Risk-Informed Changes to the Licensing Basis - II

22.39 Elements of Reactor Design, Operations, and Safety

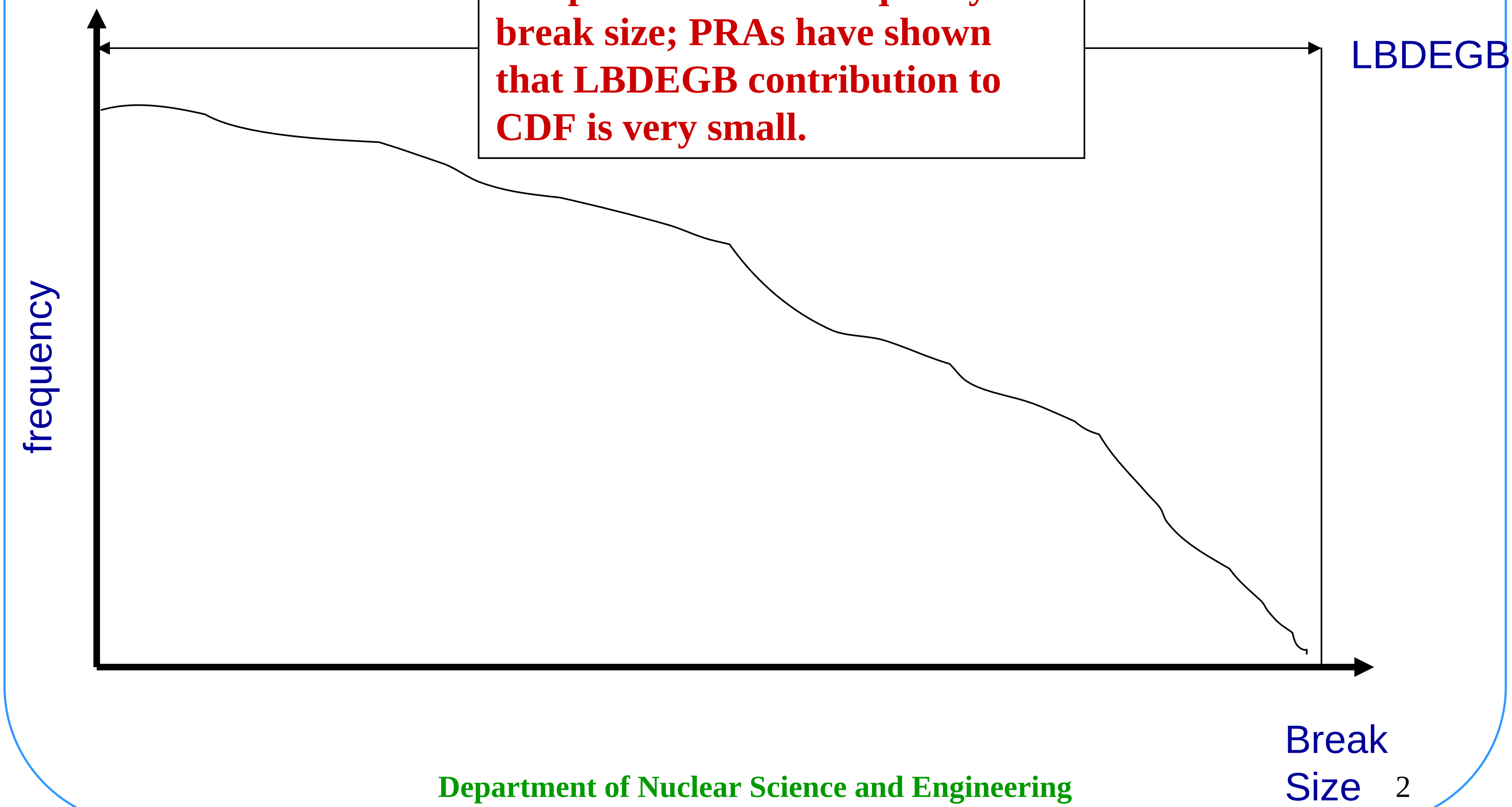
Lecture 14

Fall 2006

George E. Apostolakis
Massachusetts Institute of Technology

Current Situation

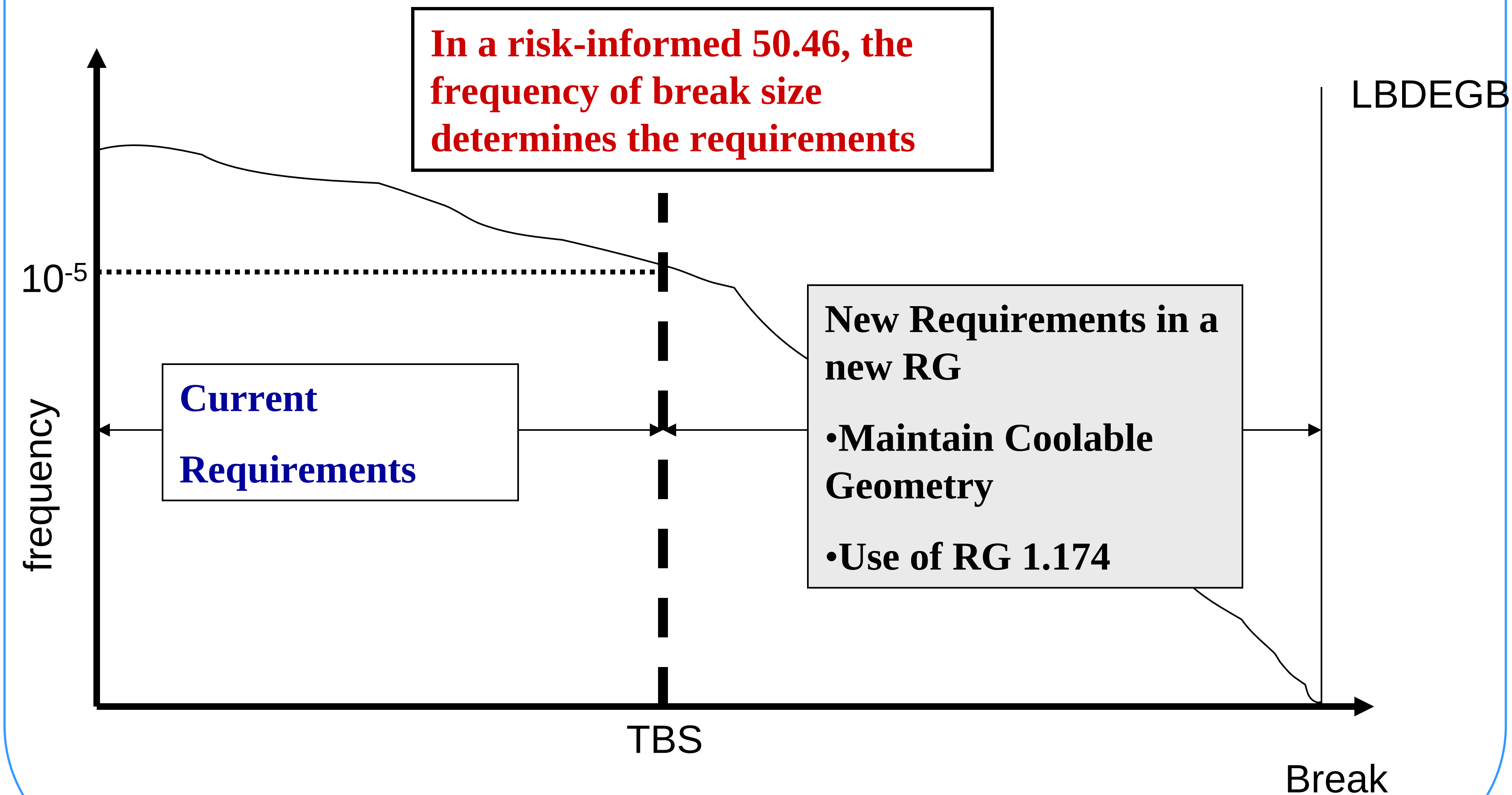
Current requirements are independent of the frequency of break size; PRAs have shown that LBDEGB contribution to CDF is very small.



Draft Rule Structure

- Existing § 50.46 essentially unchanged
- Voluntary alternative rule added (§ 50.46a, now 50.46b)
- 50.46a defines alternative acceptance criteria
- 50.46b addresses LOCA redefinition only
- LOCA break spectrum divided into 2 regions by "transition" break size (TBS)
  - based upon frequency and other considerations
- Breaks in smaller break region continue to be DBAs; must meet current § 50.46 analysis requirements and acceptance criteria
- Breaks larger than TBS become beyond design-basis accidents, but mitigation capability must be demonstrated up to full DEGB
  - less stringent analysis assumptions/acceptance criteria
  - demonstrate for all at-power operating configurations

Proposal for Risk-Informing 50.46



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.**

- **BWRS**
  - ➢ **Expert judgment: 6 to 14 inches.**
  - ➢ **The larger of the feedwater line inside containment or the residual heat removal line inside containment.**

Breaks at or below the TBS (50.46a)

(i) *Peak cladding temperature*. The calculated maximum fuel element cladding temperature must not exceed 2200°F.
(ii) *Maximum cladding oxidation*. The calculated total oxidation of the cladding must not at any location exceed 0.17 times the total cladding thickness before oxidation.
(iii) *Maximum hydrogen generation*. The calculated total amount of hydrogen generated from the chemical reaction of the cladding with water or steam must not exceed 0.01 times the hypothetical amount that would be generated if all of the metal in the cladding cylinders surrounding the fuel, excluding the cladding surrounding the plenum volume, were to react.
(iv) *Coolable geometry*. Calculated changes in core geometry must be such that the core remains amenable to cooling.
(v) *Long term cooling*. After any calculated successful initial operation of the ECCS, the calculated core temperature must be maintained at an acceptably low value and decay heat must be removed for the extended period of time required by the long-lived radioactivity remaining in the core.

Breaks larger than the TBS (50.46a)

- The evaluation must be performed for a number of postulated LOCAs of different sizes and locations sufficient to provide assurance that the most severe postulated LOCAs larger than the TBS up to the double-ended rupture of the largest pipe in the reactor coolant system are analyzed. These calculations may take credit for the availability of offsite power and do not require the assumption of a single failure. Realistic initial conditions and availability of safety-related or non safety-related equipment may be assumed if supported by plant-specific data or analysis.

- **(i) *Coolable geometry*. Calculated changes in core geometry must be such that the core remains amenable to cooling.**

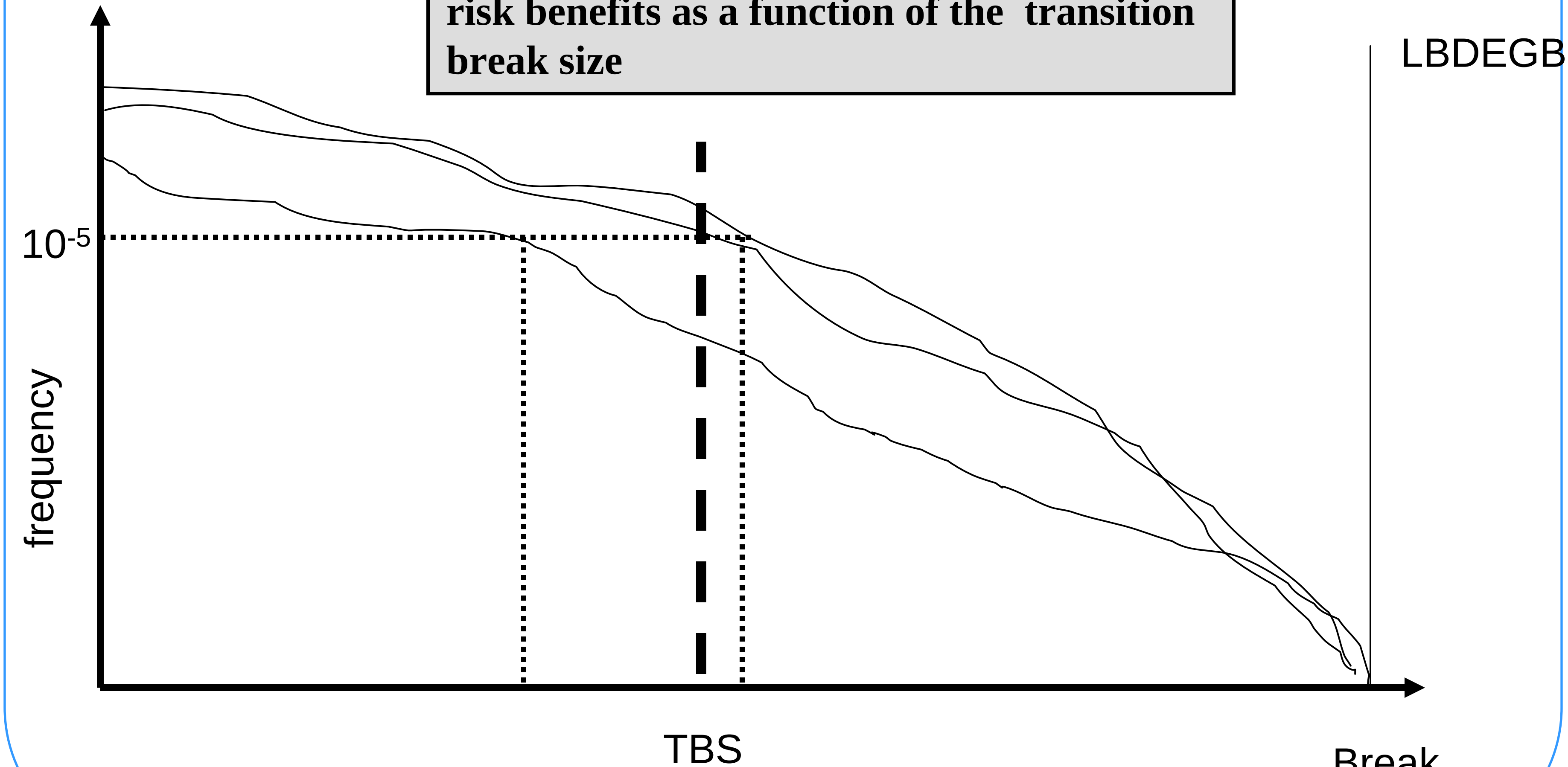
- **(ii) *Long term cooling*. After any calculated successful initial operation of the ECCS, the calculated core temperature must be maintained at an acceptably low value and decay heat must be removed for the extended period of time required by the long-lived radioactivity remaining in the core.**

Plant Changes Under § 50.46b

- **License amendment submittals must be risk-informed:**
  - **Must meet criteria consistent with RG 1.174 (defense-in-depth, safety margins, monitoring program, and acceptable risk)**
  - **Must meet PRA quality and scope requirements**
  - **The licensee shall periodically assess the cumulative effect of changes to the plant, operational practices, equipment performance, and plant operational experience. The assessment must be based upon updated PRA and risk assessments. The assessment must be completed in a timely manner, but no less often than once every two refueling outages.**

Complications

Uncertainties in expert opinions create uncertainty in TBS determination; We need a quantitative understanding of the possible risk benefits as a function of the transition break size



Summary of the Expert Opinion Elicitation Process

- **Formal elicitation process used to estimate generic BWR and PWR passive-system LOCA frequencies associated with material degradation.**
- **Developed quantitative estimates for piping and non-piping base cases for anchoring elicitation responses.**
- **Panelists provided quantitative estimates supported by qualitative rationale for underlying technical issues in individual elicitations.**
  - **Generally good agreement about LOCA contributing factors.**
  - **Large individual uncertainty and panel variability in quantifying estimates.**
- **Quantitative results determined by aggregating individual panelists' estimates.**
- **LOCA elicitation provides a sufficient technical basis to support transition break size development.**

NUREG-1829, *Estimating LOCA Frequencies through the Elicitation Process*, Nuclear Regulatory Commission, Washington, DC, June 2005.

Elicitation Objectives and Scope

- **Develop generic BWR and PWR piping and non-piping passive system LOCA frequency distributions as function of break size and operating time.**
  - **LOCAs which initiate in unisolable portion of reactor coolant system.**
  - **LOCAs related to passive component aging, tempered by mitigation measures.**
  - **Small, medium, and large-break LOCAs examined. Large break category further subdivided to consider LOCA sizes up to complete break of largest RCS piping.**
  - **Time frames considered: 25 years (current day), 40 years (end of original license), and 60 years (end of life extension).**
- **Primary focus: frequencies associated with normal operating loads and expected transients.**
- **Assume that no significant changes will occur in the plant operating profiles.**

Formal Elicitation Approach

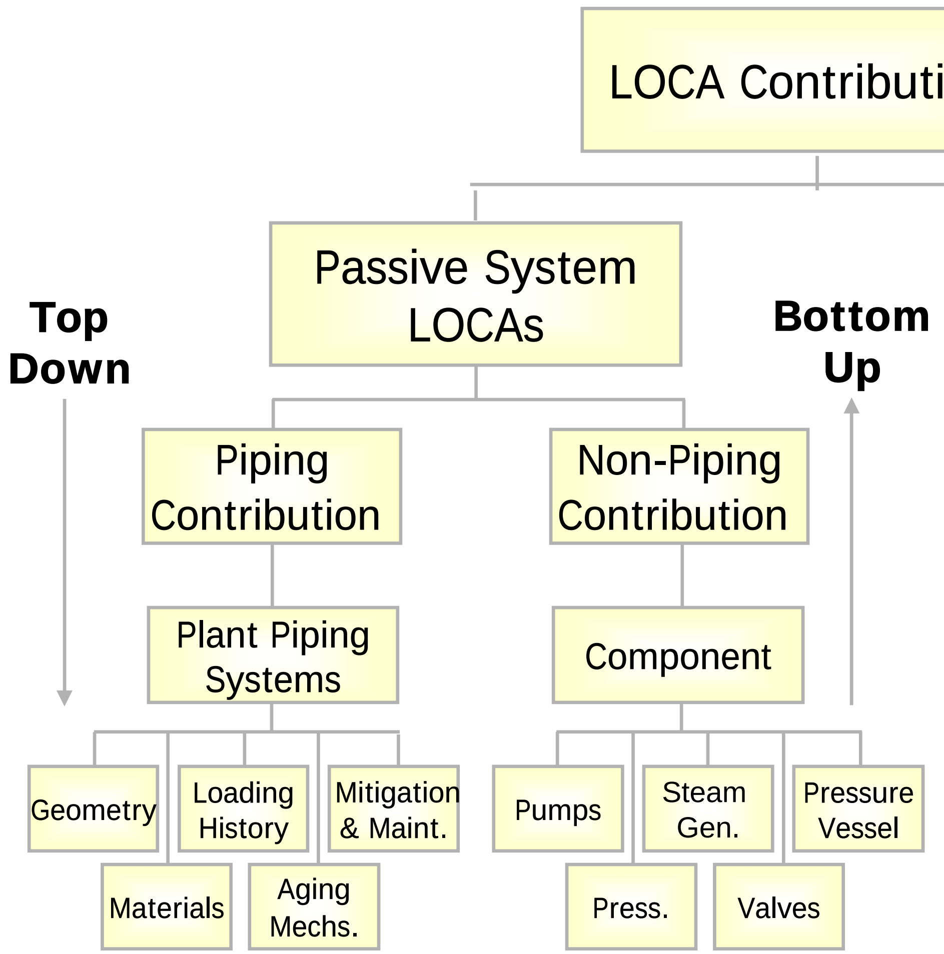
- Conduct preliminary elicitation.
- Select panel and facilitation team.
- Develop technical issues.
- Quantify base case estimates.
- Formulate elicitation questions.
- Conduct individual elicitations.
- Analyze quantitative results and qualitative rationale.
- Summarize and document results.
- Conduct internal and external review of process and results.

LOCA Size Classification

- **LOCA sizes based on leak rate to group into classes having similar mitigation measures.**
  - **First three categories similar to NUREG-1150 and NUREG/CR-5750.**
  - **Three additional LBLOCA categories used to determine larger break size frequencies.**
- **Correlations developed to relate flow rate to effective break area.**

Category	**Flow Rate Threshold (gpm)**	**LOCA Size**
1	> 100	SB
2	> 1500	MB
3	> 5000	LB
4	> 25,000	LB a
5	> 100,000	LB b
6	> 500,000	LB c

Technical Issues Structure



- Elicitation focuses on passive system LOCAs.
- Important piping and non-piping variables identified.
- Elicitation structure supports top down and bottom up analyses.

Piping Base Case Development

- All elicitation responses relative to the base cases.
- Base case conditions specify the piping system, piping size, material, loading, degradation mechanism(s), and mitigation procedures.
- Five Base Cases Defined.
  - BWR
    - Recirculation System (BWR-1)
    - Feedwater System (BWR-2)
  - PWR
    - Hot Leg (PWR-1)
    - Surge Line (PWR-2)
    - High Pressure Injection makeup (PWR-3)
- The LOCA frequency for each base case condition is calculated as a function of flow rate and operating time.
- Four panel members individually estimated frequencies: two using operating experience and two using probabilistic fracture mechanics.

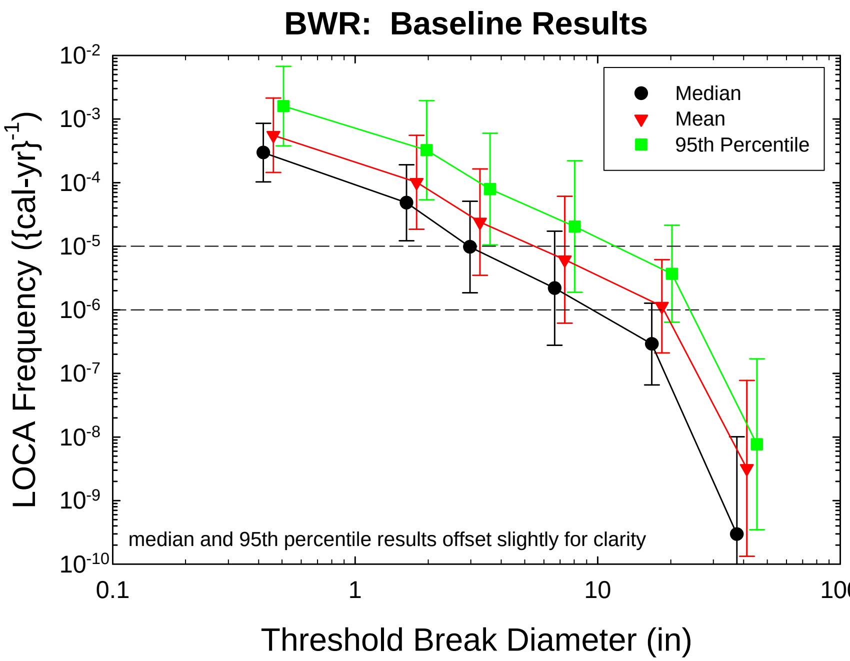
Elicitation Questions

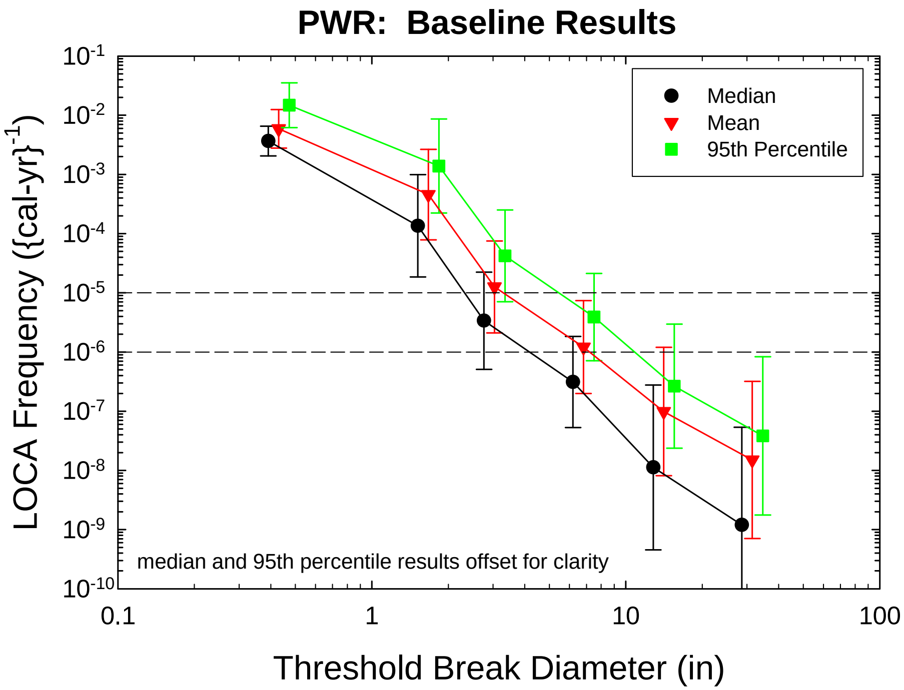
- Questions on the following topic areas.
  - Base Case Evaluation.
  - Regulatory and Utility Safety Culture pertaining to LOCA initiating events.
  - LOCA frequencies of Piping Components.
  - LOCA frequencies of Non-Piping Components.
- Quantitative Responses:
  - Questions are relative to a set of chosen base case conditions.
  - Each question asks for mid, low, and high values.
  - Questions can be answered using a top-down or bottom-up approach.
- Qualitative Rationale:
  - Rationale is provided and discussed for important issues to support quantitative values provided by each panelist.
  - Possible inconsistencies between answers and rationales brought to panelists' attention.

Elicitation Insights: BWR & PWR Plants

- **BWR Plants**
  - Thermal fatigue, intergranular stress corrosion cracking (IGSCC), mechanical fatigue, flow accelerated corrosion (FAC) identified as important degradation mechanisms.
  - Increased operating transients (e.g., water hammer) compared to PWR plants.
  - BWR community has more experience identifying and mitigating degradation due to IGSCC experience in the early 1980s.
  - BWR service experience must be carefully evaluated due to preponderance of pre-mitigation IGSCC precursor events.
- **PWR Plants**
  - Primary water stress corrosion cracking (PWSCC), thermal fatigue, and mechanical fatigue identified as important degradation mechanisms.
  - PWSCC concerns paramount for panel.
    - Near-term frequency increases due to PWSCC are likely before effective mitigation is developed.
    - Most panelists believe that issue will be successfully resolved within the next several years.

Total LOCA Frequencies: Current Day





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

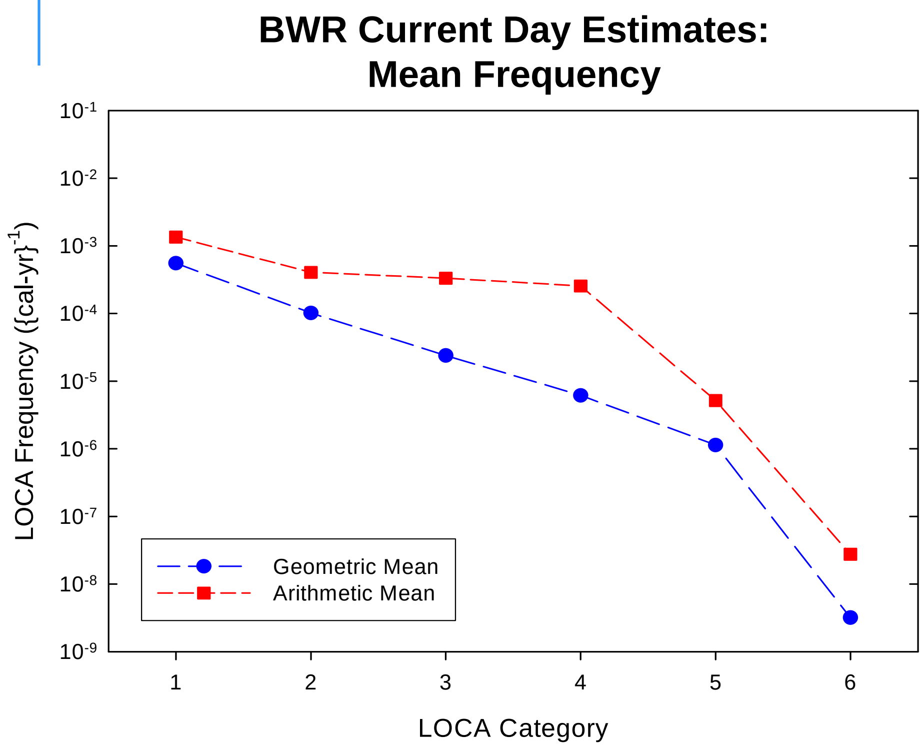
Sensitivity Analyses: Overconfidence Adjustment

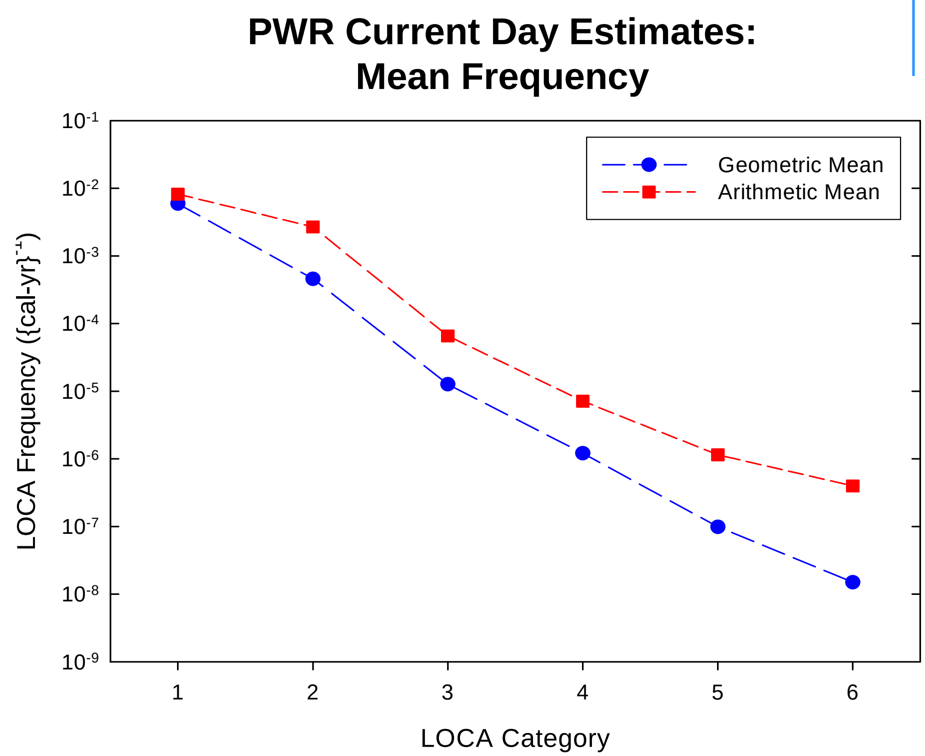
- **Experts are generally overconfident about their uncertainty.**
  - **Demonstrated using almanac-type questions with known answers.**
  - **Rule of thumb: true coverage level is approximately half the nominal coverage level.**
    - **Nominal elicitation coverage level: 90% (95^{th} – 5^{th} percentiles)**
    - **Implication is that true coverage level is about 50% (75^{th} – 25^{th} percentile).**
- **Evaluate the effect of adjusting the nominal coverage level.**
  - **No change in the mid value responses**
  - **Evaluate adjustments of error factors associated with bottom line responses for each panelist.**
  - **More ad hoc broad and targeted adjustment schemes evaluated and discussed in NUREG, but not as attractive.**

Sensitivity Analyses: Aggregating Expert Opinion

- Baseline method uses geometric mean of the individual panelist estimates to determine group estimates for all total LOCA frequency parameters: 5^{th}, 50^{th}, 95^{th}, mean.
  - Based on assumed lognormal structure of individual estimates.
  - Ensures estimates are not significantly influenced by outliers.
  - Results using median or trimmed geometric mean are similar to baseline method.
- Alternative method is to use the arithmetic mean all the individual panelist distributions (mixture distribution).
  - Assumes that individual results are obtained from equally credible models that are randomly sampled from population of models.
  - Key regulatory parameters may be dominated by outliers.
  - Difference between 5^{th} and 95^{th} percentiles is much wider.

Aggregating Expert Opinion: Arithmetic (AM) vs. Geometric (GM) Mean





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

Selecting the TBS

- **NRC staff adjusted results of expert elicitation process to account for: uncertainties in elicitation process, LOCAs caused by inadvertent actuation of active components, LOCAs caused by large loads (such as heavy loads, seismic, waterhammer), and other considerations (such as degradation in specific piping, specific pipe sizes).**

EXAMPLE BREAKS