SCREENING ANALYSIS APPROACH USED IN THE EVALUATION OF EXTERNAL FLOOD AND OTHER HAZARDS FOR THE U.S. NUCLEAR REGULATORY COMMISSION FULL-SCOPE SITE LEVEL 3 PROBABILISTIC RISK ASSESSMENT

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This paper discusses the approach used in the evaluation of external flood and other hazards for U.S. Nuclear Regulatory Commission (NRC) Full-Scope Site Level 3 PRA Project with a focus on the progressive screening analysis. Hazards that are screened out by this process do not require the development of a hazard-specific PRA. This evaluation is part of the Level 1, reactor, at-power probabilistic risk assessment (PRA) that is being performed for the. The term "other hazards" refers to those hazards, both internal and external, that are not considered in the internal events, internal flood, internal fire, seismic, high winds, or external flood hazards analyses. The approach used for this external flood and other hazards evaluation includes 1) a review of plant licensing bases and plant-specific data 2) identifying the hazards to be considered, 3) performing a progressive screening analysis, and 4) performing a PRA for those hazards that cannot be screened out from further consideration. This paper presents a discussion of the qualitative and quantitative screening criteria used in the evaluation as well as the bases for their derivation and comparisons with existing screening criteria.

I. INTRODUCTION

The U.S. Nuclear Regulatory Commission, in their Staff Requirements Memorandum SRM-SECY-11-0089, "Options for Proceeding with Future Level 3 Probabilistic Risk Assessment Activities[1]," approved the NRC Full-Scope Site Level 3 PRA Project (henceforth referred to as the "Level 3 PRA Project" for brevity). The objectives of this project are as follows:

- Develop a Level 3 PRA, generally based on current state-of-practice methods, tools, and data, that reflects technical advances since completion of the PRA studies documented in NUREG-1150, "Severe Accident Risks: An Assessment for Five U.S. Nuclear Power Plants[2]," and addresses scope considerations that were not previously considered (e.g., low power and shutdown, multi-unit risk, and spent fuel storage).
- Extract new risk insights to enhance regulatory decision making and help focus limited agency resources on issues most directly related to the agency's mission to protect public health and safety.
- Enhance PRA staff capability and expertise and improve documentation practices to make PRA information more accessible, retrievable, and understandable.
- Obtain insights into the technical feasibility and cost of developing new Level 3 PRAs.

The scope of the Level 3 PRA Project includes consideration of internal and external hazards for at-power, low-power, and shutdown operational modes. These hazards and operational modes are evaluated for all major radiological sources at Units 1 and 2 of the Vogtle Electric Generating Plant (VEGP) (i.e., reactors, spent fuel pools, dry cask storage).

The external floods and other hazards evaluations described herein are being performed for the Level 1, reactor, at-power PRA. The external flood hazard analysis includes, but is not limited to consideration of local intense precipitation, flooding resulting from dam failure, and flooding from rivers and streams. The other hazards analysis considers all other hazards, both internal and external, that are not considered in the internal events, internal flood, internal fire, seismic, high winds, or external flood hazards analyses. Examples of other internal hazards are the turbine-generated missile hazard and onsite storage of hazardous materials. Examples of other external hazards are the aircraft impact hazard and industrial or military facility accidents.

The seismic hazard is being evaluated quantitatively given that 1) the level of detail needed for a screening analysis is anticipated to be nearly as much as would be needed for a PRA and 2) past seismic analyses have demonstrated that seismic hazards can be risk significant and would likely not screen out. The high winds hazard—i.e., strong straight winds, tornadoes, hurricanes—is also being evaluated quantitatively in the interest of achieving better alignment with the current PRA state-of-practice.

As discussed in the NRC Level 3 PRA Technical Analysis Approach Plan (TAAP)[3], the Level 1, reactor, at-power portion of the Level 3 PRA Project is being developed to meet the technical requirements documented in ASME/ANS RA-Sa-2009, "Standard for Level 1/Large Early Release Frequency Probabilistic Risk Assessment for Nuclear Power Plant Applications[4]," and as endorsed in Regulatory Guide (RG) 1.200, "An Approach for Determining the Technical Adequacy of Probabilistic Risk Assessment Results for Risk-Informed Activities[5]." In particular, the technical requirements relevant to the different aspects of the external flood and other hazards evaluation are detailed in the following parts of ASME/ANS RA-Sa-2009. Part 6 provides requirements for the hazards identification process and screening analysis. Included in this part is Appendix 6-A, which contains a list of other hazards to consider during the hazards identification process. Part 8 provides requirements for performing an external flood PRA and Part 9 provides requirements for performing a PRA for any internal or external hazard other than the internal events, internal flood, internal fire, seismic, high winds, or external flood hazards.

ASME/ANS RA-Sb-2013, "Standard for Level 1/Large Early Release Frequency Probabilistic Risk Assessment for Nuclear Power Plant Applications[6]," was published in 2013 and provides an update to the technical requirements in ASME/ANS RA-Sa-2009, including revisions to the screening criteria in Part 6 and Appendix 6-A. Although not formally endorsed by the NRC, ASME/ANS RA-Sb-2013 offers some of the most recent thinking on the technical requirements for the screening analysis and was used to inform the hazard identification and the progressive screening analysis approach used in the external flood and other hazards evaluation for the Level 3 PRA Project.

As discussed in the TAAP, each portion of the Level 3 PRA Project is subject to several separate internal and external reviews. Currently, the NRC is in the process of collecting substantial comments from internal and external reviews related to this external flood and other hazards evaluation and, as such, the results are not presented in this paper. Instead, the primary focus of this paper is on the discussion on the screening approach and screening criteria used in the external flood and other hazards evaluation.

II. EVALUATION APPROACH

The general approach for the external flood and other hazards evaluation consists of four major steps: 1) review of plant licensing bases and plant-specific data, 2) identification of a complete set of hazards to be considered in the analysis, 3) performance of a progressive screening analysis to eliminate non-risk-significant hazards from further consideration, and 4) performance of a detailed probabilistic analysis for hazards that are not screened out.

This approach is based primarily on the guidance provided in NUREG-1407, "Procedural and Submittal Guidance for the Individual Plant Examination of External Events (IPEEE) for Severe Accident Vulnerabilities[7]." Other guidance documents that were reviewed included NUREG/CR-2300, "PRA Procedures Guide[8]," the draft of Revision 1 to NUREG-1855, "Guidance on the Treatment of Uncertainties Associated with PRAs in Risk-Informed Decisionmaking[9]," and the Electric Power Research Institute (EPRI) report 1022997, "Identification of External Hazards for Analysis in Probabilistic Risk Assessment[10]." The following sections discuss the details of each of the four major steps of the evaluation process.

II.A Review of Plant Licensing Bases and Data

The review of the VEGP Units 1 and 2 licensing bases and plant-specific data included review of licensing documents and licensee PRA documentation. Several databases were queried for site-specific statistical data. In particular, the National Climatic Data Center maintains meteorological data; the Federal Aviation Administration maintains data related to airport operations and other relevant aviation statistics; the U.S. Department of Transportation maintains data related to highway and railroad transportation accidents; and the U.S. Army Corps of Engineers maintains data related to marine transportation and waterborne commerce.

Although the VEGP Units 3 and 4 site does not fall within the scope of the Level 3 PRA Project, the information review included an examination of the VEGP Units 3 and 4 Early Site Permit application for information on potential hazards relevant to both VEGP Units 1 and 2 and Units 3 and 4, such as the aircraft impact hazard and transportation accident hazard. Additionally, reviews of the Licensee Event Report database were used help inform the bases for the application of screening criteria, as discussed further in Section II.C.

II.B The Hazards Identification Process

The purpose of the hazards identification process is to identify a complete set of hazards to be considered in the progressive screening analysis. In doing so, the identification process is intended to be more inclusive so as not to presumptively omit hazards based on a perception that they would be inevitably be screened out. The set of hazards identified for the external flood and other hazards evaluation was based on a review of several documents that identify sets of hazards to consider in such a PRA analysis.

Appendix 6-A of ASME/ANS RA-Sa-2009 provides a list of external hazards to consider for a Level 1, reactor, at-power PRA, and is adapted from NUREG/CR-2300. Appendix 6-A in ASME/ANS RA-Sb-2013 includes a new version of the table from Appendix 6-A of ASME/ANS RA-Sa-2009, and includes additional hazards, heavy-load drops for example, as well as a reorganization of the list of hazards. EPRI 1022997 includes a list of hazards that were developed based on a survey of several domestic and international industry and regulatory documents related to nuclear power plant safety. NUREG-1407 identifies a set of external hazards to be included in the performance of an IPEEE, as derived from the results of the study documented in NUREG/CR-5042, "Evaluation of External Hazards to Nuclear Power Plants in the United States[11]." Additionally, the licensing bases, relevant licensee PRA documentation, and plant-specific data were reviewed for VEGP Units 1 and 2 to identify any plant-specific hazards that warranted consideration.

II.C Progressive Screening Analysis

The progressive screening analysis is a process that applies increasing levels of detail and effort to a given hazard analysis so as to demonstrate—via meeting pre-defined screening criteria—that the hazard does not represent a significant contribution to the overall plant core damage frequency (CDF). Hazards that are screened out from the PRA by this process do not require the development of a detailed probabilistic analysis. The progressive screening analysis reduces the number of hazards that require development of a detailed probabilistic analysis so that resources can be better focused on analyzing hazards that do require such an analysis.

The progressive screening approach starts with a qualitative analysis that assesses the general relevance and/or applicability of a hazard to the plant. When a hazard cannot be shown to meet any of the screening criteria on a qualitative basis alone, the hazard is analyzed in greater detail via a bounding analysis to demonstrate that, even the hazard event of the greatest plausible magnitude cannot affect the plant. When a hazard cannot be shown to meet any of the screening criteria via a bounding analysis, the hazard is analyzed in greater detail to demonstrate that a conservatively estimated value of the risk contribution from the hazard is not significant, with consideration of the range of magnitudes and frequencies of interest.

The screening criteria used for the external flood and other hazards analysis were developed based primarily on guidance from the draft of Revision 1 to NUREG-1855 and the technical requirements in Part 6 of ASME/ANS RA-Sa-2009. Additionally, the screening criteria selection process was informed by Part 6 of ASME/ANS RA-Sb-2013, insights from the development of the recently published draft of the NRC Interim Staff Guidance document DC/COL-ISG-028, "Assessing the Technical Adequacy of the Advanced Light-Water Reactor Probabilistic Risk Assessment for the Design Certification Application and Combined License Application[12]," and insights gained from recent activities related the finalization of Revision 1 to NUREG-1855 for publication.

The draft Revision 1 of NUREG-1855 provides NRC guidance on acceptable screening criteria and their application in a PRA. This guidance was developed to meet the intent of the related technical requirements in Part 6 of ASME/ANS RA-Sa-2009. The following sections describe the screening criteria that have been adopted for the external flood and other hazards analysis.

II.C.1 Qualitative Screening Criteria

The following qualitative screening criteria were derived from existing criteria for use in the external flood and other hazards evaluation. The screening criteria listed below are organized from least to greatest in terms of the relative level of detail and scrutiny needed in a given hazard analysis to justify the application of a criterion. The criteria are compared against the guidance in the draft of Revision 1 of NUREG-1855 and the technical requirements in Part 6 of ASME/ANS RA-Sa-2009. Hypothetical examples of the application of the criteria are provided for some of the criteria.

1. *The hazard is included in the definition of another analyzed hazard.*

This criterion is the analogous to Criterion 4 of SR EXT-B1 in ASME/ANS RA-Sa-2009 and is included in the draft Revision 1 to NUREG-1855. This criterion would not used for screening, per se, but instead is applied to exclude from the other hazards—but not the entire PRA—those hazards that are already accounted for in another hazard analysis. As an example, this criterion could potentially be applied to a hail hazard if the effects from hail can be shown to be bounded by the effects from wind-borne missiles, as evaluated in a high winds hazard analysis.

2. *The impacts of the hazard cannot occur close enough to the plant to affect it.*

This criterion is analogous to Criterion 3 of supporting requirement (SR) EXT-B1 in ASME/ANS RA-Sa-2009 and is included in the draft Revision 1 to NUREG-1855. As an example, this criterion could potentially be applied to screen out the coastal erosion hazard for a plant that is hundreds of miles away from a coastline.

3. *The hazard does not result in a plant trip (manual or automatic) or a controlled manual shutdown and does not impact any structures, systems, and components (SSCs) that are required for accident mitigation from at-power transients or accidents. If credit is taken for operator actions to correct a condition to avoid a plant trip or controlled shutdown, it needs to be ensured that the credited operator actions and associated equipment have an exceedingly low probability of failure (i.e., collectively less than or equal to $1{\times}10^{-5}$) following the applicable supporting requirements in subsection 2-2.5 in Part 2 of part ASME/ANS RA-Sa-2009.*

The above criterion is taken from the draft Revision 1 of NUREG-1855 and is adapted based on the guidance in DC/COL-ISG-028. The above criterion is related to Criterion 5 of SR EXT-B1 in ASME/ANS RA-Sa-2009. The criterion in the draft of Revision 1 to NUREG-1855 allows for screening of slowly developing events based on a demonstration that there is sufficient time for a response to the hazard. In contrast, the above criterion requires an explicit demonstration of high reliability for the credited human actions and equipment, which is to be consistent with the relevant requirements in Part 2 of ASME/ANS RA-Sa-2009. The above criterion has been augmented in this way to preclude screening based on implicit assumptions that such response actions and equipment are highly reliable, as might otherwise be allowed by the criterion in the draft of Revision 1 to NUREG-1855. As such, quantitative human reliability and equipment analyses would be performed for any credited response actions or equipment to ensure a more objective basis for the application of the above criterion.

As an example, this criterion could potentially be used to screen out the low ambient temperature hazard for a plant. In this case, both human actions and equipment may be relied upon to prepare a plant for an impending low ambient temperature condition so as to avoid a potential plant shutdown. Without a quantitative reliability analysis, a qualitative analysis of the required human actions and equipment performance may result in an assumed reliability that might otherwise be unacceptable for the application of the above criterion.

Although provided for in SR EXT-B2, for this external flood and other hazards evaluation, hazards will not be screened out based solely on whether the related design criteria provided in NUREG-0800, "Standard Review Plan for the Review of Safety Analysis Reports for Nuclear Power Plants: LWR Edition[13]," are met. This is based on the fact that the plant design bases could potentially correspond to an event that is greater than the base CDF at the site, as discussed in the NRC Interim Staff Guidance document DC/COL-ISG-028 and NUREG/CR-2300. As such, this evaluation does not make use of Criterion 1 from SR EXT-B1 or Criterion A from SR EXT-C1 in ASME/ANS RA-Sa-2009.

II.C.2 Qualitative Screening Criteria Summary

In determining which of the last two criteria can be applied to screen a given hazard, the level of detail and scrutiny required by the hazard analysis generally increases as compared to a given criterion, as presented here. For example, meeting the second criterion requires the least amount of detail and scrutiny in the hazard analysis to demonstrate that the hazard cannot occur close enough to affect the plant. For hazards that do occur close enough to affect the plant, additional scrutiny would need to be applied in the hazard analysis to show that the hazard does not cause a plant shutdown or challenge safety-related SSCs. When applying any of these qualitative screening criteria, the range of magnitudes of a given hazard are considered for the recurrence frequencies of interest.

II.C.3 Quantitative Screening Criteria

The following quantitative screening criteria were derived from existing screening criteria for use in the external flood and other hazards evaluation.

1. *The hazard has a significantly lower mean frequency of occurrence than another hazard, taking into account the uncertainties in the estimates of both frequencies, and the considered hazard could not result in worse consequences than the consequences from the compared hazard. Significantly lower means that the considered hazard has a mean frequency of occurrence that is at least two orders of magnitude (i.e., 1 percent) less than the compared hazard.*

This criterion is related to Criterion 2 of SR EXT-B1 in ASME/ANS RA-Sa-2009, but differs in that significantly lower is explicitly defined as being at least 1 percent. This definition provides an objective measure for the comparison between the mean frequencies of occurrence of the two hazards and is intended to be consistent with similar usages of the definition of "significant" in ASME/ANS RA-Sa-2009 (e.g., the definition of significant accident sequence). Without this definition, the term could be subjectively applied and allow inconsistent screening of hazards.

2. *The current design-basis hazard has a mean frequency less than 10^{-5} per year, and the mean value of the conditional core damage probability (CCDP) is assessed to be less than 10^{-1}.*

This criterion is analogous to Criterion B of SR EXT-C1 in ASME/ANS RA-Sa-2009, but is being applied with the following caveat. Before a hazard is screened using this criterion, further investigation would be performed to determine whether there is a lower magnitude, but higher frequency hazard event that could produce a mean core damage frequency (CDF) that is greater than the mean CDF produced by the design basis hazard.

As an example, consider a plant with a design-basis hazard being analyzed has a mean frequency of occurrence of 10^{-5} per year and a mean CCDP of 10^{-1}. If applying the above criterion, the screening analysis would also need to show that the same hazard with a lower mean frequency of occurrence, say 10^{-4} per year, could not result in a CDF that is greater than the CDF associated with the design-basis hazard. Moreover, it would be shown that any hazard event of a specific magnitude that is screened out would be shown to contribute less than 1 percent to the total mean CDF for the hazard; and the cumulative value of all the screened hazard events of specific magnitudes would be shown to contribute less than 5 percent to the total mean CDF for that hazard.

3. *The core damage frequency of the external hazard, calculated using a bounding or demonstrably conservative analysis, has a mean value that is less than 10^{-6} per year.*

This criterion is analogous to Criterion C of SR EXT-C1 in ASME/ANS RA-Sa-2009. As discussed in the draft of Revision 1 to NUREG-1855, a bounding probabilistic analysis would be used to provide an upper limit of the risk metrics and would include the worst credible outcome of all known possible outcomes that result from the risk assessment of that item. Such an analysis would be bounding both in terms of the potential outcome and the likelihood of that outcome. A conservative probabilistic analysis would be used to develop a mean CDF estimate that is greater than the mean CDF estimate that would result from a best-estimate evaluation, but is less than the mean CDF estimate resulting from a bounding analysis. In general, the level of conservatism is characterized by the selection of the models, data, assumptions, and the level of detail used to analyze the hazard.

II.D Perform a PRA for Unscreened Hazards

For those hazards that cannot be shown to satisfy any of the above qualitative or quantitative screening criteria, the hazard would be analyzed quantitatively through the development of a PRA model. As discussed in the introduction, Part 8 provides the technical requirements for the development of an external flood hazard PRA and Part 9 provides the technical requirements for the development of a PRA related to internal or external hazards other than those considered in an internal events, internal flood, internal fire, seismic, high winds, or external flood hazard PRA. In general these requirements relate to the hazard analysis, plant fragility analysis, and the response analysis.

III. CONCLUSIONS

The external flood and other hazards for the Level 3 PRA Project is being developed to meet the technical requirements in ASME/ANS RA-Sa-2009, as endorsed in RG 1.200, and follows the approach provided in the draft of Revision 1 to NUREG-1855. The approach being used involves 1) reviewing the plant licensing basis and plant-specific data, 2) identifying the hazards to be considered, 3) performing a progressive screening analysis to exclude those hazards that are not significant contributors to the plant site risk, and 4) performing a detailed probabilistic analysis for each hazard that cannot be screened out.

The hazard identification process was informed by a survey of several industry and NRC guidance documents, the list of hazards provided in Appendix 6-A of ASME/ANS RA-Sa-2009 and ASME/ANS RA-Sb-2013, and the review of the plant licensing bases and plant specific data. The screening criteria used for this evaluation were derived primarily from the draft Revision 1 to NUREG-1855 and Part 6 of ASME/ANS RA-Sa-2009, and were also informed by Part 6 of ASME/ANS RA-Sb-2013 and DC/COL-ISG-028. As compared to the use of the related screening criteria in Section II.C, it is anticipated that the use of the screening criteria describe in this paper may require a greater level of detail and scrutiny for some of the considered hazards.

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