parameter, which is associated with a high degree of uncertainty, is thus removed. Assumption 2 prevents the use of an overly high bottom roughness coefficient, which could artificially reduce the tsunami energy reaching the shoreline. Such an assumption is too physically unrealistic to accept for the inland regions where the roughness height may be the same order as the flow depth. For tsunami inundation, particularly for inland regions such as those currently under review, the wave would need to inundate long reaches of densely vegetated land to reach the site; therefore inclusion of a conservative measure of bottom roughness is necessary in these cases.

Tsunami and Hurricane surge induced wave run-up modeling is important, since these can cause site flooding that can lead to erosion induced failure of levee/embankment etc that may be used as safety significant water control structures at the site.

References

10 CFR Part 50, Appendix A, General Design Criterion 2, “Design Bases for Protection Against Natural Phenomena.”

10 CFR Part 50, Appendix A, General Design Criterion 44, “Cooling Water.”

10 CFR Part 52, “Early Site Permits; Standard Design Certifications; and Combined Licenses for Nuclear Power Plants.”

10 CFR Part 100, “Reactor Site Criteria.”

ANSI/ANS-2.8-1992 (ANS, 1992), “Determining Design Basis Flooding at Power Reactor Sites.”

Kammerer A., Ten Brink, U., Titov, V. (2008) “Overview of the U.S. Nuclear Regulatory Commission Collaborative Research Program to Assess Tsunami Hazard for Nuclear Power Plants on the Atlantic and Gulf Coasts.” Proceedings of the 14th World Conference on Earthquake Engineering, Beijing China, October 2008

Kammerer A., ten Brink, U., Twichell, D., Geist, E., Chaytor, J., Locat, J., Lee, H., Buczkowski, B., and Sansoucy, M. (2008) “Preliminary Results of the U.S. N.R.C. Collaborative Research Program to Assess Tsunami Hazard for Nuclear Power Plants on the Atlantic and Gulf Coasts.” Proceedings of the 14th World Conference on Earthquake Engineering, Beijing China, October 2008

NOAA Technical Memorandum OAR PMEL-136, by Gonzalez, F.I., Bernard, E., Dunbar, P., Geist, E., Jaffe, B., Kanoglu, U., Locat, J., Mofjeld, H., Moore, A., Synolakis, C., and Titov, V., (2007), “Scientific and Technical Issues in Tsunami Hazard Assessment of Nuclear Power Plant Sites,” Pacific Marine Environmental Laboratory, National Oceanic and Atmospheric Administration, Seattle, Washington.

NOAA Technical Report NWS 23 (1979), “Meteorological Criteria for Standard Project Hurricane and Probable Maximum Hurricane Windfields, Gulf and East Coasts of the United States.” NOAA National Weather Service.

Resio, D. T. and J.J. Westerink, (2008)“Modeling the Physics of Storm Surges”, Physics Today, September, 2008.

US NRC NUREG 0800, (2007), “Standard Review Plan (SRP),”

US NRC NUREG-CR 6966, (2009), “Tsunami Hazard Assessment at Nuclear Power Plant Sites in the Untied States of America”

US NRC Regulatory Guide (RG) 1.59, “Design Basis Floods for Nuclear Power Plants,” USGS Administrative Report by ten Brink, U.S., Twichell, D., Geist, E.L., Chaytor, J., Locat, J., Lee, H., Buczkowski, B., Barkan, R., Solow, A.R., Andrews, B.D., Parsons, T., 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", 302 p.

Vickery, P.J., Skerlj, P.F., Steckly, A.C., and Twisdale L.A., (2000) "Hurricane Wind field Modeling for Use in Hurricane Simulations", Journal of Structural Engineering, October, 2000.

Marine Geology Special Issue: Tsunami Hazard Along the U.S. Atlantic Coast

Twichell, D.C, Chaytor, J., ten Brink, U.S., and Buczkowski, B., (2009), "Morphology of late Quaternary Submarine Landslides along the U.S. Atlantic Continental Margin." Marine Geology Special Issue: Tsunami Hazard Along the U.S. Atlantic Coast, Volume 264, Issues 1-2, P4-15.

Chaytor, J.D., ten Brink, U.S., Solow, A.R., and Andrews, B.D., (2009), "Size distribution of submarine landslides along the U.S. Atlantic Margin: Marine Geology," Marine Geology Special Issue: Tsunami Hazard Along the U.S. Atlantic Coast, Volume 264, Issues 1-2, P19-16-27.

Locat, J., Lee, H., ten Brink, U., Twichell, D., and Geist, E. (2009) "Geomorphology, Stability and Mobility of the Currituck Slide." Marine Geology Special Issue: Tsunami Hazard Along the U.S. Atlantic Coast, Volume 264, Issues 1-2, P28-40.

Geist, E., Lynett, P., and Chaytor, J. (2009), "Hydrodynamic Modeling of Tsunamis from the Currituck Landslide." Marine Geology Special Issue: Tsunami Hazard Along the U.S. Atlantic Coast, Volume 264, Issues 1-2, P41-52.

Lee, H. (2009), "Timing of Occurrence of Large Submarine Landslides On The Atlantic Ocean Margin." Marine Geology Special Issue: Tsunami Hazard Along the U.S. Atlantic Coast, Volume 264, Issues 1-2, Page 53-64.

ten Brink, U., Lee, H., Geist, E., and Twichell, D. (2009), "Assessment of tsunami hazard to the U.S. East Coast using relationships between submarine landslides and earthquakes." Marine Geology Special Issue: Tsunami Hazard Along the U.S. Atlantic Coast, Volume 264, Issues 1-2, P65-73.

Geist, E., and Parsons, T. (2009), "Assessment of Source Probabilities for Potential Tsunamis Affecting the U.S. Atlantic Coast." Marine Geology Special Issue: Tsunami Hazard Along the U.S. Atlantic Coast, Volume 264, Issues 1-2, P98-108.

Barkana, R., ten Brink, U., and Lin, J. (2009), "Far field tsunami simulations of the 1755 Lisbon earthquake: Implications for tsunami hazard to the U.S. East Coast and the Caribbean." Marine Geology Special Issue: Tsunami Hazard Along the U.S. Atlantic Coast, Volume 264, Issues 1-2, P109-122.