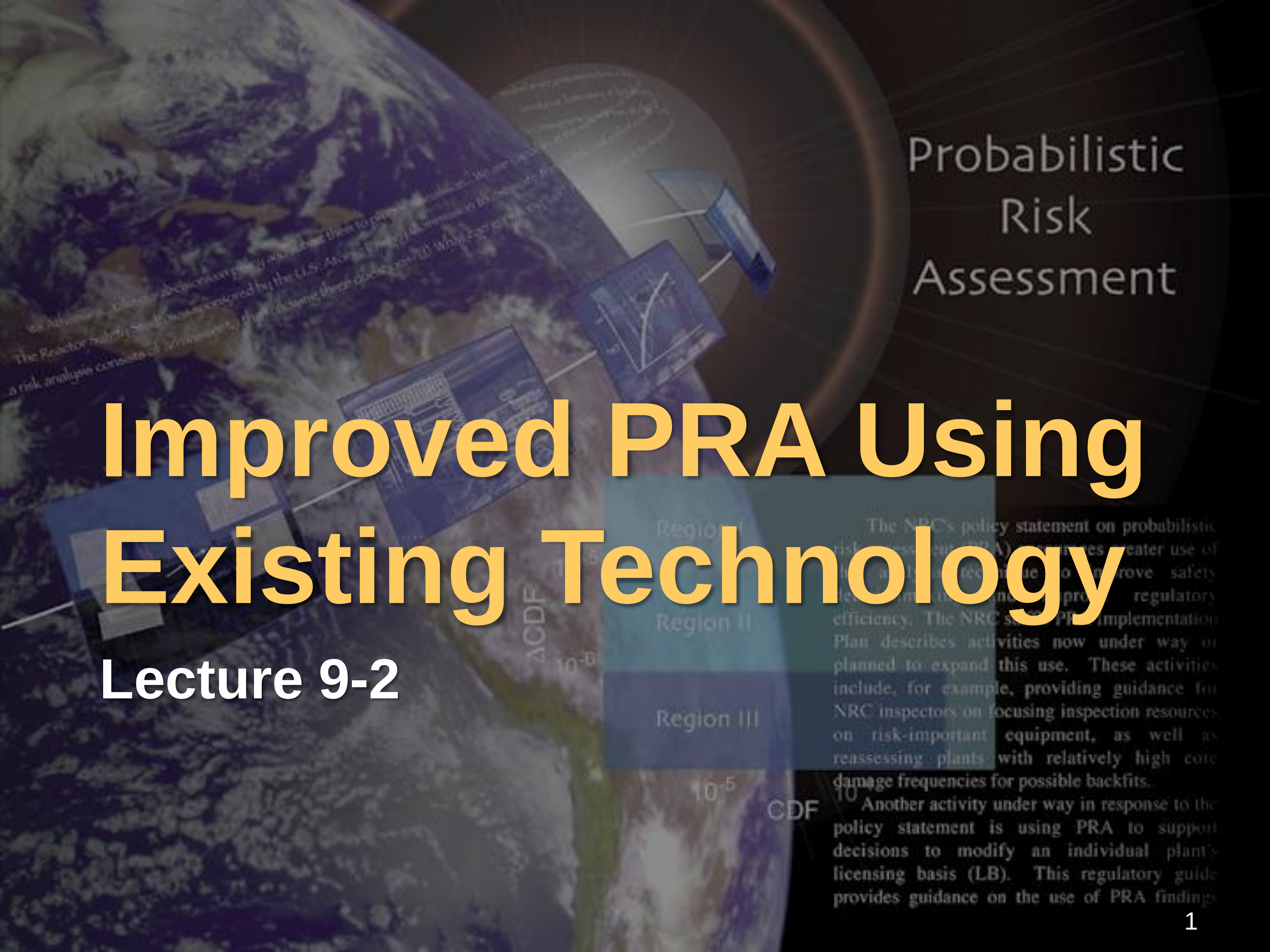

Improved PRA Using Existing Technology

Lecture 9-2

Key Topics

- Improved modeling – motivation and cautions
- Example areas
  - Non-stationary processes
  - Time dependence
  - Supplementing sparse data
    - Mechanistic models
    - Mining operational experience
  - Informative prior distributions
  - Model uncertainties

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Resources

- Markov modeling, simulation modeling, and general reliability modeling (including non-Poisson processes) are covered by numerous textbooks, e.g.,
  - A. Papoulis, *Probability, Random Variables, and Stochastic Processes*, McGraw-Hill, New York, 1965
  - P. Bratley, B.L. Fox, and L.E. Schrage, *A Guide to Simulation, Second Edition*, Springer-Verlag, New York, 1987.
  - R.E. Barlow and F. Proschan, *Statistical Theory of Reliability and Life Testing: Probability Models*, Second Edition, To Begin With, Silver Spring, MD, 1975.
- The annual Winter Simulation Conference provides a good snapshot of ongoing activities in multiple areas: https://informs-sim.org/

Other References

- Siu, N., et al., "Qualitative PRA insights from operational events," *Proceedings 14th International Conference on Probabilistic Safety Assessment and Management (PSAM 14)*, Los Angeles, CA, September 16-21, 2018. (ADAMS ML17268A021)
- P. Raynaud, et al., "Important Aspects of Probabilistic Fracture Mechanics Analyses," *TLR-RES/DE/CIB-2018-01*, U.S. Nuclear Regulatory Commission, September 14, 2018. (ADAMS ML18178A431)
- U.S. Nuclear Regulatory Commission, "Davis-Besse Reactor Pressure Vessel Head Degradation: Overview, Lessons Learned, and NRC Actions Based on Lessons Learned," *NUREG/BR-0353, Rev. 1*, August 2008.
- T. J. McIntyre and N. Siu, "Electric power recovery at TMI-1, a simulation model," *Proceedings International ANS/ENS Topical Meeting on Thermal Reactor Safety*, San Diego, California, February 2-6, 1986, pp. VIII.6-1 through VIII.6-7.
- V.N. Dang, D.L. Deoss, and N. Siu, "Event simulation for availability analysis of dynamic systems," *Transactions Eleventh International Meeting on Structural Mechanics in Reactor Technology*, Tokyo, Japan, August 18-23, 1991, Volume M, pp. 31-36.

Other References (cont.)

- J. Lane, "U.S. NRC Operational Experience Data Collection Program," NEA Workshop on the Use of Operational Experience in PSA, Boulogne-Billancourt, France, April 26-27, 2018. (ADAMS ML18123A479)
- N. Siu and D.L. Kelly, "Bayesian parameter estimation in probabilistic risk assessment," *Reliability Engineering and System Safety*, **62**, 89-116, 1998.
- C.L. Atwood, et al., "Handbook of Parameter Estimation for Probabilistic Risk Assessment," *NUREG/CR-6823*, September 2003.
- E. Droguett and A. Mosleh, "Bayesian methodology for model uncertainty using model performance data," *Risk Analysis*, **28**, No. 5, 1457-1476, 2008

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Observations

- Many PRA challenges identified in Lecture 9-1 (e.g., improved treatment of causality) can be met using currently available technology (methods, general models, tools, data)
- Technology might be routine in other disciplines and industries;* might need effort to identify and adapt
- User decisions to make use depend on familiarity and comfort as well as problem needs

*See, for example, the annual Winter Simulation Conferences: https://informs-sim.org/

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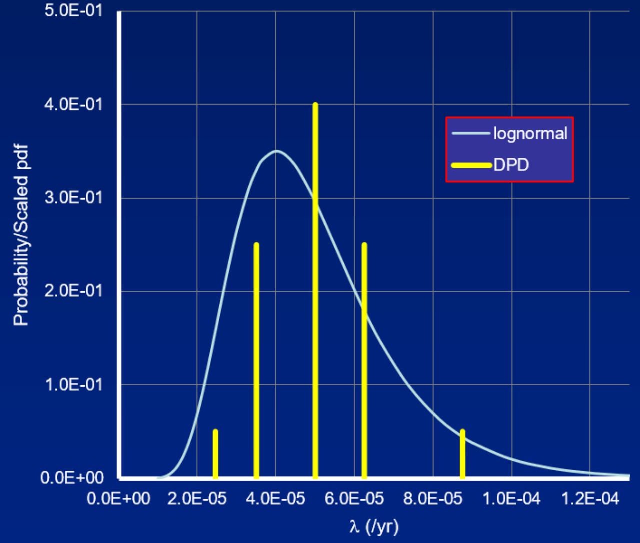
Historical Example – Discrete Probability Distributions (DPDs)

- Used in some early PRAs to quantify epistemic uncertainties
- Supported simple implementation of Bayes' Theorem
- Analyst selects anchor points and probabilities
- Application to continuous variables (example):



- Concerns
  - Loss of upper and lower tails
  - Sensitivity to choice of anchor point as well as probability
  - Amplification when applied to non-intuitive parameters (e.g., lognormal μ and σ)
- Simple, but exact numerical integration methods and tools available

Knowledge Check

- Given a DPD $\{x_i, p_i\}$, i=1,…,N what is the mean value of X?
- How does the use of DPDs help in the evaluation of Bayes' Theorem?

Motivation

Improved modeling can

- Lead to improved results and insights (relevant to the decision problem)
- Improve stakeholder
  - Confidence in PRA results and insights
  - Trust in PRA and RIDM process

Cautions

- Reminder: more detail ≠> "better"
  - Increased modeling, data, and computational requirements
  - Without treatment of new dependencies, potentially unrealistic (and unusable) results

$$P\{A \cup B\} = P\{A\} + P\{B\} - P\{A \cap B\}$$

  - To sceptics, increasing complexity can be viewed as an attempt to obfuscate and disenfranchise

Cautions (cont.)

- Often a large jump from theoretically sound ideas to practicable, “industrial-grade” solutions
- Examples
  - Mechanistic modeling of dependent failures
  - Mechanistic modeling of external hazards (tsunamis)

Dependent Failures – Example

"…manual reactor shutdown … conservatively initiated ... due to concern for the safety and well being of a diver working in the … Unit 2 circulating water pump house discharge piping … communications with one diver was [sic] lost and the retrieval efforts by a second and third diver were initially unsuccessful in reestablishing contact.. The plant equipment and systems … worked as designed. The divers were unharmed."

- LER 266/00-001

Dependent Failures – Example

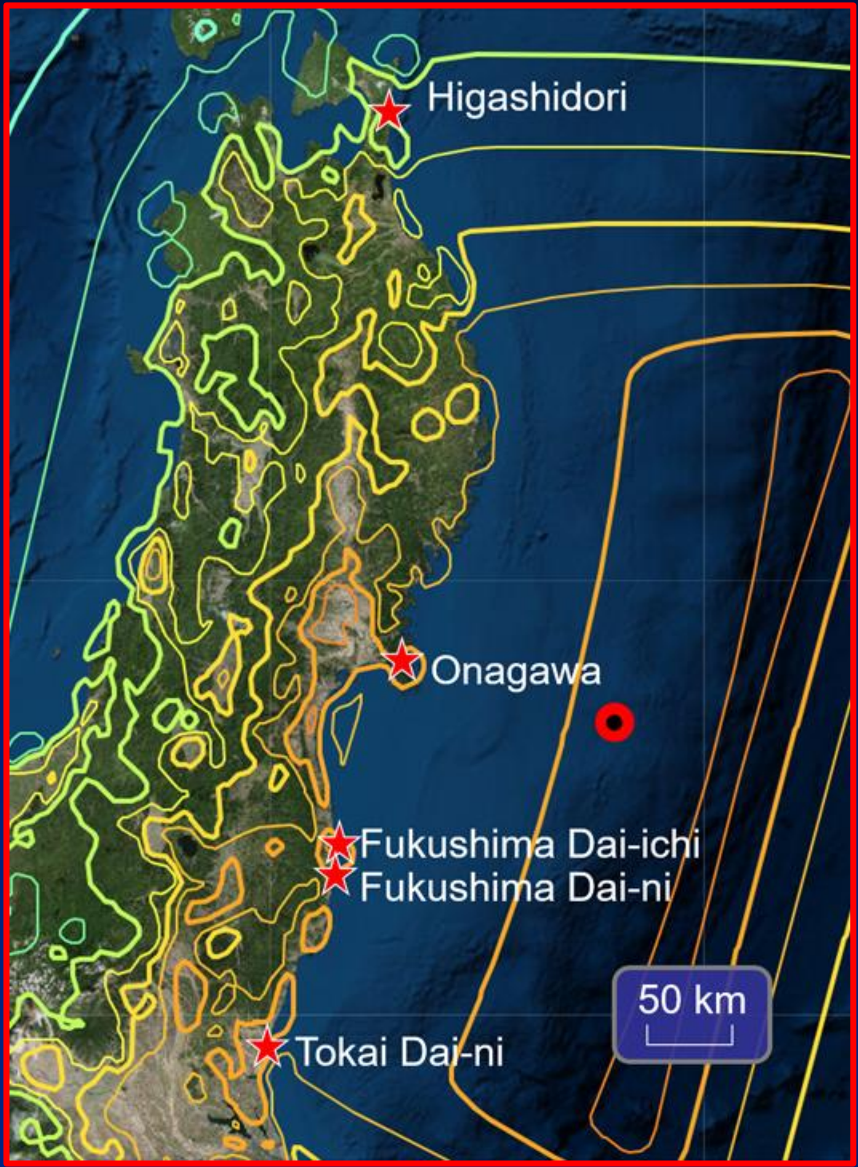
"…the station declared all Core Standby Cooling Systems (CSCS), Emergency Core Cooling Systems (ECCS), and Diesel Generators (DG) inoperable due to foreign material identified on the floor of the service water tunnel…Although the systems were declared inoperable, they were available. The foreign material was an injectable sealant foam substance which had been used … in the Lake Screen House (LSH) to seal water seepage cracks."

- LER 373/96-008

Tsunami Modeling – Example

- Heights
  - Fukushima Dai-ichi:
    - Design calculation: 6.1 m
    - Actual: 13.1 m
  - Fukushima Dai-ni:
    - Design calculation: 5.2 m
    - Actual: 9.1 m
- Reasons for site-to-site differences (~15 km separation)
  - Bathymetry
  - Superposition

=> Details matter!



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Some Current Examples

- Non-stationary processes
- Time dependence
- Supplementing sparse data
  - Mechanistic models
  - Operational experience
- Informative prior distributions
- Model uncertainties

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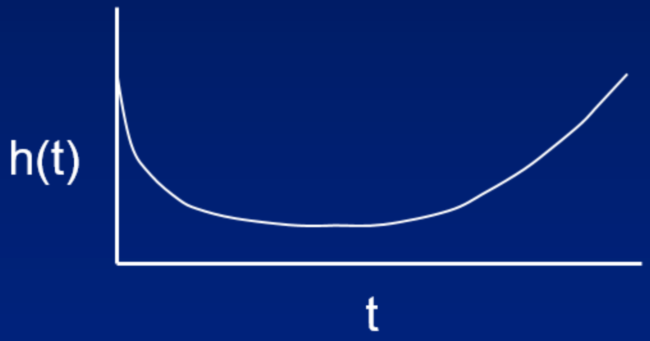
Non-Stationary Processes

- Concept: relax fundamental Poisson process modeling assumption (memoryless process)
- Available examples:
  - Ageing models
  - General reliability
- Other potential applications:
  - External hazards



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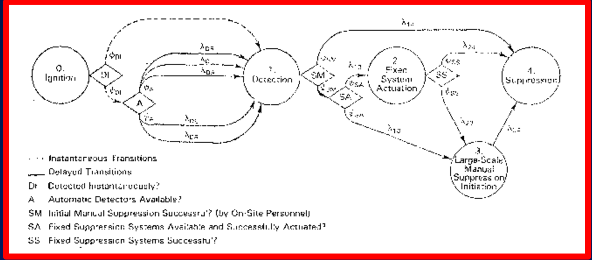
Time Dependence

- Concept: improve parametric modeling of time-dependent processes
- Available examples
  - Fire suppression
  - Internal flood frequency
- Potential future applications
  - HRA ("recovery actions" including FLEX)
  - Pre-initiator warning time and actions



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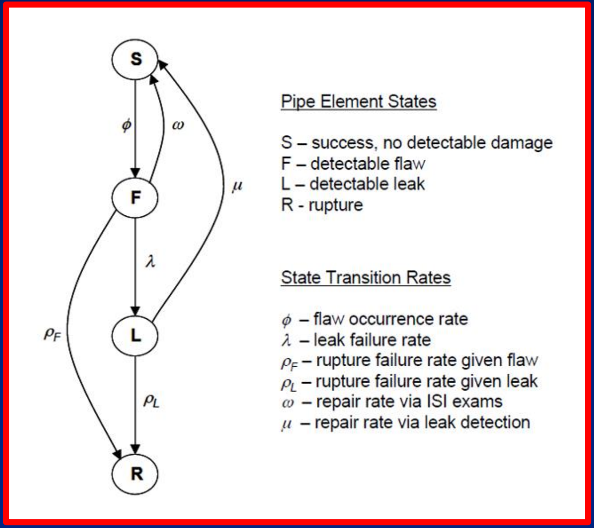

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Time-Dependence Example – Storm Preparation

- Different responses to warnings – different outcomes
  - Turkey Point and Hurricane "Andrew" (1992)
  - Blayais and Storm "Martin" (1999)
- Power is important during severe weather => pre-emptive shutdown isn't automatically the best choice
- Possibilities, consequences, likelihoods => time-dependent PRA analysis could be useful

Supplementing Sparse Data

Many forms of evidence potentially available (Lecture 5-1), not always fully used. Examples:

- "How things work/fail" – mechanistic modeling
- Operational experience

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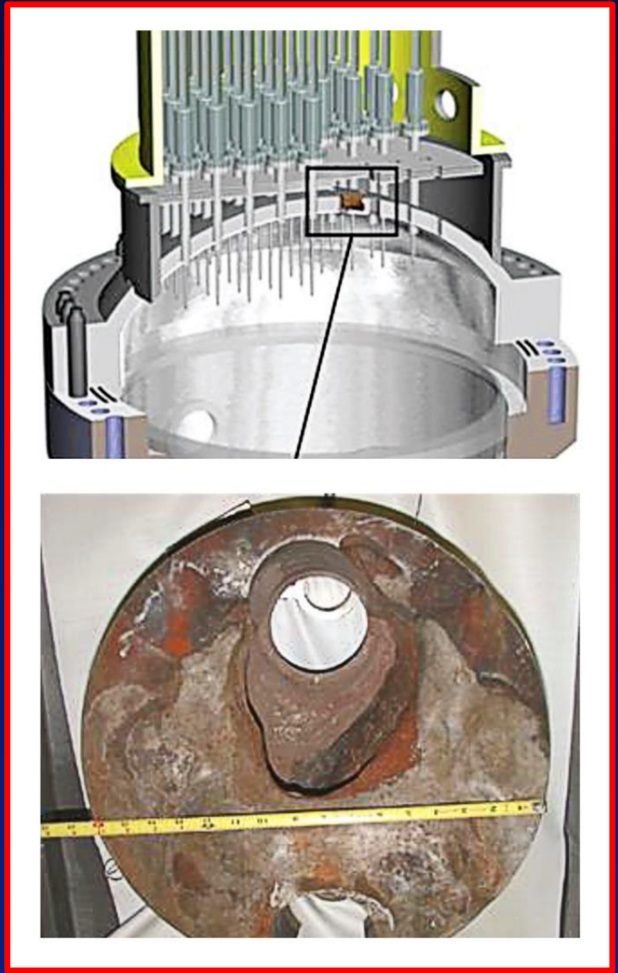
Mechanistic Modeling

- Concept: directly model (simulate) key processes
- Available examples:
  - Internal and external hazards PRA
  - Level 2 PRA
  - Level 3 PRA
- Other potential applications:
  - Time-dependent processes (e.g., HRA recovery actions)
  - RCS boundary failures (e.g., probabilistic fracture mechanics)
  - Common cause failures
  - “Conversion factor” for failure data obtained from tests



Davis-Besse Reactor Pressure Vessel Head Degradation
Adapted from NUREG/BR-0353, Rev. 1

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On Simulation Modeling

- Widely used for systems analysis in many industries (e.g., see Winter Simulation Conference https://informs-sim.org/)
- Different "flavors"
  - Continuous processes (e.g., phenomenological modeling)
  - Discrete events
- Pros and cons for NPP PRA
  - Mature technology
  - "Natural representation" supports integration of multiple disciplines
  - Can eliminate need for intermediate modeling approximations (e.g., "success criteria")
  - Potentially inefficient for rare events analysis
  - Potential loss of transparency

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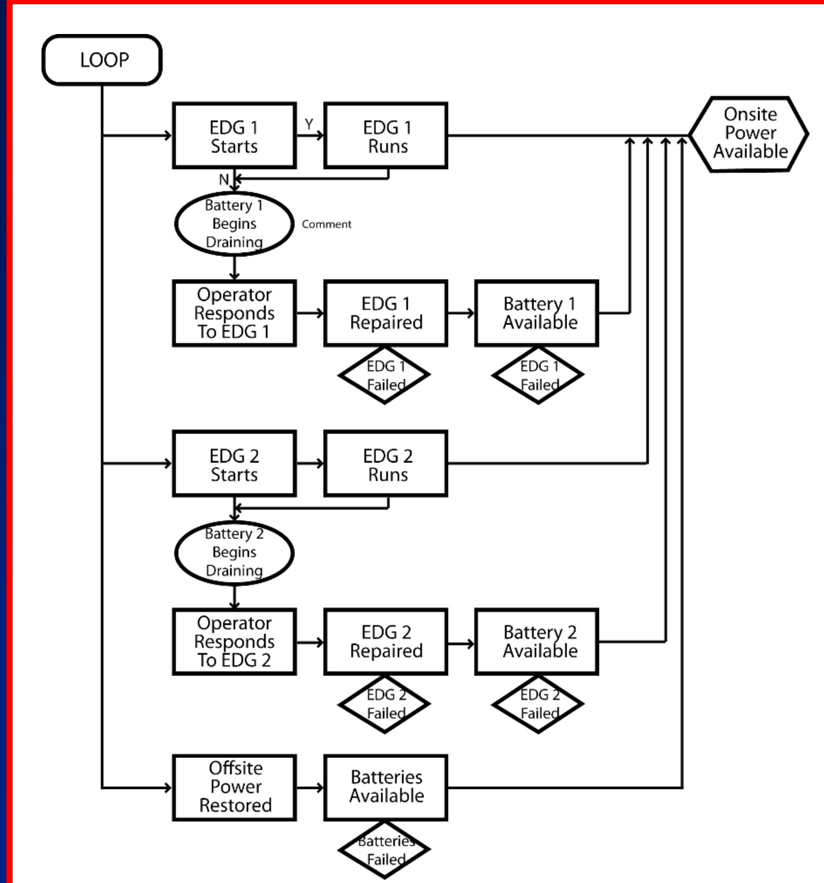
Simulation Examples

- Emergency power recovery
- Reliability engineering toolbox
- “Force-on-force” simulations

Case	Process Input	Initial State	Final State	Process Output
1	-	Failed closed	Failed closed	No
2	No	Closed	Closed	No
3	Yes	Closed	Failed closed Open	No Yes
4	No	Failed open	Failed open	No
5	Yes	Failed open	Failed open	Yes
6	No	Open	Failed open Closed	No No
7	Yes	Open	Open	Yes



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Mining Operational Experience

- Concept: increase use of information from operational events
- Current examples:
  - Initiating event, hardware basic events, CCF parameter quantification
  - PRA modeling lessons (qualitative, ad hoc)
- Other potential applications
  - HRA
    - Adjustments for context ("impact vectors")
    - Characterization of demands/successes
  - Training/resources for "how things fail"

CCF Impact Vectors

Quantify uncertainty in event applicability

- Differences in system size
- Degree of observed degradation
- Degree to which failure cause is shared
- Degree to which failures are close in time

Prior Distributions

- Concept: spend more effort on developing informative prior distributions
- Current examples:
  - Hierarchical Bayes' approaches using industry data
  - Direct elicitation for certain topics (e.g., LOCA frequency, probability of multiple fire-induced spurious operations)
- Other potential applications:
  - All parameters for which data are sparse
  - Supporting models as well as basic events

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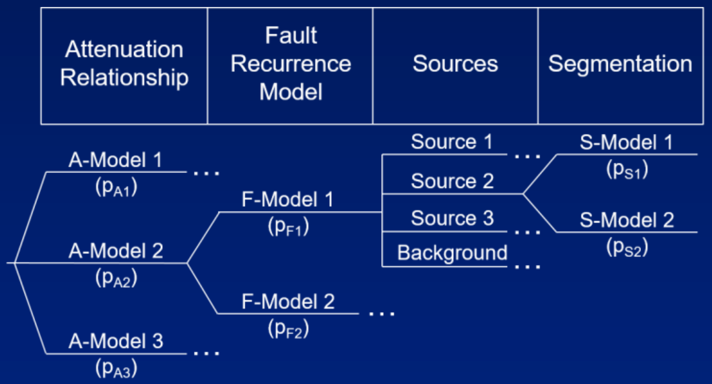
Addressing Model Uncertainties

- Concept: quantify model uncertainties to support risk communication
- Current examples:
  - Logic tree modeling
  - Fire modeling
- Other potential applications:
  - All models where quantification might affect results and insights (including consensus models)



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Closing Comments

- Improved methods and models are often available for important problems
- Recognizing sparsity of data and importance of uncertainty, PRA community (including academic community) needs change in attitude:

All the reasons X is “wrong” → How can I use what X provides?