UNITED STATES NUCLEAR REGULATORY COMMISSION

Protecting People and the Environment

Managing Uncertainties in the Regulation of Nuclear Facilities and Materials

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U.S. Nuclear Regulatory Commission

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NRC Mission

- **To license and regulate the nation's civilian use of byproduct, source, and special nuclear materials to ensure adequate protection of public health and safety, promote the common defense and security, and protect the environment.**

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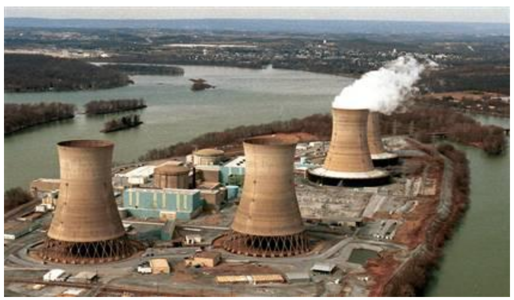
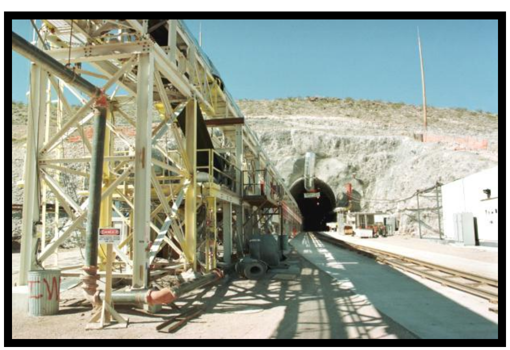
NRC Oversight





The Traditional Approach (Before Risk Assessment)

- **Management of (unquantified at the time) uncertainty was always a concern.**

- **Defense-in-depth and safety margins became embedded in the regulations (*structuralist* approach)**

- **"*Defense-in-Depth* is an element of the NRC's safety philosophy that employs successive compensatory measures to prevent accidents or mitigate damage if a malfunction, accident, or naturally caused event occurs at a nuclear facility." [Commission's White Paper, February, 1999]**

- **Questions that the structuralist defense in depth addresses:**
  - **What if we are wrong?**
  - **Can we protect ourselves from the unknown unkowns?**

The Single-Failure Criterion

- **"Fluid and electric systems are considered to be designed against an assumed single failure if neither (1) a single failure of any active component (assuming passive components function properly) nor (2) a single failure of a passive component (assuming active components function properly), results in a loss of the capability of the system to perform its safety functions."**

- **The intent is to achieve high reliability (probability of success) without quantifying it.**

- **Looking for the worst possible single failure leads to better system understanding.**

Design Basis Accidents

- **A DBA is a postulated accident that a facility is designed and built to withstand without exceeding the offsite exposure guidelines of the NRC's siting regulation.**
- **They are very unlikely events.**
- **They protect against "unknown unknowns."**

Emergency Core Cooling System

- **An ECCS must be designed to withstand the following postulated LOCA: a double-ended break of the largest reactor coolant line, the concurrent loss of offsite power, and a single failure of an active ECCS component in the worst possible place.**

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Evaluation of Uncertainties in the Materials Program

- **Uncertainties in the analysis models generally fall into three categories:**
  - ✓ **Material properties,**
  - ✓ **Gaps within the manufactured cask or package, and**
  - ✓ **Phenomena for which there are little or no experimental data.**

Material Properties

- Sufficient published data for the materials used
- If data are lacking, staff will rely upon a reasonable argument for a range of material properties that allow for a conservative prediction of the system behavior
- As materials approach their operational limits, more scrutiny is placed on the cask or package design to insure that adequate margin exists
- An area of significant uncertainty currently is the performance of high burn-up fuel cladding. Little data exists, and operational limits have to be conservatively estimated.

Gaps within the Manufactured Components

- Gaps in a cask or package can significantly affect both the thermal and structural performance of a system
- Recent analytical efforts have indicated that when gaps are not effectively accounted for in a structural impact (drop test) analysis, the impact forces are significantly underpredicted
- While manufacturing tolerances provide some indication of what gaps should exist in the design, fabrication of new packages/casks have demonstrated that gaps are not always accurately predicted
- The staff generally requests sensitivity studies for variations of gaps in cask/package designs be conducted and reported so the staff can review them as part of the certification process

Lack of Experimental Data

- Although may appear straight forward (from an engineering perspective), certain phenomena in the designs may not be well characterized by experimental data. Examples of this include impact limiter performance and heat transfer in external liquid neutron shields (for transfer casks)
  - Impact limiters vary in design and the use of impact absorbing materials (wood, aluminum honeycomb, foam)
  - Performance of impact limiters are difficult to characterize due to their highly non-linear behavior and are often design and material specific
- Assessments are based on an understanding of the physical system and how it might actually perform (what does the “physics” of the problem tell you)
- The staff employs a conservative modeling approach which characterizes the “worst case” to compensate for the uncertainty related to the actual performance of the design
- If adequate experimental data do not exist, the uncertainties in the performance of the impact limiter must be accounted for with a conservative analysis

Technological Risk Assessment (Reactors)

- **Study the system as an integrated *socio-technical* system.**

<u>Probabilistic Risk Assessment (PRA) supports Risk Management by answering the questions:</u>

- **What can go wrong? (accident sequences or scenarios)**
- **How likely are these scenarios?**
- **What are their consequences?**
- **Which systems and components contribute the most to risk?**

PRA Policy Statement (1995)

- **The use of PRA should be increased to the extent supported by the state of the art and data and in a manner that complements the defense-in-depth philosophy.**

- **PRA should be used to reduce unnecessary conservatisms associated with current regulatory requirements.**

How are decisions made?

- **Risk-informed decision making:**
  - **PRA results are one input to a subjective decision-making process that includes elements of traditional engineering approaches such as defense in depth.**

U. S. Nuclear Regulatory Commission, Regulatory Guide 1.174, "An Approach for Using Probabilistic Risk Assessment in Risk-Informed Decisions on Plant-Specific Changes to the Current Licensing Basis," Rev. 1, 2002.

- **The Analytic-Deliberative Process:**
  - ***Analysis* uses rigorous, replicable methods, evaluated under the agreed protocols of an expert community - such as those of disciplines in the natural, social, or decision sciences, as well as mathematics, logic, and law - to arrive at answers to factual questions.**
  - ***Deliberation* is any formal or informal process for communication and collective consideration of issues.**

National Research Council, *Understanding Risk*, Washington, DC, 1996.

The Analysis

- **The Bayesian approach is widely accepted and used.**
- ***For communication purposes only:***
  - **A distinction is made between aleatory and epistemic uncertainties.**
  - **Epistemic uncertainties are further categorized as being due to unknown parameter values, model assumptions, and incomplete analyses.**
- **Multi-attribute Utility Theory (MAUT) is not used.**
- **Further guidance is provided by comparing analytical results with numerical goals:** $\overline{R} < L$ **where** $\overline{\mathrm{R}}$ **is the average aleatory probability of a risk metric and L is the goal.**

The Deliberation

- **The decision maker and the stakeholders deliberate. Their values are included in the decision-making process.**
- **For expert opinion integration, the concept of a Technical Facilitator/Integrator has been proposed.**

Senior Seismic Hazard Analysis Committee (SSHAC). ***Recommendations for Probabilistic Seismic Hazard Analysis: Guidance on Uncertainty and Use of Experts,*** **NUREG/CR-6372, 1996.**

- **The analytical results are scrutinized and sensitivity analyses are produced. Conservatism is added as appropriate.**
- **As $\bar{R}$ approaches L, "increased management attention" is applied:**
  - **How much of the distribution of R is beyond L?**
  - **What are the conservative and questionable assumptions embedded in the distribution of R?**
- **How conservative is L and how should this fact affect decision making?**

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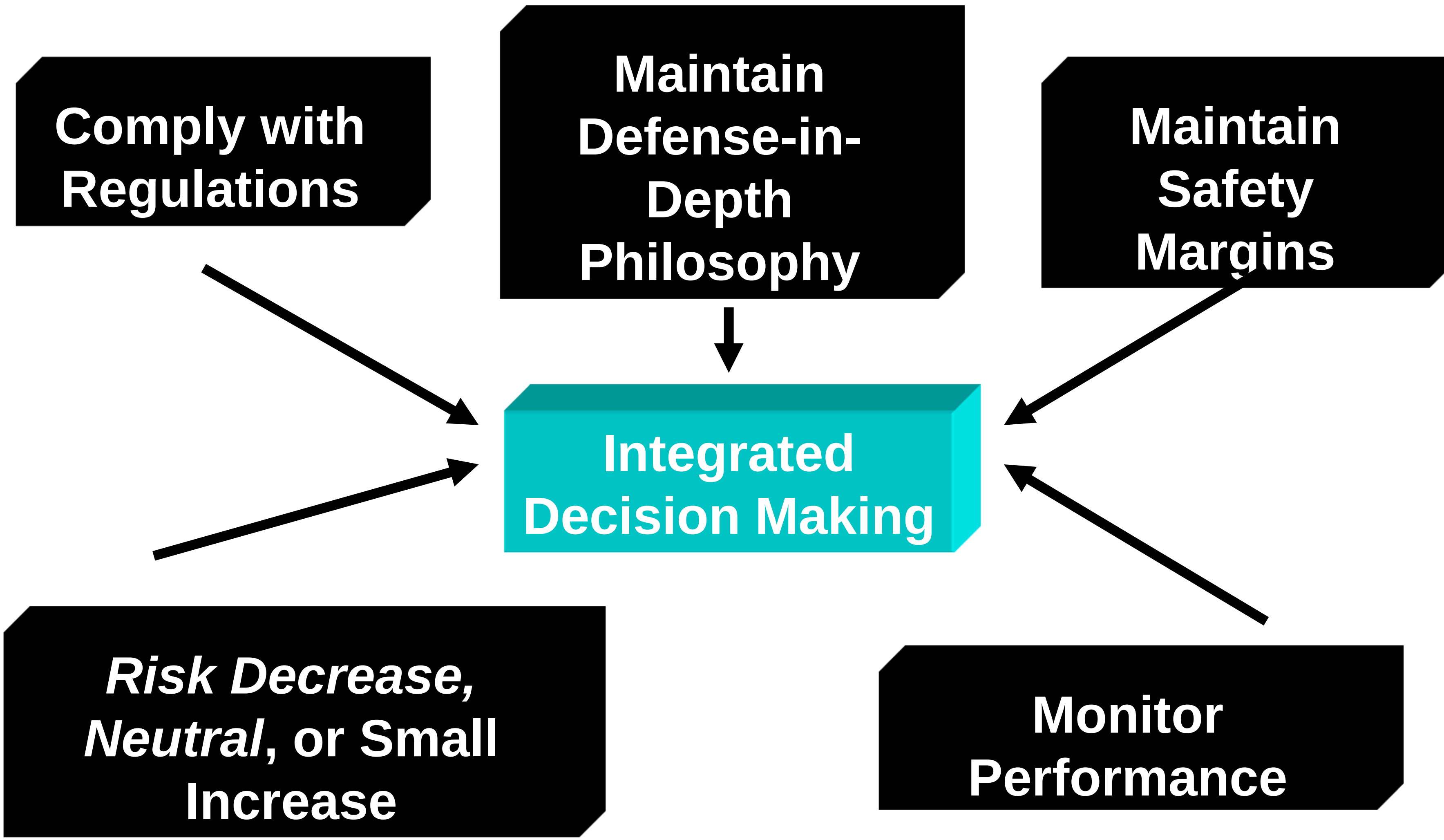
Risk-Informed Decision Making for Licensing Basis Changes (RG 1.174, 1998)



Conflicts arise between Traditional and Risk-Informed Frameworks

Traditional "Deterministic" Approaches

- Unquantified Probabilities
- Design-Basis Accidents
- Structuralist Defense in Depth
- Can impose heavy regulatory burden
- Incomplete

Risk-Informed Approach

- Combination of traditional and risk-based approaches

Risk-Based Approach

- Quantified Probabilities
- Scenario Based
- Realistic
- Rationalist Defense in Depth
- Incomplete
- Quality is an issue

Special Treatment Requirements

- Requirements imposed on structures, systems, and components (SSCs) that go beyond industry-established requirements for commercial SSCs.

- *Safety-related* SSCs are subject to special treatment, including quality assurance, testing, inspection, condition monitoring, assessment, evaluation and resolution of deviations.

- *Non-safety-related* SSCs are not.

- The categorization of SSCs as *safety-related* and *non-safety-related* does not have a rational basis.

- These requirements are very expensive.

- The impact of special treatment on SSC performance is not known.

Traditional SSC Categorization

Safety-Related	Non-Safety Related

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SSC Risk Categorization

Importance Measures ↑		
	RISC - 1 **Safety-Related,** **Safety Significant** **FV>0.005 and RAW>2** **One plant experience:** **3,971 (6.0%)**	**RISC - 2** **Non-Safety Related,** **Safety Significant** **FV>0.005 or RAW>2** **One plant experience:** **456 (0.7%)**
	RISC - 3 **Safety-Related,** **Low Safety Significant** **FV<0.005 and RAW<2** **One plant experience:** **13,755 (20.8%)**	**RISC - 4** **Non-Safety Related,** **Low Safety Significant** **FV<0.005 and RAW<2** **One plant experience:** **47,876 (72.5%)**

Traditional →

Emergency Core Cooling System

- **An ECCS must be designed to withstand the following postulated LOCA: a double-ended break of the largest reactor coolant line, the concurrent loss of offsite power, and a single failure of an active ECCS component in the worst possible place.**

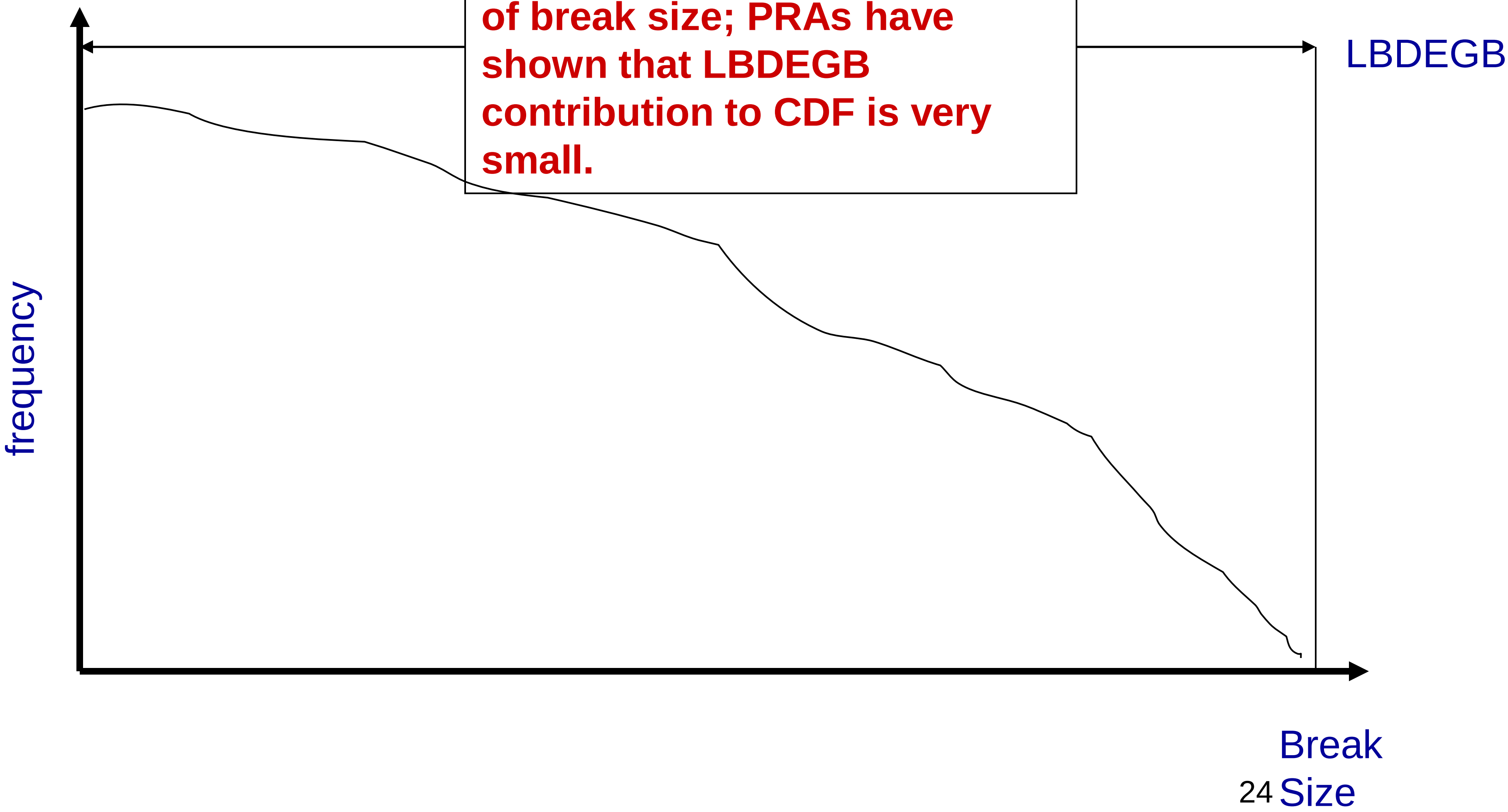
ECCS Design

- **Computer codes are reviewed and approved by the NRC staff after being benchmarked against scaled test facilities**

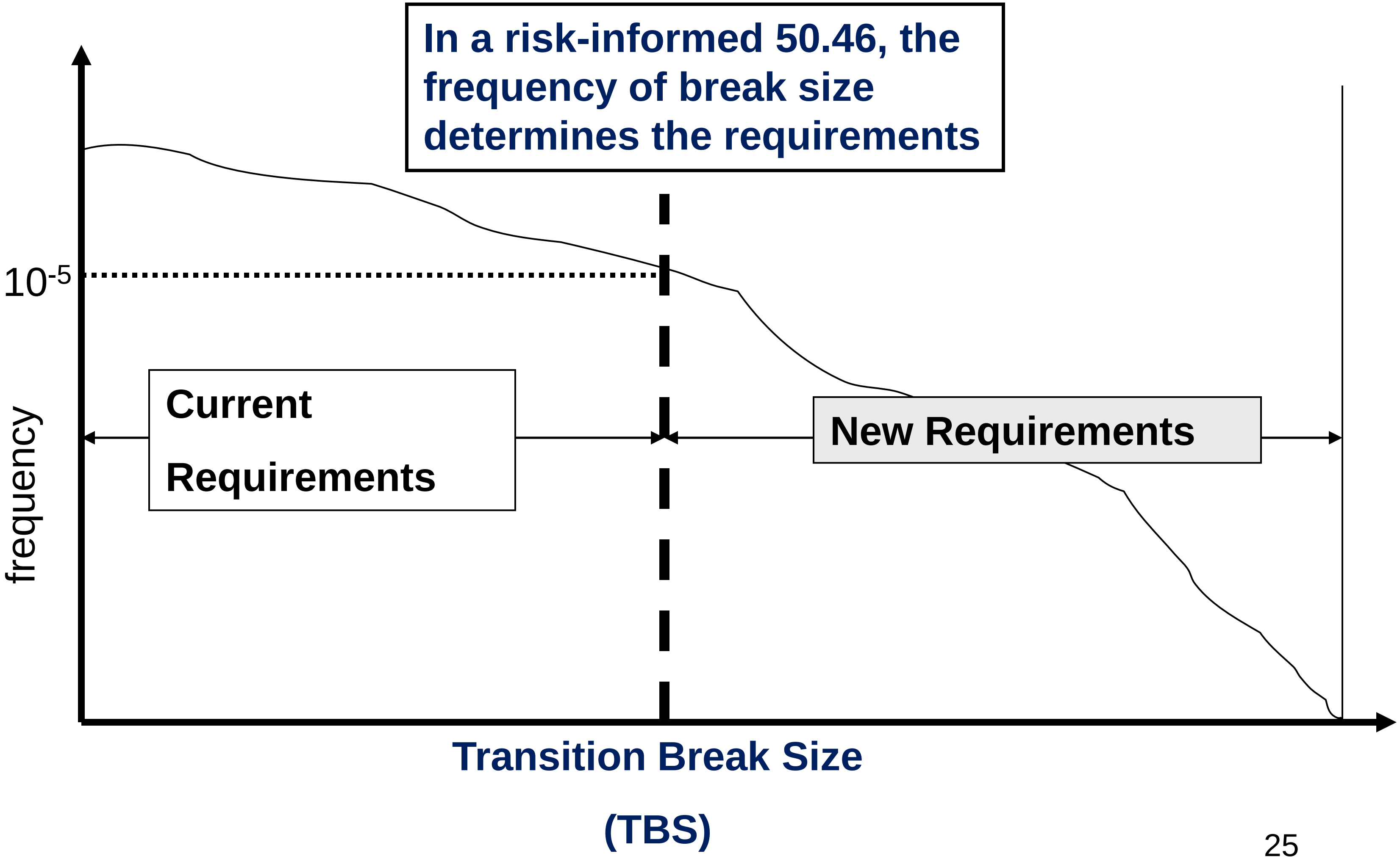
- **Codes use conservative input assumptions to ensure peak cladding temperature of 2200 ºF is not exceeded**

Current Situation

Current requirements are independent of the frequency of break size; PRAs have shown that LBDEGB contribution to CDF is very small.

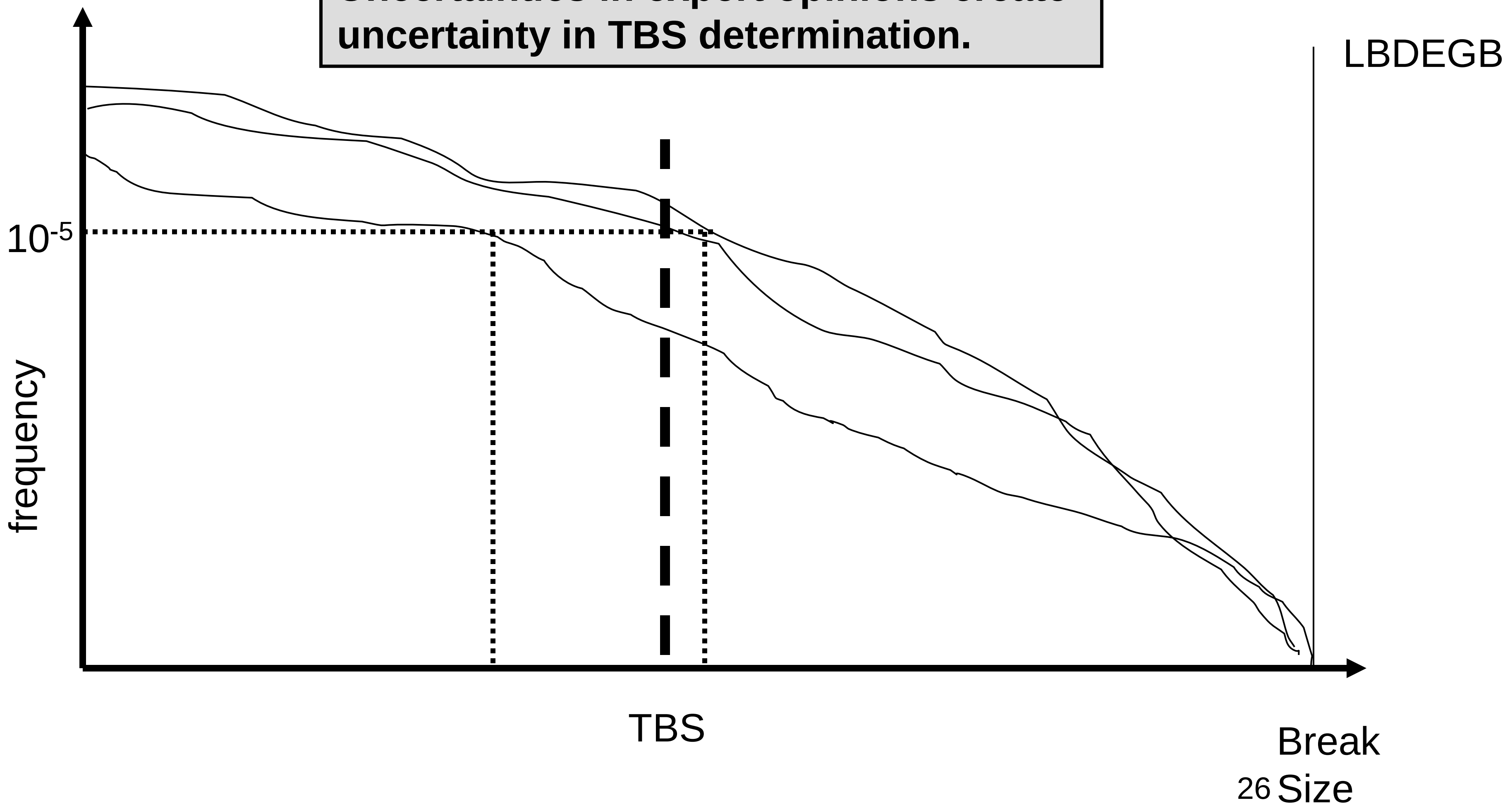


Proposal for Risk-Informing the ECCS Rule (50.46)

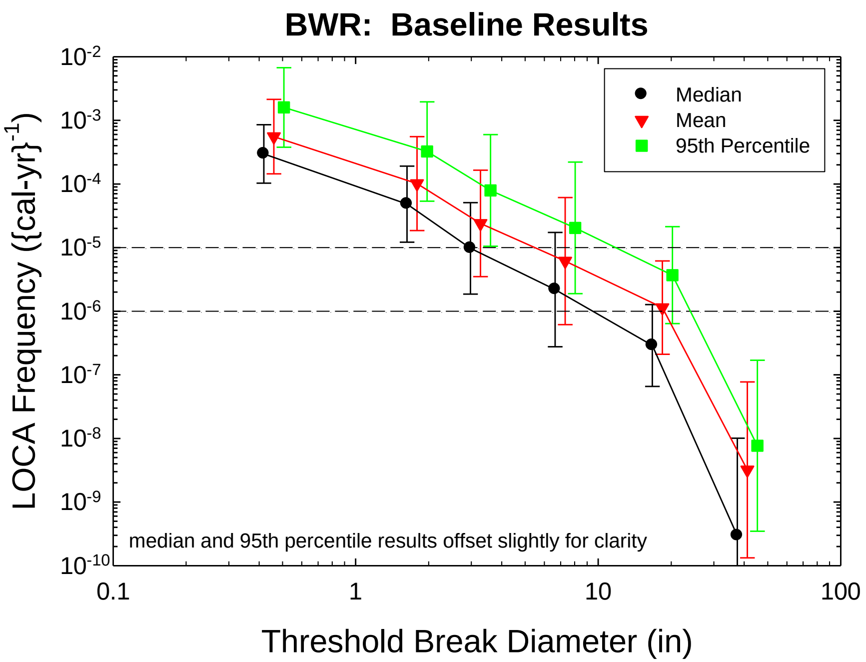


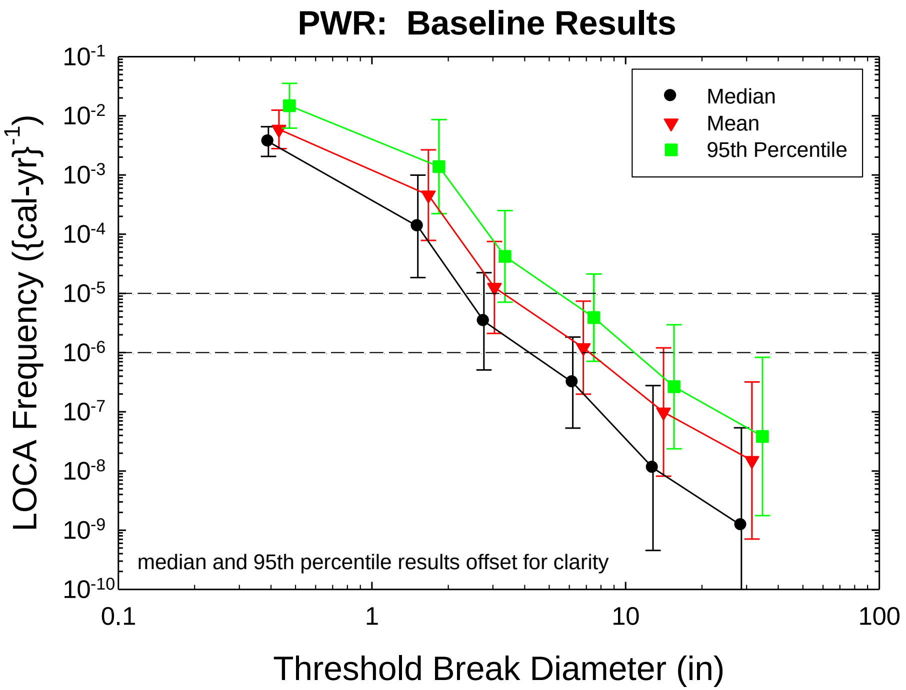
Complications

Uncertainties in expert opinions create uncertainty in TBS determination.



Total LOCA Frequencies





- Error bars represent 95% confidence bounds accounting for variability among panelist responses.
- Differences between median and 95th percentile estimates reflect individual panelist uncertainty.

Transition Break Size (50.46a)

- **A break of area equal to the cross-sectional area of the inside diameter of specified piping of a specific reactor.**

- **PWRs**
  - ➢ **Expert judgment: 4 to 7 inches.**
  - ➢ **The largest piping attached to the reactor coolant system (10-13 inches).**

- **BWRs**
  - ➢ **Expert judgment: 6 to 14 inches.**
  - ➢ **The larger of the feedwater line inside containment or the residual heat removal line inside containment (about 20 inches).**

Key Messages

- Regulatory decisions regarding technical matters are always the result of deliberation.
- Traditional conservative methods of handling uncertainties may lead to unnecessary regulatory burden and may miss important accident scenarios.
- Probabilistic analyses have been very useful making the system more rational.
- The issue of unknown unknowns always leads to conservatism.