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Improved Basis and Requirements for Break Location Postulation

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Presentation Objective

- Provide a basis for revising NUREG-0800, BTP 3-4 criterion for postulating High Energy Line Break (HELB) locations.
- In the interim, allow utilities to use the alternate approach presented here to the existing fatigue usage criterion for postulating HELB locations on a case-by-case basis.

Introduction/Background

- Currently, for plants with piping systems designed to ASME III, a cumulative usage factor (CUF) of 0.1 is a criterion for postulating break locations in reactor coolant pressure boundary piping (NUREG-0800, BTP 3-4).
  - Continued use of the 0.1 CUF criterion may result in additional costs without any risk benefit for new plants and plants pursuing extended operation.
  - No clear technical basis exists for this value.
  - The original objective was to provide margin to the Code limit of 1.0 to account for uncertainties.
  - Over 4 decades of industry experience demonstrates that large leaks from fatigue damage does not occur from design transients used in CUF calculations.
  - A number of damage mechanisms have been identified and dispositioned since the CUF criterion was promulgated.

Introduction/Background

- A risk-informed approach would provide a technical basis for revising the current fatigue criterion, consistent with the NRC's Risk-Informed and Performance-Based Plan (RPP) initiative.
- Rupture probability, combined with consequences would be a good measure for assessing the risk of postulated breaks.
- Leak probability is suggested as a surrogate for rupture probability
  - More straightforward to estimate than rupture probability.
  - Computation less controversial.
  - More conservative, overall.

Introduction/Background

- EPRI contracted with Structural Integrity Associates (SI) to explore break location postulation criteria other than CUF=0.1.
- Industry operating experience insights are summarized.
- The results of analyses to explore leak probability and fatigue usage factors for a selection of components are also presented.
  - CUF without consideration of environment.
  - CUF_{en} (CUF considering environmental influence on fatigue).

Insights from Industry Operating Experience

- Available sources of piping system failures (NRC, EPRI, SI, and others) were reviewed.
  - Over 4,900 worldwide events were collected representing over 9,000 reactor critical years between 1970 and 2005.
- Data was lacking to quantitatively relate design CUF to failures in service.
- Less than 5% of piping cracks, leaks or ruptures were associated with thermal fatigue.
- Several sources noted that the majority of these failures were associated with a few well-documented generic issues which had not been anticipated during design (next slide).

Insights from Industry Operating Experience

- Some of the damage mechanisms that have been identified and dispositioned through improved regulatory guidance since the CUF criterion was promulgated include:
  - BWR feedwater and CRD nozzle cracking (NUREG-0619).
  - Feedwater piping cracking in PWRs (Bulletin 79-13).
  - Stagnant borated water systems (Bulletin 79-17).
  - Intergranular stress corrosion cracking (Generic Letter 88-01).
  - Leakage at valves (Bulletin 88-08).
  - Thermal stratification (Bulletin 88-11).
  - Erosion/corrosion (Generic Letter 89-08).
  - Reactor water environmental effects on fatigue (NUREG/CR-6909 and other documents identified in NUREG-1801).

Methodology & Analytical Approach

- Methodology based on NUREG/CR-6674 Fatigue Analysis of Components for 60-Year Plant Life):
  - Consistent with prior studies.
  - Considers environmental effects on fatigue usage.
  - Considers Impact on Core Damage Frequency.
  - Addresses a range of fatigue-sensitive locations for each plant design as well as newer and older vintage plants.

Methodology & Analytical Approach

- Information used from NUREG/CR-6674:
  - Estimated fatigue stresses and cycles.
  - Reactor water environmental parameters (strain rate, oxygen content and temperature).
  - Leak probabilities and cumulative usage factors.
  - Leak probabilities use pcPRAISE with older probabilistic strain-life relations (NUREG/CR-6335).

Methodology & Analytical Approach

- Updated ANL strain-life relationships from NUREG/CR-6909 were used to address environmental effects.
  - pc-PRAISE used to calculate leak probabilities vs. operating time using cyclic stresses and environments from NUREG/CR-6674.
  - CUF_{en} computed using new ASME design fatigue curve including environment.
  - Convert operating time to CUF_{en} assuming linear fatigue damage accumulation with time.
  - Evaluate core damage frequency using information from NUREG/CR-6674 [P (core damage)|rupture]
  - Plot Core Damage Frequency (CDF) vs. CUF_{en}
  - Compare CDF to PSA Applications Guide (TR-105396) Criteria

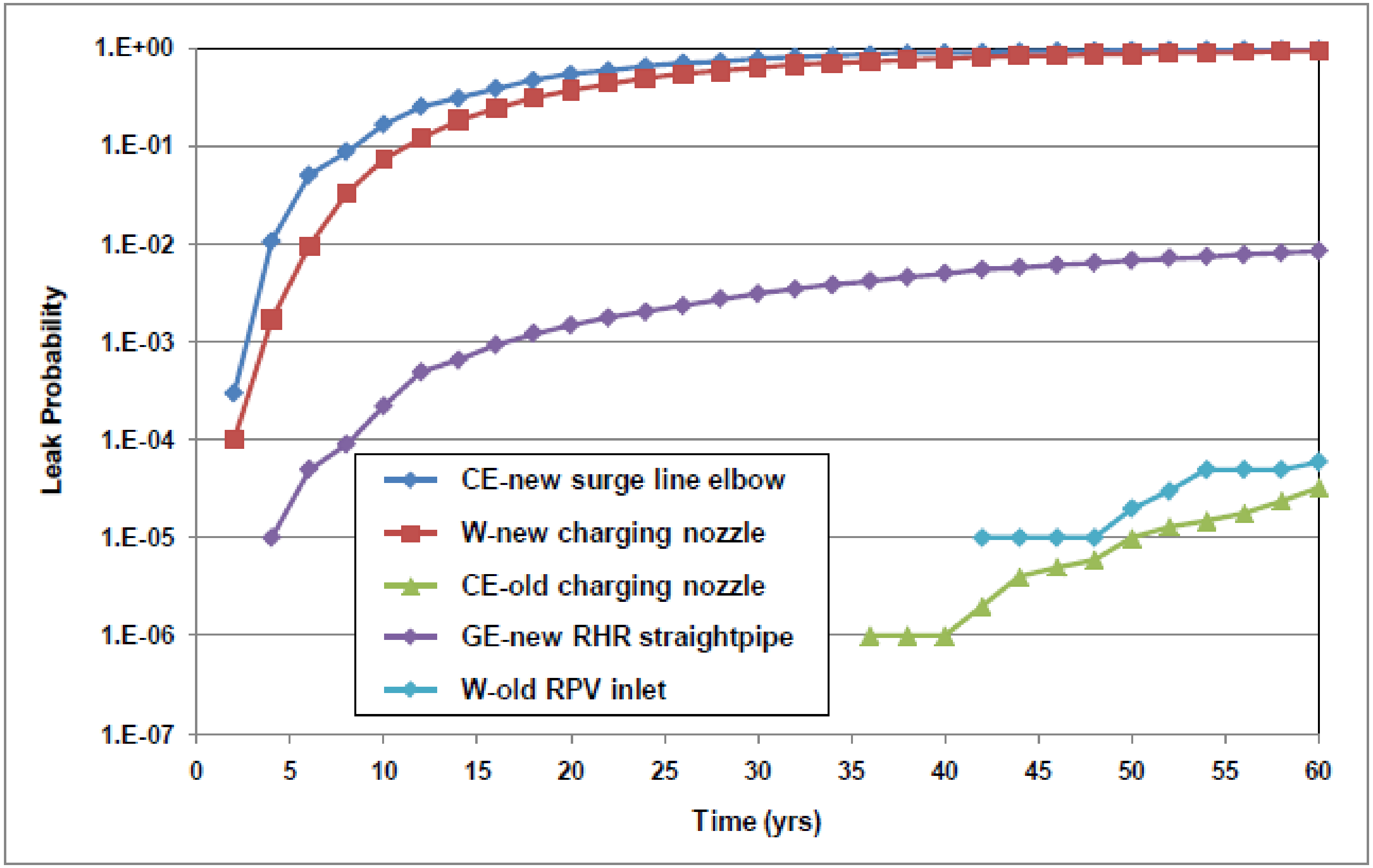
Component Selection

5 components were selected from NUREG/CR-6674, considering material type, cumulative usage and environment (env/air is ratio of fatigue usage factor based on a comparison of air and reactor water results from NUREG/CR-6674).

#	Name	NUREG/ CR-6260 Section	matl	*CUFen(60)*	*Env air*	$P_{lk}(60)$	Comment
4	CE-new surge line elbow	5.1.3	SS	3.90	2.65	0.998	high failure prob.
24	W-new charging nozzle	5.4.4	SS	5.06	4.08	0.963	
14	CE-old charging nozzle	5.2.4	SS	0.843	2.11	$6.0x10^{-4}$	low CUF, low env. factor
39	GE-new RHR straightpipe	5.6.6	LAS	16.9	27.6 6	0.621	high CUF, high env. factor
28	W-old RPV inlet	5.5.2	LAS	0.453	2.23	0.0504	low CUf, low env. factor

Cumulative Leak Probability for Selected Components

pc-PRAISE leak probability calculations were based on NUREG/CR-6909. Cumulative leak probability results are plotted below.



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Core Damage Frequency Estimation

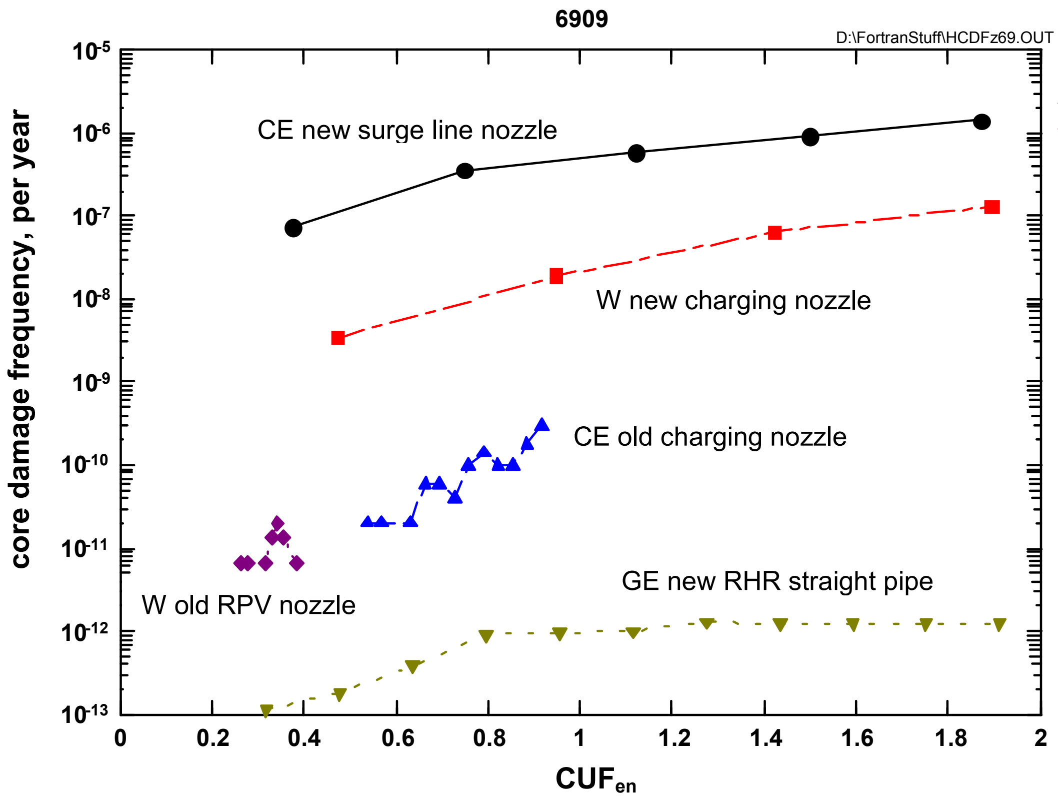
Core Damage Frequency is related to leak frequency using the following information from NUREG/CR-6674.

#	name	matl	*P(CD | leak)*
4	CE-new surge line elbow	SS	$2.85x10^{-5}$
24	W-new charging nozzle	SS	$8.00x10^{-6}$
14	CE-old charging nozzle	SS	$8.00x10^{-5}$
39	GE-new RHR straightpipe	LAS	$9.02x10^{-9}$
28	W-old RPV inlet	LAS	$2.70x10^{-6}$

Core Damage Frequency Estimation

- pc-PRAISE results two slides earlier show the cumulative distribution function for the leak probabilities.
- These are converted to leak frequencies by taking the slope of the curve *dPlk(t)/dt*.
- Leak Frequency is converted to Core Damage Frequency by multiplying by P(CD|leak) from the previous slide.
- Operating time is converted to CUF_{en} using NUREG/CR-6909 fatigue design curves with linear fatigue damage accumulation with time.

Core Damage Frequency vs. CUF_{en} Results



The lack of a direct correlation between Core Damage Frequency and component CUF_{en} values compromises efforts to use specific values of CUF_{en} as a criterion for postulating HELB locations.

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No Direct CUF_{en} Correlation with Leak – Why?

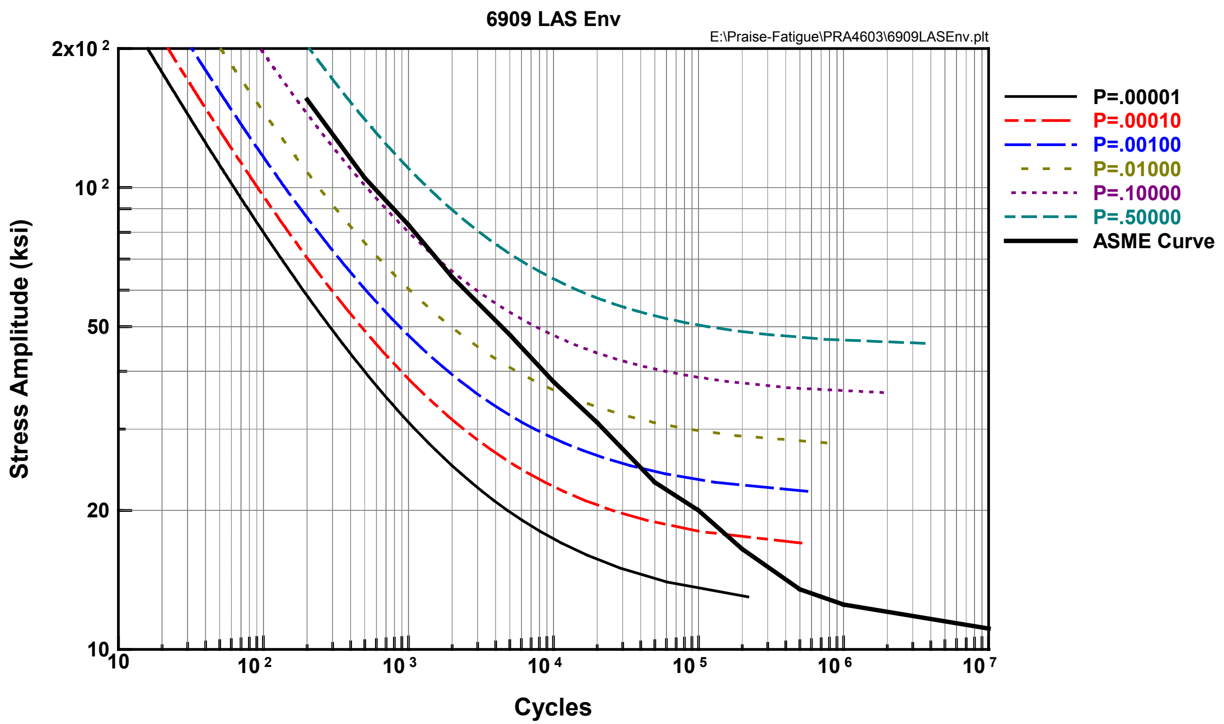
- Intuitively CUF_{en} should correlate well with initiation / leak probability.
- There are many factors that compromise the relationship between leak frequency and ASME calculated CUF_{en} factors. These factors include:
  - Stress profile (membrane, bending, radial gradient thermal)
  - Geometry (use of stress indices)
  - CUF methodology (strain-life correlations)
  - Stress evaluation methods (NB-3600 vs. NB-3200)
  - Crack growth considerations
  - Material, temperature
  - Crack growth relationships

No CDF vs. CUF_{en} Correlation – Why?

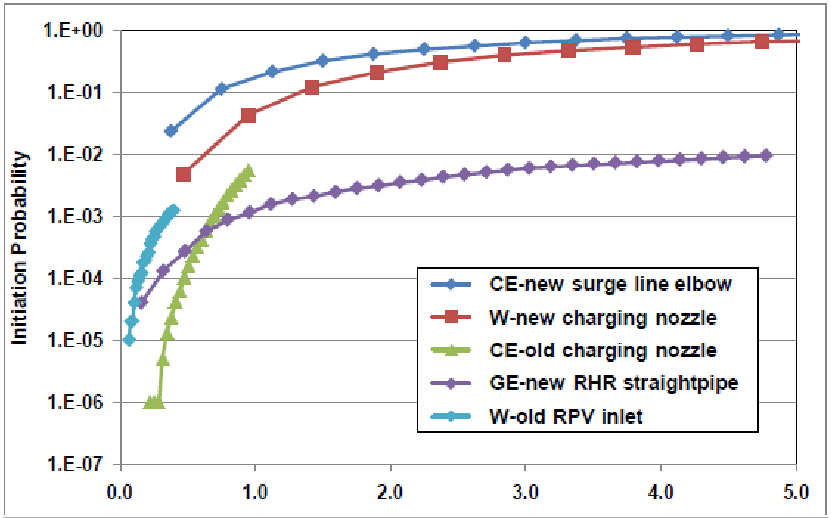
- Earlier slide shows no direct correlation between component CUF_{en} values and Core Damage Frequency among components evaluated.
- Probabilistic initiation data vs. ASME design curves
  - ASME design curves do not follow a line of constant crack initiation probability.
- Probability of CDF given leakage varies for different components.
  - Even if there was a good correlation between leak probability and CUF_{en}, agreement would be eliminated by component-specific P(CD|leak) relationships.

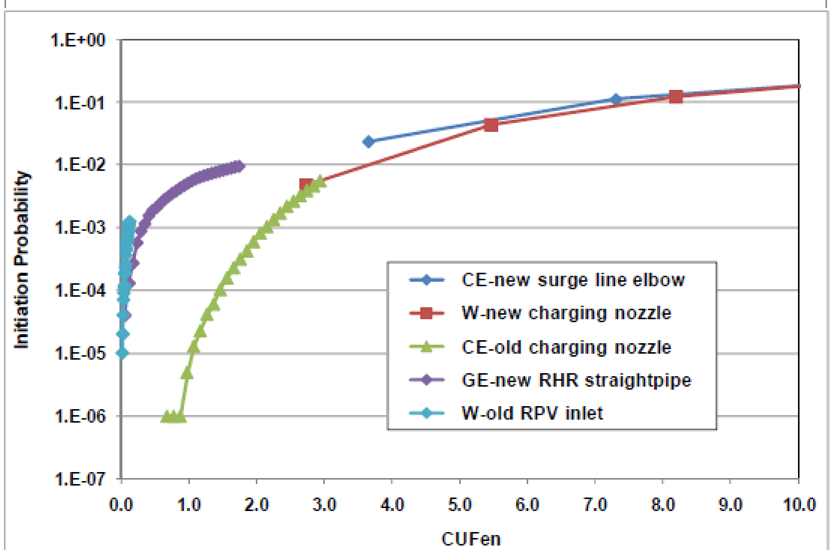
No CDF vs. CUF$_{en}$ Correlation – Why?

The ASME Design curve is not consistent with initiation probability fractiles based on statistical analysis of fatigue data used in pc-PRAISE initiation and leak probability calculations.



Initiation Probability Comparison of ASME Design Curve vs. Fatigue Data Fractiles





- Top plot shows initiation probabilities plotted versus to CUF_{en} factors calculated using the ASME design curve.
- No direct correlation observed due to inconsistency between fatigue initiation fractiles and the ASME design curve.

- Bottom plot shows initiation probabilities plotted versus CUF_{en} factors calculated using the 0.1% fractile of the fatigue data.
- Better correlation observed.
- SS and LAS separate out.

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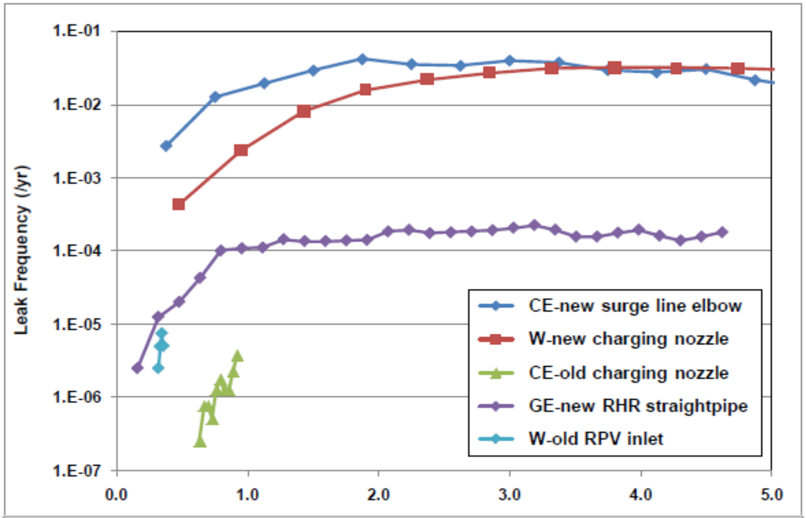
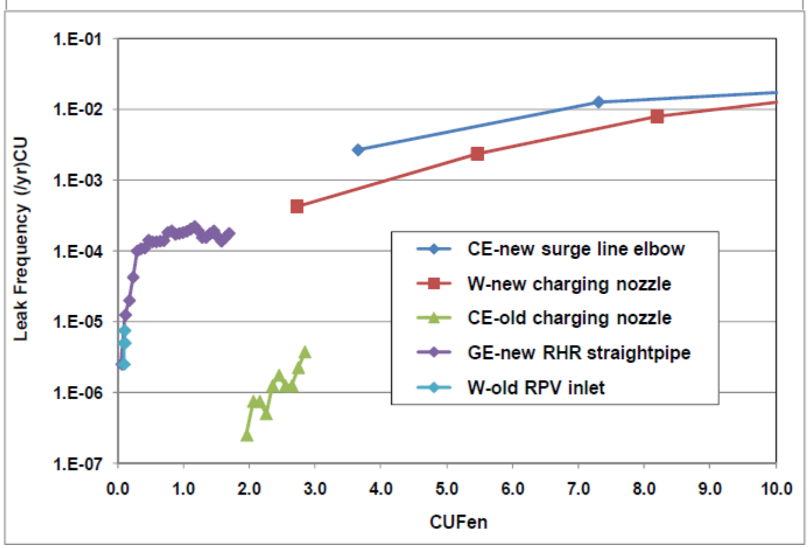
Leak Probability Comparison of ASME Design Curve vs. Fatigue Data Fractiles





- Top plot shows influence of using ASME design curve on the relationship between leak frequency and component CUF_{en}.
- Poor correlation observed when using ASME design curve.

- Bottom plot shows leak frequencies versus CUF_{en} calculated using the 0.1% fractile of the fatigue data.
- Comparison to corresponding initiation probabilities shows influence of geometry, spatial stress gradients, KIC and da/dN material relationships.

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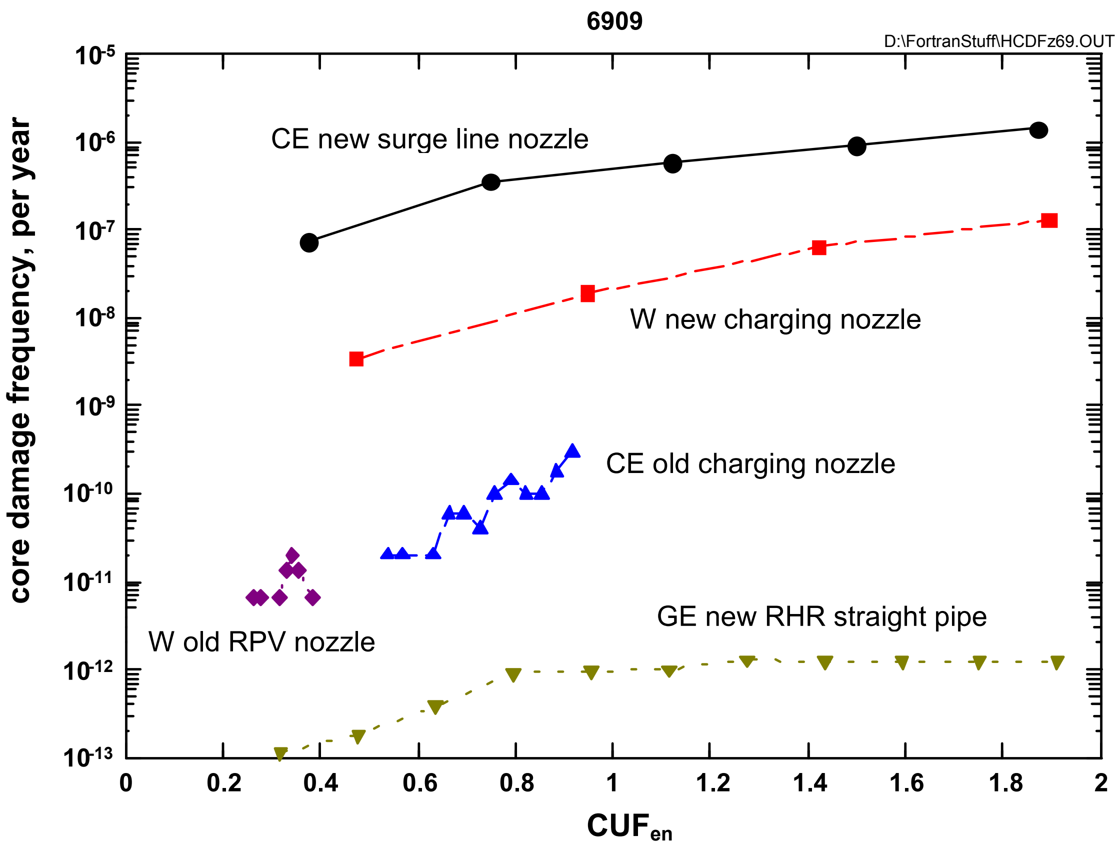
What Fatigue Criterion Would be Appropriate?

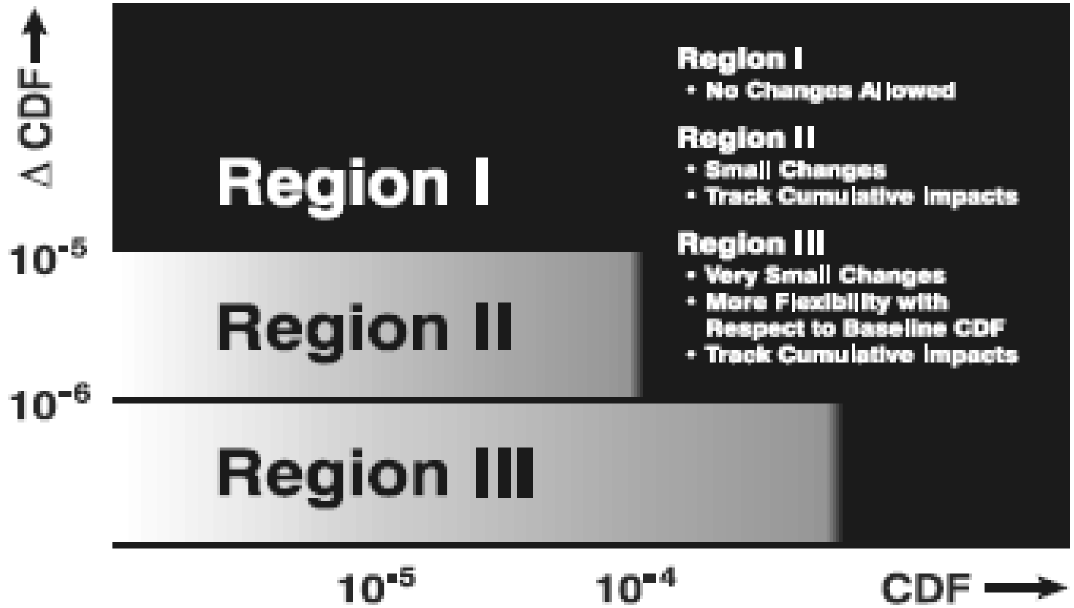
- From the previous slides, it is clear that evaluating the change in CUF_{en} criterion from that of 0.1 to some other value is significantly hampered due to inconsistencies in the impact of CUF_{en} on initiation, leak probability, and CDF.
- Therefore, the impact of an CUF_{en} value of 1.0 was evaluated, consistent with the ASME Code and what is considered to be acceptable for other plant locations, per NUREG-1801.
- The risk associated with the design of the plant is compared to the NRC's CDF goal of less than $1x10^{-4}$/year promulgated in SECY-90-016 and to Regulatory Guide 1.174 for changes from baseline CDF values.

Core Damage Frequency vs. CUF_{en} Results



The above plot shows that an CUF_{en} of 1 results in a CDF less than $1x10^{-6}$ in all cases for the selected components.

Acceptance Guidelines for Change in Core Damage Frequency



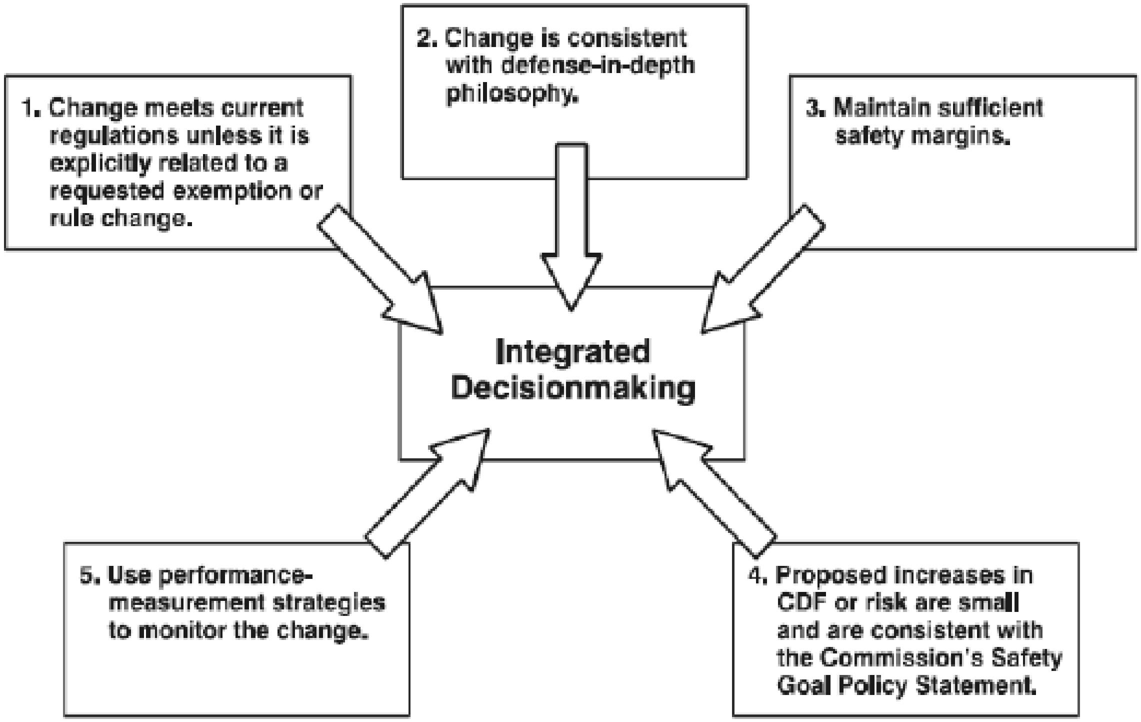
- A change in CDF of 1×10^{-6} (Region III) will be considered regardless of whether there is a calculation of total CDF, per Regulatory Guide 1.174.
- For this work, the calculated CDF is conservatively taken as a change from the baseline CDF.
- In addition, Large Early Release Frequency (LERF) would need to be evaluated, but was beyond the scope of this study.

Suggested Approach for Development of a Revision to BTP 3-4

- A four phase methodology is suggested for postulation of HELB locations:
    1. A screening process would eliminate low consequence locations, consistent with a risk informed ISI (RI-ISI) approach.
    2. A systematic review of degradation mechanisms would be performed to identify those needing further evaluation.
    3. Mechanisms leading to pipe rupture where rapid propagation could occur are evaluated to establish whether effective mitigation strategies exist and will be implemented.
    4. For locations not able to be dispositioned in the prior phases, apply a NRC-approved method for probabilistic evaluation such as those applied for RI-ISI (or that described earlier). Risk insights from this evaluation would be used to reduce failure probability and/or mitigate consequences of failure, as appropriate.

Suggested Approach for Development of a Revision to BTP 3-4

The proposed methodology would be consistent with the NRC policy statement for the use of PRA methods and espoused principles outlined in Regulatory Guide 1.174 (see below).



Improved Break Location Postulation: Summary

- The current CUF criterion of 0.1 for postulated break locations has no clear technical basis.
- Continued use of this criterion could result in unnecessary costs without an associated safety benefit.
- Over 4 decades of industry experience have demonstrated that design transients do not result in high energy line breaks.
- Industry experience has been used to address uncertainties that existed when the current CUF criterion was established.
- 5 components were selected from NUREG/CR-6674 for evaluation, which provided a range of loads, material types and reactor designs.
- Use of leak probabilities (versus rupture) is conservative when considering postulated high energy line breaks.

Improved Break Location Postulation: Summary

- Initiation and leak probability calculations based on NUREG/CR-6909 were performed using pc-PRAISE.
- Core Damage Frequency is related to the leak frequency, consistent with the methodology used in NUREG/CR-6674.
- Resulting Core Damage Frequency (CDF) vs. CUF_{en} plots show no direct correlation between CUF_{en} and CDF values.
- Many current plants are designed to ANSI/ASME B31.1, which does not require calculation of CUF.
- For all of the selected components, a CUF_{en} of 1.0 resulted in a CDF $\leq 1 \times 10^{-6}$, which USNRC Regulatory Guide 1.174 considers very small and is well below the 1×10^{-4} value promulgated in SECY-90-016.

Improved Break Location Postulation: Summary

- Based on the results of this study, if the use of CUF as a break location criterion is to be continued in combination with environmental fatigue analysis, a CUF_{en} of 1.0 can be used without an impact to safety.
- An approach that applies both deterministic and probabilistic elements is proposed.
- The proposed methodology is consistent with the NRC policy statement for use of PRA methods and the principles outlined in Regulatory Guide 1.147.
- Therefore, we recommend revising BTP 3-4 to apply this methodology.