U.S. NUCLEAR REGULATORY COMMISSION

STANDARD REVIEW PLAN

2.4.6 TSUNAMI HAZARDS

REVIEW RESPONSIBILITIES

Primary - Organization responsible for the review of issues related to hydrology

Secondary - None

I. AREAS OF REVIEW

Chapter 2 of the Standard Review Plan (SRP) discusses the site characteristics that could affect the safe design and siting of the plant. The staff reviews information presented by an applicant for a construction permit (CP), operating license (OL), design certification (DC), early site permit (ESP), or combined license (COL) concerning hydrological setting of the site as it relates to those structures, systems, and components (SSCs) important to safety. This SRP section applies to reviews performed for each of these types of applications. The staff's review and findings are described in the appropriate section of the safety evaluation report (SER).

In this section the site characteristic flood elevation is reviewed taking into account the effects of the tsunami flood-causing mechanism by considering all plausible tsunamigenic sources to ensure that those SSCs important to safety can perform their intended functions.

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In order to evaluate the applicant's site characteristic flood, it is necessary for the staff to first determine that tsunami or tsunami-like waves[1] are physically credible at the site, and that these waves produce consequential flooding[2]. If this flood-causing mechanism is considered to be credible at the site, then the staff should assure that the application includes a flood inundation map[3] depicting the extent and elevation of the tsunami-based flood. In addition to a flood inundation map, the staff should confirm that the application provides information on the duration of the flooding event as well as any associated effects[4].

General Design Criterion (GDC) 2 of Appendix A ("General Design Criteria for Nuclear Power Plants") to CFR Part 50 ("Domestic Licensing of Production And Utilization Facilities") requires that nuclear power plant SSCs important to safety be designed to withstand the effects of natural phenomena such as earthquakes, tornadoes, hurricanes, floods, tsunami, and seiches without loss of capability to perform their intended safety functions. The Commission's reactor siting criteria at §100.20(c)(3) also call for the estimation of the "… maximum probable flood … using historical data …." Floods (or flooding), as represented by the maximum probable flood (PMF), is thus one of the *site characteristics*[5] to be evaluated in the context of GDC 2. The key parameters in estimating the PMF at a nuclear power plant are the calculation of a water surface elevation that would occur across the footprint of the power plant site in relation to SSCs important to safety, duration of the flooding event, and associated effects. The scope of this SRP section involves the review of an applicant's estimate of the site characteristic flood at a power plant site due to plausible tsunamigenic sources.

In examining the site characteristic flood, staff's review approach should be hierarchical. The staff would first review the applicant's determination, based on geographic considerations, of whether there is the potential for flooding from tsunamigenic sources at the power plant site. If this flood-causing mechanism is considered to be physically possible, then the staff would review the applicant's determination of whether tsunamigenic sources could result in consequential flooding of the site. If consequential flooding is determined to be possible, then the staff would review the applicant's flood inundation map[6] depicting the extent and elevation of flooding across the powerblock due to the effects of tsunamigenic sources. In addition to a flood inundation map, the staff would review applicant's calculation of the duration of the flooding event as well as any associated effects. These three elements define the magnitude

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[1] For the purposes of this SRP section, the tsunami hazard is defined as that impulsive surface water wave that could possibly flood the nuclear power plant site.

[2] *Consequential flooding*: For CP, OL, and COL applications, a term used to identify conditions in which the flood severity exceeds the capability of protection features (if available), including considerations for flood level, duration and/or associated effects, such that SSCs important-to-safety may be impacted. For ESP applications, the flood severity is expected to be in reference to the site characteristic flood. Consequential flooding may occur for events that are less severe and with differing characteristics (e.g., shorter warning time) than the deterministically defined probable maximum events.

[3] An *inundation map* delineates the area of some ground surface that would be flooded by a particular flooding event. In the case of a nuclear power plant, such a map would be expected to depict the water surface elevations of flood waters in relation to various features of the reactor powerblock including SSCs important to safety.

[4] *Associated effects:* Can be defined to include those factors such as wind waves and run-up effects; hydrostatic loading; hydrodynamic loading, including debris and water velocities; effects caused by sediment deposition and erosion; concurrent site conditions, including adverse weather conditions; and groundwater ingress.

[5] Section 52.1(a) defines s*ite characteristics* "… as the actual physical, environmental and demographic features of a site. Site characteristics are specified in an early site permit or in a final safety analysis report for a combined license...."

[6] An inundation *map* delineates the area of some ground surface that would be flooded by a particular flooding event. In the case of a nuclear power plant, such a map would be expected to depict the water surface elevations of flood waters in relation to various features of the reactor powerblock including any SSCs important to safety.

and extent of the PMF that might occur at a power plant site due to tsunamigenic sources; the staff should review these elements consistent with the review criteria described elsewhere in Section II of this SRP.

The scope of the staff's review activities should include the following areas, as applicable, to confirm whether a tsunamigenic source is a flood-causing mechanism at a power reactor site.

1. Historical Tsunami Data. The staff reviews historical tsunami data, including geologic maps depicting paleo tsunami deposits, regional historical records (including reports of eyewitness accounts), and more recently available tide gauge and bottom pressure gauge data for seiche.

2. Tsunamigenic Sources. The staff reviews those tsunamigenic wave-generating sources that may pose a flooding hazard to the site. For those tsunamigenic sources identified, the staff also reviews the source's wave-generating parameters, wave propagation models, and near-shore inundation models used to estimate the flood hazard. The staff also reviews the applicant's justification of its tsunamigenic source and wave generating model. The staff's review of licensee's tsunami generating model will include the following topics:

    A. Potential tsunamigenic sources from both near field and far field

    B. Tsunamigenic source mechanisms including earthquakes that occur near or beneath the ocean, subaerial or submarine landslides, and volcanoes

    C. Characteristics of tsunamigenic sources

        i. Earthquake source parameters, including magnitude, focal depth, fault dimension and orientation, and displacement; volume and dynamics of landslides; potential landslide sources in land and submarine; and their volcanic explosions and resulting pyroclastic flows, caldera collapses and flank failures; etc.

        ii. Efficiency of tsunami generation

        iii. Maximum initial displacement of the free surface, at the respective tsunamigenic source locations

    D. Propagation of tsunami waves

        i. Propagation in deep waters (linear wave dynamics)

        ii. Propagation in shallow waters (nonlinear wave dynamics)

3. Tsunami Propagation Models

    A. The staff reviews tsunami wave propagation model(s) and model parameters used to simulate the tsunami wave propagation from the source toward the site.

B. The staff reviews input data, including bathymetry and topography data, bottom roughness, used in tsunami wave propagation model(s).

C. The staff reviews the licensee's justification for the geologic (physical) mechanism and location of its preferred tsunami generating source.

4. Wave Runup, Inundation, and Drawdown. The staff reviews the estimated wave elevation generated by the applicant's tsunami computer simulation(s). Water wave elevations may be reported to the nearest tenth of a foot. Staff should confirm that the geodetic reference datum used by the applicant to report the water surface elevation is specified in the application. The staff's review of the applicant's analysis should include consideration of the entire flood event duration along with the water surface elevation estimate. The extent and duration of wave runup during the inundation phase of the flooding event should be reviewed by staff.[7] Staff should also review the information concerning the warning time prior to the inundation phase.

5. Hydrostatic, Wave, and Hydrodynamic Forces. The staff reviews static and dynamic force metrics, including wave length and period, current speed, acceleration, inertial component, and momentum flux that quantify the forces on any SSC important to safety that may possibly be exposed to a tsunami or a tsunami-like wave.

6. Debris and Water-Borne Projectiles. The staff reviews the debris and water-borne projectiles that accompany tsunami-generated currents and may impact any SSC important to safety.

7. Effects of Sediment Erosion and Deposition. The staff reviews the effects of sediment erosion and deposition caused by a tsunami or tsunami-like waves that may result in blockage or loss of function for any SSC important to safety.

8. Consideration of Other Site-Related Evaluation Criteria. The staff reviews the potential effects of seismic and non-seismic information on the postulated design bases and how they relate to any tsunami or tsunami-like wave generated in the vicinity of the site and the site region.

9. Additional Information for 10 CFR Part 52 Applications. The staff reviews additional information that will be presented depending on the type of application. For a COL application, the need for additional information depends on whether the application references an ESP, a DC, both, or neither. Information requirements are prescribed within the "Contents of Application" sections of the applicable subparts to Title10 of the *Code of Federal Regulations* (10 CFR) Part 52, "Licenses, Certifications, and Approvals for Nuclear Power Plants."

Review Interfaces

Other SRP sections interface with this section as follows:

[7] Tsunamis typically consists of multiple waves in the form or a wave train in which the leading wave possesses the highest amplitude. Consequently, the inundation phase may extend well beyond the first wave in the wave train.

1. The flooding protection measures, if necessary, for ensuring that SSCs important to safety can perform their intended safety functions, are reviewed in SRP Section 2.4.10, "Flooding Protection Requirements."

2. The staff review to ensure that adverse environmental conditions, including those from loss of water due to drawdown during the receding tsunami wave, seiching induced by the tsunami wave, or blockage from sedimentation, will not preclude the safety function of the ultimate heat sink is performed under SRP Section 9.2.5, "Ultimate Heat Sink."

3. The NRC organization responsible for the review of issues related to seismology provides information regarding the seismic displacement that may result in tsunami or tsunami-like waves.

   For DC applications and COL applications referencing a DC rule or DC application, staff review of the site parameters in the Design Control Document (DCD) Tier 1 and Chapter 2 of the DCD Tier 2[8] submitted by the applicant is performed under SRP Section 2.0, "Site Characteristics and Site Parameters." Staff review of site characteristics and site-related design parameters in ESP applications or in COL applications referencing an ESP is also performed under Section 2.0.

The specific acceptance criteria and review procedures are contained in the referenced SRP sections.

II. ACCEPTANCE CRITERIA

Regulatory Requirements

The acceptance criteria described in this SRP section are based on addressing the following Commission regulations:

1. 10 CFR Part 100, "Reactor Site Criteria," as it relates to identifying and evaluating hydrological features of the site. The requirements to consider physical site characteristics in site evaluations are specified in 10 CFR 100.10(c) for applications before January 10, 1997, and in 10 CFR 100.20(c) for applications on or after January 10, 1997.

2. 10 CFR 100.23(d) sets forth the criteria to determine the siting factors for plant design bases with respect to seismically-induced floods and water waves at the site.

3. 10 CFR Part 50, "Domestic Licensing of Production and Utilization Facilities," Appendix A, "General Design Criteria for Nuclear Power Plants," General Design Criterion (GDC) 2, "Design Bases for Protection Against Natural Phenomena," as it relates to: (1) appropriate consideration of the most severe of the natural phenomena that have been historically reported for the site and surrounding area, with sufficient margin for the limited accuracy, quantity, and period of time in which the historical data have been accumulated, (2) appropriate combinations of the effects of normal and accident

[8] Additional supporting information of prior DC rules may be found in DCD Tier 2 Section 14.3.

conditions with the effects of the natural phenomena, and (3) importance of the safety functions to be performed.

4. 10 CFR 52.17(a)(1)(vi), for ESP applications, and 10 CFR 52.79(a)(1)(iii), for COL applications, as they relate to identifying hydrologic site characteristics with appropriate consideration of the most severe of the natural phenomena that have been historically reported for the site and surrounding areas and with sufficient margin for the limited accuracy, quantity, and period of time in which the historical data have been accumulated.

Regulatory Guides

Regulatory Guides (RGs) are issued to describe and make available to the public methods acceptable to the NRC staff of implementing specific parts of the Commission's regulations, to delineate techniques used by the staff in evaluating specific problems or postulated accidents, or to provide guidance to applicants. Regulatory Guides are not substitutes for regulations, and compliance with them is not required. Methods and solutions different from those set out in the guides will be acceptable if they provide a basis for the findings requisite to the issuance or continuance of a permit or license by the Commission.

SRP Acceptance Criteria

Specific SRP acceptance criteria acceptable to meet NRC's regulations and consistent with the scope of the review addressed in this SRP section are listed below. The following RGs should be consulted, as applicable, in connection with the review of this particular flood-causing mechanism:

- Regulatory Guide 1.27, "Ultimate Heat Sink for Nuclear Power Plants," describes the applicable ultimate heat sink capabilities.

- Regulatory Guide 1.29, "Seismic Design Classification for Nuclear Power Plants," identifies seismic design bases for SSCs important to safety.

- Regulatory Guide 1.59, "Design Basis Floods for Nuclear Power Plants," provides guidance for developing the hydro meteorological design bases.

- Regulatory Guide 1.102, "Flood Protection for Nuclear Power Plants," describes acceptable flood protection intended to prevent those SSCs important to safety from being adversely affected.

These acceptance criteria should be addressed to the extent this flood-causing mechanism is found to be consequential at the power reactor site

1. Historical Tsunami Data. To meet the requirements of GDC 2 ("Design Bases for protection Against Natural Phenomena"), GDC 44 ("Cooling Water"), 10 CFR 52.17 ("Contents of Applications; Technical Information") and 10 CFR Part 100, the staff should confirm that the application includes a complete description of historically-reported information and/or instrumentally-recorded data on tsunamis or tsunami-like

waves near the proposed plant site. The staff should confirm that this description is sufficient to establish the history of tsunamis and tsunami-like wave occurrences in the vicinity of the site.

2. Tsunamigenic Wave Sources. To meet the requirements of GDC 2, GDC 44, 10 CFR 52.17, and 10 CFR Part 100, the staff should confirm that the application includes an assessment of the tsunami flood-causing mechanism for the proposed site. The tsunami assessment should include a review of tsunamigenic sources from historical, geological, and geomorphic data, both near field and far field, relevant to the proposed plant site. If no tsunami hazard for the proposed site is identified in the application, the staff should confirm that the application includes a justification based on the information reviewed.

   The staff should identify tsunamigenic sources in this review of the application, including earthquakes, submarine and sub-aerial landslides, and volcanoes. The staff should confirm that the characteristics of those geologic sources are described including parameter values associated with the tsunami wave generated at the site attributed to those sources. The staff should identify the location of the preferred tsunamigenic source used in the evaluation of flooding hazard and should assure that the basis for selection of the preferred source is provided.

3. Tsunami Propagation Model. To meet the requirements of GDC 2, GDC 44, 10 CFR 52.17, and 10 CFR Part 100, the staff should confirm that the application provides a description of the tsunami wave propagation model used in the applicant's safety analysis report (SAR). The staff should confirm that the results from numerical simulations of tsunami or tsunami-like waves towards the proposed site are provided. The staff should confirm that this simulation uses shallow water wave equation[9] as an approximation where appropriate, and uses nonlinear wave dynamics where the shallow water wave approximation is not valid.[10] The staff should confirm that the parameters used in the simulation of the tsunami wave propagation model are listed and discussed with respect to their conservativeness. Staff should also verify that a discussion of all data used to input the tsunami wave propagation model including boundary condition specifications is included.

4. Wave Runup, Inundation, and Drawdown. If the staff finds that the tsunami flood-causing mechanism is found to be consequential to defining the plant's design basis flood elevation, an assessment of that flood level in the application is needed to meet the requirements of GDC 2, GDC 44, 10 CFR 52.17, and 10 CFR Part 100. If this flood-causing mechanism is found to be consequential by the staff, then the application should identify the tsunami inundation and drawdown elevations estimated for the site. This information can be represented in the application through the use of inundation maps of the reactor site. The staff should also confirm the description of the methods and models used to simulate inundation and drawdown caused by the tsunami wave. The staff should confirm that the parameters used in the simulation of inundation and drawdown are discussed with respect to their conservativeness. These effects should

[9] e.g., $v=\sqrt{gd}$ where d is the mean depth of the ocean and g is the gravitational constant.
[10] A shallow water wave is typically defined based on the following condition: $H/\lambda > 1/4$, where H is the mean water depth of the ocean basin in which the tsunami is generated and λ the wavelength of the tsunami. A deep water wave is typically defined when $H/\lambda < 1/20$.

be considered by the staff in its review of the application's determination of the design bases of those affected SSCs important to safety.

5. Flood Event Duration Parameters. To meet the requirements of GDC 2, GDC 44, 10 CFR 52.17, and 10 CFR Part 100, the staff should confirm that the application includes information on the estimated warning time, duration of site inundation and drawdown near the proposed site including the powerblock. The staff should verify that the maximum extent and the longest duration of flood inundation and drawdown at the site is identified in the application for the purpose of preparing the flood protection and mitigation measures, as needed.

6. Hydrostatic and Hydrodynamic Forces. To meet the requirements of GDC 2, GDC 44, 10 CFR 52.17, and 10 CFR Part 100, the staff should confirm that the application describes the hydrostatic and hydrodynamic forces caused by the tsunami wave on those SSCs important to safety. The staff should verify that inundation and drawdown depths, current speed, acceleration, inertial component, and momentum flux near the proposed locations of those SSCs important to safety be included in connection with any description of the hydrostatic and hydrodynamic forces. These effects should be considered by the staff in its review of the application's determination of the design bases of those affected SSCs important to safety.

7. Debris and Water-Borne Projectiles. To meet the requirements of GDC 2, GDC 44, 10 CFR 52.17, and 10 CFR Part 100, the staff should confirm that the application includes an assessment of the debris and water-borne projectiles that may accompany tsunami-induced currents. Staff should verify that an assessment of the effects (consequences) posed by the debris and projectiles on those SSCs important to safety is provided in the application. These effects should be considered by the staff in its review of the application's determination of the design bases of those affected SSCs important to safety.

8. Effects of Sediment Erosion and Deposition. To meet the requirements of GDC 2, GDC 44, 10 CFR 52.17, and 10 CFR Part 100, the staff should confirm that the application includes an assessment of the effects of sediment erosion and deposition due to some tsunami near locations of those SSCs important to safety. Staff should verify that a description of and an estimate of these effects on the design bases of those SSCs important to safety is provided in the application. These effects should be considered by the staff in its review of the application's establishment of the design bases of those SSCs important to safety.

9. Consideration of Other Site-Related Evaluation Criteria. To meet the requirements of GDC 2, GDC 44, 10 CFR 52.17, and 10 CFR Part 100, the staff should confirm that the application includes an evaluation of the potential effects of site-related proximity, seismic, and non-seismic information as they affect tsunami waves near the plant site and site regions. The staff should confirm that the assessment sufficiently demonstrates that the applicant's design bases appropriately account for these effects.

Technical Rationale

The technical rationale for application of these acceptance criteria to the areas of review addressed by this SRP section is discussed in the following paragraphs:

1. Compliance with GDC 2 requires that nuclear power plant SSCs important to safety must be designed to withstand the effects of natural phenomena such as earthquake, tornado, hurricane, flood, tsunami, and seiche without loss of capability to perform their safety functions. The GDC further specifies that the design bases for those so designated SSCs shall reflect the following criteria:

   A. Appropriate consideration of the most severe natural phenomena that have been historically-reported or instrumentally-recorded for the site and surrounding area, with sufficient margin for the limited accuracy, quantity, and time period in which the data have been accumulated;

   B. Appropriate combinations of the effects of normal and accident conditions with the effects of the natural phenomena; and

   C. The importance of the safety functions to be performed.

   The first criterion was adopted in recognition of the relatively short historical/ instrumental record available for the reporting of severe natural phenomena (such as tsunamis) in North American and when, based on probabilistic considerations only, the potential for underestimating the severity of such events given that limited record. The reviewer should note that this information challenge (e.g., epistemic uncertainty) can be avoided by relying on a deterministic approach to evaluating the consequences of certain design basis events, such as tsunamis, taking into account records of past events. Such an approach will account for the practical physical limitations of natural phenomena at a proposed site that contribute to the potential severity of a given event.

   The second criterion is relevant to SRP Section 2.4.6 in that it specifies the hydrologic phenomenon that must be evaluated and analyzed at a particular reactor site. In this case, some maximum tsunami wave that could be consequential to defining the design basis flood would be evaluated. In general terms, it also specifies the level of conservatism that should be used to assess the severity of tsunami hazards for the purpose of determining the design bases for SSCs important to safety. This is a similar standard to that applied in reviewing ESP or COL applications for hydrologic site characteristics.

   For applications pursuant to 10 CFR Part 50, meeting the applicable requirements of GDC 2 provides a level of assurance that the design bases of those SSCs important to safety will reflect appropriate consideration of the most severe hydrologic site characteristics likely to occur as a result of tsunamis; the adequacy of these design bases will be evaluated by the staff pursuant to other SRP sections.

   For applications pursuant to 10 CFR Part 52, meeting the applicable requirements of 10 CFR 52.17 and 10 CFR 52.79, “Contents of applications; technical information in final safety analysis report,” that correspond to GDC 2 provides a level of assurance

that the most severe hydrologic site characteristics likely to occur as a result of tsunamis have been identified; whether GDC 2 is met with respect to the adequacy of the associated design bases will be evaluated by the staff pursuant to other SRP sections.

2. Sections 100.10(c) and 100.20(c) of 10 CFR Part 100 require that the physical characteristics of a site (including seismology, meteorology, geology, and hydrology) be taken into account when determining its acceptability for a nuclear power reactor.

   To satisfy the hydrologic requirements of 10 CFR Part 100, the staff should confirm that the applicant's SAR contains a description of the hydrogeologic and seismic characteristics of the region and an analysis of the potential hazard due to tsunami. This description should be sufficient to assess the acceptability of the site and the potential for tsunami waves to influence the design of those plant SSCs important to safety.

   Meeting the requirements of Section 100.10(c) provides a level of assurance that those plant SSCs important to safety have been designed to withstand the most severe hazards likely to occur as a result of some tsunami wave. Meeting the requirements of Section 100.20(c) provides a level of assurance that physical characteristics of the site with respect to seismology and hydrology have been considered appropriately in determining the acceptability of the site; the adequacy of the associated plant design bases will be evaluated by the staff pursuant to other SRP sections.

III. REVIEW PROCEDURES

The reviewer will select material from the procedures described below, as may be appropriate for a particular case.

The procedures outlined below are used by the staff to review CP applications, ESP applications, and COL applications that do not reference an ESP, to determine whether data and analyses for the proposed site meet the acceptance criteria given in Subsection II of this SRP section. For reviews of OL applications, these procedures are used by the staff to verify that the data and analyses remain valid and that the facility's design specifications are consistent with these data. As applicable, reviews of OLs and COLs should include a determination on whether the content of technical specifications bearing on the site characteristic flood reflect consideration of any newly-identified conditions that might now be considered unique to the site and not previously considered in either the CP or the ESP, respectively.

These review procedures also apply to COL applications that do not reference an existing ESP.

These review procedures are based on acceptance criteria identified in Subsection II of this SRP. For deviations from these acceptance criteria, the staff should review the applicant's evaluation of how the proposed alternatives provide an acceptable method of complying with the relevant NRC requirements identified in Subsection II.

The staff's review in the first instance should consist of a hierarchical bounding analysis. If the staff's preliminary assessment of tsunami flooding effects is comparable to the licensee's

preliminary analysis, the staff should concur with the applicant's findings. If the staff's preliminary bounding analysis indicates that its analysis and that prepared by the applicant are not comparable and reach different conclusions, the staff should repeat its analysis using more realistic assumptions; it may also be necessary to rely on more sophisticated analysis model. If the results of the two analyses continue to remain non-comparable then the staff should analyze the applicants' data, methods, and assumptions to determine their reasonableness. Staff may also rely on alternative analysis techniques including alternative conceptual models. Staff should also consider the need to conduct an audit with the applicant to address any differences with the applicant's findings.

1. Historically-Reported/Instrumentally-Recorded Tsunami Data. The staff reviews historically-reported information, including instrumental water-level gauge data, to determine the vulnerability of a proposed site to the occurrence of a tsunami wave. The staff should confirm whether there is historically-reported information and/or instrumentally-recorded data that may help in establishing the frequency of occurrence and other useful indicators such as the location(s) of maximum observed water height(s) of past tsunami events. The staff should review the application's discussion of the available literature, to the extent it is available, regarding any paleo-tsunami studies for the area in question that might provide geologic information on past tsunami flood extents, frequencies, and elevations.

   The National Oceanic and Atmospheric Administration (NOAA) National Geophysical Data Center (NGDC) collects and archives information on tsunami sources and effects to support tsunami modeling and engineering. The NGDC database[11] contains historical as well as paleo tsunami data. The staff should confirm that NGDC data, relevant to the proposed plant site, has been used to describe the history of tsunamis at the site. The staff should also confirm that paleo-tsunami data be included in this description. Other sources of historical data, especially international sources that are relevant for proposed plant sites exposed to far-field transoceanic tsunamis, should also be investigated.[12]

   The staff reviews the historical and paleo tsunami data for their completeness and relevance to the proposed plant site.

2. Tsunamigenic Sources. The staff reviews the locations likely to generate the maximum tsunami wave at the site with respect to the source mechanisms, the characteristics of these source mechanisms, and the simulation of the wave propagating towards the proposed plant site.

   The staff should confirm that a regional assessment of tsunamigenic sources has been submitted by an applicant to determine which geologic sources and mechanisms may generate the tsunami hazard, in terms of the maximum and/or minimum flood levels at the proposed site. The staff should confirm that the application's assessment of the geologic source mechanisms includes earthquakes, submarine and subaerial

[11] Available online at https://www.ngdc.noaa.gov/hazard/tsu_db.shtml.
[12] Certain natural but rare geologic event such as asteroid or meteor impacts have not been considered in reviewing nuclear power plant designs. Consequently, any tsunami generated from a similar impact event is considered beyond the scope of the review envisioned in this section of the SRP.

landslides, and volcanoes, as applicable. The staff should confirm that the application uses characteristics of the geologic sources that are used for the specification of the tsunami at the site that are conservative, e.g., supplemented by a larger regional or global earthquake size distribution to account for the limited period of historical records. The staff should confirm that the application's assessment of landslide sources along the continental slope/shelf transition are characterized using the maximum volume parameter determined from seafloor mappings or geologic age dating of identified historical submarine landslides near large bodies of waters. The staff should confirm that a slope-stability analysis has been performed to assess the relative maximum tsunami potential of candidate landslide sites near large bodies of water. The staff should confirm that the possible tsunamigenic sources due to volcanic activity have been considered in the application's tsunami assessment, including pyroclastic flows, submarine caldera collapse, explosions, and debris avalanches or flank failures.

The staff reviews the initial (impulsive) displacement of the water surface at the generating source that subsequently causes the radiating tsunami waves. The staff should confirm that the initial displacement of the water surface is estimated conservatively in the application.

3. Tsunami Propagation Models. The staff reviews the licensee's evaluation of tsunami propagation to the site. If the licensee used tsunami propagation models for the tsunami hazard analysis, the staff also needs to review them. Staff must confirm that the models selected by the applicant are similar, in terms of details and accuracy, to the ones used by recognized federal agencies such as NOAA, the U.S. Geological Survey (USGS), and the U.S. Army Corps of Engineers (USACE), to name a few. The staff should confirm that numerical models selected by the applicant are well accepted in the scientific communities through publications in peer-reviewed literature, or having received verification through testing and validation through widespread use.

   The staff reviews the model parameters and other input data used to simulate the propagation of tsunami waves towards the site. The staff should confirm that the values of the model parameters selected by the applicant for its computer simulations are adequately described; conservative parameter values should be used if the model was not calibrated with known historical events. Staff should confirm that all other data sources used in the computer simulations are identified and described in the application. The staff need to review bathymetric and topographic data used in the numerical models.

   The staff reviews propagation of the tsunami waves from the generating source location towards the proposed site. When appropriate, the staff should confirm that the shallow water wave equation is used to simulate propagation of the maximum tsunami waves. The staff should confirm that simulation of the propagation of the tsunami waves in shallower waters, where the shallow water wave approximation is not valid, use nonlinear wave dynamics-based approaches.

4. Wave Runup, Inundation, and Drawdown. The staff reviews the estimation of wave runup as well as total inundation and drawdown elevations generated by the bounding tsunami event. The staff should confirm that this information is communicated in the

form of an inundation map.[13] The staff will review water wave elevations reported to the nearest tenth of a foot and the geodetic reference datum used by the applicant to report the water surface elevation. The staff will review the applicant's assumed initial water surface elevation for the body of water under consideration, at the arrival of the tsunami waves at the site, similar to the review performed for the storm surges and seiches mechanisms.[14] For example, to review the estimate of the highest tsunami wave runup at a coastal site, the staff should review the 90th percentile of high tides as the initial water surface elevation near the site; to review the estimate the lowest drawdown caused by receding tsunami waves at the same site, the staff should review the 10th percentile of the low tides as the initial water surface elevation. The staff will review separate flooding levels, corresponding to different locations within the powerblock, as the flood water elevation may vary spatially owing to differences in the finished site grade and the presence of multiple as-built reactor structures.

If the maximum estimated inundation elevation exceeds the plant grade, the staff needs to review the detailed flooding levels corresponding to different locations near the SSCs important to safety. That review would include confirming that complete hydrographs were submitted by the applicant to determine the flood event duration parameters and to prepare flood protection and mitigation measures. As mentioned above, the staff should review this information, which should be contained in one or more inundation maps prepared by the applicant. The staff review should also include the estimation of flood-related. The staff reviews how the applicant's estimation of flood hazards have accounted for the location and orientation of various structures within the powerblock with particular attention to those SSCs important to safety as well as variations in the site grade.

Inundation caused by the tsunami wave may also necessitate additional flood protection measures for certain SSCs important to safety in the form of operational procedures, including manual staff actions. This information should also be reviewed by the staff.

The staff reviews the effect of the drawdown caused by that tsunami wave and how it may affect a safety-related intake structure (a type of SSC generally considered important to safety), if they are used in the plant design and are exposed to the effects of the tsunami wave. The staff also reviews the duration of the drawdown caused by the tsunami wave to estimate the time during which a safety-related intake structure may be affected. The staff should note that the suggested criteria of RG 1.27 apply when the water supply comprises part of the ultimate heat sink.

The staff should confirm that the application demonstrates that the extent and the duration of the inundation and the drawdown caused by the tsunami flood-causing

[13] The Federal Emergency Management Agency (FEMA) has an extensive flood inundation mapping program. See https://www.fema.gov/guidelines-and-standards-flood-risk-analysis-and-mapping for information on FEMA's latest inundation mapping standard.

[14] In 2002, ANSI/ANS-2.8-1992 was administratively withdrawn and is currently undergoing revision. Until such time that an update becomes available, the staff believes that applicants may still find some of the earlier guidance in this standard useful to consider.

mechanism is adequately established for the purposes of determining the power plant design basis.

5. Hydrostatic, Wave, and Hydrodynamic Forces. The staff reviews the hydrostatic, wave, and the hydrodynamic forces caused by tsunami waves on those SSCs important to safety. Since the tsunami occurs as a train of waves, the staff should confirm that several incoming and receding wave cycles with different combination of wave lengths and periods are considered to estimate the maximum wave forces. The staff should also confirm that local bathymetry and site geometry, which can significantly affect the runup height, velocity, and momentum flux near the locations of those SSCs important to safety, be accounted for in any analysis of forces. The staff should note that the suggested criteria of RG 1.27 apply when the water supply comprises part of the ultimate heat sink.

   The staff should confirm that the application demonstrates that hydrostatic and hydrodynamic forces caused by the tsunami waves are adequately established for the purposes of the plant design bases.

6. Debris and Water-Borne Projectiles. The staff reviews the estimation of debris and projectile loads caused by debris and water-borne projectiles carried along with the tsunami currents and their ability to cause damage to those SSCs important to safety. The staff should note that the suggested criteria of RG 1.27 apply when the water supply comprises part of the ultimate heat sink. The staff should confirm that it has been demonstrated in the application that any possibility of damage to those SSCs important to safety from debris and water-borne projectiles is adequately established for the purposes of the plant design bases and that the current federal guidelines by the USACE, FEMA or others were used to determine the water-borne debris loads.

7. Effects of Sediment Erosion and Deposition. The staff reviews the sediment deposition during tsunami inundation, as well as the erosion caused by the high velocity of flood waters or wave action during flood inundation and its effect on foundations of structures within the powerblock and other SSCs important to safety, to ensure that these are adequately established for the purposes of the plant's flooding design bases. The staff should confirm that any potential erosion and sediment deposition would not affect the functioning of an exposed SSC important to safety. The staff should note that the suggested criteria of RG 1.27 apply when the water supply comprises part of the ultimate heat sink.

8. Consideration of Other Site-Related Evaluation Criteria. 10 CFR Part 100 describes site-related proximity, seismic, and non-seismic evaluation criteria for power reactor applications. Subpart A to 10 CFR Part 100 addresses the requirements for applications before January 10, 1997, and Subpart B is for applications on or after January 10, 1997. If the tsunami flood-causing mechanism is determined to be consequential to defining the plant's design basis or site characteristic flood elevation, the staff's review will include evaluation of pertinent information to determine if these criteria are appropriately used in postulation of worst-case tsunami scenarios.

9. Review Procedures Specific to 10 CFR Part 52 Application Types

A. Construction Permit and Early Site Permit Reviews.

Subpart A to 10 CFR Part 52 specifies the requirements and procedures applicable to the Commission's issuance of ESPs for approval of a proposed site. Information required for an ESP includes a description of the characteristics of the proposed site. For an ESP, the scope and level of detail for reviewing data parallel those used for a CP review.

In the absence of certain circumstances, such as a compliance or adequate protection issue, 10 CFR 52.39, "Finality of early site permit determinations," precludes the staff from imposing new site characteristics, design parameters, or terms and conditions on the early site permit at the COL stage. Accordingly, the reviewer should ensure that all physical attributes of the site that could affect the design basis of SSCs important to safety are reflected in the site characteristics, design parameters, or terms and conditions of the early site permit.

B. Standard Design Certification Reviews.

Applications for design certification do not contain general descriptions of site characteristics because this information is site-specific and will be addressed by the COL applicant. However, pursuant to 10 CFR 52.47(a)(1), a DC applicant must provide site parameters postulated for the design. Site parameters associated with this SRP section are reviewed by the staff, as applicable, to verify that:

i. The postulated site parameters are representative of a reasonable number of sites that have been or may be considered for a COL application;

ii. The appropriate site parameters should be included as Tier 1 information. This convention has been used by previous DC applicants. Additional guidance on site parameters is provided in SRP Section 2.0, "Site Characteristics and Site Parameters";

iii. Pertinent parameters are stated in a site parameters summary table; and

iv. The applicant has provided a basis for each of the site parameters.

C. Combined License Reviews.

For a COL application referencing a certified standard design, the NRC staff reviews the application to ensure sufficient information was presented to demonstrate that the characteristics of the site fall within the site parameters specified in the DC rule. If the staff determines that there are site parameters associated with this SRP section and if the above condition for these parameters have not been met (i.e., the actual site characteristics do not fall within the certified standard design site parameters), then the staff will confirm that the

COL applicant demonstrates by some other means that the proposed facility is acceptable at the proposed site. For example, the staff could review the COL applicant's re-analysis or re-design of the proposed facility.

For a COL application referencing an ESP, NRC staff reviews the application to ensure the applicant provided sufficient information to demonstrate that the design of the facility falls within the site characteristics and design parameters specified in the early site permit as applicable to this SRP section. In accordance with 10 CFR 52.79(b)(2), should the design of the facility not fall within the site characteristics and design parameters, the application shall include a request for a variance from the ESP that complies with the requirements of 10 CFR 52.39 and 10 CFR 52.93, "Exemptions and variances.".

In addition, long-term environmental changes and changes to the region resulting from human or natural causes may have introduced changes to the site characteristics that could be relevant to the design basis. In the absence of certain circumstances, such as a compliance or adequate protection issue, 10 CFR 52.39 precludes the staff from imposing new site characteristics, design parameters, or terms and conditions on the early site permit at the COL stage. Consequently, a COL application referencing an ESP need not include a re-investigation of the site characteristics that have previously been accepted in the referenced ESP. However, in accordance with 10 CFR 52.6, "Completeness and Accuracy of Information," the applicant or licensee is responsible for identifying changes of which it is aware, that would satisfy the criteria specified in 10 CFR 52.39. Information provided by the applicant in accordance with 10 CFR 52.6(b) will be addressed by the staff during the review of a COL application referencing an ESP or a DC.

For a COL application referencing either an ESP or DC or both, the staff should review the corresponding sections of the ESP and DC FSER to ensure that any early site permit conditions, restrictions to the DC, or COL action items identified in the FSERs are appropriately handled in the COL application.

IV. EVALUATION FINDINGS

The review should document the staff's evaluation of site characteristics with regard to the relevant regulations and associated acceptance criteria. The evaluation should support the staff's conclusions as to whether the regulations are met. The staff should state what was done to evaluate the applicant's safety analysis report and then summarize the staff's technical evaluation of that information in its SER. The staff's evaluation may include verification that the applicant followed applicable regulatory guidance, performed independent calculations, and/or validated appropriate assumptions. The reviewer may state that certain information provided by the applicant was not considered essential to the staff's review and was not reviewed by the staff. While the reviewer may summarize or quote the information offered by the applicant in support of its application, the staff should clearly articulate the bases for the staff's conclusions that the relevant regulatory criteria have been met.

The staff verifies that the applicant has provided sufficient information to complete the review, and that the applicant's analyses and calculations (as applicable) support conclusions

described in the safety analysis report. For the purposes of the SER, the ultimate conclusion to be reached by the reviewer is that the applicant has addressed the acceptance criteria and in doing so establishes whether this flood-causing mechanism is applicable to the site. If found to be applicable, the acceptance criteria next call for a determination as whether tsunami-based flooding is consequential to defining the design basis at the site. If found to be consequential, the acceptance criteria call for the submittal of the following to establish the design basis: an inundation map depicting water surface elevations across the reactor site, information on flood event duration, and associated effects consistent with projected flooding depths and durations. As mentioned above, the staff should state the bases for confirming the conclusions reached by the applicant.

1. Construction Permit, Operating License, and Combined License Reviews

The following statements should be preceded by a summary of the site characteristics and parameters used for the plant:

> "As set forth above, the applicant has presented and substantiated information relative to the effects of the tsunami flood-causing mechanisms important to the design and siting of this plant. The staff has reviewed the available information provided and, for the reasons given above, concludes that the identification and consideration of the effects of the tsunami flood-causing mechanism at the site and in the surrounding area are acceptable and meet the relevant requirements of 10 CFR Part 100 [10 CFR Part 100.10(c) or 10 CFR Part 100.20(c), as applicable] and [10 CFR Part 50, Appendix A, General Design Criterion 2] [or] 10 CFR 52.79]], with respect to determining the acceptability of the site.
>
> The staff finds that the applicant has considered the appropriate site phenomena for establishing the design bases for SSCs important to safety. The staff has generally accepted the methodologies used to determine the effects of the tsunami flood-causing mechanism reflected in these site characteristics, as documented in safety evaluation reports for previous licensing actions. Accordingly, the staff concludes that the use of these methodologies results in site characteristics containing margin sufficient for the limited accuracy, quantity, and period of time in which the data have been accumulated. The staff concludes that the identified site characteristics meet the relevant requirement(s) of 10 CFR Part 100.10(c) [or 10 CFR Part 100.20(c)] and [10 CFR Part 50, Appendix A, General Design Criterion 2] [or] 10 CFR 52.79]], with respect to establishing the design basis for SSCs important to safety."

2. Early Site Permit Reviews

The following statements should be preceded by a summary of the site characteristics and design parameters to be included in any ESP that might be issued for the proposed site:

> "As set forth above, the applicant has presented and substantiated sufficient information pertaining to the effects of tsunami hazards at the proposed site. Section 2.4.6, "Tsunami Hazards," of NUREG-0800, Standard Review Plan, provides that the site safety analysis report should address the requirements of 10 CFR Parts 52 and 100 as they relate to identifying and evaluating the effects

of the tsunami flood-causing mechanism. Further, the applicant considered the most severe natural phenomena that have been historically reported for the site and surrounding area while describing the tsunami flood-causing mechanism, with sufficient margin for the limited accuracy, quantity, and period of time in which the historical data have been accumulated. The staff has generally accepted the methodologies used to determine the severity of the phenomena reflected in these site characteristics, as documented in safety evaluation reports for previous licensing actions. Accordingly, the staff concludes that the use of these methodologies results in site characteristics containing sufficient margin for the limited accuracy, quantity, and period of time in which the data have been accumulated. In view of the above, the site characteristics previously identified are acceptable for use in establishing the design bases for SSCs important to safety, as may be proposed in a COL or CP application.

Therefore, the staff concludes that the identification and consideration of the tsunami hazards site characteristics set forth above are acceptable and meet the requirements of 10 CFR 52.17(a)(1)(vi), 10 CFR 100.20(c), and 10 CFR 100.21(d).

In view of the above, the staff finds the applicant's proposed site characteristics related to the tsunami flood-causing mechanism for inclusion in an ESP for the applicant's site, should one be issued, to be acceptable."

3. Design Certification Reviews

The following statement should be preceded by a list of the applicable site parameters used for the plant:

"The NRC staff acknowledges that the applicant has selected the site parameters referenced above for plant design inputs (a subset of which is included as Tier 1 information), and agrees that they are representative of a reasonable number of sites that have been or may be considered for a COL application. Tsunami floods are site-specific and will be addressed by the COL applicant. This should include the provision of information sufficient to demonstrate that the design of the plant falls within the site parameters specified by the siting review."

V. IMPLEMENTATION

The staff will use this SRP section in performing safety evaluations of DC applications and license applications submitted by applicants pursuant to 10 CFR Part 50 or 10 CFR Part 52. Except when the applicant proposes an acceptable alternative method for complying with specified portions of the Commission's regulations, the staff will use the method described herein to evaluate conformance with Commission regulations.

The provisions of this SRP section apply to reviews of applications submitted six months or more after the date of issuance of this SRP section, unless superseded by a later revision.

VI. REFERENCES

1. U.S. *Code of Federal Regulations*, “Domestic Licensing of Production and Utilization Facilities,” Appendix A, “General Design Criteria for Nuclear Power Plants,” General Design Criterion 2, “Design Bases for Protection against Natural Phenomena.” Part 50, Title 10, “Energy.”

2. U.S. *Code of Federal Regulations*, Appendix A, “General Design Criteria for Nuclear Power Plants,” General Design Criterion 44, “Cooling Water.” Part 50, Title 10, “Energy.”

3. U.S. *Code of Federal Regulations*, “Licenses, Certifications, and Approvals for Nuclear Power Plants,” Part 52. Title 10, “Energy.”

4. U.S. *Code of Federal Regulations*, “Reactor Site Criteria,” Part 100, Title 10, “Energy.”

5. U.S. Nuclear Regulatory Commission “Ultimate Heat Sink for Nuclear Power Plants.” Regulatory Guide 1.27.

6. U.S. Nuclear Regulatory Commission, “Seismic Design Classification.” Regulatory Guide 1.29.

7. U.S. Nuclear Regulatory Commission, “Design Basis Floods for Nuclear Power Plants.” Regulatory Guide 1.59.

8. U.S. Nuclear Regulatory Commission, “Standard Format and Content of Safety Analysis Reports for Nuclear Power Plants,” Regulatory Guide 1.70.

9. U.S. Nuclear Regulatory Commission, “Flood Protection for Nuclear Power Plants,” Regulatory Guide 1.102.

10. U.S. Nuclear Regulatory Commission, “Physical Models for Design and Operation of Hydraulic Structures and Systems for Nuclear Power Plants,” Regulatory Guide 1.125.

11. U.S. Nuclear Regulatory Commission, “Combined License Applications for Nuclear Power Plants.” (LWR Edition), Regulatory Guide 1.206.

12. American National Standards Institute/American Nuclear Society, “Determining Design Basis Flooding at Power Reactor Sites,” ANSI/ANS-2.8-1992, [Historical technical reference].

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This Standard Review Plan contains voluntary information collections covered by 10 CFR Parts 50, 52, and Part 100 that are subject to the Paperwork Reduction Act of 1995 (44 U.S.C. 3501 et seq.). These information collections were approved by the Office of Management and Budget (OMB), under control numbers 3150-0011, 3150-0151, and 3150-0093, respectively. Send comments regarding this information collection to the Information Services Branch, U.S. Nuclear Regulatory Commission, Washington, DC 20555-0001, or by e-mail to Infocollects.Resource@nrc.gov, and to the Desk Officer, Office of Information and Regulatory Affairs, NEOB-10202, (3150-0011, 3150–0151, and 3150-0093) Office of Management and Budget, Washington, DC 20503.

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SRP Section 2.2.6
Description of Changes

Section 2.4.6 "Tsunami Hazards"

This SRP revision affirms the technical accuracy and adequacy of the guidance previously provided in Revision 3, March 2007 of this SRP (ADAMS Accession No. ML070160659). This revision captures lessons learned from the staff's review of DC, ESP, and COL applications received during the previous decade.

Changes were made to update the text with editorial and clarifying statements, including utilizing consistent terminology within this SRP section and planned updates within the other SRP 2.4 sections. A key change to this SRP section was to delete the word "probable" from both the SRP section title and elsewhere in the body of the text. This particular word implies a probabilistic aspect to an analysis that is still essentially deterministic. Similarly, the terms "maximum" and "probable maximum" have been deleted. It is the staff's view that these terms equate to the term "consequential flood" (discussed below) that is the focus of the review outlined in this SRP section. As there might be multiple flooding maxima at multiple locations within the powerblock due to tsunamis (as well as other flood-causing mechanisms), the staff's regulatory interest is in that water surface elevation that would be instrumental in defining the design basis for the purposes of the regulations; thus, the staff's preference for the use of the term "consequential flood(ing)."

As noted above, a new term "consequential flooding" has been defined and introduced. In reference to any consequential flooding, the staff is now proposing that licensees prepare inundation maps identifying the elevation of flood waters in relation to the SSCs within the reactor powerblock. Depending on the reactor sites' topography and geography, the powerblock and service water and ultimate heat sink intake structures may be at different elevations relative to each other. As a consequence, the staff is also proposing that applicants calculate separate flooding levels corresponding to these two features' locations as the tsunami's wave amplitude may vary across the reactor site owing variable site topography and the presence of multiple as-built reactor structures. The staff envisions that the requisite calculations would be represented by one of more inundation maps for the reactor powerblock and any SSCs important to safety. The staff is also proposing the applicant's analysis should include consideration of "associated effects" in any water surface elevation estimate. A definition of "associated effects" has been introduced in the SRP text.

The current version of the SRP text places cites the need to examine historically-reported information on past tsunami occurrences and properties. The staff notes that instrumentally-recorded data such as tidal records is another valuable source of information concerning past tsunamis.

The phrases "safety-related structures, systems, and components (SSCs)" and "SSCs determined to be important to safety" have been replaced in this SRP section with the phase "SSCs important to safety" to better correspond to the regulatory language cited in General Design Criteria 2.

The March 2007 version of this SRP makes reference to ANSI/ANS-2.8-1992 when estimating certain tsunami parameters. In 2002, ANSI/ANS-2.8-1992 was administratively withdrawn and is currently undergoing revision. As a consequence, reference to ANSI/ANS-2.8-1992 has been deleted from the main body of the SRP text and replaced with a footnote that until such time that an update to ANSI/ANS-2.8-1992 becomes available, the staff believes that applicants may still find some of the earlier guidance in this standard useful to consider.

Other changes incorporated in this revision include the following:

I. AREAS OF REVIEW

Updated with editorial changes as well as content changes consistent with the discussion above.

II. ACCEPTANCE CRITERIA

Updated with editorial changes as well as content changes consistent with the discussion above.

II. REVIEW PROCEDURES

Updated with editorial changes as well as content changes consistent with the discussion above.

IV. EVALUATION FINDINGS

Updated with editorial changes as well as content changes consistent with the discussion above.

V. IMPLEMENTATION

No changes.

VI. REFERENCES

Several changes have been made to this section. The first was to re-organize the references according to type (NRC regulations, NRC regulatory guides, industry codes and standards, and other pertinent technical references). The references were also arranged chronologically. This change was intended to improve the readability of this section of the SRP.

The next major change to the “References Section” of this SRP was to delete those earlier references describing tsunami wave physics, historic tsunami occurrences, tsunami numerical modeling exercises, and the like. The staff believe that in light of the current state of engineering practice in the area of tsunami-based flood hazard analyses by applicants in particular and the broader technical community in general, the inclusion of these types of references adds no real value to this particular SRP section.