Challenges Associated with the Fragility and Reliability Assessment of Flood Protection Measures and Recent Initiatives

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

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Motivation

- Benefits of probabilistic risk assessment (PRA):
  - Facilitates risk-informed regulatory framework
  - Develop risk insights
  - Quantify and manage risks
  - Improve effectiveness by focusing on risk-significant activities
  - Many others…
- Current state of practice for flooding fragilities for PRA
  - Use of external flooding fragilities for nuclear power plants (NPPs) is limited
- NRC has experience with the use of fragilities for other hazards (e.g., seismic PRA)

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Background: Flood Fragility

Flood fragility: The susceptibility of plant structures, systems and components (SSCs) to damage or failure as a function of the severity of external flooding.

- Fragility curves are a probabilistic mapping between a site-specific measure of flood severity and component (e.g., flood protection feature) performance
  - Each fragility function describes the probability that a component experiences a specified damage state or greater for a given level of flood severity
- Fragility functions may be developed using:
  - Empirical observations
  - Analytical approaches
  - Engineering judgement
  - Some combination of the above
- Flood fragility functions may be characterized by:
  - A step function (i.e., a cliff-edge) for overtopping failure modes
  - Smooth functions for failure modes associated with static and dynamic loading

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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"

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Background: PRA Standard

The **high-level requirements and supporting requirements** defined in the PRA Standard for external flood fragility analysis are not detailed expectations.

Designator	Requirement
HLR-XFFR-A	An external flood fragility evaluation shall be performed to estimate plant-specific, realistic susceptibilities, fragilities for those structures, or systems, or components, or a combination thereof, whose failure contributes to core damage or large early release, or both.
HLR-XFFR-B	Documentation of the external flood fragility analysis shall be consistent with the applicable supporting requirements.

Index No. XFHA-A	Capability Category I	Capability Category II	Capability Category III
XFFR-A1	Not Defined	In the evaluation of flood fragilities of structures and exposed equipment (low-lying equipment on the site, intake and ultimate-heat-sink equipment, etc.), USE plant-specific data. In this evaluation, INCLUDE the findings of a plant walkdown. It is acceptable in the fragility analysis for both capacity and demand to apply the standard methodology used for seismic events, with appropriate modifications unique to the flooding event being studied.	
XFFR-A2	IDENTIFY plant structures, systems, and components that are vulnerable to the flood hazards.		

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Background: PRA Standard

- PRA Standard makes several observations regarding flood fragility
  - Flood-caused failure of equipment is typically due to immersion, but the failure may be due to flow-induced phenomena (particularly for structures)
    - It is assumed that equipment submerged by the flood waters and not protected will "fail"
  - With sufficient warning time, plant staff can secure equipment
  - Walkdowns should play a major role in identifying potential problems, supplemented by an evaluation of structural drawings
  - Fragility analysis may be based on the standard methodology used for seismic events, with appropriate modifications unique to the flooding event being studied - modifications need to be subject to a peer review
- Additional experience has been gained and present understanding is evolving based on:
  - Recent operating experience
  - Insights from the NTTF R2.3 walkdowns

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Challenges

- Challenges to adapting established fragility methods to flooding
  - Availability of data for quantitative assessment (e.g., operating experience and testing) is still limited
  - Lack of standardized test protocols
  - Importance of human actions (e.g., for construction or installation of flood protection features)
  - Diversity of component types
    - walls
    - seals
    - sandbags
    - sump pumps
    - doors
    - berms
    - gates
    - others…
  - System-level aspects
  - Multi-dimensional hazard characterization (i.e., flood height, associated effects, and flood event duration)

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Current Initiatives

- Integrated assessment framework (JLD-ISG-2012-05)
  - Provides framework for deterministic assessment informed by PRA concepts and techniques (e.g., use of manual action evaluations, logic tools)
  - Also allows use of PRA and margins-type assessments
- Office of Research initiatives
  - Ongoing research projects:
    - Manual action assessment
    - Seal reliability
    - "Total plant response" assessment
  - Revision of Regulatory Guide 1.102, "Flood Protection of Nuclear Power Plants"
- Evaluation of lessons-learned:
  - NTTF R2.3 walkdowns
  - Operating experience
  - Significance Determination Process evaluations under the Reactor Oversight Process

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