Passive System LOCA Frequency Estimation and Break Size Selection

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Presentation Objectives

1. Outline LOCA elicitation chronicled in draft NUREG-1829 and used as part of the technical basis supporting the proposed 50.46 rule revision and for general use in PRA plant modeling

2. Summarize other activities associated with selecting the transition break size (TBS) for proposed 50.46 rule revision
   - Considerations associated with selecting TBS
   - NUREG-1903: Seismic considerations
   - Development of draft guidance

Historical LOCA Frequency Evaluation

- LOCA frequencies previously developed from operating history.
- Notable Previous Evaluations:
  - WASH-1400 (1975): Estimates largely based on experience in other industries
  - NUREG-1150 (1987): Updated the WASH-1400 distributions to account for the additional service since WASH-1400
  - NUREG/CR-5750, Appendix J (1998): Updated original WASH-1400 study for SB LOCAs while MB and LB LOCA frequencies were calculated from precursor leaks in class 1 systems
  - Barsebäck-1 Study (1998): Determined estimates using piping reliability attribute and influence characteristics for each degradation mechanism
- Operating history, by itself, may not accurately reflect future performance and requires significant extrapolation for MB and LB LOCA frequencies.

NUREG-1829: Scope and Objectives

- Develop piping and non-piping passive system LOCA frequencies as a function of leak rate and operating time up to the end of the license extension period using expert elicitation
  - LOCAs which initiate in unisolable portion of reactor coolant system
  - LOCAs related to passive component aging, tempered by mitigation measures

- Determine LOCA frequency distributions for typical plant operational cycle and history

- Assume that no significant changes will occur in future plant operating profiles

Expert Elicitation Process

- Classical approaches
  - Operating experience: LOCA events are rare
  - Plant modeling: Number and diversity of possible failure modes is too complex to accurately model

- Expert elicitation is a formal process for providing quantitative estimates for the frequency of physical phenomena when the required data is sparse and when the subject is too complex to accurately model.

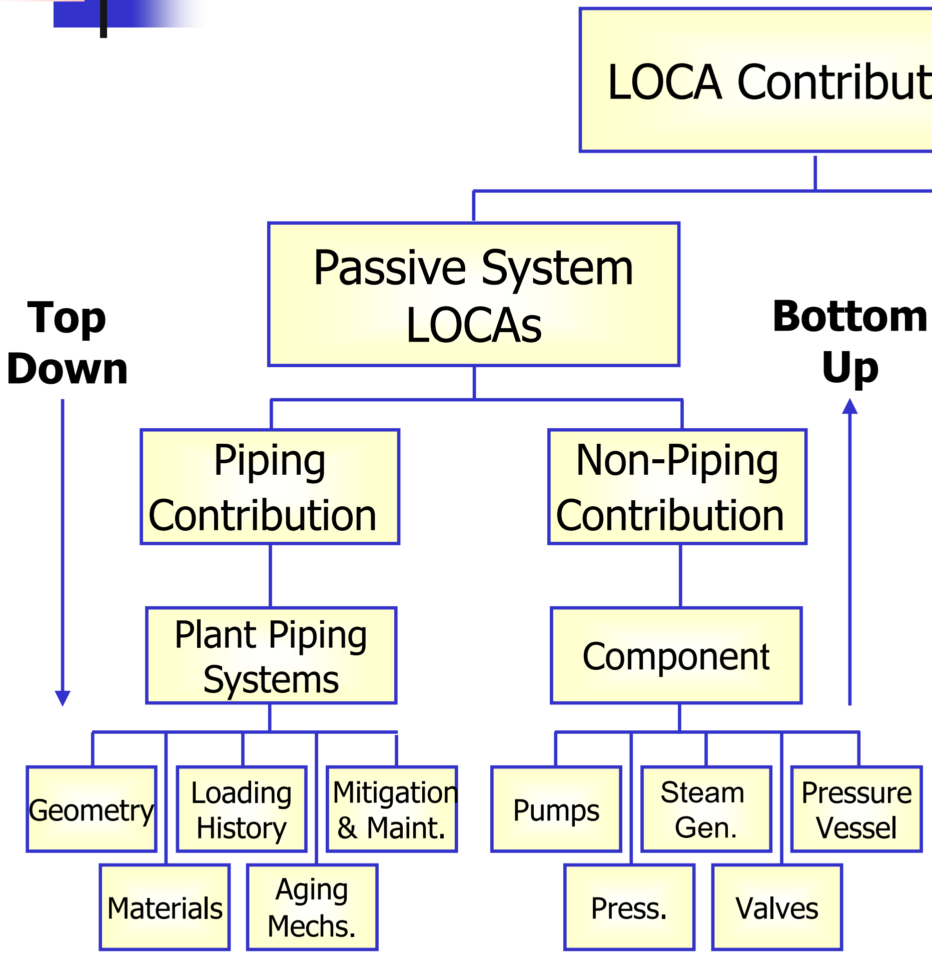
- Elicitation has often been used at NRC
  - Development of seismic hazard curves
  - Performance assessments for high-level radioactive waste repository
  - Determination of reactor pressure vessel flaw distributions

NUREG-1829: LOCA Size Classification

- LOCA sizes based on flow rate to group plant system response characteristics.
  - First three categories similar to NUREG-1150 and NUREG/CR-5750.
  - Three additional LBLOCA categories used to determine larger break frequencies.
- Correlations developed to relate flow rate to effective break area.
- Three time periods evaluated
  - Current day (average 25 years of operation)
  - End of design life (next 15 years of operation)
  - End of life extension (following 20 years of operation)

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

NUREG-1829: General Issue Classification

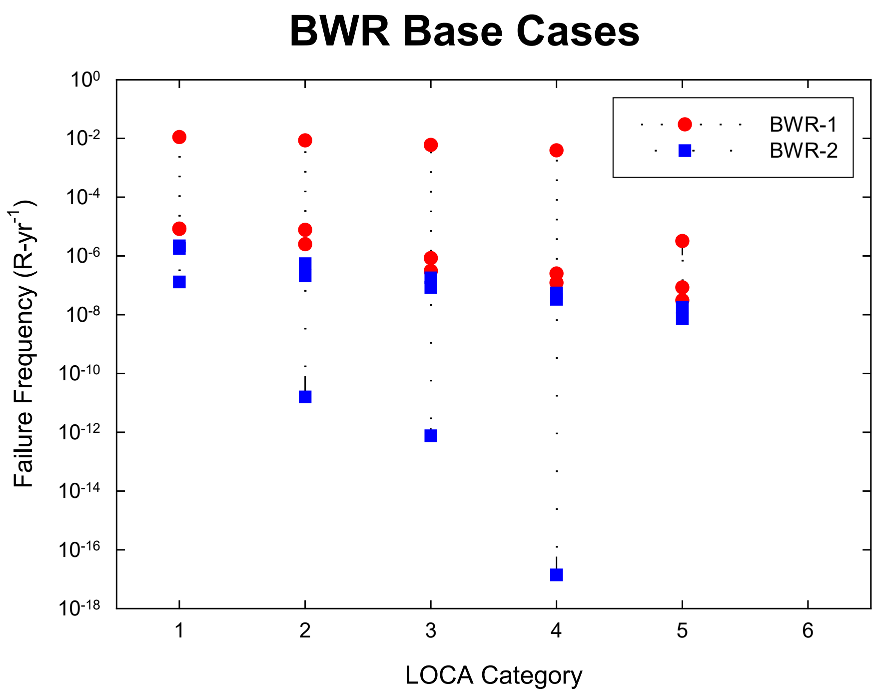


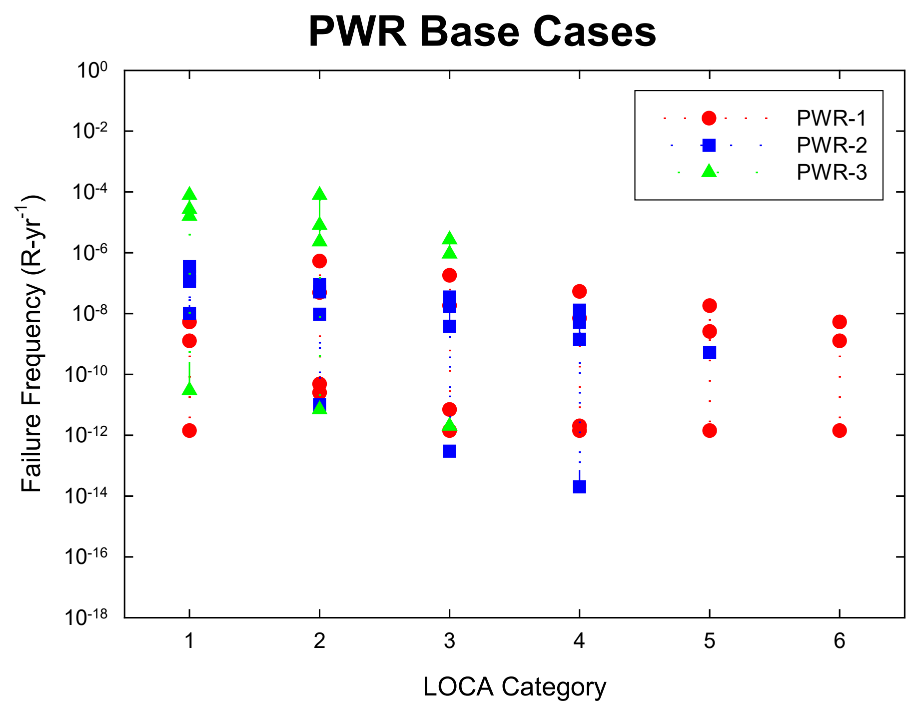
- Elicitation focuses on passive system LOCAs.
- Important piping and non-piping variables identified.
- Elicitation structure supports top down and bottom up analysis.

NUREG-1829: Piping Base Cases

- The base cases were available for anchoring the elicitation responses.
- 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.

Piping Base Case Summary Results: 25 Year Operating Period





- Large variability due to inconsistencies in both the conditions evaluated and differences in approaches.
- Each base case participant presented their approach and results to entire panel.
- Each panel member was asked to critique approaches & results during their elicitation session.

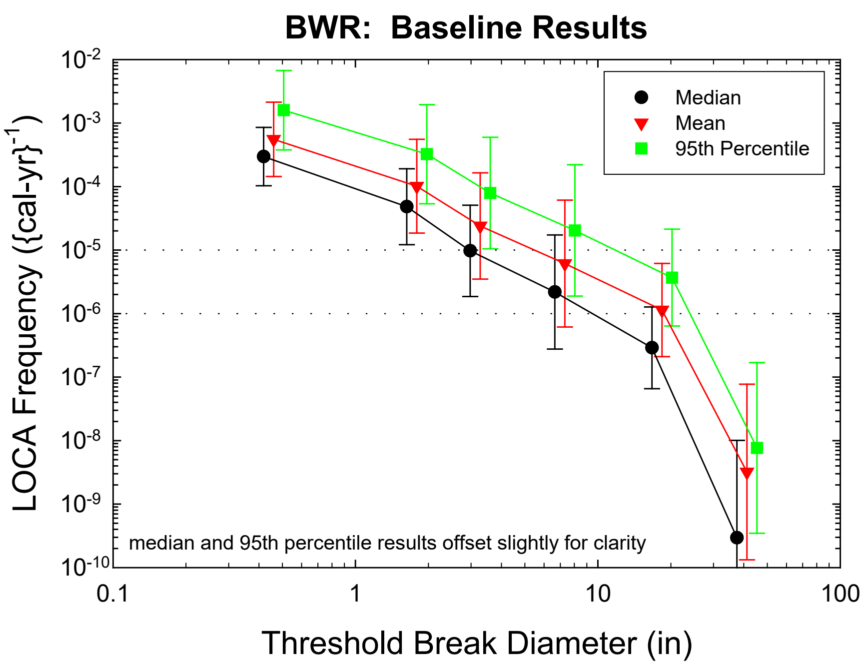
NUREG-1829: Non-Piping Base Cases

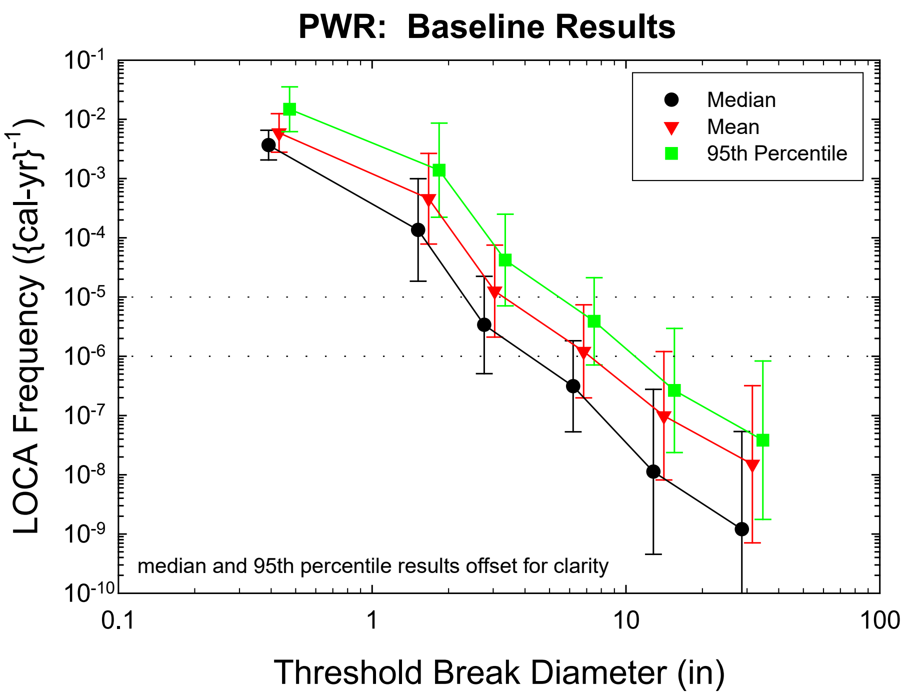
- The variety and complexity of the non-piping failure mechanisms makes the piping base case approach intractable.
- Approach
  - Develop general non-piping precursor database
  - Use PFM modeling to develop LOCA frequencies for targeted degradation mechanisms
    - CRDM ejection
    - BWR vessel rupture: normal operating and LTOP
    - PWR vessel rupture: PTS
- Analysis requirements
  - Choose appropriate base case: non-piping precursor, piping precursor, piping base case, or non-piping base case
  - Determine relative likelihood of each non-piping failure scenario compared to chosen base case

Analysis of Elicitation Responses: Framework

- Calculate individual estimates for each panelist.
  - Total BWR and PWR LOCA estimates
  - Approach is most self-consistent
- Aggregate individual estimates: Philosophy
  - Group results more accurate than any single estimate.
  - Outliers should not dominate quantitative estimates.
- Aggregate individual estimates: Approach
  - Combine parameters (mean, median, 5^{th} & 95^{th} percentiles) of individual distributions
  - Calculate confidence bounds associated with each parameter estimate
- Final LOCA distributions reflect uncertainty and variability.
  - Uncertainty: Individual panel member responses
  - Variability: Range of individual responses

NUREG-1829: Total LOCA Frequencies





- 95% confidence bounds (i.e., error bars) account for diversity among panelists
- Differences between median and 95^{th} percentiles reflect individual panelist uncertainty

NUREG-1829: Summary

- Formal elicitation process used to estimate generic BWR and PWR passive-system LOCA frequencies associated with material degradation during normal operations
- Piping and non-piping base cases were developed and evaluated for anchoring elicitation responses.
- Panelists provided quantitative estimates supported by qualitative rationale in individual elicitations for underlying technical issues.
  - Generally good agreement on qualitative LOCA contributing factors.
  - Large individual uncertainty and panel variability in quantitative estimates.
  - Results are generally comparable to NUREG/CR-5750 estimates.
- Group results determined by aggregating individual panelists' estimates.
  - Geometric mean aggregated results are consistent with elicitation objectives and results are generally comparable with NUREG/CR-5750 estimates.
  - Alternative aggregation schemes can result in higher LOCA frequencies.

Selection of Transition Break Size (TBS)

- Use NUREG-1829 results as a starting point.
- There is a range of pipe sizes which correlate to pipe break frequency of < 1E-5/cal-yr
- Selection should accommodate various uncertainties
- Other types of LOCAs should be considered in determining TBS
  - Active LOCAs
  - Load-generated LOCAs (i.e., dropped heavy loads, water hammer)
  - Seismically induced LOCAs
- Actual plant piping design and operating experience should be considered in final selection

TBS Selection

- TBS is selected as the size of the largest pipe attached to the main coolant loop
  - For PWRs, based on the size of the largest pipe attached to the cold or hot leg main loop piping
  - For BWRs, based on the size of the largest pipe in either of the RHR or Feedwater systems inside primary containment
  - Next larger pipes are significantly less likely to break
  - Accommodates uncertainties and provides regulatory stability

- TBS is defined in the proposed 50.46a rule as twice the cross-sectional flow areas of these size pipes

NUREG-1903: Objective and Approach

- **Objective**
  - Determine if seismic risk is acceptable for breaks greater than transition break size (TBS)
- **Approach**
  - Use of hybrid deterministic and probabilistic approaches
  - Six supporting activities
    - Unflawed piping
    - Flawed piping
    - Indirect failures
    - Review of past earthquake experience
    - Review of past PRAs
    - Review of a LLNL study conducted in connection with revision to GDC4

NUREG-1903: Summary

- Reviewed prior PRA, seismic studies and earthquake experience
- Analyzed direct piping failure associated with rare seismic events
  - Evaluated unflawed and flawed piping systems with diameter larger than the TBS (e.g., hot leg, cold leg, and cross-over leg)
  - Used updated seismic-hazard curves for plants east of Rocky Mountains
  - Used hybrid deterministic and probabilistic method to determine component stresses
  - Considered 10^{-5}/yr and 10^{-6}/yr seismic events
- Analyzed indirect piping failure associated with rare seismic events
  - Analyzed large component support failures that may lead to piping failure
  - Assumed that support failure leads directly to piping failure
  - Updated results from prior LLNL study to reflect new hazard and ground motion information
  - Determined mean failure probability of component supports

NUREG-1903: Summary, cont.

- Results
  - Unflawed piping: Failure frequency is much lower than 10^{-5}/yr
  - Flawed piping
    - Critical flaws for long, circumferential flaws ($\theta/\pi = 0.8$) are generally large
      - 40% of wall thickness for 10^{-5}/yr seismic event
      - 30% of wall thickness for 10^{-6}/yr seismic event
    - Conditional probability of breaks larger than the TBS should be less than 10^{-5}/yr
  - Indirect failures
    - Only two cases analyzed (W and CE plants)
    - Piping failure induced by major component support failure has a mean probability of approximately 10^{-6}/yr.

NUREG-1903: Use of Results

- **Use in §50.46a**
  - Risks of seismically induced LOCAs are expected to be acceptable
  - TBS selection is appropriate
- **Limitations**
  - Analyses may not be generically applicable
  - Indirect failure risks not generically evaluated

DG-1216 - Plant-Specific Applicability of TBS: Scope

- Consider issues and implications associated with generic aspects of NUREGs
  - Assumptions
  - Approach
  - Analysis
- Guidance proposed in several areas that may be affected by plant-specific factors
  - NUREG-1829 Applicability
    - Safety culture
    - *Current plant operation*
    - *Changes in plant operation that may affect LOCA frequencies*
  - NUREG-1903 Applicability
    - *Frequencies associated with direct piping failures caused by seismic loading*
    - *Frequencies associated with indirect piping failures caused by seismic loading*

DG-1216: Summary

- Guidance provided in areas that may be affected by plant-specific factors
  - NUREG-1829 Applicability
    - Current plant operation
    - Changes in plant operation that may affect LOCA frequencies
  - NUREG-1903 Applicability
    - Frequencies of seismically induced direct piping failures
- Evaluation required only for breaks larger than the proposed TBS
- Uses information submitted under other programs wherever possible
- No current guidance to ensure that frequencies of seismically induced indirect piping failures remain acceptable
  - Modified draft final rule based on ACRS feedback
  - Sample evaluation method has been proposed
  - Plan to add method to DG-1216
- Plan to publish interim RG in 2011 coincident with final rule
- Soliciting pilot applications for exercising RG approach

TBS Development for Risk-Informed Revision of 10 CFR 50.46

- **Commission Communication**
  - SECY-01-0133 (Feasibility): **ML011800524**
  - SECY-02-0057 (Recommended Changes): **ML020660607** / SRM: **ML030910476**
  - SECY-04-0037 (Request for Policy Direction): **ML040490133** / SRM: **ML041830412**
  - SECY-05-0052 (Initial Proposed Rule): **ML050480172** / SRM: **ML052100416**
  - SECY-07-0082 (Supplemental Proposed Rule): **ML070180692** / SRM: **ML072220595**
  - SECY-10-0161 (Final Rule): **ML102300252** / SRM: **ML12117A121**
- **Reports**
  - NUREG-1829 - Vol. 1/Vol. 2: **ML080630015**
  - NUREG-1903: **ML080880140**
  - DG-1216: **ML100430356**
- **ACRS Meetings**
  - Minutes of the 518th ACRS Meeting, Dec. 2-4, 2005: **ML081830134** (Selecting TBS)
  - Minutes of ACRS Subcommittee on Reliability and PRA, Nov. 27, 2007: **ML082530561** (NUREG-1829/1903)
  - Minutes of the 548th ACRS Meeting, Dec. 6-8, 2007: **ML080640924** (NUREG-1829/1903)
  - Transcript of ACRS Regulatory Policies and Practices Subcommittee, Sep. 22, 2010: **ML102910759** (Rule)
  - Meeting Minutes of the 576th ACRS Meeting, Oct. 7-9, 2010: **ML103120527** (DG-1216)
- **Public Meetings**
  - Information required to apply for license changes under 10 CFR 50.46a, Feb. 27, 2009: **ML090550073**
  - DG-1216, Sep. 30, 2010: **ML102910247**