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LIC-504 Effort on French SCC and Applicability to US PWRs

NRC Public Meeting with PWROG on Piping Stress Corrosion Cracking Operating Experience

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Outline

- French Stress Corrosion Cracking (SCC) Issue
- Industry Focus Group Effort
- LIC-504 Effort, Options and Recommendations

NRC Team

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French SCC issue

- Civaux 1 cracking (Oct. 2021)
  - Stress corrosion cracking (SCC): flaw propagation is intergranular – Long shallow cracks
  - Relatively “big” first layer of the weld (manual TIG weld)
  - Residual stress supports the arrest of through cracking
  - Suspected to be due to large thermal stratification loads
- Over 100 flaws were found at a variety of locations in the RHR and ECCS piping. In most cases, the cracks were long, but very shallow.
- Penly 2 Cracking (March 2023)
  - Safety injection piping near hot leg
  - Suspected SCC 85% deep, 6-inch-long circumferential crack in HAZ
  - Little to no thermal stratification
  - Weld was repaired twice – suspected driver

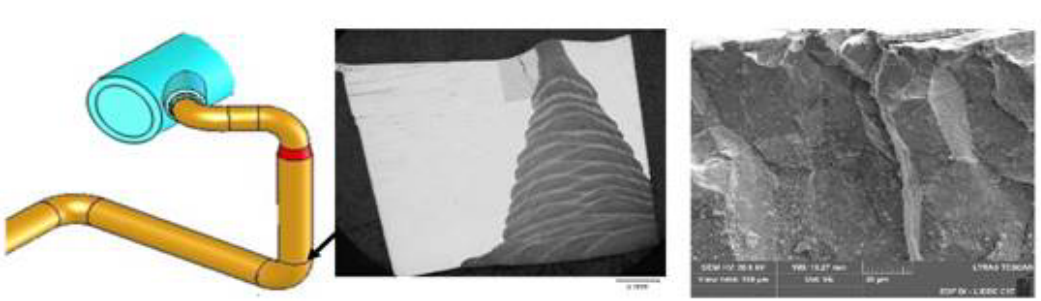
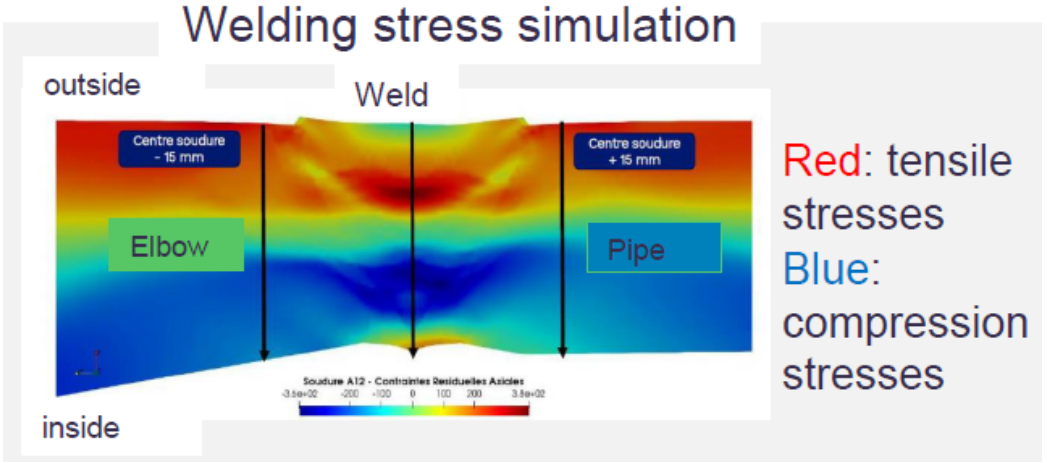


Figure 10: Location of IGSCC observed in a HAZ tube weld of Civaux Unit 1.



Industry Focus Group Efforts

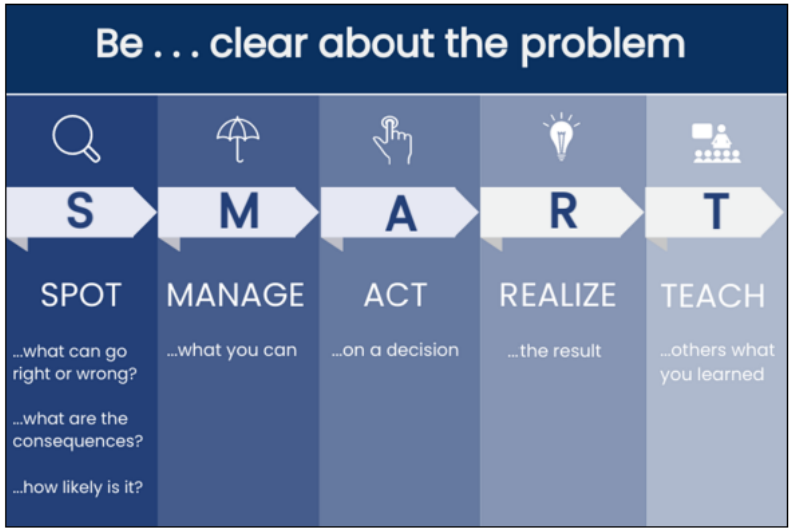
- Coordinating efforts between Pressurized Water Reactor Owners Group (PWROG) and the Electric Power Research Institute (EPRI)
- Focus:
  - Understanding causal factors associated with recent auxiliary piping SCC operating experience and the potential relevance to the rest of the industry
  - Development of industry positions and/or guidance as needed
  - Regulatory interactions
- PWROG Current Work
  - Safety Assessment
    - Purpose: Assess potential safety impact of EDF OE on the industry
  - Applicability Assessment
    - Purpose: Assess applicability of EDF OE to the industry

Industry Focus Group Efforts – NEI 03-08 “needed”

- *Intergranular stress corrosion cracking (IGSCC) specific ultrasonic testing (UT) examination techniques and personnel qualifications should be implemented when performing the planned (next and future) volumetric inspections of the locations of interest: elbow weld heat-affected zone (HAZ) (both sides) for the non-isolable portions of passive safety injection (SI) piping (i.e., Westinghouse (W) SI piping, Combustion Engineering (CE) SI piping, and Babcock and Wilcox (B&W) core flood piping), residual heat removal (RHR) suction piping (i.e., W RHR piping, CE shutdown cooling piping, and B&W decay heat piping), and pressurizer spray line piping (i.e., W, CE, and B&W). This recommendation does not require new inspections, but instead only recommends that the IGSCC specific examination methods be used for the volumetric inspections that are already planned (next and future). If inspections are scheduled for less than a year from the time of issuance of this recommendation, then the recommendation can instead be implemented at the subsequent inspection interval.*

Safety Implications of SCC Issue – NRC effort

- Could SCC cracking occur in US fleet?
- If it can, what are the safety implications?
  - Cracks are in non-isolable section of pipe
    - Break can cause loss of coolant accident (LOCA)
    - Only one ECCS train is affected?
    - Can earthquake or startup of ECCS cause failure?
  - New cracking was very long and deep
- Staff looked at risk-triplet through their BeRiskSMART process (NUREG/KM-0016)
  - What can go wrong/what can go right
  - What are the consequences
  - What is the expected likelihood
  - Qualitative assessment



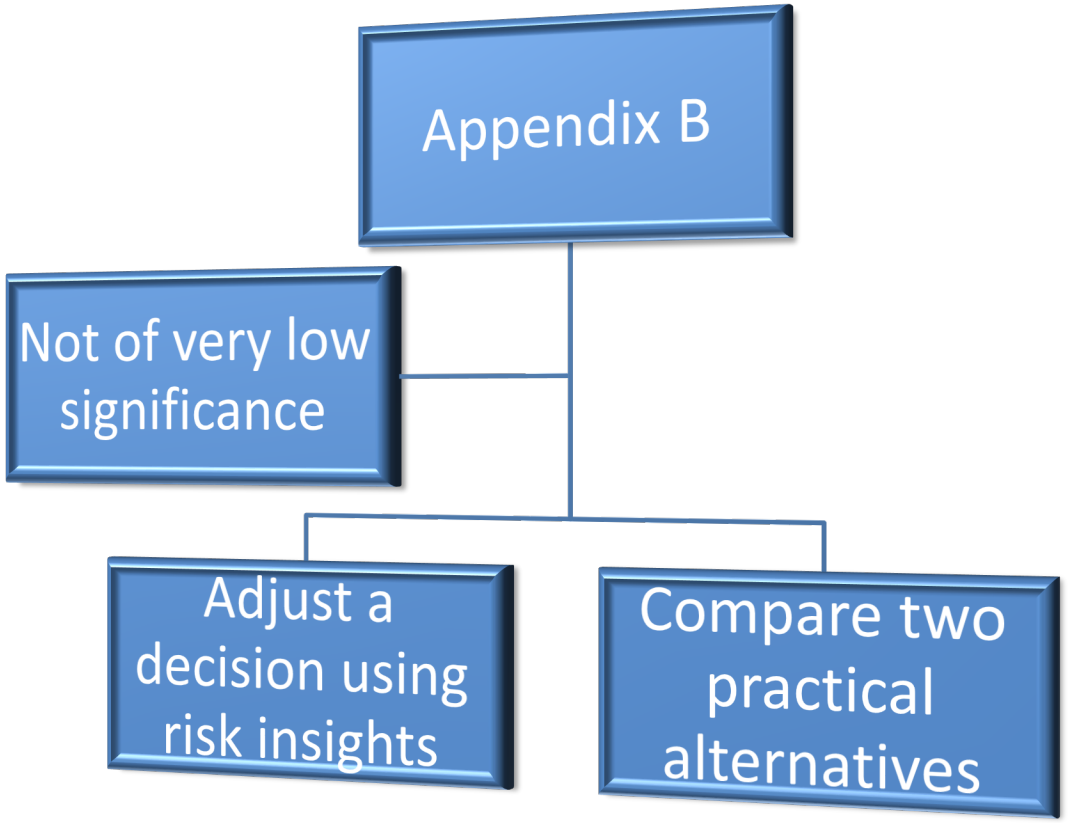
Safety Implications of SCC Issue – NRC effort

- Conclusion from BeRiskSMART
  - Uncertainties are large with unknown impact of break on plant safety
    - Are our plants susceptible? Water chemistry, etc.
    - Do we have unknown (undocumented/unrecorded) weld repairs in these locations?
    - Even though these systems are susceptible to thermal fatigue, are we inspecting these locations, i.e. are these welds in the risk-informed program?
    - What is the impact to the plant if we lose this system?

- Staff concluded that a more quantitative analysis is needed
  - Conducted a LIC-504 , "Integrated Risk-Informed Decisionmaking Process for Emergent Issues."
  - Used a Simplified approach

S SPOT
M MANAGE
A ACT
R REALIZE
T TEACH

LIC-504 Appendix B - Simplified



Performance goals – 3 months to complete effort

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LIC-504 Analyses - Rationale

- These piping system are part of a Risk-informed inspection program due to susceptibility to thermal fatigue. These are sampling programs
- We have a history of undocumented weld repairs in the US
- Given these and the OE, a large undetected circumferential crack forming in these pipe systems in the US is a reasonable possibility
- Even though the stainless-steel piping is highly flaw tolerant, the loss of a non-isolable piping system within the safety injection system can limit the ability to cool the core in the case of a loss of coolant accident

LIC-504 Analyses – Options Considered

#	Option	Evaluation Criteria
1	Establish targeted inspections and revision of inspection requirements for these piping locations	This option would be appropriate if the issue is not an imminent safety concern, and the evaluation determines that some additional information is needed to ensure that: • Adequate defense-in-depth is maintained • Sufficient safety margin is maintained • An acceptable level of risk is maintained • the aforementioned evaluation has an adequate degree of conservatism, and the uncertainties are properly addressed • Performance monitoring is met
2	Take No Action but continue to monitor industry action	This option would be appropriate if the issue is not an imminent safety concern, and the evaluation determines that monitoring industry action is sufficient to ensure that: • Adequate defense-in-depth is maintained • Sufficient safety margin is maintained • An acceptable level of risk is maintained • The adequacy of defense-in-depth, safety margin, and risk level have a degree of conservatism that provides reasonable assurance of structural integrity, and the uncertainties are properly addressed • Performance monitoring is met

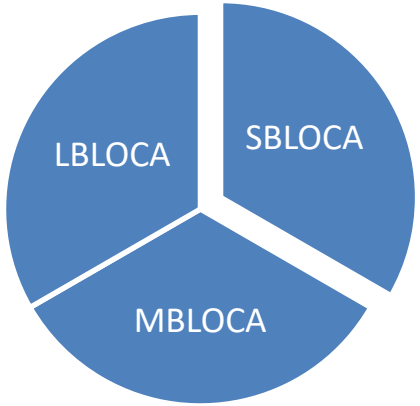
LIC-504 Analyses - Immediate Regulatory Action

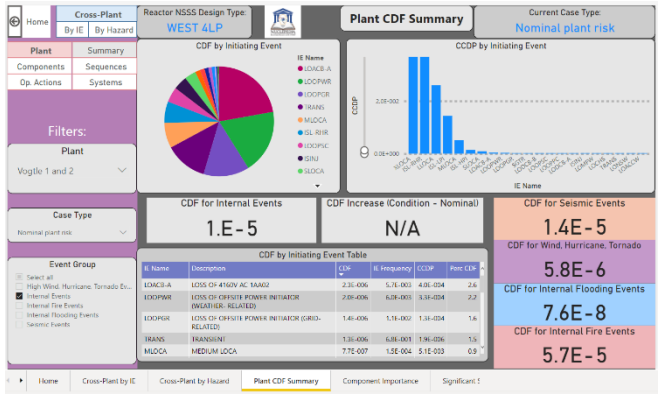
- Per LIC-504 – Is immediate regulatory action is needed?
- Considerations included:
  - Although the French have found cracking in some of their ECCS, no similar issues have been found in US reactors at this point.
  - The reactor designs in which SCC has been found are predominantly in French PWR designs by Framatome, which are not the same design as in US reactors and operate at higher power than US reactors.
  - SCC has been found in French designs like 4 loop Westinghouse PWRs. These French reactors are rated at 1300 MWe (US 4 loop reactors are of lower power), and the French have determined that these reactor designs are not highly sensitive to inter-granular SCC. The smaller MW French reactors (900 MWe) that are based on Westinghouse 3 loop designs have been found to not be sensitive to IGSCC.
- Staff determined no immediate action was required. This communication was made to the management lead and was documented in ADAMS under ML23151A238

LIC-504 Analyses – Quantitative Analyses

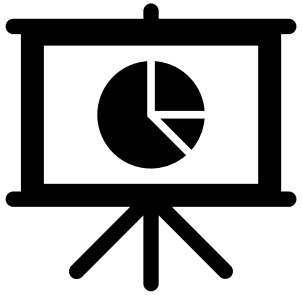
Base analysis

Sensitivity studies





SPAR-DASH



Probabilistic Fracture Mechanics → Initiating Event Frequency → **Probabilistic Risk Assessment** → ΔCDF

LIC-504 Analyses – Probabilistic Fracture Mechanics (PFM) Analyses

Developed a representative case to run with the Extremely Low Probability of Rupture (xLPR) PFM code

- 10.75-inch outer diameter pipe
- 1-inch thickness
- Polynomial weld residual stress profile
- Leak rate detection (LD) set to 1 gpm

Collected estimated Small Break (SB), Medium Break (MB), Large Break (LB) LOCA probabilities from xLPR outputs after 100,000 realizations

From the LOCA probabilities, developed conditional LOCA initiating event annual frequencies (1/CY)

- Assumed 20 potential cracked welds in plant

	Mean SBLOCA|LD (1/CY)	Mean MBLOCA|LD (1/CY)	Mean LBLOCA|LD (1/CY)
40 CY	2.7×10^{-4} $\pm 2.6 \times 10^{-4}$	$< 1.5 \times 10^{-5}$	$< 1.5 \times 10^{-5}$
80 CY	3.0×10^{-4} $\pm 2.0 \times 10^{-4}$	$< 7.5 \times 10^{-6}$	$< 7.5 \times 10^{-6}$

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Sensitivity Analyses – Flaw Aspect Ratio

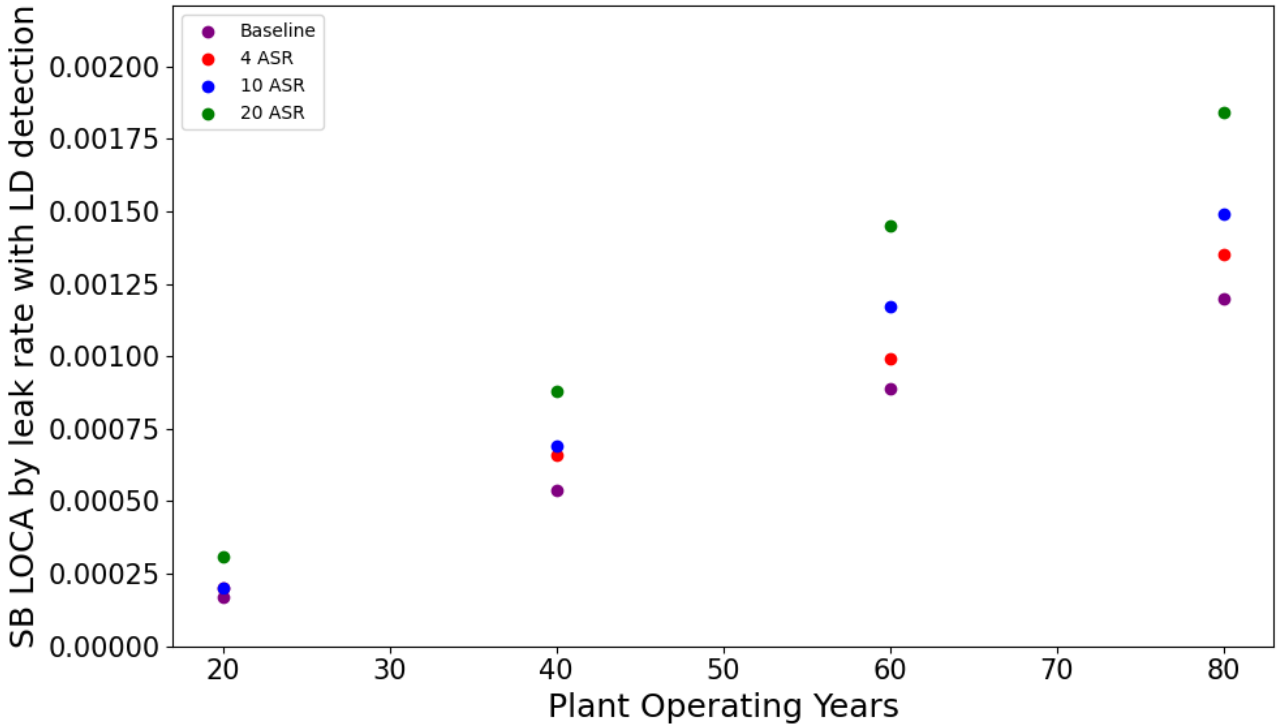
Initial flaw size in baseline analysis was selected from a distribution representative of PWSCC

- Average aspect ratio (length/depth) = 3.2

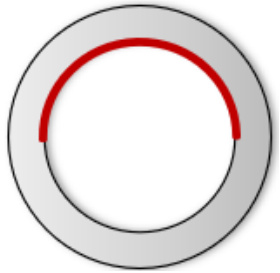
Given the potential for longer flaws, the impact of longer flaw lengths (and therefore larger aspect ratios) was investigated.

The baseline xLPR analysis was repeated for aspect ratios of 4, 10, and 20

- Found that SBLOCA probabilities increased with aspect ratio, but not significantly



Sensitivity Analyses – Long Flaw with Inservice Inspection

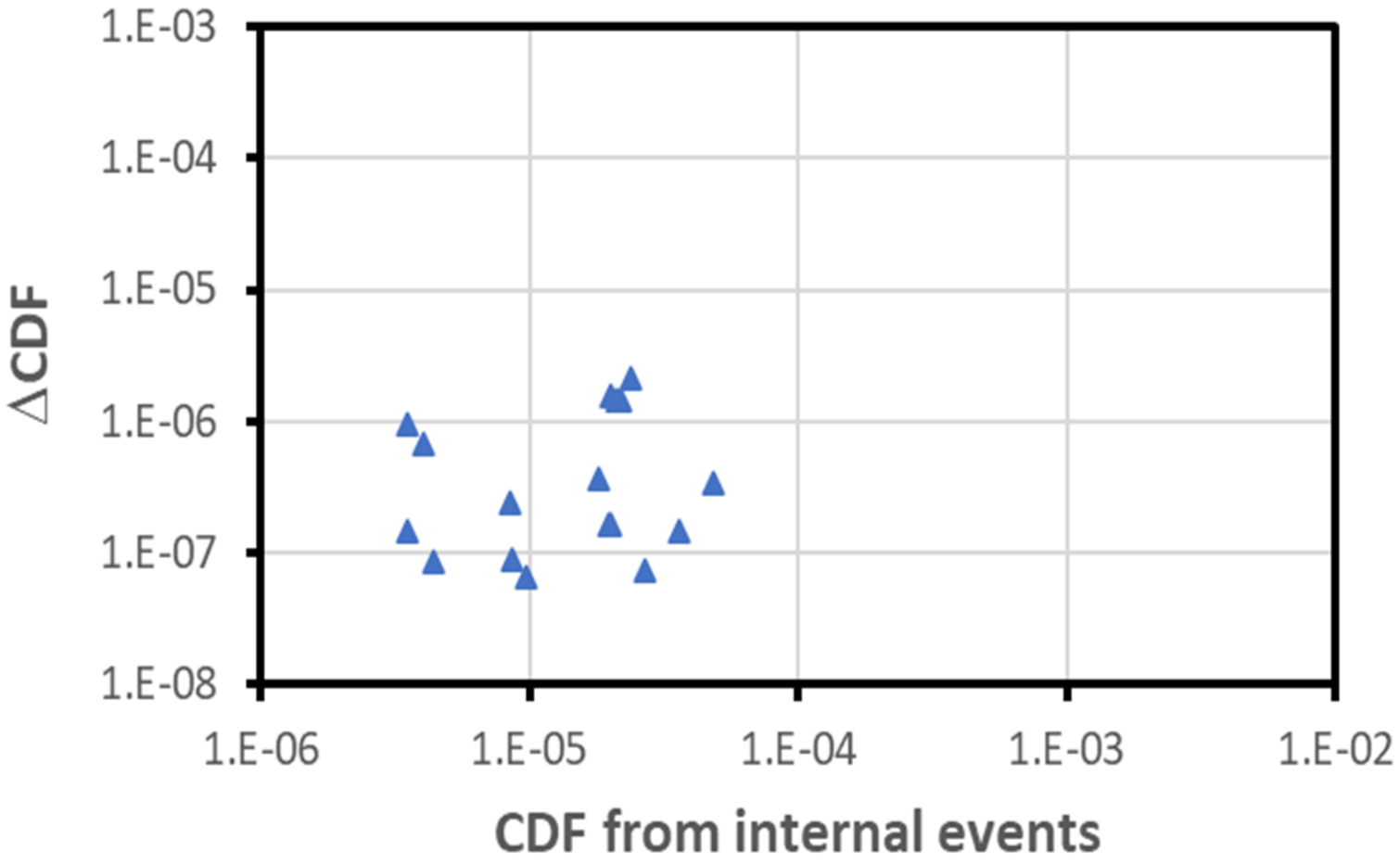


- Some inspections found flaws with lengths greater than 180 degrees
  - No equivalent flaw has been found in US plants and is highly unlikely to grow undetected to this length
  - Nevertheless, a PFM analysis was performed with an initial flaw length of 180 degrees
  - LOCA frequencies were much greater than the baseline case
- Inservice inspections using ultrasonic tests (UT) greatly reduce LOCA frequencies
  - An order of magnitude greater reduction when inspections start at 2 years versus 8 years.

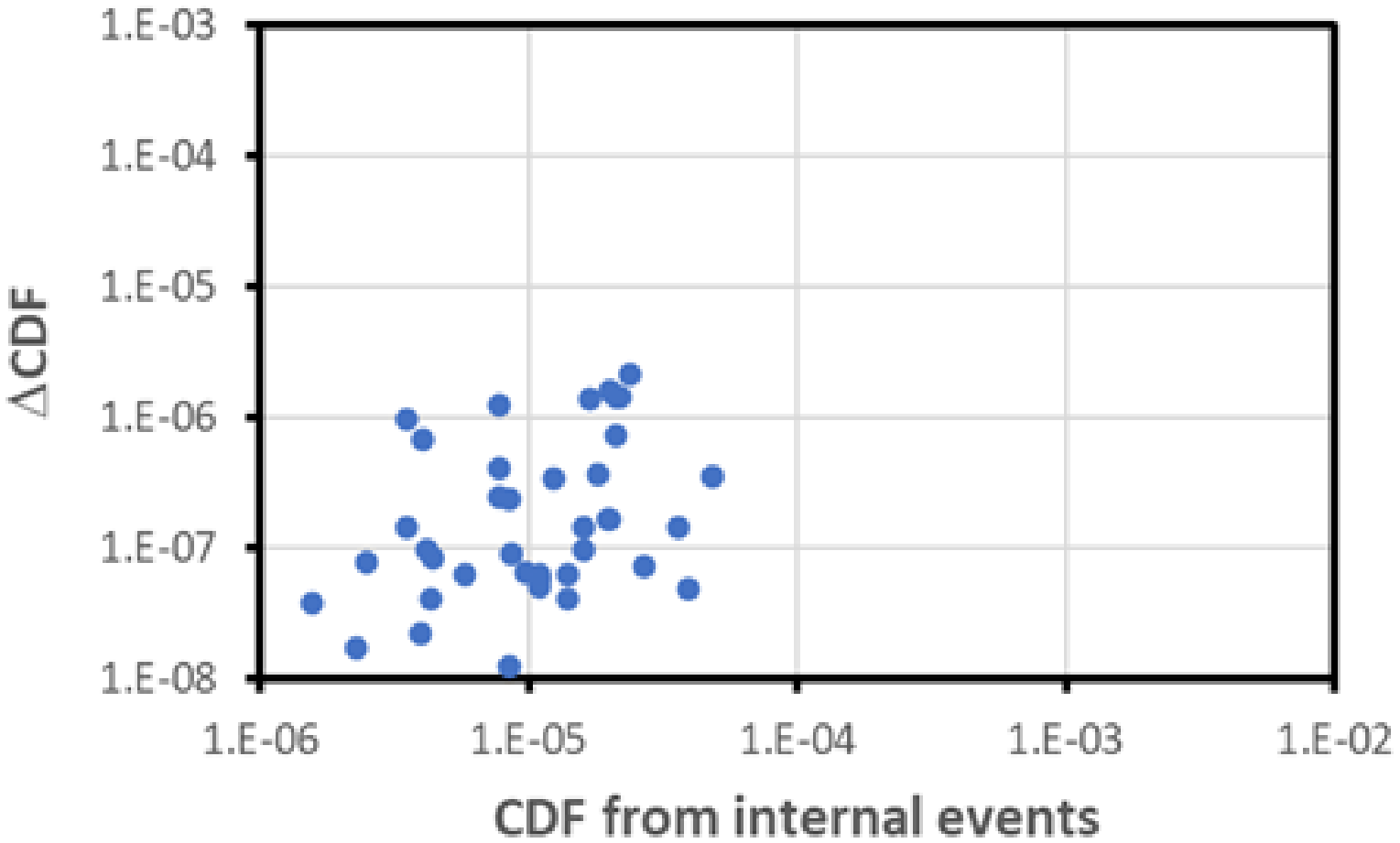
LIC-504 Analyses – Risk Analysis

- The fracture mechanic analysis had some key risk insights to inform the PRA:
  - Any flaw is overwhelmingly likely to manifest itself as a small leak prior to becoming a LOCA
  - The mechanical analysis pointed only to small LOCAs. MBLOCA and LBLOCAs were not found in their data.
  - The analysis was able to provide an increased probability of a SBLOCA of 3 x 10^{-4}/yr
- By adding this increased probability to the baseline probability for a SBLOCA resulted in an Initiating Event Frequency (IEF) of about 6 x 10^{-4}/yr
- Using the new IEF, ΔCDFs for every PWR was calculated
- Risk results were relatively low
- Risk fell between a range of 1.3 x 10^{-8}/yr and 2.2 x 10^{-6}/yr

LIC-504 Analyses – Risk Analysis – All 4-loop PWRs



LIC-504 Analyses – Risk Analysis – All PWRs



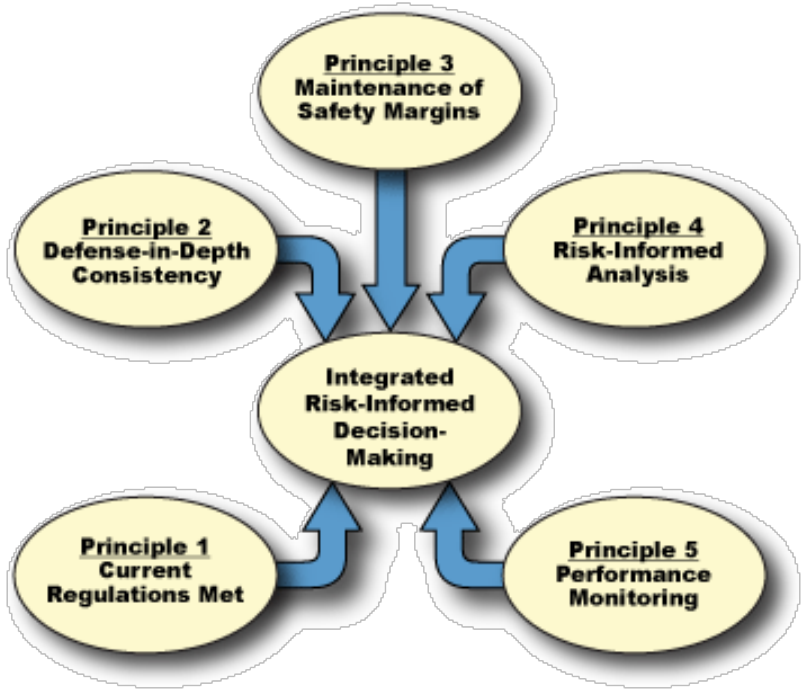
LIC-504 Analyses - Low Risk – Is that Enough?

Risk-informed decision making (RIDM) is a holistic framework supporting decision making at the NRC. The RIDM framework enables holistic evaluation of risk-insights with other considerations.

Within this framework, PFM/PRA often supports Principle 4, Risk-Informed Analysis, in balance with the other Principles.

With the current and ongoing inspection program, and with the known degradation, are performance monitoring, safety margins, and defense-in-depth maintained?

Since there has been no evidence of SCC at these locations in US fleet, there is no direct evidence of loss of defense-in-depth.



Safety Margins and Performance Monitoring

- Safety margins and performance monitoring *may be impacted* with the current inspection programs at these locations
  - Current inspections are not qualified to detect SCC flaws
  - A sampling program, not focused on SCC, may not detect growing defects
  - With no, or inadequate, inspections, both safety margins and performance monitoring are impacted
- With the implementation of the NEI 03-08 “needed” recommendation, the locations most susceptible in the non-isolable piping will be inspected with a SCC qualified technique
  - Safety margins and performance monitoring will be maintained

LIC-504 Analyses – Recommendation

- The level of risk increase for both options is low and acceptable
- Safety margins and performance monitoring
  - With current inspection plan, safety margins and performance monitoring may be impacted
  - Option 1, NRC targeted inspections - safety margins and performance monitoring will be maintained
  - Option 2, NEI 03-08 “needed” recommendation, the safety margins and performance monitoring will be maintained
- Therefore, the staff recommended Option 2 because it provides reasonable assurance of safety in an efficient and economical manner.
- In addition to continuing to monitor the industry actions, e.g., review the PWROG applicability report when published, verify the “needed” recommendation is implemented, etc., the staff will also hold a public meeting to discuss results
- If similar OE occurs in the US fleet, the staff may want to revisit Option 1

LIC-504 Analyses – Management Lead Decision

- On August 17, 2023, the LIC-504 Team presented its recommendation to the NRC management lead

- After discussion, management agreed with the team's recommendation and recommended the team move forward with implementation. The LIC-504 report was publicly released on September 8, 2023, and can be found at ML23236A052

- These results will be published through a peer-reviewed conference proceedings. The information and process will be presented through internal knowledge management efforts

ANY QUESTIONS