Integrated Use of Modeling and Simulation in High Winds Probabilistic Risk Assessment

LWRS LIGHT WATER REACTOR SUSTAINABILITY

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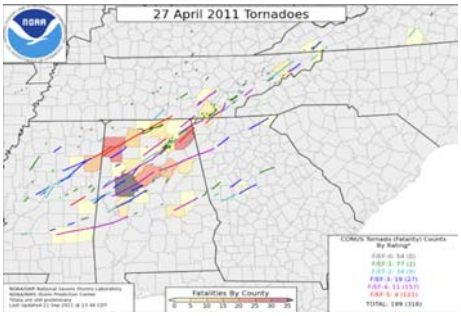
External Hazards Risk-Informed Decision-making Activities: Flooding and High Winds

Acknowledgements

- **Research team**
  - Stephen Hess – Jensen Hughes
  - Steven Prescott – Idaho National Laboratory
  - Linyu Lin – North Carolina State University
  - Nam Dinh – North Carolina State University
  - Ramprasad Sampath – Centroid Lab
  - Niels Montanari – Centroid Lab
- **Research supported by the U.S. Department of Energy through the Light Water Reactor Sustainability (LWRS) Program**

Example of significant high winds Events at nuclear power plant (NPP) sites

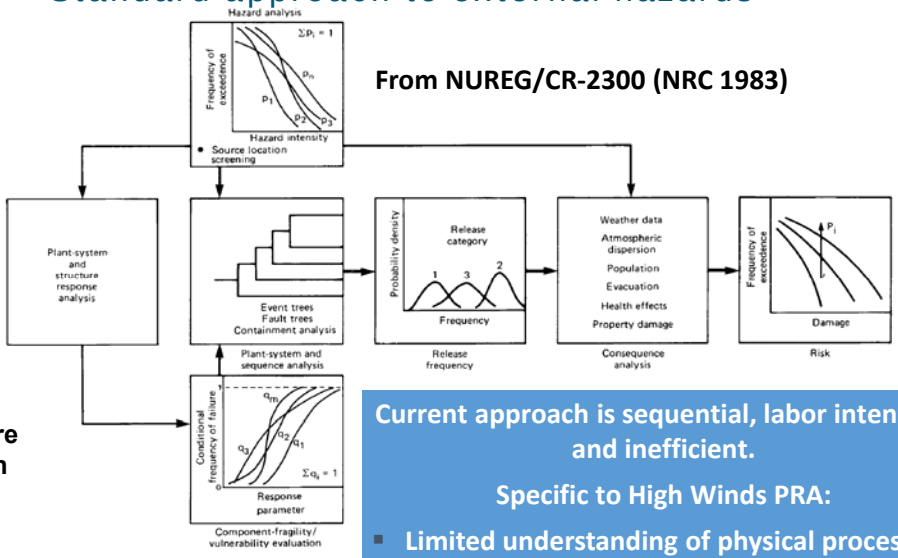
- **Turkey Point – Hurricane Andrew**
  - 1992 Category 4 hurricane
  - Extensive precautions taken by NPP site in preparation of event
  - Loss of off-site power for 5 days
  - Significant damage to local infrastructure / some damage on-site
- **Browns Ferry – Tornado Events**
  - Widespread severe weather over 4 days in April 2011
  - More than 200 tornadoes over 5 states
  - Trip of all three reactors and loss of off-site power for 3 days



Complete compilation of events in EPRI 3002003107

Standard approach to external hazards

- Conduct hazard characterization
  - Hazard intensity versus frequency
- Estimate probability of hazard impact on plant infrastructure (e.g., components)
- Determine infrastructure failure probability given hazard event
  - Fragility models
- Integrate into plant Probabilistic Risk Assessment (PRA) using standard event tree/fault tree methods



From NUREG/CR-2300 (NRC 1983)

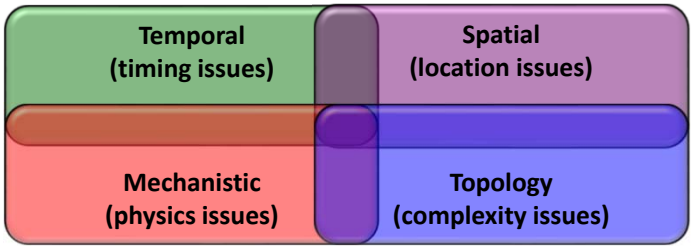
Current approach is sequential, labor intensive, and inefficient.

Specific to High Winds PRA:

- Limited understanding of physical processes → large uncertainties
- Limited availability of data
  - Records for 50 to 100 years
  - Rely on correlations rather than physics
  - Limited fragility data
- Sensitivity of results to assumptions

Modeling and simulation within risk assessment

- **Consistent methods are needed to enable decision-makers to evaluate risks, e.g., impact on safety**
- **Integrated modeling and simulation (Mod Sim) can provide predictive capabilities to better understand facilities and increase confidence**
  - This approach ties physics to predictive models
- **Can use visualization capabilities for insights & decision-making support**
- **Four areas that are a challenge to the traditional approach to risk**
  - These are addressed directly in modeling and simulation
  - Results are produced in terms of these areas (e.g., the time when something happens is provided)
- **Computers are improving**
- **Software is improving**
- **Our predictive models are improving**



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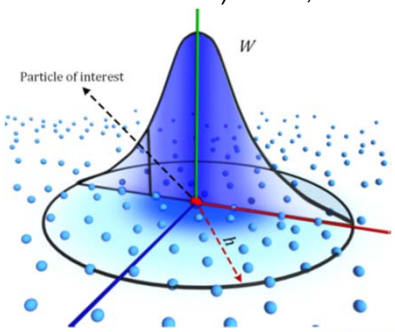
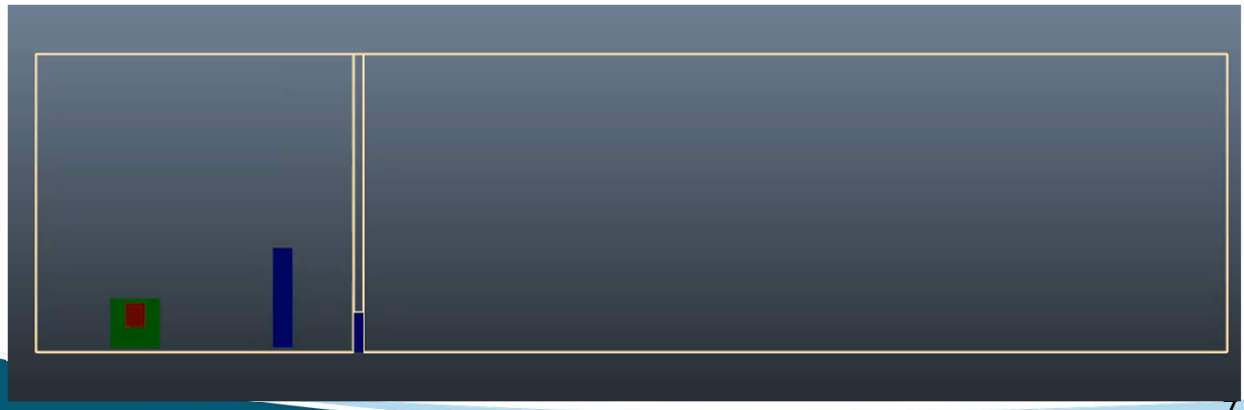
Our research has investigated simulation into phenomena such as high winds

- **Wind phenomena to be modeled in Mod/Sim Framework**
  - Aerodynamics of the local windfield
  - Structural loading and response of plant systems, structures, or components (SSCs)
  - Wind generated missiles (lift, flight trajectory, etc.) and whether or not they impact particular plant SSCs
  - Damage imparted to plant SSCs due to impact with a wind-borne missile
- **Research has investigated Smooth Particle Hydrodynamics (SPH)**
  - Selected based on promising results in application to external flooding hazard
    - However, some challenges when moving from slow, dense fluid (external flood water) to fast, less-dense fluid (air in high winds)
- **SPH originally developed in late 1970s**
  - Mesh-free fluid simulation → fluid as individual particles
  - Properties and equations of motion based on fluid dynamics
  - Allows evaluation of complex interfaces, multiple fluids



SPH wind example (with “debris”)

- **Repurpose SPH tool (originally developed for flooding → water as the fluid of interest)**
- **This tool has been coupled to a “scenario generator” tool that describes the probabilistic elements of a potential risk sequence, for example**
  - River flood enters the NPP site boundary
  - High-wind event is experienced at the NPP
- **Captures the physics directly in the risk scenario**



Conclusions

- Our team is demonstrating a Mod/Sim risk-assessment by combining physics-based models with probabilistic analysis
- Provides opportunity to enhance realism in external hazards risk models
  - Also provides direct solutions to many of vexing issues found in PRA
    - Timing
    - Phenomena representation
    - Spatial considerations
  - A Mod/Sim approach captures the NPP characteristics directly
    - For example, scenario time represented by core heat-up versus abstracted mission-time

Sustaining National Nuclear Assets

http://lwrs.inl.gov