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Attached is the draft Tsunami/Surge ISG for discussion at the next public meeting.

Ed Miller
x-2481

U.S.NRC
UNITED STATES NUCLEAR REGULATORY COMMISSION
Protecting People and the Environment

JAPAN LESSONS-LEARNED PROJECT DIRECTORATE

JLD-ISG-2012-06

Guidance for Performing a Tsunami, Surge, or Seiche Hazard Assessment

DRAFT Interim Staff Guidance

(Draft for use at public meeting on October 16, 2012)

Date ML#

JAPAN LESSONS-LEARNED PROJECT DIRECTORATE

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INTERIM STAFF GUIDANCE
JAPAN LESSONS-LEARNED PROJECT DIRECTORATE
GUIDANCE FOR PERFORMING A TSUNAMI, SURGE, OR SEICHE HAZARD ASSESSMENT
JLD-ISG-12-06

PURPOSE

This interim staff guidance is being issued to describe to stakeholders methods acceptable to the staff of the U.S. Nuclear Regulatory Commission (NRC) for performing tsunami, surge, or seiche hazard assessments in response to NRC's March 12, 2012 request for information (Ref. (1)) issued pursuant to "Title 10, Code of Federal Regulations, Part 50, Section 54 (10 CFR 50.54)" regarding Recommendation 2.1 of the enclosure to SECY-11-0093, "Recommendations for Enhancing Reactor Safety in the 21st Century, the Near-Term Task Force Review of Insights from the Fukushima Dai-ichi Accident" (Ref. (2)). This ISG will assist operating power reactor respondents and holders of construction permits under 10 CFR Part 50 with performance of hazard assessments for tsunami, surge, or seiche. It should be noted that the guidance provided in this ISG is not intended to describe methods for use in regulatory activities beyond the scope of the March 12, 2012, 50.54(f) letter.

BACKGROUND

Following the events at the Fukushima Dai-ichi nuclear power plant, the NRC established a senior-level agency task force referred to as the Near-Term Task Force (NTTF). The NTTF conducted a systematic and methodical review of the NRC regulations and processes and determined if the agency should make additional improvements to these programs in light of the events at Fukushima Dai-ichi. As a result of this review, the NTTF developed a comprehensive set of recommendations, documented in the enclosure to SECY-11-0093 (Ref. (2)). These recommendations were enhanced by the NRC staff following interactions with stakeholders. Documentation of the NRC staff's efforts is contained in SECY-11-0124, "Recommended Actions to Be Taken without Delay from the Near-Term Task Force Report," dated September 9, 2011 (Ref.(3)), and SECY-11-0137, "Prioritization of Recommended Actions To Be Taken in Response to Fukushima Lessons Learned," dated October 3, 2011(Ref. (4)).

As directed by the staff requirements memorandum for the enclosure to SECY-11-0093 (Ref. (2)), the NRC staff reviewed the NTTF recommendations within the context of the NRC's existing regulatory framework and considered the various regulatory vehicles available to the NRC to implement the recommendations. SECY-11-0124 and SECY-11-0137 established the staff's prioritization of the recommendations based upon the potential safety enhancements.

As part of the staff requirements memorandum for SECY-11-0124, dated October 18, 2011 (Ref.(3)), the Commission approved the staff's proposed actions, including the development of three information requests under 10 CFR 50.54(f). The information collected would be used to support the NRC staff's evaluation of whether further regulatory action should be pursued in the areas of seismic and flooding design, and emergency preparedness.

In addition to Commission direction, the Consolidated Appropriations Act, Public Law 112-074, was signed into law on December 23, 2011. Section 402 of the law requires a reevaluation of licensees' design basis for external hazards.

In response to the aforementioned Commission and Congressional direction, the NRC issued a request for information to all power reactor licensees and holders of construction permits under 10 CFR Part 50 on March 12, 2012 (Ref.(1)). The March 12, 2012 50.54(f) letter includes a request that respondents reevaluate flooding hazards at nuclear power plant sites using updated flooding hazard information and present-day regulatory guidance and methodologies. The NRC staff will review the responses to this request for information and determine whether regulatory actions are necessary to provide additional protection against flooding.

RATIONALE

On March 12, 2012, NRC issued a request for information to all power reactor licensees and holders of construction permits under 10 CFR Part 50. The request was issued in accordance with the provisions of Sections 161.c, 103.b, and 182.a of the Atomic Energy Act of 1954, as amended (the Act), and NRC regulation in Title 10 of the *Code of Federal Regulations*, Part 50, Paragraph 50.54(f). Pursuant to these provisions of the Act or this regulation, respondents were required to provide information to enable the staff to determine whether a nuclear plant license should be modified, suspended, or revoked.

This ISG describes an approach acceptable to the staff for performing tsunami, surge or seiche flooding hazard assessment.

APPLICABILITY

This ISG shall be implemented on the day following its approval. It shall remain in effect until it has been superseded or withdrawn.

PROPOSED GUIDANCE

This ISG is applicable to holders of operating power reactor licenses and construction permits under 10 CFR Part 50 from whom a flooding hazard reevaluation is requested. For combined license holders under 10 CFR Part 52, the issues in NTTF Recommendation 2.1 and 2.3 regarding seismic and flooding reevaluations and walkdowns are resolved and thus this ISG is not applicable.

IMPLEMENTATION

Except in those cases in which a licensee or construction permit holder under 10 CFR Part 50 proposes an acceptable alternative method for performing the tsunami, surge, or seiche assessment, the NRC staff will use the methods described in this ISG to evaluate the results of the reevaluation of flood hazards.

BACKFITTING DISCUSSION

Licensees and construction permit holders under 10 CFR Part 50 may use the guidance in this document to perform the tsunami, surge, or seiche hazard assessments. Accordingly, the NRC staff issuance of this ISG is not considered backfitting, as defined in 10 CFR 50.109(a)(1), nor is it deemed to be in conflict with any of the issue finality provisions in 10 CFR Part 52.

FINAL RESOLUTION

The contents of this ISG, or a portion thereof, may subsequently be incorporated into other guidance documents, as appropriate.

ENCLOSURE

1. Guidance for performance of surge or seiche hazard assessments
2. Guidance for performance of tsunami hazard assessments
3. Appendix: Glossary and acronyms

REFERENCES

1. U.S. Nuclear Regulatory Commission. Request for information pursuant to Title 10 of the Code of Federal Regulations 50.54(f) regarding Recommendations 2.1, 2.3, and 9.3, of the Near-Term Task Force Review of Insights from the Fukushima Dai-ichi Accident. March 12, 2012. ADAMS Accession No. ML12053A340.

2. —. "Recommendations for Enhancing Reactor Safety in the 21st Century, The Near-Term Task Force Review of Insights from the Fukushima Dai-ichi Accident," Enclosure to SECY-11-0093. July 12, 2011. ADAMS Accession No. ML111861807.

3. —. "Recommended Actions To Be Taken Without Delay From the Near Term Task Force Report," SECY-11-0124. September 9, 2011. ADAMS Accession No. ML11245A158.

4. —. "Prioritization of Recommended Actions to Be Taken in Response to Fukushima Lessons Learned," SECY-11-0137. October 2011. ADAMS Accession No. ML11272A111.

ENCLOSURE 1

GUIDANCE FOR PERFORMANING A SURGE OR SEICHE HAZARD ASSESSMENT

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ENCLOSURE 1

GUIDANCE FOR PERFORMING A SURGE OR SEICHE HAZARD ASSESSMENT

1. Introduction

The purpose of this interim staff guidance (ISG) is to provide the NRC staff with a technical basis for reviewing storm surge or seiche hazard assessments per the recent 50.54(f) letters issued to operating nuclear power plants and holders of construction permits in accordance with the provisions of Sections 161.c, 103.b, and 182.a of the Atomic Energy Act of 1954, as amended (the Act), and NRC regulation in Title 10 of the *Code of Federal Regulations*, Part 50, Paragraph 50.54(f).

All coastal nuclear power plant sites must consider the potential for flooding from hurricanes, windstorms and squall lines must consider storm surge, seiche, and windwaves as part of the hazard reevaluation.

1.1 Format of Guidance

Section 1.2 (Historical Perspective) discusses the evolution in surge and seiche regulatory guidance during the time period between the licensing of the operating plants and the licensing activities for new reactors. Section 2 (Acceptance Criteria) continues with a discussion of existing regulatory guidance (Section 2.1) and guidance updates (Section 2.2) based upon the ongoing new reactor safety reviews and current state of knowledge. Section 2 gives particular attention to terms and definitions as well as current good practices.

Section 3 (Surge Hazard Assessment) closely follows the format provided in Section 2.4.6 of Regulatory Guide 1.206 and NUREG-0800 (Standard Review Plan). Section 3.1 (Overview) describes the Hierarchical Hazard Assessment (HHA) approach and the role that deterministic and combined deterministic-probabilistic methods play in surge hazard assessments. Section 3.2 (Meteorological Parameters) describes deterministic and combined deterministic-probabilistic storm generating methods for input into numerical surge models, which are discussed in Section 3.3. In Section 3.3 (Surge Parameters), pre-surge modeling steps are discussed beginning with vertical datums (Section 3.3.1) followed by antecedent water levels (Section 3.3.2). Section 3.3.3 (Surge Water Levels) provides a discussion of two state-of-the-art surge models currently used by NRC and other federal agencies.

A discussion of seiche hazard assessment is provided in Section 4. This is followed by Section 5 (Wave and Inundation Effects for Surge and Seiche), which discusses post numerical modeling effects. Factors that must be considered in all surge and seiche hazard assessments include coincident wave heights, inundation, wave runup and drawdown, which are are described in Sections 5.1 through 5.4. Sections 5.5 through 5.7, discuss factors that must be considered for “wet” sites including hydrostatic/hydrodynamic forces, debris and water-borne projectiles, and effects of sediment erosion and deposition. References are provided in Section 7.

1.2 Historical Perspective

In 1959, the U.S. Army Corps of Engineers (USACE) contracted the National Weather Service (NWS) to develop a hypothetical hurricane that could be used to design hurricane protection projects along the Gulf and Atlantic coasts of the United States. At that time the NWS, as part of its National Hurricane Research Project, set out to define “the most severe storm that is considered reasonably characteristic of a region." A storm with such characteristics was termed the "Standard Project Hurricane" (SPH). This effort is described in U.S. Weather Bureau Report No. 33 (Graham and Nunn, 1959).

NWS Technical Report 23 (Schwerdt et al*.,* 1979) redefined the SPH as "a steady state hurricane having a severe combination of values of meteorological parameters that will give high sustained wind speeds reasonably characteristic of a given region," removing the idea from the definition of the SPH that the SPH pertained to the "most severe storm" for a particular area. The concept of a "Probable Maximum Hurricane" (PMH) was also introduced as "a hypothetical steady-state hurricane having a combination of values of meteorological parameters that will give the highest sustained wind speed that can probably occur at a specified coastal location." The PMH was intended to be an event much rarer than the SPH; but no objective definition was offered in NWS 23. In 2007, the evaluation of the PMH characteristics was superseded by the adoption of the Probable Maximum Storm Surge (PMSS) hazard assessment.

Historically, design-basis surge and seiche hazard flood estimates for nuclear power plants (NPPs) have been developed using deterministic analysis approaches based on the "probable maximum" or "maximum credible" event concept (i.e., the event thought to have "virtually no risk of exceedance"). The level of analysis may range from very conservative based on simplifying assumptions, to detailed analytical estimates of each facet of the flood-causing mechanism being studied.

In response to Hurricane Katrina in 2005, NRC formed a storm surge research program focused on developing modern hazard, risk informed, assessment techniques and additional guidance through cooperation with the National Oceanic and Atmospheric Administration (NOAA) and United States Army Corps of Engineers (USACE). This research program produced several technical reports. NOAA, Department of Energy (DOE) laboratories, USACE and commercial contractors are currently assisting with NRC Office of New Reactors (NRO) reviews of storm surge hazards as well as updates of regulatory guidance.

In 2009, the USACE Engineer Research and Development Center/Coastal and Hydraulics Laboratory (ERDC CHL) was tasked by the Nuclear Regulatory Commission's Office of Nuclear Regulatory Research (RES) to review the NOAA Technical Report NWS 23 ("Meteorological Criteria for Standard Project Hurricane (SPH) and Probable Maximum Hurricane (PMH) Wind fields, Gulf and East Coasts of the United States") and the NRC Regulatory Guide 1.59 ("Design Basis Floods for Nuclear Power Plants"). ERDC CHL found that several assumptions in the PMH described in NWS 23 are not consistent with the current state of knowledge and recommended that the PMH concept be updated in accordance with new theoretical concepts and data (USACE, 2009).

The 2009 ERDC CHL report also states that the ocean model recommended in Regulatory Guide 1.59 (1977) 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" (Resio et al., 2012 and USACE, 2009). The review findings recommended that a modern coupled system of wind, wave, and coastal circulation models be adopted that properly define the physical system and include an appropriate non-linear coupling of the relevant processes.

2. Acceptance Criteria

2.1 Existing Regulatory Guidance

The applicable regulatory requirements for identifying surge and seiche hazards are as follows:

- *10 CFR Part 50*, "Licensing of Production and Utilization Facilities." General Design Criterion 2 (GDC2), "Design Bases for Protection Against Natural Phenomena," of Appendix A, requires that structures, systems, and components important to safety be designed to withstand the effects of natural phenomena such as floods, tsunami and seiches without loss of capability to perform their safety functions. Criterion 2 also requires that design bases for these structures, systems, and components reflect (1) appropriate consideration of the most severe of the natural phenomena that have been historically reported for the site ad surrounding region with sufficient margin for the limited accuracy and quantity of the historical data and the period of time in which the data have been accumulated, (2) appropriate combinations of the effects of normal and accident conditions with the effects of the natural phenomena, and (3) the importance of the safety functions to be performed.

- *10 CFR Part 100*, "Reactor Site Criteria," requires that physical characteristics of the site, including seismology, meteorology, geology, and hydrology, be taken into account in determining the acceptability of a site for a nuclear power reactor.

Other NRC guidance documents such as NUREGs and Regulatory Guides describe methods that the NRC staff considers acceptable for use in implementing specific parts of the agency's regulations, to explain techniques that the staff uses in evaluating specific problems or postulated accidents, and to provide guidance to applicants and licensees. Compliance with recommendations contained in them is not mandated. Thus, in addition to the applicable regulatory requirements, the NRC staff uses appropriate sections of the following guidance documents for the identified acceptance criteria:

- *NUREG-0800*, "Standard Review Plan for the Review of Safety Analysis Reports for Nuclear Power Plants (LWR Edition)" provides guidance to NRC staff in performing safety reviews under 10 CFR Part 50 and 10 CFR Part 52. Section 2.4.5 provides general guidance for estimating flooding due to storm surge and seiche.

- *NUREG/CR-7046*, "Design Basis Flood Estimation for Site Characterization at Nuclear Power Plants in the United States of America," November 2011 provides present-day methodologies and technologies that can used to estimate design-basis floods at nuclear power plants for a range of flooding mechanisms. Section 3.5, 3.6, Appendix E and Appendix F provides additional guidance and an illustrative case study for a probable maximum storm surge analysis (Prasad et al., 2011).

- *Regulatory Guide 1.59*, "Design Basis Floods for Nuclear Power Plants," Revision 2, August 1977 as supplemented by best current practices (NRC, 1977).

- *Regulatory Guide 1.27*, "Ultimate Heat Sink for Nuclear Power Plants," Revision 2 (NRC, 1976a).

- *Regulatory Guide 1.102*, “Flood Protection for Nuclear Power Plants,” Revision 1 (NRC, 1976b) provides guidance for the protection of nuclear power plants from flooding.

- *Regulatory Guide 1.206*, “Combined License Applications for Nuclear Power Plants.” Section C.I.2.4.5 provides general guidance for estimating flooding due to storm surge and seiche (NRC, 2007).

- *ANSI/ANS-2.8-1992*, “American National Standard for Determining Design Basis Flooding at Nuclear Reactor Sites.” Provides methodology for estimating storm surges and seiches at estuaries and coastal areas on oceans and large lakes. Appendix C gives a simplified method of estimating surges on the Atlantic and gulf coasts (ANS, 1992). Throughout this ISG, this standard is referred to as ANSI/ANS-2.8-1992.

- JLD-ISG-2012-05, provides guidance for performing the Integrated Assessment for flooding, when necessary (NRC, 2012b).

2.2 Updates to Guidance

In the 2007 update of the Standard Review Plan (SRP), the evaluation of the PMH characteristics was superseded by the adoption of the Probable Maximum Storm Surge (PMSS). The PMH was also clarified in the 2007 update to the SRP. The SRP relates the PMSS and the PMH when it states that the “PMSS is the surge that results from a combination of meteorological parameters of a probable maximum hurricane (PMH)…and has virtually no probability of being exceeded in the region involved.” To avoid confusion with strictly probabilistic flood hazard assessments, the “probable maximum” terminology referenced in NUREG-0800, Regulatory Guide 1.59, Regulatory Guide 1.206 and ANSI/ANS-2.8-1992 is not used. Instead the terms “*simulated*” and “*design basis*” are used in this guide and defined in the Appendix (“Glossary and Acronyms”). The following terms are also defined in the Appendix:

- Design Basis Flood (DBF)
- Simulated Hurricane (SH)
- Simulated Wind Storm (SWS)
- Simulated Storm Surge (SSS)
- Design Basis Storm Surge (DBSS)

In current practice for storm surge, other federal agencies such as the U.S. Army Corps of Engineers (USACE), National Oceanic and Atmospheric Administration (NOAA) and Federal Emergency Management Agency (FEMA) *no longer use* the “probable maximum” or “standard project” terminology. However, existing NRC guidance continues to use these terms.

The NUREG-0800, Revision 3 (March 2007) recommends that the DBSS induced by the PMH should be estimated as recommended by Regulatory Guide 1.59 and supplemented by current best practices. However, the determination of the storm surge from bathystrophic models (Bretschneider, 1966; Bodine, 1969; Pararas-Carayannis, 1975) used in Regulatory Guide 1.59, which is based on earlier windfield calculations, is not consistent with the current state of knowledge. Therefore, the DBSS estimates from Regulatory Guide 1.59 are not considered further in this ISG.[1] The current practice in storm-surge modeling is based on the use of coupled hydrodynamic ocean circulation and wave models, both driven by a planetary boundary layer (PBL) model that provides the atmospheric forcing (Figure 1). Storm surge models should be validated using historical information and data in the region of interest.

For seiche, analytical methods can be used for screening. However, if seiche cannot be eliminated from further consideration using analytical methods, numerical modeling will be required. Seiche models should be validated using historical information and data in the region of interest.

3. Surge Hazard Assessment

All coastal nuclear power plant sites and nuclear power plant sites located adjacent to cooling ponds or reservoirs subject to potential hurricanes, windstorms and squall lines must consider the potential for inundation from storm surge and windwaves. For example, a hurricane, extra-tropical storm or squall line could cause a water level change in an adjacent body of water. The resulting high water levels, if not considered in the project design, could impact safety-related structures located at the plant site. The NRC Website (NRC, 2012) provides COL and ESP safety analysis reports and NRC requests for information (RAIs) addressing the evaluations of surge, and windwaves associated with recent new reactor reviews.

All water wave processes, including surge, consist of generation, propagation and dissipation. Section 3 of this ISG (Surge Hazard Assessment) describes the HHA approach and the role that deterministic and combined deterministic-probabilistic methods play in surge hazard assessments. Section 3.2 (Meteorological Parameters) provides three surge generation approaches. For hurricanes, Section 3.2.1 (Hurricane Parameters) discuses a deterministic approach in Section 3.2.1.1 (Probable Maximum Hurricane) and a combined deterministic-probabilistic approach in Section 3.2.1.2 (Joint Probability Method). Similarly for extra-tropical storms and squalls lines (Section 3.2.2), Section 3.2.2.1 (ANSI/ANS-2.8-1992) and Section 3.2.2.2 (Empirical Simulation Technique) provide deterministic and combined deterministic-probabilistic surge generation approaches, respectively.

Section 3.3 (Surge Parameters) addresses the propagation of surge phase beginning with a discussion of datums (Section 3.3.1). Starting a surge hazard assessment with bathymetric and topographic data using appropriate vertical datums is essential to correctly reference water levels with site elevations. For additional margin, Section 3.3.2 (Antecedent Water Levels) provides guidance on the determination of pre-surge model propagation stillwater levels using astronomical tides (Section 3.3.2.1), initial rise (Section 3.3.2.2) and sea level rise (Section 3.3.2.3). Section 3 ends with the surge propagation phase described in

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[1] Appendix C of Regulatory Guide 1.59 presents a timesaving methods for estimating the maximum stillwater level of the PMS from hurricanes at open coast sites on the Atlantic Ocean and Gulf of Mexico. The Bodine model (Bodine, 1971) was used by the NRC to develop default storm surge estimates at the open coast in support of Regulatory Guide 1.59 and is cited as an acceptable methodology for such analyses by ANSI/ANS-2.8-1992. However, the windfield calculations in Regulatory Guide 1.59 are based on an interim and unpublished 1959 report that has been superseded by NWS 23 (Schwerdt et al., 1979).

Section 3.3.3 (Surge Water Levels). Section 3.3.3.1 (ADCIRC) and Section 3.3.3.2 (SLOSH) provide a discussion of two state-of-the-art surge models currently used by NRC and other federal agencies.

3.1 Overview

Site hazard assessments follow a progressive screening approach, consisting of a series of progressively refined methods that increasingly use more detailed site specific data to demonstrate whether the site is protected from the adverse effects of severe floods. This approach (Figure 2) has been formalized in the HHA approach described in NUREG/CR-7046 (Prasad et al., 2011). The HHA methodology provides a roadmap for applying a hierarchy of conceptual and mathematical models for the efficient determination of design-basis flood mechanisms and levels.

Deterministic methods are intended to produce a single result. Such a method implies: (1) that the precise set of forcing conditions that can create the maximum surge at a given location is known and (2) that there was no uncertainty in either the predictive models utilized or the limiting estimates of the inputs to the predictive model. However, because neither of these conditions exists, it is recognized that deterministic methods may not represent the actual maximum condition (or a very-low-probability event) expected at a given location (Resio et al., 2012).

On the other hand, the use of probabilistic methods facilitates estimation of a range of storm surge values and their associated probabilities rather than focusing on a single, large event that is construed to represent an upper bound. In general, probabilistic methods consider a range of events along with the probabilities of those events (e.g. a relationship between surge levels and return period). The current state-of-the-art methodology for developing design criteria for storm surge events involves the simulation and selection of a stochastic set of storm tracks, 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 (Phan et al., 2007 and Resio et al., 2007).

The USACE has developed a combined probabilistic-deterministic methodology for storm surge hazard assessment that can be combined with the HHA to provide a DBSS with risk information. The methodology utilizes an integrative, interdisciplinary approach that incorporates state-of-the-art knowledge in hurricane science, hydrology, and probabilistic methods. This methodology involves the following steps:

(1) selection of a stochastic set of simulated storm tracks affecting the region of interest,

(2) hydrodynamic simulation of the region of interest using a high resolution surge model and the simulated storm tracks to generate time histories of wind speeds and corresponding time histories of storm surge heights at sites within the affected region, and

(3) use of wind speed and storm surge height data generated in Steps (1) and (2) to develop probabilistic information on the joint probability of wind speed/storm surge height events (Resio et al., 2012).

Regardless of whether a deterministic, probabilistic, or combined deterministic-probabilistic method is used, an assessment of sensitivities and uncertainties should be provided for model parameters that may have significant influence on design-basis flood estimates.

3.2 Meteorological Parameters

Storm surge can result from several different types of storms (e.g., tropical cyclones, extra-tropical cyclones, squall lines, and hybrid storms). For example, extra-tropical cyclones, also known as Northeasters, move along the Atlantic coast with winds from the northeast onto the shoreline, typically producing winds ranging from 30 to 40 mph (48 to 64 km/h) with gusts that can exceed 74 mph (119 km/h). Although below hurricane force, these winds can persist for several days to a week and hence generate large waves and storm surges. In comparison, hurricanes are more severe in terms of wind speed and storm surge elevations, their shoreline effects tend to be more localized, and they are generally confined to stretches of coastline of about 65 mi (105 km) or less.

For the storm surge hazard assessments, each storm type appropriate for the region should be examined to determine estimates for extreme winds. This detailed analysis of historical storm events in the region should be augmented by synthetic storms parameterized to account for conditions more severe than those in the historical record, but considered to be reasonably possible on the basis of meteorological reasoning.

Four techniques are considered in this guidance for synthetic storm generation:

- Probable Maximum Hurricane (PMH)
- Joint Probability Method (JPM)
- ANSI/ANS-2.8-1992
- Empirical Simulation Technique (EST)

The first two methods (PMH and JPM) are used for generation of synthetic hurricanes. The next two methods (ANSI/ANS-2.8-1992 and EST) are used to generation of synthetic extra-tropical storms and squall lines.

3.2.1 Hurricane Parameters

This section applies to all coastal sites, excluding the Great Lakes, as described in ANSI/ANS-2.8-1992.

3.2.1.1 Probable Maximum Hurricane (PMH)

The NOAA NWS Technical Report 23 (Schwerdt et al., 1979) was a joint USACE, NOAA and NRC project, which describes the PMH method in detail. PMH meteorological parameters, as described in NUREG-0800 Section 2.4.5, define the physical attributes of the PMH to derive wind fields that can serve as input into an atmospheric model. Storm surge model simulations are performed with numerous combinations of PMH parameters to obtain the highest design basis storm surge (DBSS) at the site.

NOAA NWS Technical Report 23 (NWS 23) provides methods for estimating PMH wind fields. The study that was the basis for this report was funded jointly by NRC and USACE. The PMH is defined as a hypothetical steady-state hurricane having a combination of values of meteorological parameters that will give the highest sustained wind speed that can probably occur at a specified coastal location (NOAA, 1979). The term steady state is meant to indicate that there is no change in the value of hurricane wind-field parameters during at least the last several hours before the PMH makes landfall. The meteorological parameters that define the PMH wind field include the hurricane peripheral pressure, central pressure, radius of maximum winds, forward speed, and track direction. Note that the NWS 23 method provides no risk information (e.g., return period) and is only applicable to the deterministic storm surge analysis of hurricanes.

The PMH parameter values in NWS 23 were based on data from historical hurricanes from 1851 to 1977 and were presented for multiple locations along the Gulf of Mexico and Atlantic Ocean coastlines corresponding to their milepost distances from the U.S.-Mexico border. Comparisons of hurricane climatology during the period evaluated in NWS 23 with hurricanes making landfall after 1975 indicate that the NWS 23 parameters for the PMH are still applicable (NOAA, 2007; Ho et al., 1987; Knutson et al., 2010). However, consistent with NUREG-0800 Section 2.3, a detailed site/region specific hurricane climatology study should be provided to show that the PMH parameters are consistent with the current state of knowledge.

Safety evaluation reviews of applications for new reactor COL and ESP indicate that surge elevation increases with increasing hurricane size. In addition, based on site specific topography/bathymetry, the increase in storm surge with increasing hurricane size may reach an upper bound. Thus, this behavior should be further investigated by varying the PMH size (radius of maximum wind) beyond the upper bound specified in NWS 23 for a PMH approaching the site (Irish et al., 2008a, Resio and Westerink, 2008). ANSI/ANS-2.8-1992, Section 7 provides additional guidance on the critical combinations of PMH parameters.

Appendix E of NUREG/CR-7046 contains an example of how the PMH wind field is estimated using the NWS 23 procedure. For the application of the NWS 23 method to new reactors, the NRC Website (NRC, 2012) provides COL and ESP safety analysis reports and NRC RAIs.

3.2.1.2 Joint Probability Method (JPM)

The JPM (Myers, 1970) approach quantifies the return periods of storm surges. Statistical simulation methods such as JPM are required for coastal flood frequency analysis primarily because of the unavailability of sufficient historical record from which to derive frequencies by more conventional means, such as gage analysis. Hurricanes, for example, are both sporadic and of limited spatial extent, contributing to a great deal of sample variation (sample error) in local tide gage records. For this reason, JPM is widely used in coastal flood studies performed by the USACE and FEMA. For example, the JPM was adopted by federal agencies for critical post-Katrina determinations of hurricane surge frequencies.

The JPM has been used for simulating hurricanes since the late 1960's. The original JPM application, while not called JPM, was developed by Larry Russell (Russell, 1968), for predicting wave loads on offshore structures in the Gulf of Mexico. The JPM approach used by Russell was a full Monte Carlo simulation where model hurricanes were simulated using straight-line segments with wind and wave fields computed using hurricane wind and wave models. The methodology was first introduced because the number of historical events (hurricanes) at any one location is insufficient to enable standard statistical techniques (such as extreme value analyses) to estimate flood risk, wave height risk, wind speed risk, etc. The JPM method can be used as an alternative to PMH for deterministic storm surge analysis or used as an option in a combined deterministic-probabilistic analysis for risk information.

The JPM approach is a simulation methodology that relies on the development of statistical distributions of key hurricane input variables (central pressure, radius of maximum winds, translation speed, and heading) and sampling from these distributions to develop model hurricanes. The simulation results in a family of modeled storms that preserve the relationships between the various input model components, but provides a means to model the effects and probabilities of storms that have not yet occurred. The method known as JPM-OS (Joint Probability Method - Optimum Sampling) can also be used, which reduces the number of required JPM simulated storms (Toro et al., 2010).

For coastal risk assessment, the introduction of long duration tracks that mimic the behavior of hurricanes while they are offshore (and generating a wave field) was first introduced by Resio et al., (2007). Modeling the full storm track from a wind only point of view was introduced by Vickery et al. (2000a). The simulation methodologies employed by Resio et al. (2007), and Vickery et al. (2000b) both attempt to properly model the correlations between storm intensity (central pressure) and radius to maximum winds (RMW). Vickery et al. (2000a) also modeled a relationship between RMW and the Holland B (Holland, 1980) parameter. Overall, the JPM approach has the conceptual advantage of considering all possible storms consistent with the local climatology, each weighted by its appropriate rate of occurrence. Unlike the NWS 23 method, the key model hurricane parameters are developed through an analysis of continuously updated local climatology derived from NOAA's historical hurricane database (HURDAT; Landsea et al., 1996, Landsea et al., 2004, Blake et al., 2007, Blake and Gibney, 2011, and NOAA, 2012b). All possible parameter combinations (each defining a synthetic storm) should be simulated using a surge model constructed to accurately represent the bathymetry, topography, and ground cover of the site.

For examples of detailed discussions and guidance on the application of the JPM to coastal issues see Ferro (2007), Niedorodu et al. (2010), Phan et al. (2007), Resio et al. (2007; 2012), Schmalz (1983), Scheffner et al. (1996) and Toro (2007). A comparison of JPM and EST methods is also provided by Divoky and Resio (2007).

The JPM method was also used by NRC and the American Society of Civil Engineers (ASCE) for design-basis hurricane wind speeds for nuclear power plants (Vickery et al., 2011; NRC, 2011) and minimum design loads for buildings and other structures (ASCE, 2010), respectively.

3.2.2 Extra-tropical Storms and Squall Lines Parameters

A detailed site/regional specific meteorological study consistent with SRP Section 2.3 should be conducted to identify applicable mechanisms. This applies to all coastal sites, including the Great Lakes, to verify that the ANSI/ANS-2.8-1992 assumptions reflect the most severe meteorological parameters.

3.2.2.1 ANSI/ANS-2.8-1992

The ANSI/ANS-2.8-1992 standards provide detailed guidance on extra-tropical windstorms (Section 7.2 of ANSI/ANS-2.8-1992) and squall lines (Section 7.3 of ANSI/ANS-2.8-1992). For the Great Lakes, a set of fixed criteria of extra-tropical storm parameters is provided in lieu of a meteorological study (Sections 7.2.2.3.1 and 7.2.2.3.3 of ANSI/ANS-2.8-1992). In addition, Section 7.2.3.1 of ANSI/ANS-2.8-1992 states that “[a] moving squall line should be considered for the locations along Lake Michigan where significant surges have been observed because of such a meteorological event. The possible region of occurrence includes others of the Great Lakes.”

3.2.2.2 Empirical Simulation Technique (EST)

The EST (Scheffner et al., 1999) quantifies the return periods of storm surges. Statistical simulation methods such as EST are required for coastal flood frequency analysis primarily because there is an insufficient historical record from which frequencies could be derived by more conventional means, such as gage analysis. For this reason, EST is widely used in coastal flood studies performed by the USACE and FEMA.

The EST method can be used as an option in a combined deterministic-probabilistic methodology. However, unlike tropical storms, extra-tropical storms are not easily represented by a set of storm parameters. Thus, the EST frequency analysis is recommended to determine storm surge stillwater return periods for extra-tropical storms.

EST estimates for a site are based entirely on the historical storms and flood levels observed at that site. Alternate life cycles are simulated by assuming that storm occurrence follows a Poisson process and by implementing a bootstrap resampling from the set of observed events to construct synthetic records. Flood frequency and variability estimates are then derived from this synthetic data. The only assumption is that future events will be statistically similar in magnitude and frequency to past events. The method begins with an analysis of historical events that have impacted a specific location. The selected database of events is then parameterized to define the characteristics of the event and the impacts of that event. Parameters that define the storm are referred to as input vectors. Response vectors define storm-related impacts such as surge elevation, inundation, shoreline/dune erosion, etc. These input and response vectors are then used as a basis for generating life-cycle simulations of storm-event activity with corresponding impacts.

For detailed discussions and guidance on the application of the EST method to coastal issues see, for example, Scheffner et al. (1996), Scheffner et al. (1999), Wilbury et al. (2007), Zimmer (2008), RENCI (2011), and FEMA (2011; 2012). An EST model for the generation of storm profiles (USACE, 2012b) is included in the USACE Coastal Engineering Design and Analysis System (CEDAS). A comparison of JPM and EST methods is provided by Divoky and Resio (2007).

3.3 Surge Parameters

This section provides guidance on propagation of the surge phase and includes a discussion of datums and antecedent water levels (astronomical tides, initial rise, and sea level rise). In addition, this section provides guidance on determination of surge water levels.

3.3.1 Datums

Datums are of two types: tidal and fixed. For example, mean sea level pertains to the local mean sea level (MSL), which is a tidal datum as it is based on astronomical tides. A tidal datum is determined over a 19-year National Tidal Datum Epoch. North American Vertical Datum of 1988 (NAVD88) and National Geodetic Vertical Datum of 1929 (NGVD29) are fixed geodetic datums whose elevation relationships to local MSL and other tidal datums may not be consistent from one location to another. NAVD88 replaced NGVD29 as the national standard geodetic reference for heights. With the exception of the Great Lakes that use regional datums, elevations should be documented as NAVD88. Benchmark elevations relative to NAVD88 are available from the National Geodetic Survey (NGS) website.

3.3.2 Antecedent Water Levels

Regulatory Guide 1.59 (NRC, 1977) and ANSI/ANS-2.8-1992 state that the 10 percent exceedance high spring tide including initial rise should be used to represent the DBSS antecedent water level. For example, antecedent water level be the sum of the stillwater depth, 10 percent exceedance high tide, initial rise and long term sea level rise. Due to non-linear wave effects, the antecedent water level should be applied as the initial storm surge model still water level. Post modeling storm surge water level additions such as wind waves and wave runup are addressed in Section 5.

3.3.2.1 Astronomical Tides

Regulatory Guide 1.59 and ANSI/ANS-2.8-1992 define the 10 percent exceedance high spring tide as the high tide level that is equaled or exceeded by 10 percent of the maximum monthly tides over a continuous 21-year period. NOAA maintains tide gage stations along the United States shoreline. Historical, current and predicted tide data can be found on the NOAA Tides and Currents website (NOAA, 2012a).

3.3.2.2 Initial Rise

For locations where the 10 percent exceedance high spring tide is estimated from observed tide data, Regulatory Guide 1.59 and ANSI/ANS-2.8-1992 indicate that a separate estimate of the initial rise is not necessary. This approach for estimating 10 percent exceedance high tide, based on recorded tides, intrinsically includes the effects of initial rise.

3.3.2.3 Sea Level Rise

Relative sea-level rise is the combined effect of water level change and land subsidence. It is monitored and reported by the NOAA National Ocean Service, the U.S. Global Change Research Program, and the Intergovernmental Panel on Climate Change (IPCC) and should be included in design-basis flood analysis for coastal sites (IPCC, 2007).

NOAA maintains tide gage stations along the United States shoreline (NOAA, 2012a) and has evaluated the trend of sea level rise. Measurements at any given tide station include both global sea level rise and vertical land motion, such as subsidence, glacial rebound, or large-scale tectonic motion. Thus, the long term sea level rise should be derived for the expected life of the nuclear power plant based upon the trend in site/regional tide gage station data. As part of the HHA process, regional/global sea level rise trends can be added in initial storm surge simulations to the site/regional observed trend for additional margin.

3.3.3 Surge Water Levels

This section provides guidance on methods for computation of surge water levels. In particular, the following models are described:

- ADCIRC

- SLOSH

3.3.3.1 ADCIRC (ADvanced CIRCulation) Surge Model

The ADCIRC model was developed at the USACE Dredging Research Program as a family of two- and three-dimensional finite element-based models (Luettich, Westerink, and Scheffner 1992; Westerink et al., 2008). An important feature of the model is that it can simulate tidal circulation and storm-surge propagation over very large computational domains while simultaneously providing high resolution in areas of complex shoreline configuration and bathymetry.

The USACE hurricane modeling system used for the safety evaluation of new reactor COL applications (Resio, 2012) combined various wind models (TC96 PBL), the WAM offshore and STWAVE nearshore wave models, and the ADCIRC basin to channel scale unstructured grid circulation model (Figure 1).

For detailed discussions and guidance on the application of ADCIRC to coastal issues see, for example, Dean et al. (2004), Luettich and Westerink (2004), Coastal Protection and Restoration Authority of Louisiana, (2007), IPET (2007), Toro (2007), Blandon and Vickery, (2008), Westerink et al. (2008), Resio et al. (2007; 2012). For the application of the ADCIRC model to new reactors using the JPM-OS method, see Resio (2012).

3.3.3.2 SLOSH (Sea, Lake, Overland Surge from Hurricanes)

The SLOSH (Sea, Lake, Overland Surge from Hurricanes) computer model was developed to forecast real-time hurricane storm surge levels on continental shelves, across inland bodies of water and along coastlines, including inland routing of water levels. SLOSH is a depth-averaged two-dimensional finite difference model on curvilinear polar, elliptical, or hyperbolic grid schemes. Modification of storm surges due to the overtopping of barriers (including levees, dunes, and spoil banks), the flow through channels and floodplains, and barrier cuts/breaches are included in the model. The effects of local bathymetry and hydrography are also included in the SLOSH simulation.

An atmospheric model for tropical cyclones is contained within SLOSH. Thus, the NOAA SLOSH model only requires the hurricane pressure difference, hurricane track description including landfall location, forward speed, and size, given as the radius of maximum wind, as input to define the physical attributes of a hurricane in performing a storm surge simulation (Jelesnianski, 1992). NOAA provides two models; (1) SLOSH Display Program, and (2) SLOSH v3.95 FORTRAN code. The SLOSH Display Program was designed for the use of trained Emergency Managers, FEMA personnel, and NWS forecasters to assist emergency planners with evacuations, display the latest NHC real-time runs and help educate decision makers. In addition, the SLOSH Display Program is only valid for Category 1 through Category 5 hurricanes. The SLOSH v3.95 FORTRAN code was provided to the NRC and nuclear power industry/contractors for storm surge hazard assessments using the NWS 23 PMH method for new reactor applications. Details of SLOSH model formulation and application can be found in Jelesnianski (1992), NOAA (2006, 2009) and Glahn et al. (2009).

SLOSH model predictions have been validated against observed hurricane surge levels at several locations (Jelesnianski, 1992; Jarvinen, 1985). For example, as an emergency management tool, SLOSH has been applied to the entire U. S. East Coast, Gulf of Mexico coastlines, Hawaii, Guam, Puerto Rico, and the U. S. Virgin Islands. The errors of the

SLOSH model predictions, defined by subtracting the observed surge water levels from model predictions, were evaluated for ten storms in eight SLOSH model basins, 90 percent of which were in the Gulf of Mexico. Based on a comparison of the SLOSH simulated surge heights against observations, NOAA concludes that the model results generally stayed within ± 20% for significant surges (Jarvinen, 1985).

SLOSH does not include astronomical tides, wave runup or additional heights generated by wind-driven/breaking waves on top of the stillwater storm surge. In addition, the SLOSH v3.95 FORTRAN code provided by NWS contains a limitation wherein grid cells with elevations greater than 10.7 m (35 ft) NAVD88 were removed from the flooding computation (i.e., these cells could never be flooded). It was confirmed from NWS that the 10.7 m (35 ft) limit for surge in the SLOSH program is historical and does not pose any particular problems when it is relaxed. The SLOSH program code should be validated with and without the changes in the code to determine that the changes in the code are effective and accurate in allowing flooding at elevations greater than 10.7 m (35 ft). One method is to compare the same hurricane scenario for each code by validation against historical storm surge data.

NOAA has developed the Extra-Tropical Storm Surge Model (ET-Surge; NOAA, 2012d) that can use a separate planetary boundary wind model in conjunction with a modified SLOSH model to predict storm surge based on large extra-tropical storms as opposed to the tropical storms that SLOSH was originally developed for (Kim et al., 1996).

Appendix E of NUREG/CR-7046 contains an example of how the DBSS is estimated using SLOSH and the NWS 23 procedure. For the application of the SLOSH model to new reactors, the NRC Website (NRC, 2012a) provides COL and ESP safety analysis reports and NRC RAIs.

4. Seiche Hazard Assessment

Seiche is a wave that oscillates in lakes, bays or gulfs from a few minutes to a few hours as a result of seismic or atmospheric disturbances. The oscillatory modes for the body of water in question should be calculated from a variety of potential sources. Sources to consider include: (1) local or regional forcing phenomena such as barometric pressure fluctuations, strong winds, rapid changes in wind direction, and surge associated with passage of local storms; and (2) distant but large forcing mechanisms such as distant storms, tsunami, or earthquake-generated seismic waves. For bodies of water with simple geometries, modes of oscillation can be predicted from the shape of the basin using analytical formulas. For example, the resonance within a makeup water reservoir may be approximated by a rectangular basin(s) using an approach provided in the USACE Coastal Engineering Manual (CEM) (USACE, 2008; Dean and Dalrymple, 1991).

Most natural bodies of water have variable bathymetry and irregular shorelines and may be driven by a combination of forcing. For such bodies, seiche periods and water surface profiles should be determined through numerical long-wave modeling. The USACE SMS or CEDAS modeling systems, as well as well documented models such as the Princeton Ocean Model, should be used for complex seiche analyses. Appendix F of NUREG/CR-7046 (Prasad et al., 2011) provides a case study for seiche flooding using analytical formulas.

5. Wave and Inundation Effects Associated with Surge or Seiche

This section deals with the wave dissipation phase where surge and seiche wave action can directly impact the site. Wave action includes deep and shallow water wave generation. Wind-generated wave activity that can occur independently of or coincidentally with storm surge or seiche should be included in surge and seiche flood hazard analyses. Available records should be used to characterize the wave climate near the site using measures such as significant and maximum wave heights. Tides, wave setup, wave runup, splash, or overtopping, as appropriate, should also be considered in the analyses and included in surge and seiche flooding estimates.

Section 5.1 (Coincident Wave Heights) provides guidance on the calculation of wind waves that can occur coincidentally with the storm surge or seiche stillwater level. Inundation (Section 5.2) then looks at the horizontal distance that surge/seiche propagates inland before dissipation (wave breaking). If the inundation reaches the site, other factors such as wave runup (Section 5.3), drawdown (Section 5.4), hydrostatic/hydrodynamic forces (Section 5.5), debris and water-borne projectiles (Section 5.6) and the effects of sediment erosion and deposition (Section 5.7) must be considered, as appropriate.

5.1 Coincident Wave Heights

ANSI/ANS-2.8-1992 recommends using the USACE Shore Protection Manual (SPM) (USACE, 1984) for analyzing wave action. However, the SPM has been superseded by the USACE CEM (USACE, 2008). The CEM recommends that, except for areas with very simple bathymetry, a numerical model should be used for nearshore wave studies.

Currently, the SLOSH model does not include the additional heights generated by wind-driven waves on top of the stillwater storm surge. Therefore, wind-driven wave height needs to be determined using the procedure described in the USACE CEM (USACE, 2008), ANSI/ANS-2.8-1992 and Regulatory Guide 1.102 (NRC, 1976b).

The current practice in storm-surge modeling is the use of coupled hydrodynamic ocean circulation and wave models, both driven by a planetary boundary layer (PBL) model that provides the atmospheric forcing (Figure 1). Per USACE CEM guidance, off-coast wave activity is determined using either the WAM (WAve prediction Model) or WAVEWATCHIII models. For nearshore and surf zone wave processes, SWAN (Simulating Waves Nearshore) or STWAVE (STeady State spectral WAVE) provide the wave conditions. For detailed discussions and guidance on the application of these models, see Smith et al. (2001), Smith and Sherlock (2007) and USACE (2012).

5.2 Inundation

Inundation is the distance that a storm surge penetrates onto the shore, measured horizontally from the mean sea level position of the water's edge. It is usually measured as the maximum distance for a particular segment of the coast. Inundation effects should be evaluated and are typically available from standard surge models.

5.3 Wave Runup

Wave runup can be calculated using the lesser of the maximum wave height (1.67 x the significant wave height) or the maximum breaker height, in accordance with ANSI/ANS-2.8-

1992 and the USACE CEM (USACE, 2008). Wave run-up models can also be used in addition to the calculation of overtopping rates when waves encounter a shoreline or embankment. The required inputs include wave type, breaking criteria, wave height, wave period, structure slope, structure height, slope type, material used (e.g., rip-rap, rubble, tetrapods) and roughness coefficient. In calculating overtopping rates, the relative heights of the embankment to the still-water level are important. For state-of-the-art solutions to wave runup, the USACE Automated Coastal Engineering System (ACES) is available from the CEDAS interface (USACE, 2012b).

5.4 Drawdown (Low Water Level)

Drawdown is an issue when safety related structures/equipment (e.g., UHS intakes) depend on water sources that have the potential to be impacted by storm surge or seiche (NRC, 1976a).

Numerical models such as ADCIRC and SLOSH provide a visual/quantitative estimation of low water level conditions. Thus, storm surge/seiche model flooding elevation data should be retained and used for a detailed analysis of low flow conditions. For an example of a drawdown analysis on a safety related structure (UHS intake), the NRC Website (NRC, 2012a) provides COL and ESP safety analysis reports and NRC RAIs.

5.5 Hydrostatic and Hydrodynamic Forces

The determination of the hydrostatic and hydrodynamic forces is required when storm surge/seiche flood levels impinge on flood protection or safety-related SSCs. Thus, storm surge/seiche model current velocity, wave and wind data should be retained and used for a detailed analysis of hydrostatic and hydrodynamic forces.

For coastal structures, the USACE CEM provides guidance on hydrostatic and hydrodynamic forces (USACE, 2008). For an example of a hydrostatic and hydrodynamic force analysis, the NRC Website (NRC, 2012a) provides COL and ESP safety analysis reports and NRC RAIs.

5.6 Debris and Water-Borne Projectiles

The determination of the effect from debris and water-borne projectiles must be considered when storm surge/seiche flood levels impinge on flood protection or safety-related SSCs. Thus, storm surge/seiche model current velocity, wave and wind data should be retained and used for a detailed analysis of debris and water-borne projectiles.

5.7 Effects of Sediment Erosion or Deposition

The determination of the impact of sediment erosion and deposition must be considered when storm surge/seiche flood levels impinge on flood protection, safety-related SSCs and foundation materials. Thus, storm surge/seiche model current velocity, wave and wind data should be retained and used for a detailed analysis of the effects of sediment erosion and deposition.

For coastal structures, the USACE CEM provides guidance on the impacts of sediment erosion and deposition (USACE, 2008). For an example of an analysis of the effects of sediment erosion and deposition, the NRC Website (NRC, 2012a) provides COL and ESP safety analysis reports and NRC RAIs.

6. Figures

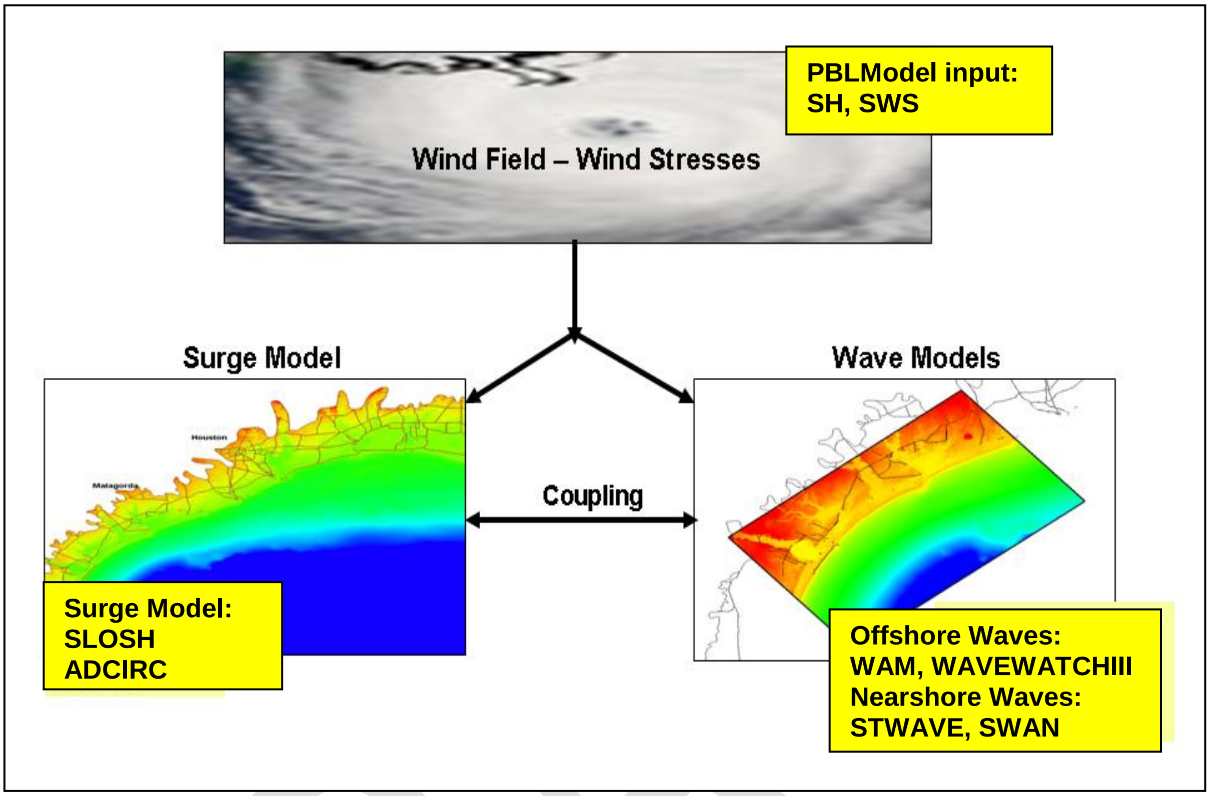

Figure 1: Storm surge modeling system (Resio et al., 2012)

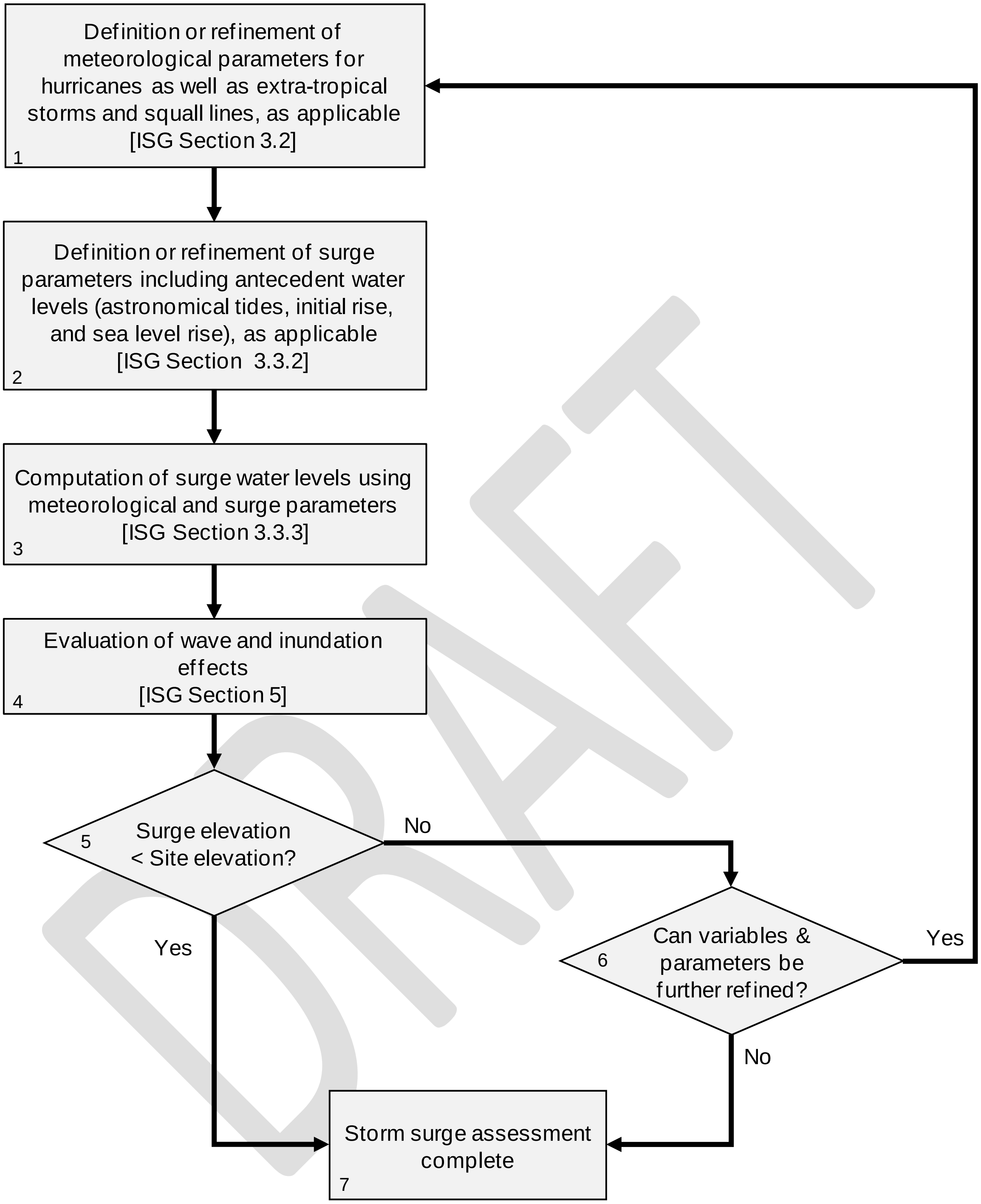

Figure 2: Storm Surge Hierarchical Hazard Assessment

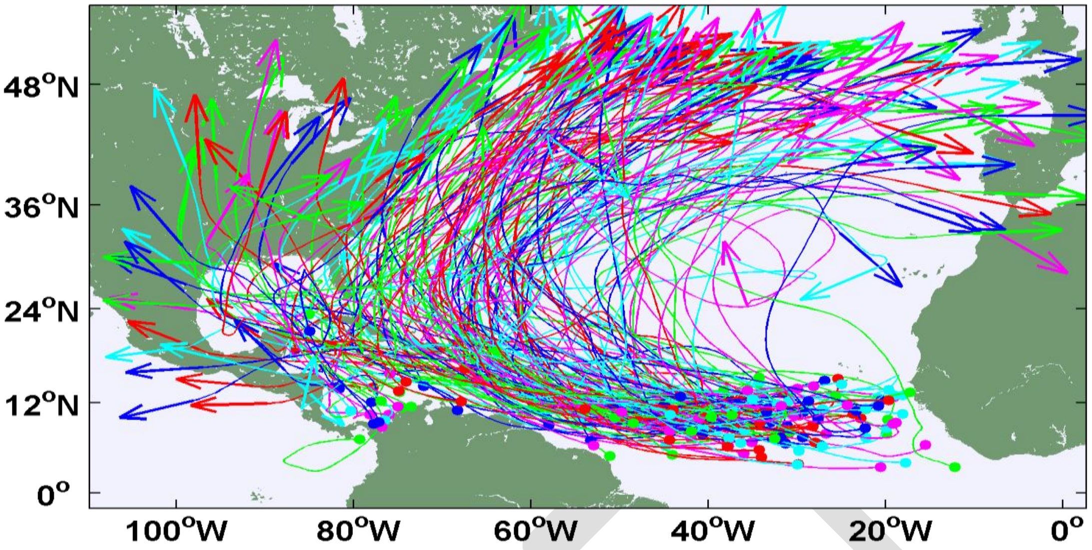

Figure 3: Illustration of 200 Synthetic storm tracks (Emanuel, 2012)

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ENCLOSURE 2

GUIDANCE FOR PERFORMING A TSUNAMI HAZARD SAFETY ANALYSIS

TABLE OF CONTENTS

ENCLOSURE 2

GUIDANCE FOR PERFORMING A TSUNAMI HAZARD SAFETY ANALYSIS

1. Introduction

The purpose of this interim staff guidance is to provide the NRC staff with a technical basis for reviewing tsunami hazard site characteristics per the recent 50.54(f) letters issued to operating nuclear power plants in accordance with the provisions of Sections 161.c, 103.b, and 182.a of the Atomic Energy Act of 1954, as amended (the Act), and NRC regulation in Title 10 of the *Code of Federal Regulations*, Part 50, Paragraph 50.54(f)..

1.1 Format of Guidance

Section 1.2 (Historical Perspective) discusses the evolution in tsunami regulatory guidance during the time between the licensing of the operating plants and the licensing activities for new reactors. Section 2 (Acceptance Criteria) continues with a discussion of the existing regulatory guidance (Section 2.1) and guidance updates (Section 2.2) based upon the ongoing new reactor safety reviews and current state of knowledge. Particular attention is given here to tsunami term definitions and current best practices.

Section 3.1 (Overview) describes the Hierarchical Hazard Assessment (HHA) approach and the role that deterministic and combined deterministic-probabilistic methods play in tsunami hazard assessments. The tsunami source generation is discussed in Section 3.2 (Historical Tsunami Data) and Section 3.3 (Source Generator Characteristics). Section 3.4 discusses tsunami model initial conditions. Section 3.5 (Tsunami Propagation Models) describes the state-of-the-art tsunami models currently used by NRC, industry and other federal agencies.

Section 4 (Wave and Inundation Effects of Tsunami) deals with tsunami wave dissipation and where tsunami wave action can directly impact the site. Wave action includes deep and shallow water wave generation. Tides, wave setup, wave runup, splash, or overtopping, as appropriate, should be considered in the analyses and included in tsunami flooding estimates. Inundation (Section 4.1) looks at the horizontal distance that tsunami wave propagates inland before dissipation (wave breaking). If the inundation reaches the site, wave runup (Section 4.2), drawdown (Section 4.3), hydrostatic/hydrodynamic forces (Section 4.4), debris and water-borne projectiles (Section 4.5) and the effects of sediment erosion and deposition (Section 4.6) must be considered. References are provided in Section 5.

1.2 Historical Perspective

In response to the 2004 Indian Ocean tsunami, the NRC coordinated a tsunami safety study in 2005 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 (PNNL) and the Pacific Marine and Environmental Laboratory (PMEL) which is a part of NOAA. This early effort resulted in the publication of two documents. They were NUREG-CR 6966 (Prasad, 2008), 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.

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 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 publications and made important contributions to tsunami modeling approach and standards, as summarized in conference papers by Kammerer (2008).

The NRC research program includes assessment of both seismic- and landslide-based tsunamigenic sources in both the near and 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, a compendium of eight papers were 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.

In the current phase of NRC research, additional field investigations are being conducted in key locations of interest and additional analysis of the data is being undertaken. The Method of Splitting Tsunami (MOST) generation and propagation model used by NOAA was enhanced to include landslide-based initiation mechanisms and is being used to investigate the impact of the tsunamigenic sources as identified and characterized by the USGS. The potential for probabilistic tsunami hazard assessment will also be explored in the final phases of the NRC research program. The state-of-the art tsunami hazard assessment methods currently established by the USGS, which are being used for new reactor applications, are described in this guidance.

2. Acceptance Criteria

2.1 Regulatory Guidance

The applicable regulatory requirements for identifying tsunami hazards are as follows:

- _10 CFR Part 50_, "Licensing of Production and Utilization Facilities." General Design Criterion 2 (GDC2), "Design Bases for Protection Against Natural Phenomena," of Appendix A, requires that structures, systems, and components important to safety be designed to withstand the effects of natural phenomena such as floods, tsunami and seiches without loss of capability to perform their safety functions. Criterion 2 also requires that design bases for these structures, systems, and components reflect (1) appropriate consideration of the most severe of the natural phenomena that have been historically reported for the site ad surrounding region with sufficient margin for the limited accuracy and quantity of the historical data and the period of time in which the data have been accumulated, (2) appropriate combinations of the effects of normal and accident conditions with the effects of the natural phenomena, and (3) the importance of the safety functions to be performed.

- *10 CFR Part 100*, “Reactor Site Criteria,” requires that physical characteristics of the site, including seismology, meteorology, geology, and hydrology, be taken into account in determining the acceptability of a site for a nuclear power reactor.

Other NRC guidance documents, such as NUREGs and Regulatory Guides (RGs) describe methods that the NRC staff consider acceptable for use in implementing specific parts of the agency’s regulations, to explain techniques that the staff uses in evaluating specific problems or postulated accidents, and to provide guidance to applicants and licensees. Compliance with recommendations contained in them is not mandated. Thus, in addition to the applicable regulatory requirements, the staff used appropriate sections of the following guidance documents for the identified acceptance criteria:

The NRC staff uses appropriate sections of the following regulatory guides for the identified acceptance criteria:

- *NUREG-0800*, “Standard Review Plan for the Review of Safety Analysis Reports for Nuclear Power Plants (LWR Edition)” provides guidance to NRC staff in performing safety reviews under 10 CFR Part 50 and 10 CFR Part 52. Section 2.4.5 provides general guidance for estimating flooding due to tsunami hazards.

- *NUREG/CR-6966*, “Tsunami Hazard Assessment at Nuclear Power Plant Sites in the United States of America”, provides present-day methodologies and technologies that can used to estimate design-basis floods at nuclear power plants for tsunami hazards (Prasad, 2009).

- *Regulatory Guide 1.27*, “Ultimate Heat Sink for Nuclear Power Plants, Revision 2” (NRC, 1976a)

- *Regulatory Guide 1.206*, “Combined License Applications for Nuclear Power Plants,” 2007**.** Section C.I.2.4.5 provides general guidance for estimating flooding due to tsunami hazards (NRC, 2007)

- *Regulatory Guide 1.102*, “Flood Protection for Nuclear Power Plants,” Revision 1 (NRC, 1976b) provides guidance for the protection of nuclear power plants from flooding.

- JLD-ISG-2012-05, provides guidance for performing the Integrated Assessment for flooding, when necessary (NRC, 2012b).

2.2 Updates to Guidance

Section 2.4.6 of NUREG – 75/087 (1975) provided guidance on tsunami hazard safety reviews. However, this guidance included few details or quantitative techniques. To fill this information gap, NRC funded a study of tsunami hazard on the Pacific, Atlantic, and Gulf coasts of the United States which was published as NUREG/CR-1106 (Brandsma et al., 1979). However, NUREG/CR-1106 only addresses distant seismic generated tsunami and does not consider the effects of locally generated tsunami (e.g., submarine landslides).

Regulatory Guide 1.59 (1977) briefly mentions tsunami as a source of flooding but does not provide guidance on tsunami hazards. ANSI/ANS-2.8-1992 “*Determining Design Basis Flooding at Power Reactor Sites*” (this standard will be referred to as ANSI/ANS-2.8-1992 throughout this ISG) and NUREG/CR-7046 (Prasad et al., 2011) provide no guidance on tsunami hazards. However, both documents are currently used for guidance on determining the antecedent water levels and coincident wave activity for tsunami, storm surge and seiche.

NOAA Technical Memorandum OAR PMEL-135 (“Standards, Criteria, and Procedures for NOAA Evaluation of Tsunami numerical Models”) and NOAA Technical Memorandum OAR PMEL-136 (“Scientific and Technical Issues in Tsunami Hazard Assessment of Nuclear Power Plant Sites”) were produced in response to the 2004 Indian Ocean tsunami. These documents form the basis of the 2007 tsunami-related updates to NUREG-0800. Additional publications addressing tsunami hazards include NUREG/CR-6966 (Prasad, 2008), and the work of ten Brink et al. (2008).

For consistency with other federal agencies and to avoid confusion with probabilistic flood hazard methodology, the “probable maximum” referenced in NUREG-0800 is replaced in this guidance with “simulated” and “design basis.” The Glossary (Appendix) provides the definitions of Design Basis Flood (DBF), Simulated Tsunami (ST) and Design Basis Tsunami (DBT).

3. Tsunami Hazard Assessment

All coastal nuclear power plant sites (including sites located adjacent to oceans, seas, lakes, rivers, and other inland bodies of water) must consider tsunami. For example, a tsunami could cause a water level change in an adjacent body of water. The resulting high water levels, if not considered in the project design, could impact safety-related structures located at the plant site. If eliminated from consideration, detailed hydrological and geological reasoning should be provided and should be consistent with Sections 2.4 and 2.5 of the Standard Review Plan. The NRC Website (NRC, 2012) provides Combined License (COL) and Early Site Permit (ESP) safety analysis reports and NRC requests for information (RAIs) addressing the evaluations of tsunami.

All water wave processes, including tsunami, consist of generation, propagation and dissipation. Section 3.1 (Overview) describes the Hierarchical Hazard Assessment (HHA) approach and the role that deterministic and combined deterministic-probabilistic methods plays in tsunami hazard assessments. The tsunami source generation phase is discussed in Section 3.2 (Historical Tsunami Data) and Section 3.3 (Source Generator Characteristics).

Section 3.4 discusses tsunami model initial conditions, beginning with guidance on vertical datums (Section 3.4.1). Starting a tsunami hazard assessment with bathymetric and topographic data using appropriate vertical datums is essential to correctly reference water levels with site elevations. For additional margin, Section 3.4.2 (Antecedent Water Levels) provides guidance on the determination of pre-tsunami model propagation stillwater levels using astronomical tides (Section 3.4.2.1), initial rise (Section 3.4.2.2) and sea level rise (Section 3.4.2.3). Section 3.5 (Tsunami Propagation Models) ends the tsunami propagation phase with descriptions the state-of-the-art tsunami models currently used by NRC, industry and other federal agencies.

3.1 Overview

All coastal nuclear power plant sites and nuclear power plant sites containing, or adjacent to, large reservoirs (including man-made lakes) subject to potential landslides, submarine landslides and earthquakes must consider tsunami hazards. Design Basis Flood (DBF) estimation for power plant sites in tsunami hazard zones should consider the effects of tsunami or tsunami-like waves, including runup, flooding, erosion, debris loads and rundown or return flow of water. The absence of tsunami events in the site/regional historical record and/or upriver location from a coast is not sufficient to eliminate the requirement for a detailed tsunami hazard assessment.

If a regional or site specific screening, as described in NUREG/CR-6966 (Prasad, 2008), determines a site is subject to tsunami hazards, a detailed assessment should be undertaken to ensure that the plant design bases account for these hazards adequately. This step should include postulation of DBT source mechanisms, estimation of DBT source characteristics, initiation of the DBT wave, propagation of the DBT wave from the source toward the site, and estimation of tsunami hazards at the site. A detailed description of the controlling tsunami generator (e.g., location, dimensions, orientation, and maximum displacement) should be provided. In addition, a detailed description of the analysis procedure and models used to estimate tsunami wave height and period at the site, as well as the development of input parameters should be included.

For tsunami hazard safety evaluations, NRC applies a deterministic screening approach consisting of a series of progressively refined methods that increasingly use more detailed site specific data to demonstrate whether the site is protected from the adverse effects of severe floods. This approach has been formalized in the HHA approach described in NUREG/CR-7046 (Prasad et al., 2011) and NUREG/CR-6966 (Prasad, 2008).

On the other hand, the use of probabilistic methods facilitates estimation of a range of tsunami and their associated probabilities rather than focusing on a single, large tsunami that is construed to represent an upper bound. Probabilistic Tsunami Hazard Assessment (PTHA) combines the use of deterministic hydrodynamic ocean wave and source generation models and probabilistic methods. However, a widely accepted framework and toolset for PTHA is not available. NRC continues to sponsor research in this area with USGS and NOAA (Gonzalez et al., 2009; Geist and Parsons, 2006; ten Brink et al., 2009)

Regardless of which approach is adopted, an assessment of sensitivities and uncertainties that may have significant influence on DBT estimates should be provided in a tsunami hazard submittal.

3.2 Historical Tsunami Data

Reviews should be conducted of historical tsunami data, including NUREG-0800 mappings and interpretations, regional records, eyewitness reports, and recently available tide gauge and real-time bottom pressure gauge data (NUREG-0800 and RG 1.206). NUREG/CR-6966 (Prasad, 2008) provides further details and additional guidance. For examples of new reactor tsunami hazard safety assessments, the NRC Website (NRC, 2012a) provides COL and ESP Safety Analysis Reports and NRC RAIs.

3.3 Source Generator Characteristics

A regional or site specific survey and assessment of tsunamigenic sources should be performed to determine if a tsunami poses a hazard to the site. The survey and assessment should include all potential near-field and far-field sources and mechanisms that could generate tsunami. Nuclear power plant sites located near the ocean should consider hazards from oceanic tsunami. Inland sites should consider the possibility of tsunami-like waves generated in water bodies within the region (e.g., due to hill-slope failure or seismic sources). Any relevant paleo-tsunami evidence should also be assessed. NUREG/CR-6966 (Prasad, 2008) provides further details and additional guidance. The USGS technical report "Evaluation of Tsunami Sources with the Potential to Impact the U.S. Atlantic and Gulf Coasts" (ten Brink et al., 2008) also provides additional guidance. For examples of new reactor tsunami hazard safety assessments, the NRC Website (NRC, 2012a) provides COL and ESP safety analysis reports and NRC RAIs.

3.4 Tsunami Model Initial Conditions

3.4.1 Datums

Datums are of two types: tidal and fixed. For example, mean sea level pertains to the local mean sea level (MSL), which is a tidal datum as it is based on astronomical tides. A tidal datum is determined over a 19-year National Tidal Datum Epoch. North American Vertical Datum of 1988 (NAVD88) and National Geodetic Vertical Datum of 1929 (NGVD29) are fixed geodetic datums whose elevation relationships to local MSL and other tidal datums may not be consistent from one location to another. NAVD88 replaced NGVD29 as the national standard geodetic reference for heights. With the exception of the Great Lakes that use regional datums, elevations should be documented as NAVD88. Benchmark elevations relative to NAVD88 are available from the National Geodetic Survey website .

3.4.2 Antecedent Water Levels

Regulatory Guide 1.59 (NRC, 1977) and ANSI/ANS-2.8-1992 state that the 10 percent exceedance high spring tide including initial rise should be used to represent the DBT antecedent water level. For example, the antecedent water level is the sum of the DBT stillwater depth, 10 percent exceedance high tide, initial rise and long term sea level rise. Due to wave non-linear effects, the antecedent water level should be applied as the initial tsunami model stillwater level. Post modeling tsunami water level additions such as wind waves and wave runup are addressed in Section 4.

3.4.2.1 Astronomical Tides

Regulatory Guide 1.59 and ANSI/ANS-2.8-1992 define the 10 percent exceedance high spring tide as the high tide level that is equaled or exceeded by 10 percent of the maximum monthly tides over a continuous 21-year period. NOAA maintains tide gage stations along the United States shoreline. Historical, current and predicted tide data can be found on the NOAA Tides and Currents website (NOAA, 2012a).

3.4.2.2 Initial Rise

For locations where the 10 percent exceedance high spring tide is estimated from observed tide data, Regulatory Guide 1.59 and ANSI/ANS-2.8-1992 indicate that a separate estimate of the initial rise is not necessary. This approach for estimating 10 percent exceedance high tide, based on recorded tides, intrinsically includes the effects of initial rise.

3.4.2.3 Sea Level Rise

Relative sea-level rise is the combined effect of water level change and land subsidence. It is monitored and reported by the NOAA National Ocean Service, the U.S. Global Change Research Program, and the Intergovernmental Panel on Climate Change (IPCC) should be included in design-basis flood analysis for coastal sites (IPCC, 2007).

NOAA maintains tide gage stations along the United States shoreline (NOAA, 2012a) and has evaluated the trend of sea level rise. Measurements at any given tide station include both global sea level rise and vertical land motion, such as subsidence, glacial rebound, or large-scale tectonic motion. Thus, the long term sea level rise should be derived for the expected life of the nuclear power plant based upon the trend in site/regional tide gage station data. As part of the HHA process, regional/global sea level rise trends can be added in initial tsunami simulations to the site/regional observed trend for additional margin.

3.5 Tsunami Propagation Models

This section describes the tsunami propagation phase with a discussion of the state-of-the-art tsunami models currently used by NRC, industry and other federal agencies.

Several complex tsunami computational models are currently used in the national Tsunami Hazard Mitigation Program, sponsored by NOAA, to produce tsunami inundation and evacuation maps for Alaska, California, Hawaii, Oregon, and Washington. The computational models include MOST, developed originally by researchers at the University of Southern California (1998); COMCOT (Cornell Multi-grid Coupled Tsunami Model), developed at Cornell University (1995); and TSUNAMI2, developed at Tohoku University in Japan (1996). All three models solve the same depth-integrated and 2D horizontal (2HD) non-linear shallow-water equations with differing finite-difference algorithms. There are a number of additional tsunami computer models including the finite element model ADCIRC (ADvanced CIRCulation Model for Oceanic, Coastal and Estuarine Waters, 1994).

The shallow-water equation models have been shown to be reasonably accurate throughout the evolution of a tsunami, and are widely used. However, these models lack the capability to simulate dispersive waves, which could be the predominate features in landslide-generated tsunami, and for tsunami traveling a long distance. Several higher-order depth-integrated wave hydrodynamics models (Boussinesq models) are now available for simulating non-linear and weakly dispersive waves, such as COULWAVE (Cornell University Long and Intermediate Wave Modeling Package, 2002) and FUNWAVE (Fully Nonlinear Boussinesq Wave Model, 2000). The major difference between the two is their treatment of moving shoreline boundaries. During 2003, COULWAVE was applied to the 1998 Papua New Guinea tsunami with a landslide source; the results agreed reasonably well with field surveys and observed data. Recently, several finite element models also have been developed based on Boussinesq-type equations. NUREG/CR-6966 (Prasad, 2008) provides additional details and guidance.

The MOST, FUNWAVE and COULWAVE models have recently been used for tsunami hazard safety reviews in new reactor applications.

See NOAA Technical

Memorandum OAR PMEL-135 “Standards, Criteria, and Procedures for NOAA Evaluation of Tsunami Numerical Models” (Gonzalez et al., 2007) for additional guidance on validation, benchmarking and quality control. For examples of new reactor tsunami hazard safety assessments, the NRC Website (NRC, 2012a) provides COL and ESP safety analysis reports and NRC RAIs.

4. Wave and Inundation Effects for Tsunami

This section deals with the wave dissipation phase where tsunami wave action can directly impact the site. Wave action includes deep and shallow water wave generation. Tides, wave setup, wave runup, splash, or overtopping, as appropriate, should be considered in the analyses and included in tsunami flooding estimates.

Section 4.1 (Inundation) looks at the horizontal distance that tsunami wave propagates inland before dissipation (wave breaking). If the inundation reaches the site, other factors such as wave runup (Section 4.2), drawdown (Section 4.3), hydrostatic/hydrodynamic forces (Section 4.4), debris and water-borne projectiles (Section 4.5) and the effects of sediment erosion and deposition (Section 4.6) must be considered, as appropriate.

4.1 Inundation

Inundation is the distance that tsunami penetrates onto the shore, measured horizontally from the mean sea level position of the water's edge. It is usually measured as the maximum distance for a particular segment of the coast. Inundation effects should be evaluated and are typically available from standard tsunami models.

4.2 Wave Runup

Wave runup can be calculated using the lesser of the maximum wave height (1.67 x the significant wave height) or the maximum breaker height, in accordance with ANSI/ANS-2.8-1992 and the Coastal Engineering Manual (CEM; USACE, 2008). Wave run-up models can also be used in addition to the calculation of overtopping rates when waves encounter a shoreline or embankment. The required inputs include wave type, breaking criteria, wave height, wave period, structure slope, structure height, slope type, material used (e.g., rip-rap, rubble, tetrapods) and roughness coefficient. In calculating overtopping rates, the relative heights of the embankment to the still-water level are important. For state-of-the-art solutions to wave runup, the USACE Automated Coastal Engineering System is available from the Coastal Engineering Design and Analysis System interface (USACE, 2012b).

4.3 Drawdown (Low Water Level)

Drawdown is an issue when safety related structures/equipment (e.g., UHS intakes) depend on water sources that have the potential to be impacted by tsunami (NRC, 1976a).

Numerical models such as ADCIRC and Sea, Lake, Overland Surge from Hurricanes (SLOSH) provide a visual/quantitative estimation of low water level conditions. Thus, tsunami model flooding elevation data should be retained and used for a detailed analysis of low flow conditions. For an example of a drawdown analysis on a safety related structure (UHS intake), the NRC Website (NRC, 2012a) provides COL and ESP safety analysis reports and NRC RAIs.

4.4 Hydrostatic and Hydrodynamic Forces

The determination of the hydrostatic and hydrodynamic forces is required when tsunami flood levels impinge on flood protection or safety-related SSCs. Thus, tsunami model current velocity, wave and wind data should be retained and used for a detailed analysis of hydrostatic and hydrodynamic forces.

For coastal structures, the USACE CEM provides guidance on hydrostatic and hydrodynamic forces (USACE, 2008). For an example of a hydrostatic and hydrodynamic force analysis, the NRC Website (NRC, 2012a) provides COL and ESP safety analysis reports and NRC RAIs.

4.5 Debris and water-Borne Projectiles

The determination of the effect from debris and water-borne projectiles must be considered when tsunami flood levels impinge on flood protection or safety-related SSCs. Thus, tsunami model current velocity, wave and wind data should be retained and used for a detailed analysis of debris and water-borne projectiles.

4.6 Effect of Sediment Erosion and Deposition

The determination of the impact of sediment erosion and deposition must be considered when tsunami flood levels impinge on flood protection, safety-related SSCs and foundation materials. Thus, tsunami model current velocity, wave and wind data should be retained and used for a detailed analysis of the effects of sediment erosion and deposition.

For coastal structures, the USACE CEM provides guidance on the impacts of sediment erosion and deposition (USACE, 2008). For an example of an analysis of the effects of sediment erosion and deposition, the NRC Website (NRC, 2012a) provides COL and ESP safety analysis reports and NRC RAIs.

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ENCLOSURE 3

APPENDIX: GLOSSARY AND ACRONYMS

ADCIRC – Advanced Circulation Model.

ASCE- American Society of Civil Engineers

ANS - American Nuclear Society

ANSI - American national Standards Institute

Bootstrap Sampling - Bootstrapping is the practice of estimating properties of an estimator (such as its variance) by measuring those properties when sampling from an approximating distribution. One standard choice for an approximating distribution is the empirical distribution of the observed data. In the case where a set of observations can be assumed to be from an independent and identically distributed population, this can be implemented by constructing a number of re-samples of the observed dataset (and of equal size to the observed dataset), each of which is obtained by random sampling with replacement from the original dataset.

CFR - Code of Federal Regulations

Coastal: Refers to the near-shore regions of any water body (e.g., ocean, bay, sea, sound, lake, or estuary) where wind wave or gravity wave phenomena may occur, not just regions adjacent to the open ocean.

Coastal Storm Modeling System (C-Storm) - The US Army Corps of Engineers' Engineering Research and Development Center's Coastal Storm Modeling System (CSTORM-MS) is a physics-based modeling capability for simulating tropical and extra-tropical storm, wind, wave, water level and coastal response (erosion, breaching, and accretion).

Design Basis Flood (DBF) - A design-basis flood is a flood caused by one or an appropriate combination of several hydrometeorological, geo-seismic, or structural-failure phenomena, which results in the most severe hazards to structures, systems, and components (SSCs) important to the safety of a nuclear power plant.

Design Basis Storm Surge (DBSS) - The most adverse storm surge flooding at the nuclear power plant site caused by a Simulated Wind Storm (SWS) or Simulated Hurricane (SH) due to a combination of severe meteorological storm parameters, critical path, and rate of movement.

Empirical Simulation Technique (EST) - Procedure for simulating multiple life-cycle sequences of non-deterministic multi-parameter systems. Based on a Bootstrap "resampling-with-replacement, interpolation, and subsequent smoothing technique, EST employs random sampling of a finite length database to generate a larger database. The basic assumption is that future events are statistically similar in magnitude and frequency to past events.

Extra-tropical Cyclone - A storm that forms outside the tropics, sometimes as a tropical storm or hurricane.

Grade Elevation - Topographical elevation of the site near facilities of the nuclear power plant usually used as a base reference to describe elevations of other structures systems and components..

Hierarchical Hazard Assessment (HHA) Approach – HHA is a progressively refined, stepwise estimation of site-specific hazards that evaluates the safety of SSCs with the most conservative plausible assumptions consistent with available data. The HHA process starts with the most conservative simplifying assumptions that maximize the hazards from the probable maximum event for each natural flood-causing phenomenon expected to occur in the vicinity of a proposed site.

HURDAT-- The National Weather Service and the National Hurricane Center's official hurricane database for the Atlantic Ocean, Gulf of Mexico, and Caribbean Sea, including those that have made landfall in the United States, is currently being updated, see Landsea et al. (2004).

Hurricane **-** A tropical cyclone with winds of 74 mph or more. Normally applied to such storms in the Atlantic Basin and the Pacific Ocean east of the International Date Line**.**

Hydrodynamic Loads - Hydrodynamic loads are loads that result from water flowing against and around a rigid structural element or system. The hydrodynamic loads can include the effects of broken and non-breaking waves striking structures, initial impact of a rapidly varying flood wave (e.g. dam break or tsunami flood wave), and drag forces on a structure (caused by the pressure differential between the upstream and downstream side of the structure).

Inundation - The distance that a storm surge penetrates onto the shore, measured horizontally from the mean sea level position of the water's edge. It is usually measured as the maximum distance for a particular segment of the coast.

Joint Probability Method (JPM) – JPM is a simulation methodology that relies on the development of statistical distributions of key tropical or extratropical wind storm parameters and sampling from these distributions. The simulation results in a group of modeled storms that preserves the relationships with the historical storms but provides a means to model the effects and probabilities of storms that have not yet occurred.

JPM-OS - JPM-Optimal Sampling

Maximum Breaker Height - The maximum wave height that can be achieved during shoaling.

NAVD88 - North American Vertical Datum of 1988

NGVD29 - National Geodetic Vertical Datum of 1929

NOAA - National Oceanic and Atmospheric Administration

NRC - U.S. Nuclear Regulatory Commission

NWS - National Weather Service

Planetary Boundary Layer (PBL) – The planetary boundary layer (PBL), also known as the atmospheric boundary layer (ABL), is the lowest part of the atmosphere and its behavior is directly influenced by its contact with a planetary surface.

Probable Maximum Events - Probable maximum events are thought to approach the physical limits of the phenomena, are deterministic in nature, and are thought to exceed historical occurrences of the phenomena at the time of the analysis.

Probable Maximum Hurricane (PMH) - The PMH is a hypothetical hurricane having a combination of characteristics that generate the most severe that can reasonably occur in the particular region.

Probable Maximum Wind Storm (PMWS**)** - A hypothetical extratropical cyclone that might result from the most severe combination of meteorological storm parameters that is considered reasonably possible in the region involved. The windstorm approaches the point under study along a critical path and at an optimum rate of movement, which will result in the most adverse flooding.

Probable Maximum Storm Surge (PMSS**) -** The PMSS is generated by the Probable Maximum Hurricane (PMH) or Probable Maximum Windstorm (PMWS).

RAI - Request for additional information

Seiche - An oscillation of the water surface in an enclosed or semi-enclosed water body that is initiated by an external cause (e.g., barometric pressure fluctuations, strong winds, rapid changes in wind direction, surge associated with passage of storms, tsunami, or local landslides).

SER - Safety Evaluation Report

Significant Wave Height - In physical oceanography, the significant wave height (SWH or H_s) is defined traditionally as the mean wave height (trough to crest) of the highest third of the waves ($H_{1/3}$). Nowadays it is usually defined as four times the standard deviation of the surface elevation – or equivalently as four times the square root of the zeroth-order moment (area) of the wave spectrum. The symbol H_{m0} is usually used for that latter definition. The significant wave height may thus refer to H_{m0} or $H_{1/3}$; the difference in magnitude between the two definitions is only a few percent.

Simulated Hurricane (SH) - A hypothetical tropical cyclone (Hurricane) generated by the probable maximum hurricane (PMH) or synthetic storm methodology (JPM and EST) using a combination of meteorological storm parameters considered reasonably possible for the region involved. The simulated hurricanes approach the nuclear power plant site along multiple paths and rates of movement.

Simulated Wind Storm (SWS) – A hypothetical extratropical cyclone generated through the synthetic storm methodology (JPM and EST) using a combination of meteorological storm parameters considered reasonably possible for the region involved. The SWS approaches the nuclear power plant site along multiple paths and rates of movement.

SLOSH - Sea, Lake, Overland Surge from Hurricanes

SMS – Surface Modeling System

SPH - Standard Project Hurricane

Still Water Level (SWL) – The water level in the absence of wave effects.

Storm Surge: Storm surge is the rise of offshore water elevation caused principally by the shear force of tropical or extratropical winds acting on the water surface and the associated pressure differential.

SWAN – Simulating Waves Nearshore.

STWAVE - STeady State spectral WAVE

Tropical Cyclone - low-pressure weather system in which the central core is warmer than the surrounding atmosphere. The term "tropical cyclone" is also used in the Indian Ocean and around the Coral Sea off northeastern Australia to describe storms called "hurricanes" and "typhoons" in other areas.

Tsunami - A series of water waves caused by the displacement of a large volume of a body of water, typically an ocean or a large lake. Earthquakes, landslides, submarine landslides, glacier calvings, meteorite impacts and other disturbances above or below water all have the potential to generate a tsunami.

UHS - ultimate heat sink

USACE - U.S. Army Corps of Engineers

WAM - WAve prediction Model

Wave Runup - Wave runup is the maximum vertical extent of wave uprush on a beach or structure above the still water level (SWL).

Wave Setup - Additional water level that is due to the transfer of wave-related momentum to the water column during the wave-breaking process.

Wind Waves - Waves generated by wind passing over the surface of an open body of water caused by wind shear forces along the water surface and air pressure differences across the wave crest.