Managing Uncertainties in the Regulation of Nuclear Facilities: The Issue of Unknown Unknowns

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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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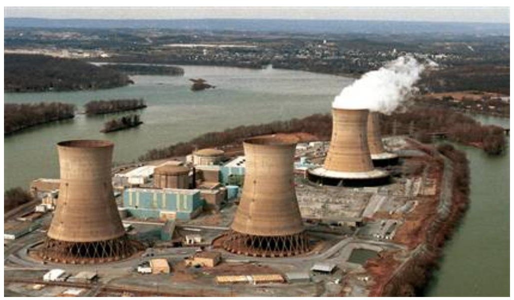
NRC Oversight



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?**
  - **How can we protect ourselves from the unknown unknowns?**

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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 Loss-of-Coolant Accident: 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.**

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 is not used. Decisions are based on judgment.**

The Deliberation

- **The decision maker and the stakeholders deliberate. Their values are included in the decision-making process.**
- **The analytical results are scrutinized and sensitivity analyses are produced. Conservatism is added as appropriate.**

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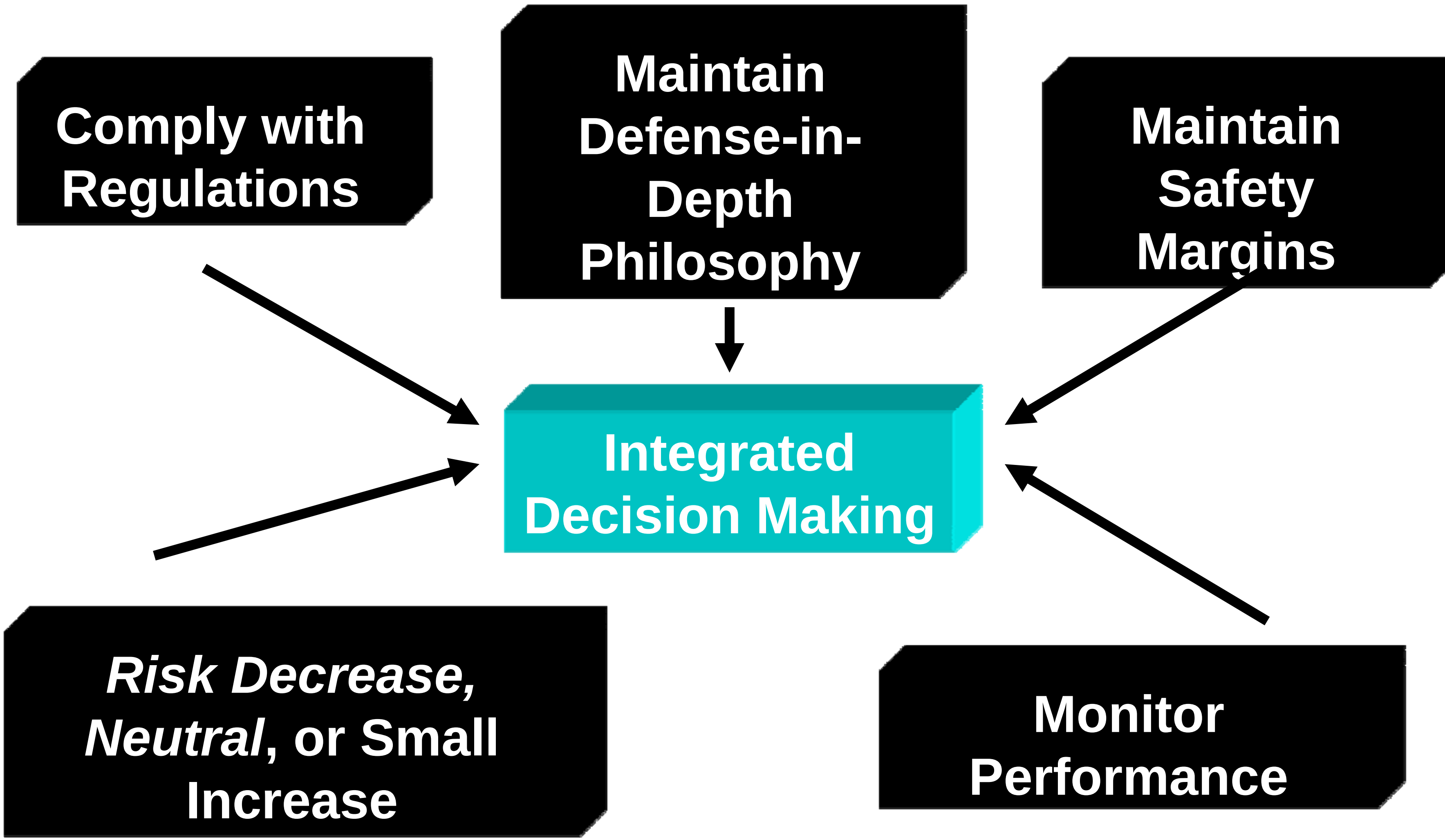
Risk-Informed Decision Making for Licensing Basis Changes (RG 1.174, 1998)



Conflicts arise between Traditional and Risk-Based Frameworks

Traditional "Deterministic" Approaches

- Unquantified Probabilities
- Design-Basis Accidents
- 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
- Incomplete
- Quality is an issue

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.**

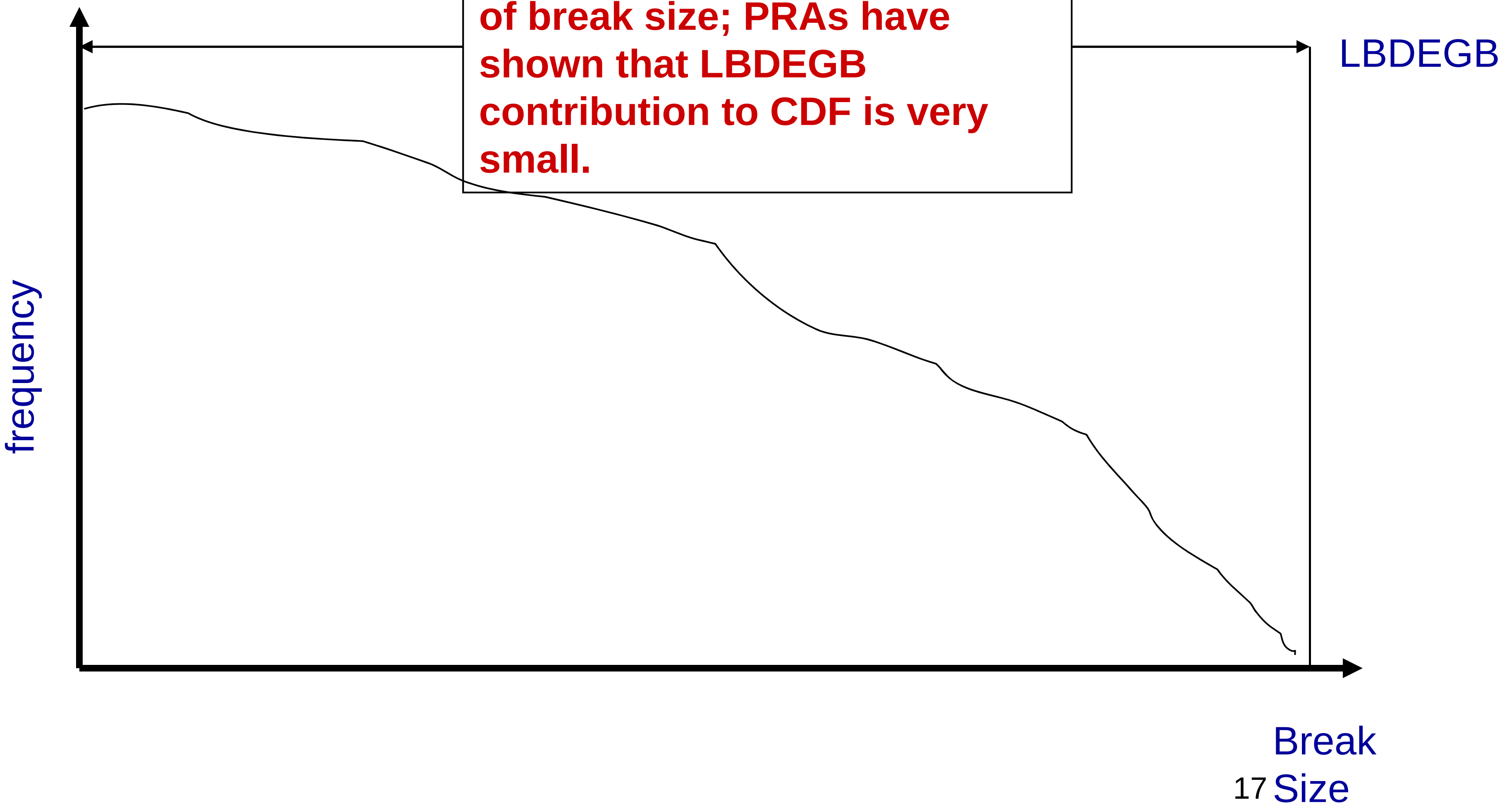
ECCS Design

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

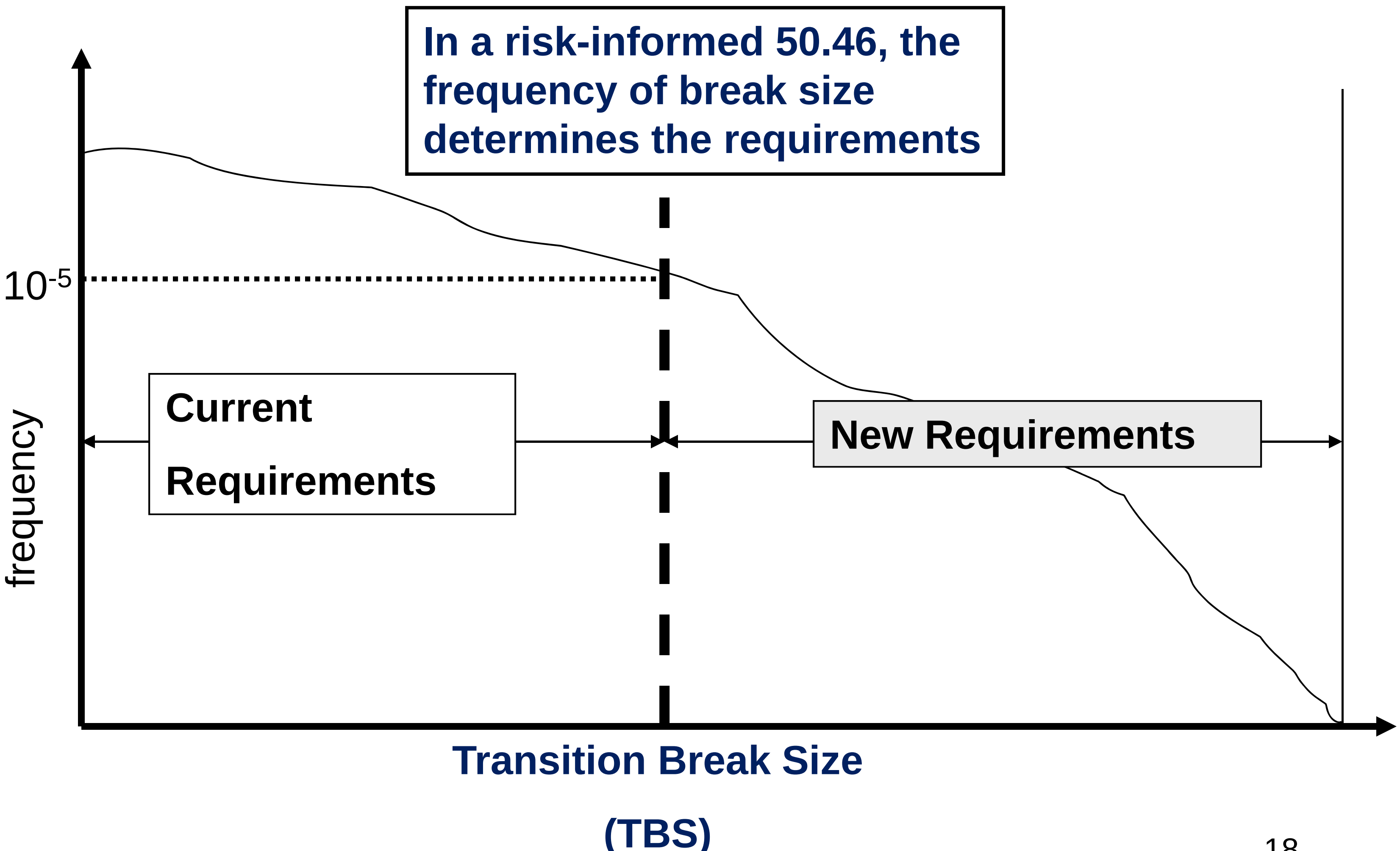
- **Codes use conservative input assumptions to ensure peak cladding temperature of 2200 ºF is not exceeded**

Current Situation

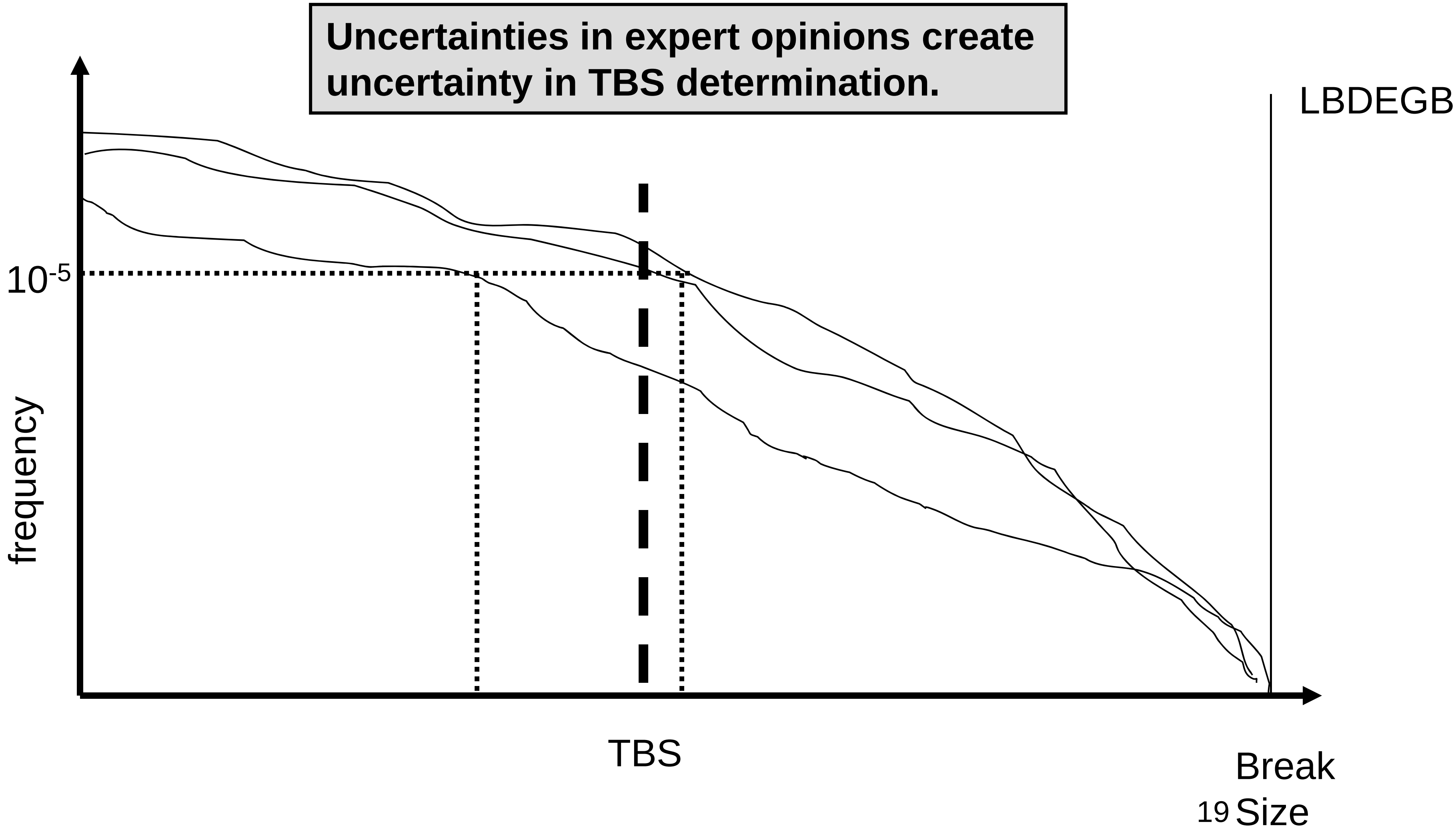
Current requirements are independent of the frequency of break size; PRAs have shown that LBDEGB contribution to CDF is very small.



Proposal for Risk-Informing the ECCS Rule (50.46a)

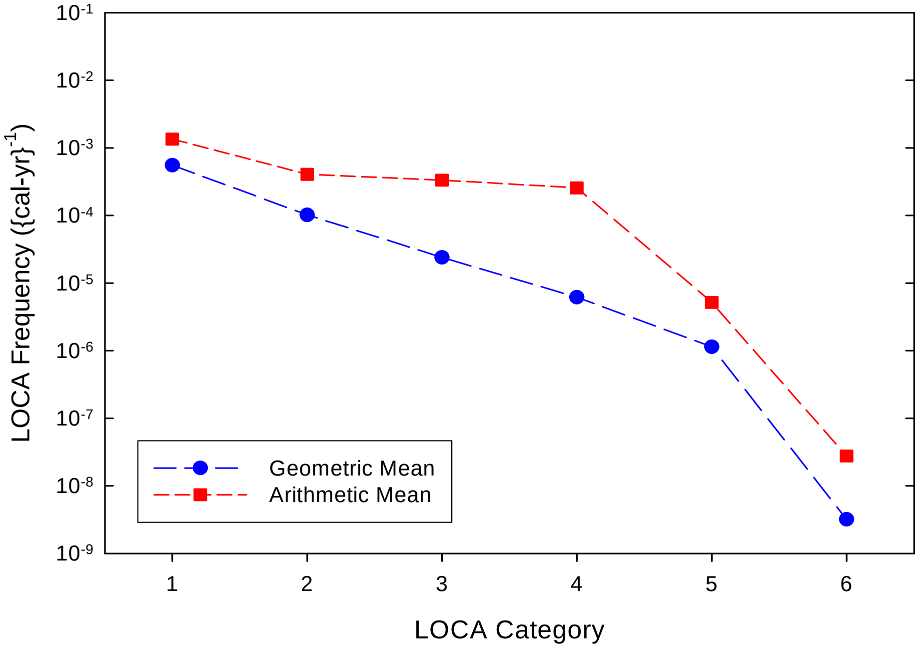


Complications

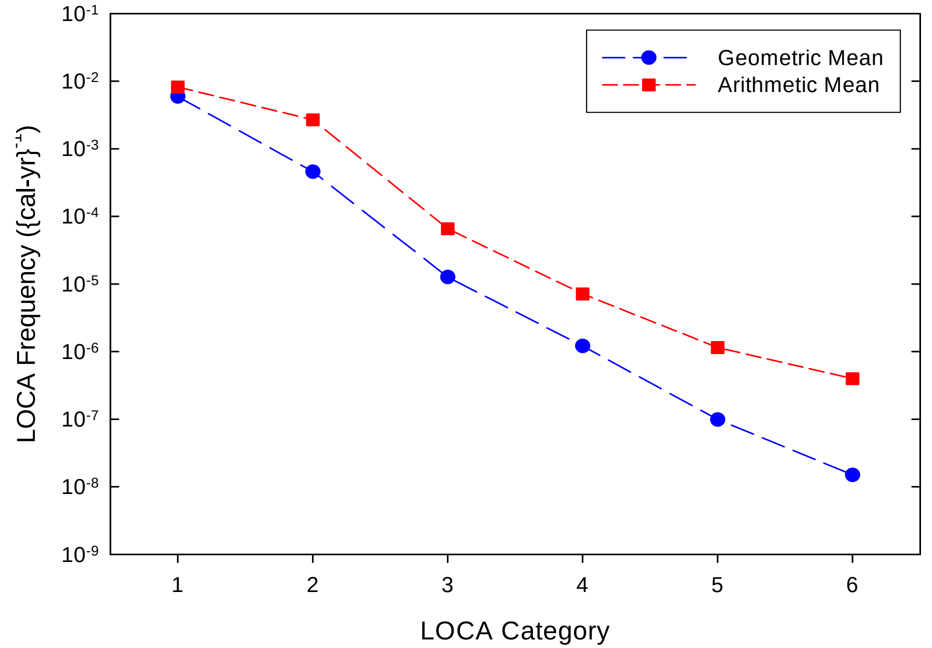


Uncertainties: Aggregation Method Example

BWR Current Day Estimates: Mean Frequency



PWR Current Day Estimates: Mean Frequency



- **Aggregated estimates can be affected significantly by approach.**
- **Similar difference among 95th percentile estimates.**

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.**
  - **Conservative Choice: The largest piping attached to the reactor coolant system (10-13 inches).**

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

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ACRS Recommendations

(November 16, 2006)

- **The Rule to risk-inform 10 CFR 50.46 should not be issued in its current form. It should be revised to strengthen the assurance of defense in depth for breaks beyond the transition break size (TBS). Such assurance would reduce concerns about uncertainties in determining the TBS.**

- **…the requirements for mitigation capabilities for breaks beyond the TBS should be based on defense-in-depth considerations to provide margin against unanticipated degradation phenomena, human errors, extremely large loads such as those associated with earthquakes beyond the safe shutdown earthquake, and other unanticipated events. The degree of defense in depth required can only be determined by judgment based on experience and best attempts to quantify uncertainties.**

NRC Staff Response

(May 16, 2007)

- **The staff believes that the ACRS recommendation to establish defense in depth based on engineering judgment conflicts with previous Commission direction in that the Commission directed that defense in depth be based upon risk significance. The particular changes recommended by the ACRS are more conservative than the approach in the draft rule since they would result in additional requirements to increase assurance of mitigation capability for breaks larger than the TBS.**

- **The staff believes that risk significance of beyond TBS breaks is too low to warrant such additional requirements.**

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Concluding Remarks

- An updated proposed rule will be submitted by the NRC staff to the Commission soon.
- The concern about unknown unknowns creates conflicts in risk-informed decision making thus diminishing the benefits of a purely risk-based approach.
- The 1995 PRA Policy Statement states that PRA should be used to reduce unnecessary conservatisms associated with current regulatory requirements.
- What are "unnecessary conservatisms" is debatable.