3rd International Seminar On Probabilistic Methodologies for Nuclear Applications

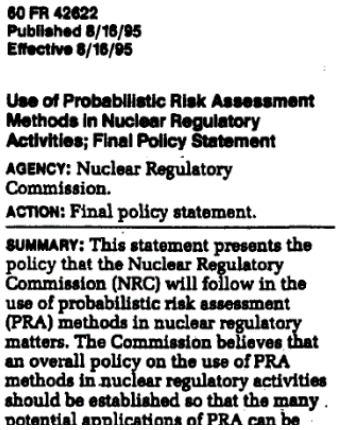
U.S.NRC
United States Nuclear Regulatory Commission
Protecting People and the Environment

Development of NRC Guidance on Probabilistic Fracture Mechanics for US Nuclear Applications

Patrick Raynaud
Senior Materials Engineer
U.S. NRC Office of Research

Probabilistic Fracture Mechanics (PFM) at the NRC: A Little Bit of History…

- Historical reliance on deterministic fracture mechanics and conservatisms
- Risk-Informed policies in place since the mid-1990s
- Gradual shift to probabilistic approaches and best-estimate with quantified uncertainties
- Recent increased use of probabilistic methods
  - Unanticipated factors
  - Risk informed cost benefit analyses
  - Plant aging, license extensions: highly conservative safety factors impractical for plant life extension



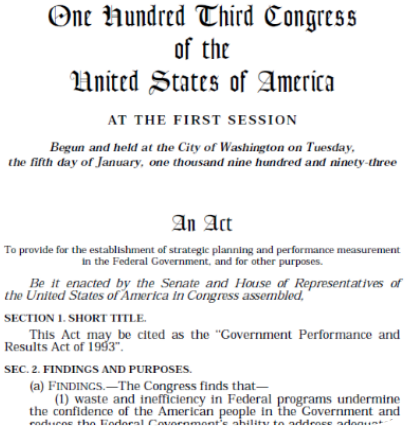
60 FR 42622
Published 8/16/95
Effective 8/16/95

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



One Hundred Third Congress
of the
United States of America

AT THE FIRST SESSION

Begun and held at the City of Washington on Tuesday, the fifth day of January, one thousand nine hundred and ninety-three

An Act

To provide for the establishment of strategic planning and performance measurement in the Federal Government, and for other purposes.

Be it enacted by the Senate and House of Representatives of the United States of America in Congress assembled,

SECTION 1. SHORT TITLE.

This Act may be cited as the "Government Performance and Results Act of 1993".

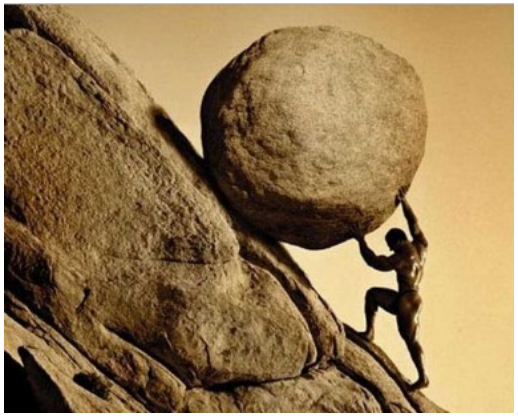
SEC. 2. FINDINGS AND PURPOSES.

(a) FINDINGS.—The Congress finds that—

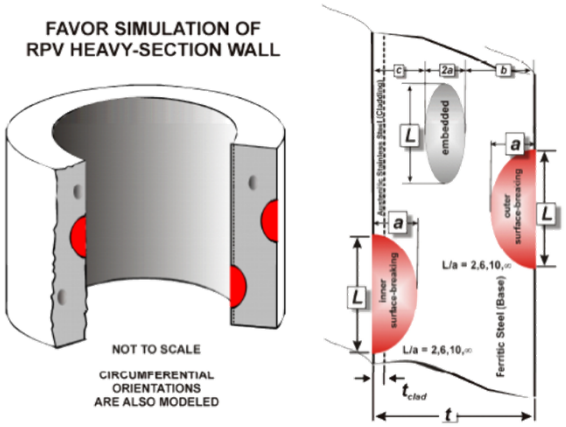
(1) waste and inefficiency in Federal programs undermine the confidence of the American people in the Government and

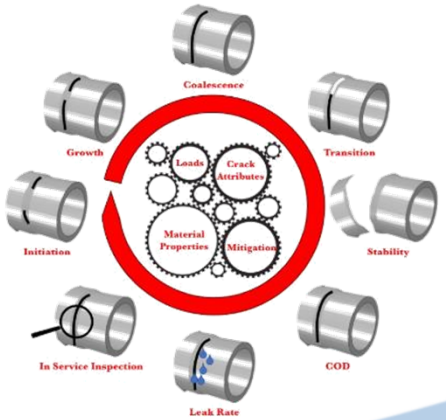
NRC's Current Research on PFM: Motivations

- Increased complexity of probabilistic analyses and associated regulatory difficulties
  - Importance of QA and V&V
  - Cultural change in engineering approach



- NRC's PFM tools for component integrity assessment
  - FAVOR (1994-Present)
  - xLPR (2009-Present)





PFM Best-Practices Guidance Development

- NRC research project to develop best-practices guidance for PFM code development and analyses

- Objectives:
  - Develop a robust technical basis for PFM codes and analyses
  - Provide guidance on desirable attributes for PFM tools in view of regulatory acceptance
  - Provide guidance on acceptable methodologies for PFM analyses in support of licensing actions
  - Remediate difficulties in reviewing industry submittals using PFM

- Technical Letter Report on NRC's preliminary thoughts on increasing confidence in PFM analyses publicly available at ML18178A431

- Focus of this presentation is on developing a graded approach for PFM submittals

Graded Approach Overview

- Based on EPRI's white paper on minimum contents for PFM submittal
  - Supplemented with additional contents and explanation from NRC
  - EPRI BWRVIP 2019-016 white paper: "Suggested Content for PFM Submittals to the NRC", ML19241A545
    - All content in green boxes in subsequent slides is from EPRI BWRVIP 2019-016 white paper
- Performed cross-walk between NRC's steps for PFM analysis and EPRI white paper
- Analyzed proposed thresholds/considerations for when additional information would be required
- Created bins for software QA and V&V

PFM Submittal Recommended Minimum Contents (NOT Requirements) [1/3]

1. Software information made available to NRC staff with PFM submittals
   - Need to be able to access the code in following cases
     - High safety significance
     - Generic application of plant specific code
     - Complex code
     - Extent of differences with codes previously approved by NRC
   - In person or virtual audits

2. Models
   - May need more details in these cases:
     - New failure mode
     - Emergent vs. ongoing: extent of plant experience and Operational Experience for new phenomena
     - Implications of unknowns

1	Information Made Available to NRC Staff with PFM Submittal	• The submitter should have a plan for making the PFM software and supporting documents available to the NRC to enable their review of the PFM submittal
1.1	PFM Software	• In cases that a sufficiently similar PFM code is not available for NRC to perform a meaningful benchmarking comparison, propose a way to give NRC sufficient access to the PFM software, for example through an informal review meeting
1.2	Supporting Documents	• As appropriate, the supporting technical and quality assurance (QA) documents and procedures for the PFM software should be available for examination by NRC staff in an in-person review meeting
2	Models	• Document the model or models to a sufficient level of detail that a competent analyst already familiar with the relevant subject area could independently implement the model(s) • Provide a basis for all significant aspects of the model(s), including why the selected models are sufficiently reliable for the intended application, with identification of important uncertainties or conservatisms • Document any algorithms or numerical methods needed to implement the model(s) • Discuss any significant assumptions, approximations, and simplifications, including their potential impacts on the analysis

PFM Submittal Recommended Minimum Contents (NOT Requirements) [2/3]

3. Inputs
   - Provide basis for categorization of uncertainty between epistemic and aleatory

4. Convergence
   - Make sure convergence is achieved for Quantities of Interest (QoI), not necessarily for other things we don't care about
   - Justify why sampling uncertainty is small enough for intended purpose

5. Input Importance and Sensitivity Studies
   - Document following details
     - Sensitivity Analysis (SA) technique, assumptions, and results
     - Which QoI are the rankings based on?
     - Explain how SA results influenced subsequent analysis
   - Describe sensitivity studies

3	Inputs	• Document the inputs in detail, including specifying their values and whether they are treated as deterministic or probabilistic (and if probabilistic, document the distribution from which the inputs are sampled) • Provide the basis for the input values used, including why the input basis is considered sufficiently reliable for the application • Document use of interpolation, extrapolation, and truncation schemes, as well as curve fitting of data • Document the approach for treatment of correlation or statistical independence of inputs, along with the corresponding basis for the approach • Ensure that selected or sampled inputs remain consistent and physically valid if inputs are dependent on each other, e.g., due to physical processes • Present the method and basis for treating epistemic and aleatory uncertainties
4	Convergence	• Explicitly demonstrate convergence for all temporal and spatial discretizations, as well as statistical convergence of the Monte Carlo simulation
5	Input Importance and Sensitivity Studies	• Document an assessment of input importance, with the objective to identify the subset of inputs that have the greatest impact on the analysis results or conclusions • Revisit the most important inputs and discuss how the values or distributions for the most important inputs were confirmed to be treated appropriately

PFM Submittal Recommended Minimum Contents (NOT Requirements) [3/3]

6. Verification and Validation
   - Allow for audit of software QA documentation
   - Identify different code categories (see next slide)

7. Uncertainty propagation and output uncertainty characterization
   - Describe output uncertainty characterization for QoI

8. Acceptance Criteria
   - PFM outputs should be relevant for desired regulatory outcome
   - Acceptance criteria are beyond scope of NRC's PFM guidance but should be derived based on risk informed decisionmaking principles
     - RG-1.200
     - RG-1.174

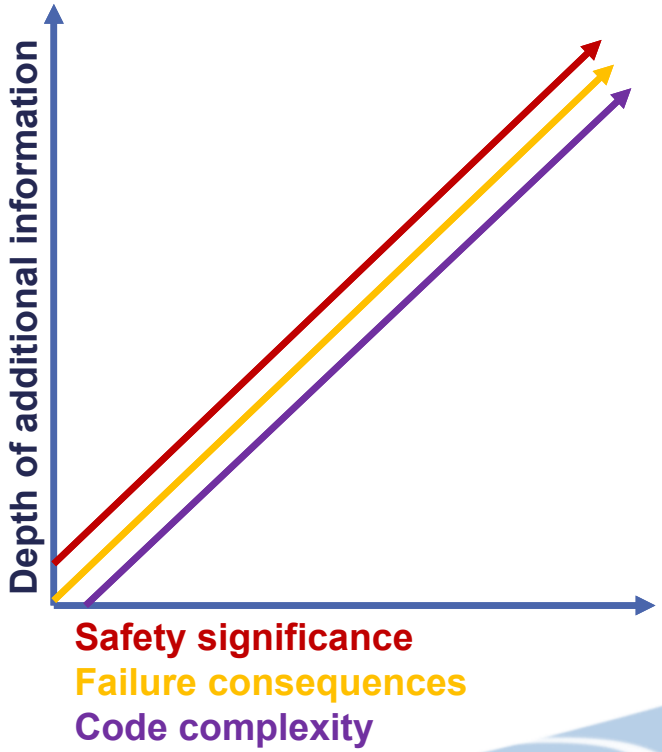
6	Verification and Validation	• Identify the applicable QA program, plan, and/or procedures, as well as the QA standards met • Include a basic description of the measures for quality assurance, including verification and validation of the PFM software as applied in the subject report • Include confirmation that the verification and validation cover the ranges of input values considered in the submittal • Document any benchmarking activities performed for the PFM software
7	Uncertainties	• Summarize the overall Monte Carlo sampling structure (or other probabilistic treatment) and simulation framework, including their basis • Include descriptions of the pseudo-random number generation, sampling methods, sampling frequencies, and applied spatial or temporal discretization (each as applicable) • Discuss the basis for any conservative treatments of input values or models • Include a summary discussion of key uncertainties or biases stemming from assumptions and simplifications to make real-world phenomena tractable, based, at a minimum, upon qualitative assessment
8	Acceptance Criteria	• Document the probabilistic acceptance criteria and their basis, for example a previous established precedent

Software QA and V&V Categories

- Category 1: NRC approved code
  - Category 1A: NRC approved or endorsed code within validated range
    - Demonstrate code applicability within validated range
  - Category 1B: NRC approved or endorsed code outside of validated range
    - Provide justification for new applicability range (additional V&V?)
  - Category 1C: Modified NRC approved or endorsed code
    - SQA summary and V&V description for modified portions of the code
    - Demonstration that the code was not 'broken' as a result of changes
    - Detailed documentation available for further review upon request (audit)
- Category 2: commercial off-the-shelf (COTS) software designed for the specific purpose of the application
  - Generally not Excel, GoldSim, FE software
    - Demonstrate code applicability
    - Description of the software and its pedigree
    - Software and documentation available for review upon request (audit)
- Category 3: custom code
  - Summary of SQA program and implementation (standards?)
  - Summary of V&V activities (data, benchmarking…)
  - Very simple applications: provide source code instead of standardized SQA and V&V?
- Normal care needs to be taken for pre and post processing codes…

Considerations for Submittal of Additional Depth of Information [1/3]

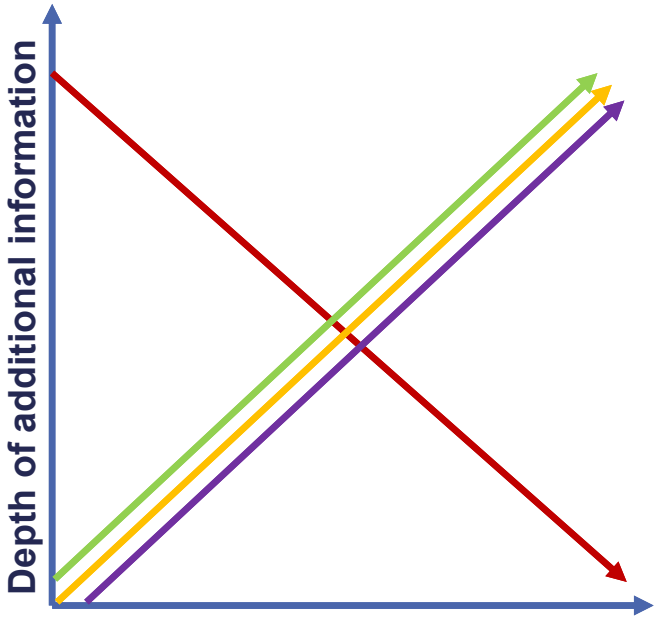
- Safety significance
  - In general, level of detail should scale with the safety significance while still taking into consideration the recommended minimum contents
  - The recommended minima are satisfactory for class 1 components, and thus also sufficient for lower class components
  - The extent to which some recommendations may be relaxed should inversely scale with the complexity and novelty of the application
- Failure mode
  - Highly energetic failure mode, impact on other systems or on the safety of personnel, poorly understood failure mode, newly modeled phenomenon
  - Impact on submittal
    - Higher emphasis on model description
    - Better description of model inputs
    - Better documentation of sensitivities of model
- Code complexity
  - High number of I/O, large number of phenomena modeled, many code model interdependencies, complex interactions between different physics in the code
  - Impact on submittal
    - More sensitivity studies to ensure behavior is well understood
    - More robust SQA and V&V



NRC would encourage pre-submittal meeting to provide direction on which areas might require additional work in the submittal

Considerations for Submittal of Additional Depth of Information [2/3]

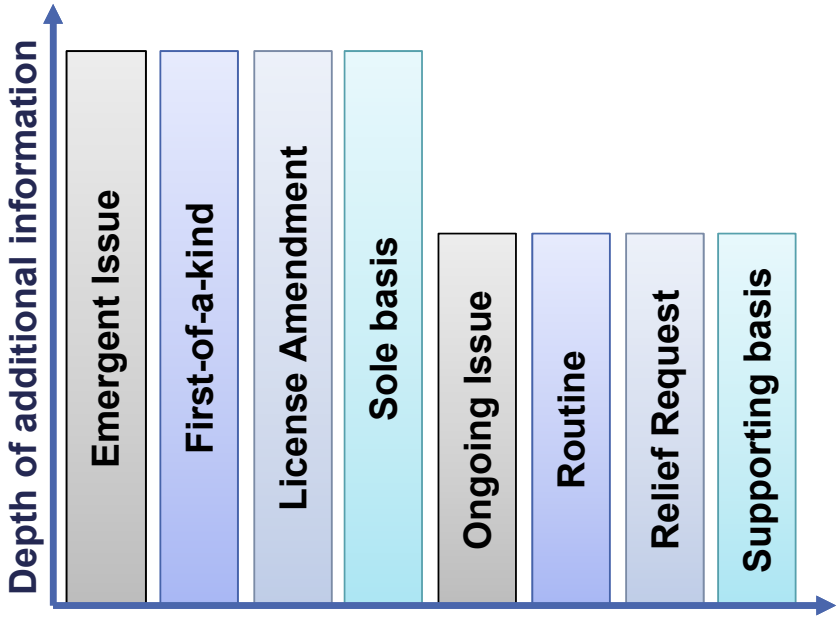
- Margin to acceptance criteria
  - Does 95th percentile cross threshold?
  - Impact on submittal:
    - Higher emphasis on input distributions for low margin
    - Better documentation of output uncertainty (tails) for low margin
    - Potential relaxation of convergence requirements if lots of margin
- Plant specific vs. generic
  - Additional information for generic applications
  - Baseline level of information for plant specific applications
    - Exception: if plant has unique feature requiring special software or inputs
  - Impact on submittal:
    - Additional proof that inputs cover wide range of generic application
    - Additional proof that models cover wide range of generic application
    - For plant with unique feature, additional description of specialized software and inputs
- Implications of potential unknowns
  - If perceived uncharacterized uncertainties are high, recommend additional sensitivity studies
  - The higher the consequence, the broader the scope of investigation
- Difference from ASME requirements
  - The bigger the difference, the more additional information may be needed



NRC would encourage pre-submittal meeting to provide direction on which areas might require additional work in the submittal

Considerations for Submittal of Additional Depth of Information [3/3]

- Emergent or ongoing issue
  - Emergent issues require more information than ongoing issues
  - Impact on submittal:
    - Better documentation of inputs and models
- First of a kind vs routine applications
  - First of a kind applications require more information than routine applications
  - Impact on submittal:
    - Better documentation of inputs and models
    - Better characterization of importance and sensitivities
- Change to plant licensing basis
  - More information required if plant licensing basis is impacted
  - Impact on submittal:
    - Better documentation and characterization of margins via uncertainty analysis as well as sensitivity analyses and studies
    - PRA requirements
- PFM sole basis vs. supporting basis of submittal
  - If other supporting analyses, relax recommendations
  - Impact on submittal
    - Less need for sensitivity analyses and sensitivity studies if other analyses to show trends, etc.



NRC would encourage pre-submittal meeting to provide direction on which areas might require additional work in the submittal

Summary of NRC's Proposed Graded Approach for PFM Regulatory Submittals in the US

- NRC used EPRI's proposed contents for a PFM submittal as a starting point
  - EPRI BWRVIP 2019-016 white paper: "Suggested Content for PFM Submittals to the NRC", ML19241A545
- NRC adopted the majority of EPRI's recommendations and added recommendations where deemed necessary and appropriate
- NRC defined a categorization scheme for PFM software, and described recommended supporting information for each category
- NRC reviewed EPRI's recommended considerations for submittal of additional depth of information and provided additional guidance where deemed necessary and appropriate

Next Steps in NRC's Development of PFM Guidance for US Regulatory Applications

- NRC is in the process of developing final drafts of a Regulatory Guide and supporting NUREG technical bases
  - Contents will follow the general principles described in Technical Letter Report on NRC's preliminary thoughts on increasing confidence in PFM analyses (publicly available at ML18178A431)
  - A graded approach for PFM will be recommended (starting point is EPRI recommendations from "Suggested Content for PFM Submittals to the NRC", publicly available at ML19241A545)

- Once documents are finalized and internal concurrence is obtained, NRC will hold public meeting to describe the draft guidance

- Process for publication of the PFM Regulatory Guide will include chances for stakeholder feedback

Acknowledgements

NRC wishes to acknowledge EPRI's important contributions to the PFM guidance project, through public interactions and feedback, and especially through the development of their white paper on "Suggested Content for PFM Submittals to the NRC"

- NRC staff involved in the PFM Guidance project: David Rudland, Stephen Cumblidge, Mike Benson, Matt Homiack, Mark Kirk (now at PEAI and CRIEPI)
- Sandia National Labs staff involved in the project: Mike Starr, Nevin Martin, Remi Dingreville, Nevin Martin (SNL), Lauren B. Hund, Zach Stuart, John R. Lewis, Josh Mullins, Dusty Brooks, Aubrey C. Eckert-Gallup
- Emc^2 staff involved in the project: Cedric Sallaberry, Bob Kurth, Elizabeth Kurth