Thoughts on Increasing Confidence in Probabilistic Fracture Mechanics Analyses

David L. Rudland
Chief, RES/DE
United States Nuclear Regulatory Commission (U.S.NRC)
Washington, DC, 20555, USA
Tel: +1-301-415-1896
Email: david.rudland@nrc.gov

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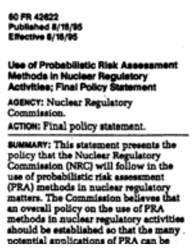
Background

- Initial NRC Regulations use prescriptive, deterministic requirements
  - Experience, test results and expert judgement


One Hundred Third Congress of the United States of America
AT THE FIRST SESSION
An Act

Focus on results, service quality and customer satisfaction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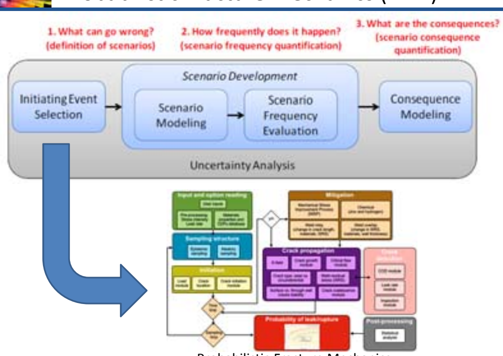
Use of Probabilistic Risk Assessment Methods in Nuclear Regulatory Activities; Final Policy Statement

AGENCY: Nuclear Regulatory Commission.
ACTION: Final policy statement.

SUMMARY: This statement presents the policy that the Nuclear Regulatory Commission (NRC) will follow in the use of probabilistic risk assessment (PRA) methods in nuclear regulatory matters. The Commission believes that an overall policy on the use of PRA methods in nuclear regulatory activities should be established so that the many potential applications of PRA can be

Formalized NRC commitment to risk-informed regulation

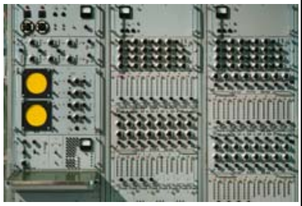
Probabilistic Risk Assessment(PRA) vs. Probabilistic Fracture Mechanics (PFM)



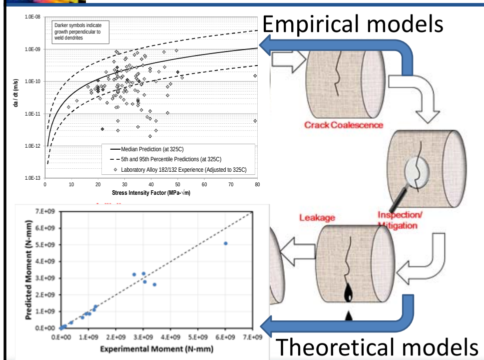
Probabilistic Fracture Mechanics

Using Probabilistic Fracture Mechanics

- PFM is not a tool where you turn knobs or flip switches to get the answer you want
- PFM allows greater insight into structural integrity by directly representing uncertainties through best estimate models and distributed inputs
- Can be complicated and difficult to conduct

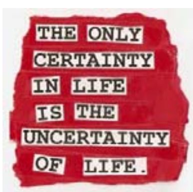


PFM Model Development



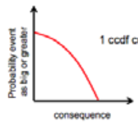
Objectives of uncertainty characterization in PFM

- Capture uncertainty in inputs and models
- Determine uncertainty in predicted response
- Determine how likely certain outcomes are if some aspects of the system are not exactly known
- Uncertainty propagation: "Mapping" uncertainty from inputs to outputs → How important are the input/model uncertainties

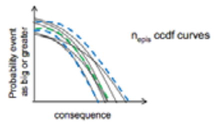


Uncertainty Characterization and Propagation

- **Aleatory uncertainty:** (Perceived) randomness in the occurrence of future events.
- **Epistemic uncertainty:** Lack of knowledge with regard to the appropriate value to use for a quantity that has a fixed, but poorly known, value in the context of a specific analysis.



Aleatory uncertainty asks "How likely is it for the event to happen"



Epistemic uncertainty asks "How confident are we in the first answer"

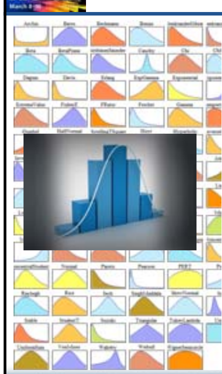
- Uncertainty (both aleatory and epistemic) is usually characterized using probability distributions – others available

Uncertainty Characterization and Propagation

- Parameters may be aleatory, epistemic or both – How to choose?

- Questions to ask
  - Do you have any control over the variability, e.g., earthquakes?
  - Can further research , model development or testing help reduce uncertainty?
- If the variable characterization can not be defended - treat as epistemic and rank importance to output uncertainty

Defining Distributions



- Many choices available
- More data is better
- Traditional techniques to generate distribution include:
  – Expert review: used when no data is available.
  – Bayesian updating: used when data becomes available, to update expert elicitation
  – Maximum entropy/likelihood: used when enough data is available to fit distribution
  – Bootstrap: used when some data is available
  – Other techniques.
- Does the kurtosis-skewness of data and fit compare? – Sensitivity studies needed?

Sampling

- Many sampling based methods are available
  - Random sampling (Monte Carlo sampling)
  - Latin Hypercube Sampling (LHS)
  - Discrete Probability Distribution (DPD)
  - Importance sampling
  - Adaptive sampling
  - Other methods exist (quasi-Monte Carlo, etc).
- Needs to represent population
- Convergence studies are needed to demonstrate sufficient sample size

Verification and Validation

- All software used in support of safety-related systems must comply with 10 CFR 50 Appendix B
- Software can be commercially dedicated
- Validation should occur at both the model and integrated code level
- Validation of one output does not assure validation for all outputs
- Validating low probability events can be challenging
  - Sensitivity studies and benchmarking may be used to add assurance to the validity of low probability events

Conducting PFM analyses

- My models are good, my input distributions are defined, and the calculated probability of failure is below the maximum allowable failure probability! Am I done??
- Questions remain…
  - Is it a converged solution?
  - What's the output uncertainty?
  - What's driving the problem?
  - How sensitive are the results to those drivers?

Conducting PFM analyses

- One PFM run is not sufficient for reliable, realistic, understandable results
- Use Epistemic uncertainty to define output uncertainty
- Temporal and solution convergence must be demonstrated
  - Replicates, sample size, bootstrap can be used
- What input uncertainty is driving the output uncertainty
  - Sensitivity analyses can rank importance – rank regression for monotonic behavior
  - Sensitivity studies may be needed for determining sensitivity - Is current basis sufficient or is more data needed?

Thoughts on PFM Analyses

- Use best estimated models that properly model process and are well validated
- Strong basis for uncertainty determination and classification – separate input uncertainty to understand uncertainty in result
- Strong basis for input distribution selection
- Quality Assurance and Verification and Validation to comply with Appendix B
- Demonstration of temporal and statistical convergence
- Demonstration of what input uncertainty is driving the output uncertainty
  - Demonstration of input parameter sensitivity