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Use of Probabilistic Fracture Mechanics for ISI Extension

A Regulatory Perspective

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What is the risk of extending ISI for a component?

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Probabilistic fracture mechanics (PFM) has been used to answer this, at least partially. (Part 1)

To what extent can PFM address the question of risk? (Part 2)

PFM in a nutshell

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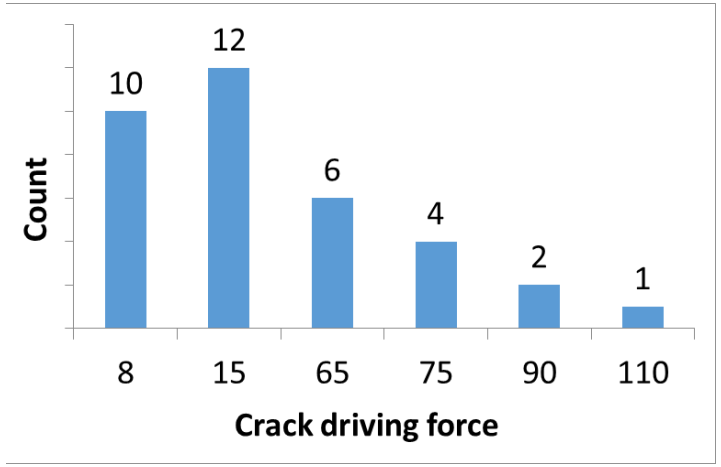
Fracture mechanics, crack driving force < material resistance

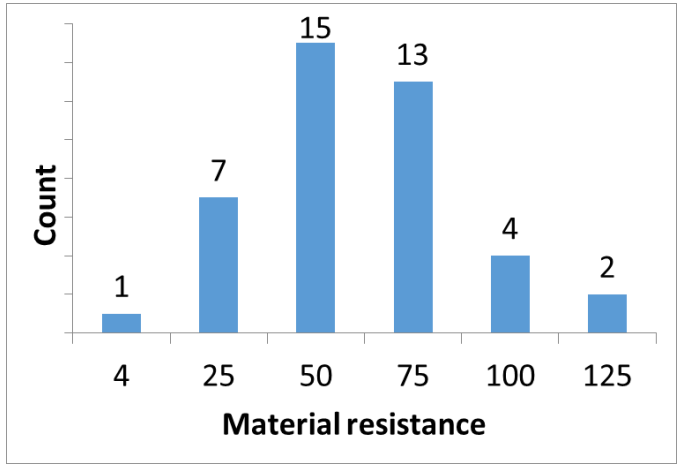
In deterministic fracture mechanics, you apply safety factors on either side (or both) and perform one calculation.

PFM is performing many fracture mechanics calculations in which the crack driving force is compared to the material resistance, then counting how many failures you get.

Many calculations are performed because the input parameters are not a single value, but a **distribution of values** that are sampled.

PFM illustration





Sample (trial or realization)	Crack driving force	Material resistance	Fail? (crack driving force > material resistance?)
1	8	75	No
2	15	50	No
3	75	25	Yes
. . . 10 million	. . . 65	. . . 100	. . . No

Probability of failure = number of failures ÷ number of samples

PFM is complex

Performed with computer codes such as FAVOR and xLPR

PFM input parameters, each with distributed values:

- Flaw size/density
- Fracture toughness (or associated parameters such as RT_{NDT})
- Probability of detection
- Weld residual stress
- Fluence
- Crack growth rate

PFM guidance: Regulatory Guide 1.245 and NUREG/CR-7278

Two points in using PFM for ISI extension

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Effect of ISI and examination coverage need to be included

If generic PFM results are used, the ISI and examination coverage in the generic analysis would need to closely align with the ISI and examination coverage that have been performed for the specific component.

Sensitivity analyses (SA) and sensitivity studies (SS) performed to address and understand uncertainties

SA helps flush out the inputs that are driving the desired analysis output (e.g., probability of failure); therefore, this is a **global** look at the analysis.

SS helps in determining the effect of a particular input in the analysis (e.g., stress); this is a **local** look at the analysis.

In a PFM analysis, probability of failure (PoF) is often queried as the output.

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PoF is counting the number of failures out of all possible scenarios that arise from the uncertainties in the input parameters.

Provided that the resulting PoF is less than the specified criteria, is going by PoF alone sufficient for extending ISI? (moving into Part 2)

Underlying concept behind ISI

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Monitor the condition of a component throughout its operating life. But why?

Components are designed with safety margins, and so at the start of operation (baseline condition) the component is deemed acceptable.

Monitor condition of the component to compare with the baseline condition to determine if there has been a **change** (which could mean presence of service-induced **degradation** that must be addressed). This ensures the **safety margins** in the component are maintained, so that it will continue to perform its intended function, and thereby provide reasonable assurance of overall plant safety.

Extending ISI period reduces ISI examinations, and this impacts the intent of ISI

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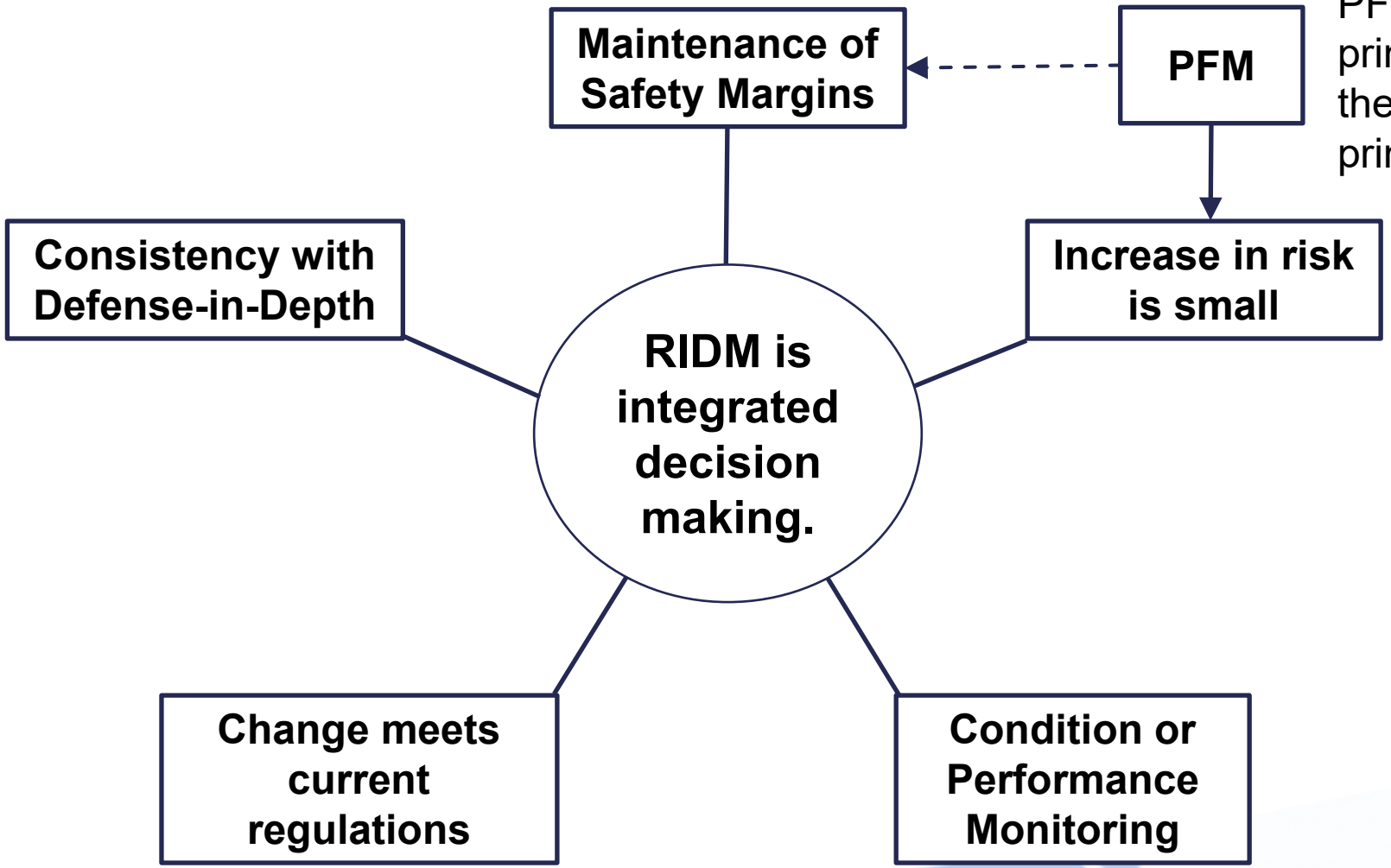
Risk of this reduction must be addressed.

Other aspects that must be addressed based on ISI concept:

- Monitoring condition
- Degradation
- Safety margins

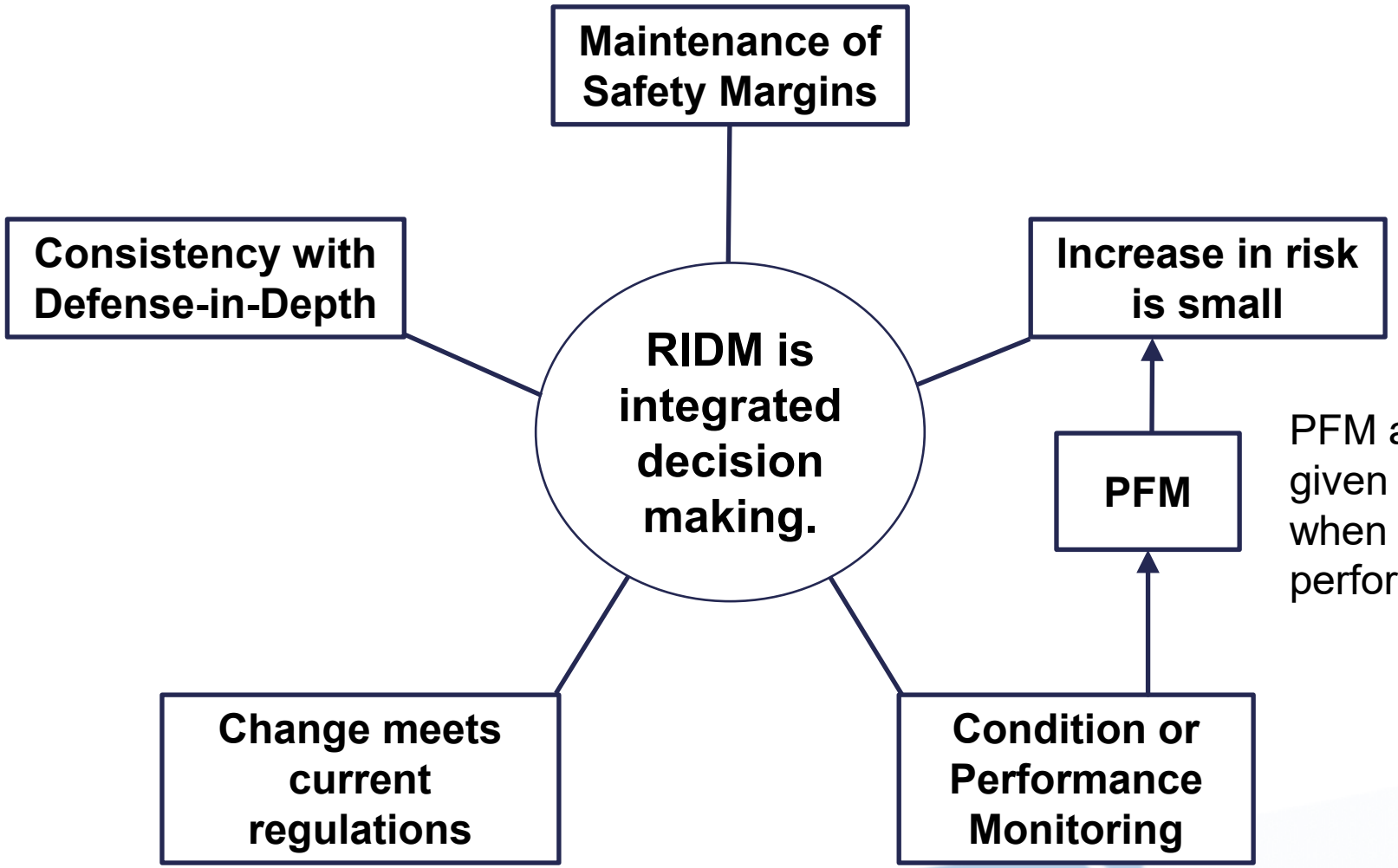
This makes extending ISI a risk-informed decision.

Risk-Informed Decision Making (RIDM)



PFM addresses the risk principle and can inform the “safety margin” principle.

Risk-Informed Decision Making (RIDM)



PFM allows weight to be given to the risk principle when combined with performance monitoring.

Aspects of performance monitoring

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Starting with keywords from ISI concept…

- Monitor condition for change in degradation
- Maintenance of safety margin

Three key aspects of performance monitoring can be derived.

- Direct evidence of presence and/or extent of degradation
- Timely method to detect novel and/or unexpected degradation
- Validation/confirmation of continued adequacy of analyses

Performance monitoring is important for ISI extension, especially extensions during long-term operation because of increased uncertainty.

Examples of PFM + performance monitoring as basis for ISI extension

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Elimination ISI of BWR vessel circumferential welds (covered in presentation tomorrow)

20-year ISI extension of PWR vessel welds

- PFM: FAVOR analyses
- Performance monitoring: coordinated ISI of the same-fleet units to ensure regular fleet ISI data; one-time ISI for subsequent extensions to validate that generic flaw-distribution used in the PFM analysis is bounding for the unit.

Note: both are implemented through the alternative request process in NRC regulations.

Summary

PFM alone is not an adequate basis for ISI extension.

For ISI extension, PFM allows weight to be given to the risk principle of RIDM when combined with performance monitoring.