Initial Thoughts on Attributes of Probabilistic Flood Hazard Assessment for Nuclear Power Plants

Michelle T. Bensi, Ph.D.
U.S. Nuclear Regulatory Commission
Office of New Reactors
Division of Site Safety and Environmental Analysis

9th Nuclear Plant Current Issues Symposium: Moving Forward
December 7-10, 2014

Motivation

- Benefits of probabilistic risk assessment (PRA):
  - Facilitates risk-informed regulatory framework
  - Develop risk insights
  - Quantify and manage risk
  - Improve effectiveness by focusing on risk-significant activities
  - Many others…
- Current state of practice for flooding PRA
  - Experience with external flooding PRA for nuclear power plants (NPPs) is limited.
  - A well-established and broadly accepted method does not yet exist for performing probabilistic flood hazard assessment (PFHA) to address the range of exceedance frequencies of relevance for NPP PRAs.
- Extensive experience with other hazards
  - NRC has experience with probabilistic characterization of other hazards (e.g., probabilistic seismic hazard assessment, PSHA).
  - High-level concepts and approaches from PSHA may be generalized and applied to PFHA to define a series of attributes.

U.S.NRC
United States Nuclear Regulatory Commission
Protecting People and the Environment

Background: PFHA

Probabilistic flood hazard assessment: A systematic assessment of the frequency that a specified parameter or set of parameters representing flood severity (e.g., flood elevation, flood event duration, and associated effects) will be exceeded at a site or in a region during a specified exposure time.

- The results of a PFHA are expressed as estimated probabilities per unit time or estimated frequencies.
- Estimates of flood hazard can be attained only with significant uncertainty, particularly for low exceedance frequencies.
- It is critical to properly assess, account for, and propagate relevant uncertainties.

Background: Existing Resources

- Regulatory Guide 1.200 endorses ASME/ANS RA-Sa-2009 (PRA Standard)*
- Part 8 of the PRA Standard establishes technical requirements for a PRA of the external flood hazard group
- Part 8 describes three technical elements
  1. External Flood Hazard Analysis
  2. External Flood Fragility Evaluation
  3. External Flood Plant Response Model and Quantification

*RG 1.200 is titled: “An Approach for Determining the Technical Adequacy of Probabilistic Risk Assessment Results for Risk-Informed Activities”
ASME/ANS RA-Sa-2009 is titled: “Addenda to ASME/ANS RA-Sa-2009 Standard for Level 1 / Large Early Release Frequency Probabilistic Risk Assessment for Nuclear Power Plant Applications”

Background: PRA Standard

The **high-level requirements** defined in the PRA Standard for external flooding hazard analysis are not detailed expectations.

Designator	Requirement
HLR-XFHA-A	The frequency of external flooding at the site shall be based on site-specific probabilistic hazard analysis (existing or new) that reflects recent available regional and site-specific information. The external-flooding hazard analysis shall use up-to-date databases. Uncertainties in the models and parameter values shall be properly accounted for and fully propagated to obtain a family of hazard curves from which a mean hazard curve can be derived.
HLR-XFHA-B	Documentation of the external flood hazard analysis shall be consistent with the applicable supporting requirements.

The lack of detail for flooding hazard may be contrasted with the more detailed expectations with respect to seismic PRA.

U.S.NRC
United States Nuclear Regulatory Commission
Protecting People and the Environment

Background: PRA Standard

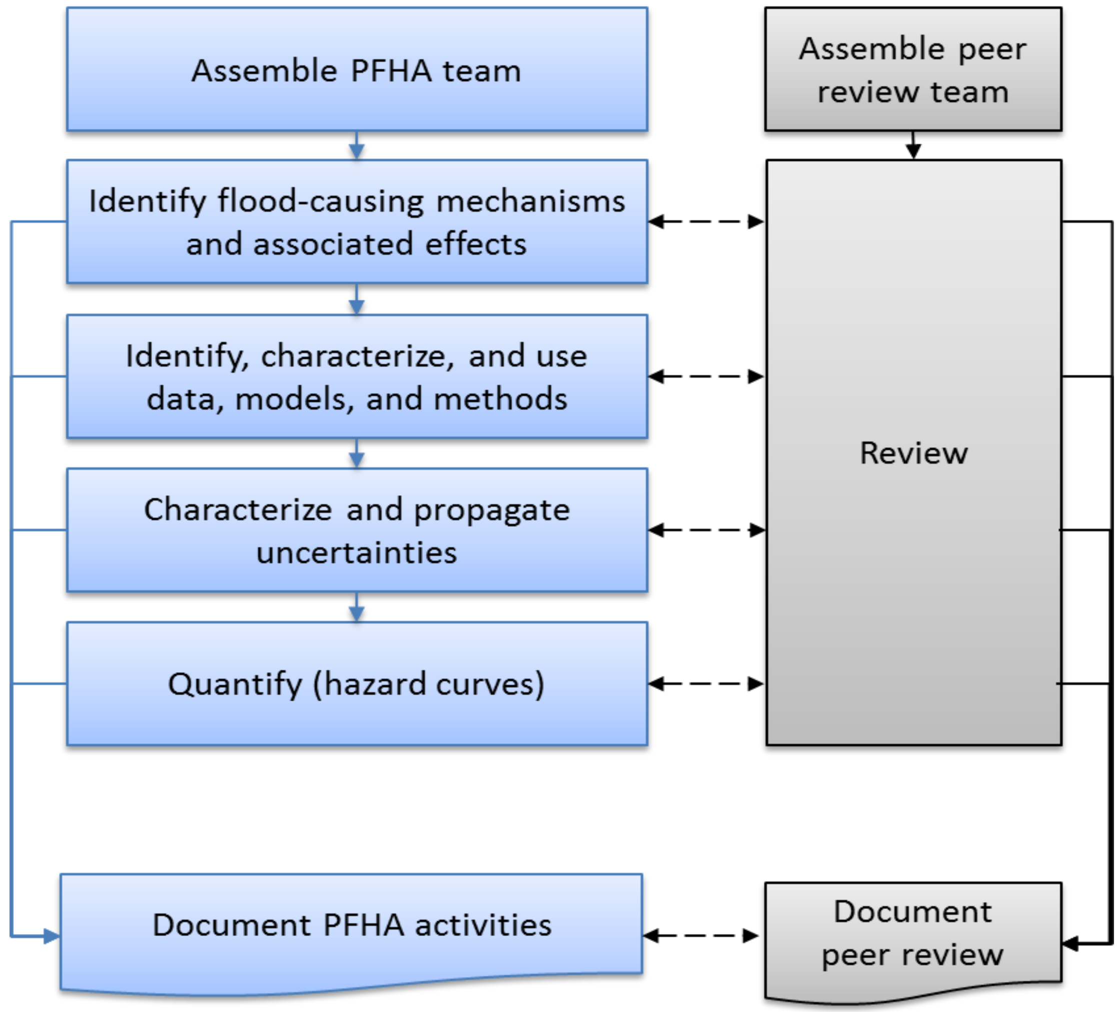
The **supporting requirements** in the PRA Standard call for use of regional and site-specific information and up-to-date data.

Index No. XFHA-A	Capability Category I	Capability Category II	Capability Category III
XFHA-A1	Not Defined	In the hazard analysis for extreme local precipitation, USE up-to-date data for the relevant phenomena. It is acceptable to utilize both site-specific and regional data.	
XFHA-A2	Not Defined	In the hazard analysis for extreme river flooding, including floods due to single or cascading dam failures, USE up-to-date data for the relevant phenomena. It is acceptable to utilize both site-specific and regional data.	
XFHA-A3	Not Defined	In the hazard analysis for extreme ocean (coastal and estuary) flooding, USE up-to-date data for the relevant phenomena. It is acceptable to utilize both site-specific and regional data.	
XFHA-A4	Not Defined	In the hazard analysis for extreme lake flooding, USE up-to- date data for the relevant phenomena. ACCOUNT for high water levels, surges, and wind-wave effects.	
XFHA-A5	Not Defined	In the hazard analysis for extreme tsunami flooding, USE up-to-date data for the relevant phenomena. It is acceptable to utilize both site-specific and regional or ocean wide data.	
XFHA-A6	Not Defined	In the hazard analysis for flooding caused by the failure of a dam, levee, or dike, USE up-to-date data for the failure probabilities and effects.	

Background: PRA Standard

- PRA Standard makes several observations regarding the current state of practice
  - Collective experience with external-flooding PRA is limited
  - Detailed guidance documents are unavailable
  - A flood PRA may need to "improvise its approach to external-flooding analysis following the overall methodology requirements in [Part 8]."
- PRA Standard stresses the importance of peer review
- Additional experience has been gained and present understanding is evolving

Initial Thoughts: Elements of PFHA for NPPs



Attribute: Comprehensive Evaluation

Challenges

A hazard curve represents the frequency of exceeding a relevant parameter of interest when considering all relevant flood-causing mechanisms and combined events. The PRA then aggregates risk from all mechanisms.

Attributes

- Captures the contributions from all relevant flood hazard mechanisms affecting the site (including combinations of events)
- Characterizes the hazard using flood height and associated effects as well as flood event duration
- Treats all combinations of contributing factors and events that are consistent with local and regional hydrometeorological characteristics
- Considers contributions from all relevant durations and temporal distributions

U.S.NRC
United States Nuclear Regulatory Commission
Protecting People and the Environment

Attribute: Team Approach

Challenges

- Gaps in collective understanding
- Limitations in technical understanding lead to differences in technical opinion regarding appropriate data, models, and methods (DMMs)
- Limited observations increase the importance and degree to which expert judgment may be employed

Attributes

- Team of analysts develops the PFHA
  - Expertise in the fields of relevance (e.g., hydrology, meteorology, oceanography, probability/statistics)
  - Sufficient size that the backgrounds of analysts are diverse and complementary
- Explicitly captures and accounts for the center, body, and range of technically defensible interpretations of available DMMs
- Uses transparent, repeatable, and structured process involving appropriate experts

Attribute: Technically defensible DMMs

Challenges

- Reliability of commonly applied flood frequency estimation methods depends heavily on the length, stationarity, and spatial homogeneity of the input data record
- Traditional sources of information have non-ideal characteristics that result in limits on the credible and technically defensible extrapolation of conventional flood frequency analysis
- Experience has shown that a single approach may not be sufficient for providing estimates of extreme floods over the full range of annual exceedance frequencies

Attributes

- Results from a number of approaches are appropriately considered to capture epistemic uncertainties and to yield a family of hazard curves
- Results from technically defensible DMMs are considered, including alternative, composite, and new DMMs
- Use of conventional flood frequency analysis alone to estimate flooding hazards for long return periods is not generally supported

Attribute: Uncertainties and quantification

Challenge

Understanding uncertainties is an important component of deterministic or probabilistic hazard assessment.

Attributes

- Accounts for aleatory variability and epistemic uncertainty
  - Aleatory variability (inherent randomness in a process)
    - Hazard calculations integrate over the distributions representing variability to yield a single hazard curve
  - Epistemic uncertainties (from lack of knowledge)
    - Expressed by incorporating multiple assumptions and technically defensible DMMs
    - Multiple interpretations are propagated through the analysis
- Hazard characterization represented as a family or suite of hazard curves from which the statistics of the hazard estimates are calculated, yielding fractiles and the mean and median hazard
- Explicit and transparent method to account for and propagate aleatory variability and epistemic uncertainty

Attribute: Peer Review

Challenges

The PRA Standard states:

> "The collective experience with PRA external-flooding analysis is limited. Because of this limited experience, and the unavailability of any detailed methodology guidance documents, the analyst team may need to improvise its approach to external-flooding analysis following the overall methodology requirements in this Part. Given the above, an extensive peer review is very important if an analysis under [Part 8] is undertaken."

Attributes

- Reviewed by an independent peer review team, preferably using an in-process review
- The peer reviewers focus on their review on factors such as:
  - Appropriateness of the flood-causing mechanisms considered
  - Means by which the contributions of mechanisms are aggregated
  - Sufficiency of the incorporation of the center, body, and range of technically defensible DMMs
  - Assumptions
  - The treatment of aleatory variability and epistemic uncertainty
  - Validation and verification of DMMs
- Peer reviewers have expertise in fields of relevance
- Peer review team of sufficient size that the backgrounds of reviewers are appropriately diverse and complementary

U.S.NRC
United States Nuclear Regulatory Commission
Protecting People and the Environment

Summary

- Experience with PFHA for NPPs is limited.
- PFHAs developed for other applications are generally not directly applicable to many NPP PRA applications due to return periods of relevance.
- NRC has experience with probabilistic characterization of other hazards (e.g., PSHA).
- High-level concepts and approaches from PSHA may be generalized and applied to PFHA to yield a series of attributes.

Disclaimer

Any opinions, findings and conclusions expressed in this presentation are those of the author and do not necessarily reflect the views of the United States Nuclear Regulatory Commission

Acknowledgement

The presenter acknowledges the contributions to the material in this presentation from her colleagues in the Office of New Reactors, the Office of Nuclear Reactor Regulation, and the Office of Research.