Probabilistic Flood Hazard Assessment
Storm Surge

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2016 DOE Natural Phenomena Hazards
October 19, 2016
Design Bases vs. Probabilistic Risk Assessment

- Nuclear power plants are designed using “Design Basis” assumptions
  - Bounding assessments are used to encompass any event that could affect a nuclear power plant
  - The plant is designed to survive various “design basis accidents”
    - Loss of Coolant Accident (LOCA)
    - Loss of Offsite Power (LOOP)
    - Seismic event
    - External Flooding

- An alternative way to assess the safety of nuclear power plants is through a Probabilistic Risk Assessment (PRA)
  - Allows the plant to quantitatively assess risk
  - Identifies vulnerabilities that design bases does not consider
Deterministic/Bounding vs. Probabilistic Risk Assessments

Deterministic/Bounding Assessment

- Single point of failure – any single component can fail, but no more than one component will fail
- Worst-case operating conditions assumed
- No maintenance unavailability considered
- No human actions allowed for first 10 minutes, followed by no failure of subsequent human actions
- No common cause failures assumed

Probabilistic Risk Assessment

- Component can fail, but failure is based on probability from plant and industry operating experience
- Nominal operating conditions assumed
- Maintenance unavailability based on plant history
- Probability of failure assigned to required human actions
- Common cause is explicitly considered with probability based on industry experience
Lessons Learned from Nuclear Accidents

- **Three Mile Island**
  - Operators may not take appropriate actions
  - An event that is smaller than the Design Basis accident can still lead to core damage
  - More than one thing can go wrong

- **Chernobyl**
  - Failure to follow procedures and adhere to safety requirements can lead to disaster
  - Safety Culture is important to safe operation of nuclear power plants

- **Fukushima Dai-ichi**
  - Beyond design basis accidents can and do occur
  - External events have the potential to disable multiple safety systems
A PRA requires an estimate of the frequency of an initiating event
   – An initiating event is an event that causes or demands the immediate shut-down (SCRAM) of a nuclear power plant

A Probabilistic Flood Hazard Assessment (PFHA) is used to estimate the frequency of external flooding hazards

Historical records are limited to a few hundred years at best

Extrapolation to extremely low frequencies is required to assess risk to nuclear power plants
   – For example, frequency of $10^{-6}$/yr – equivalent to an Annual Exceedance Probability (AEP) of $10^{-6}$

Design bases uses the concept of a Probable Maximum Flood (PMF), but makes no attempt to calculate the frequency of occurrence of such a flood
Frequency Analysis as Part of a PFHA

- Extrapolation beyond twice the historical record is not considered to be credible
- A variety of methods are used to extend the effective historical record
  - Use of independent, but applicable measurements (e.g., rain gauges)
  - Transposition of observed storms from one location to another
  - Development of synthetic storms to simulate flooding impact with Monte Carlo analysis
  - Use of paleo (i.e., outside of the historical observation) evidence to inform the data
- All of these techniques involve uncertainty, so it is important to characterize the uncertainty
- Independent peer reviewers lend credence to the analysis
EPRI Report on Storm Surge

- ERPI report 3002008111, Probabilistic Flooding Hazard Assessment for Storm Surge with an Example Based on Historical Water Levels
- Provides generic PFHA process as applied to Storm Surge
- Available data and storm type that leads to storm surges for site of interest determines the simulation approach
  - Controlling storm is a hurricane: atmospheric parameters such as central pressure deficit, radius of maximum wind, and maximum wind speed as well as tidal levels can be modeled in the Monte Carlo simulation
  - Controlling storm is not hurricane: historical water levels can be utilized to determine mean sea level or average lake level, storm surge level, and wind-wave effects using Monte Carlo simulation techniques
Example PFHA for Storm Surge

- Site located on one of the Great Lakes
- Site is not subject to fully formed hurricanes, so using a Joint Probability Method that models the atmospheric parameters is not appropriate
- Long history (greater than 100 years) of lake levels is available including paleo data that can extend the record to 4000 years
- Lake buoys provide water level data
- Wave height, period, and direction determined by U.S. Army Corps of Engineers hindcast datasets
Monte Carlo Simulation for Storm Surge

- Probability density functions (PDFs) created to represent:
  - Initial lake level
  - Storm surge height
  - Wind-wave parameters

- It is not always obvious which PDF provides the best fit to the existing data and which data source is most applicable:
  - Logic trees used to weight alternative PDFs and data sources to each parameter
  - Process is similar to what is used by the Senior Seismic Hazard Analysis Committee (SSHAC)

- Monte Carlo simulations used to develop still water level hazard curve and total water level (including wave run-up) hazard curve:
  - Sensitivity studies can be run to determine the sensitivity of the analysis results to particular assumptions
Probabilistic Storm Surge Hazard Assessment Example

Environmental Variables

Data

Surge height data from water level gauges
Lake level data from gauges and paleo reconstructions
Wind-wave data from USACE hindcast study

Models

Surge height
Multiple PDFs
Surge Height AEP

Lake level
Multiple PDFs
Probability Lake Level AEP

Wind-Waves
Multiple PDFs
Wind-Waves AEP

Monte Carlo Simulation

Sample from stochastic models and account for correlations

Compute total water level

Continue sampling until sufficient number of samples is achieved for stable total water level hazard curve
Example Logic Tree to Determine Weighted PDF

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<th>Variable</th>
<th>PDF Type</th>
<th>PDF Shape Parameter</th>
<th>Cumulative Subjective Weight</th>
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</tbody>
</table>

Expert judgement and objective criteria used to set weighting parameters
Example of Storm Surge Height Weighted Mean

Mean level determined after applying the logic tree’s weighting factors
Example Still Water and Total Water Levels

Structures may be impacted by waves at frequencies below $1 \times 10^{-3}$/year
Uncertainty and Peer Review

- Two important aspects of a PFHA are uncertainty analysis and peer review.
- Uncertainty analysis attempts to characterize the range of uncertainty in the analysis.
  - Logic trees and sensitivity studies are techniques to control and characterize the uncertainty.
- Peer reviews lends credibility to the analysis by getting independent experts to provide comments and findings.
  - Engaging a peer review team early and often in the PFHA process helps prevent significant re-work if the peer review team identifies an important issue that needs to be resolved.
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