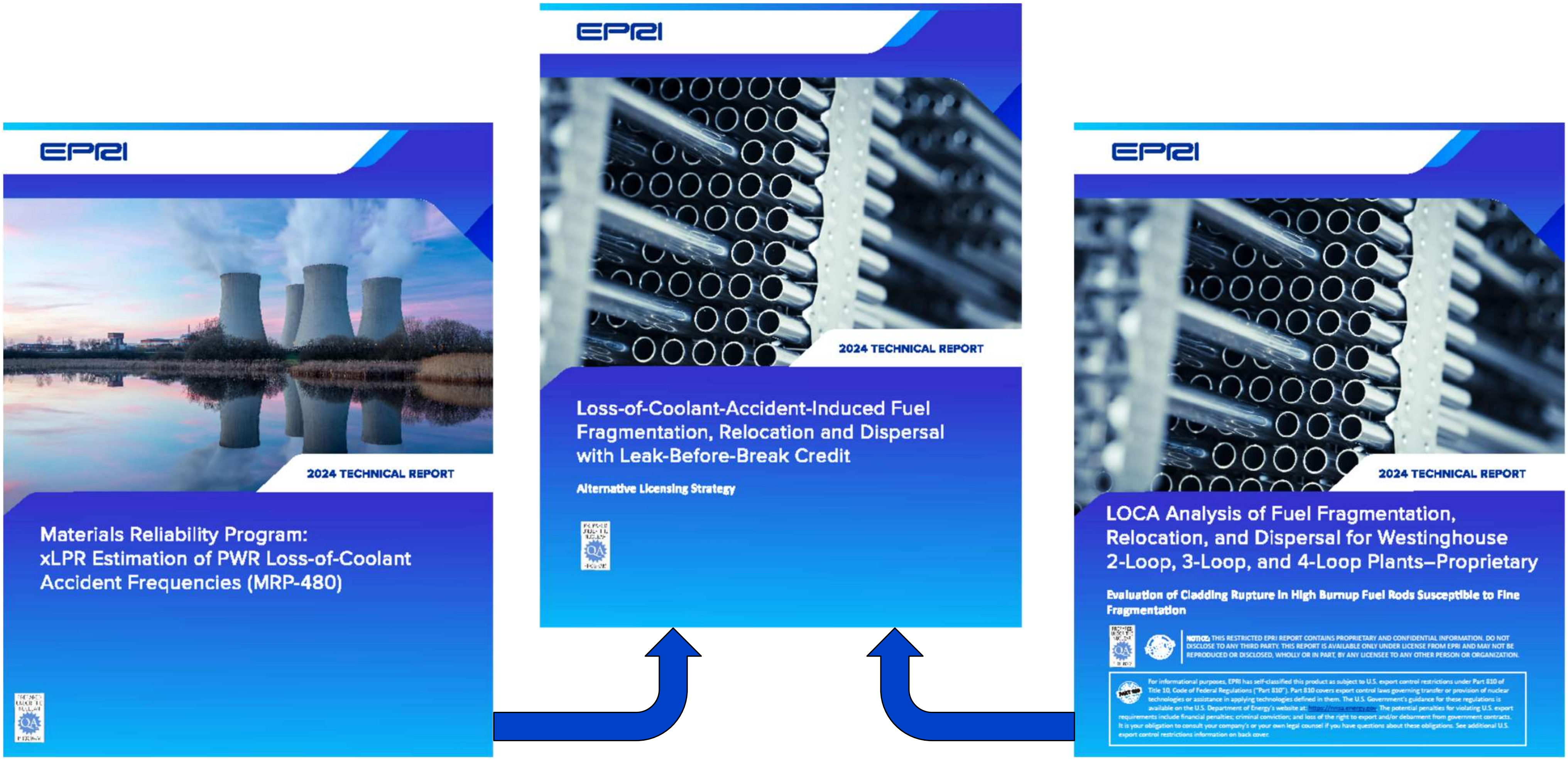
Introduction to EPRI's Alternative Licensing Strategy to Address LOCA induced FFRD

Fred Smith
Sr. Technical Executive

NRC Public Meeting to discuss EPRI ALS Topical Report

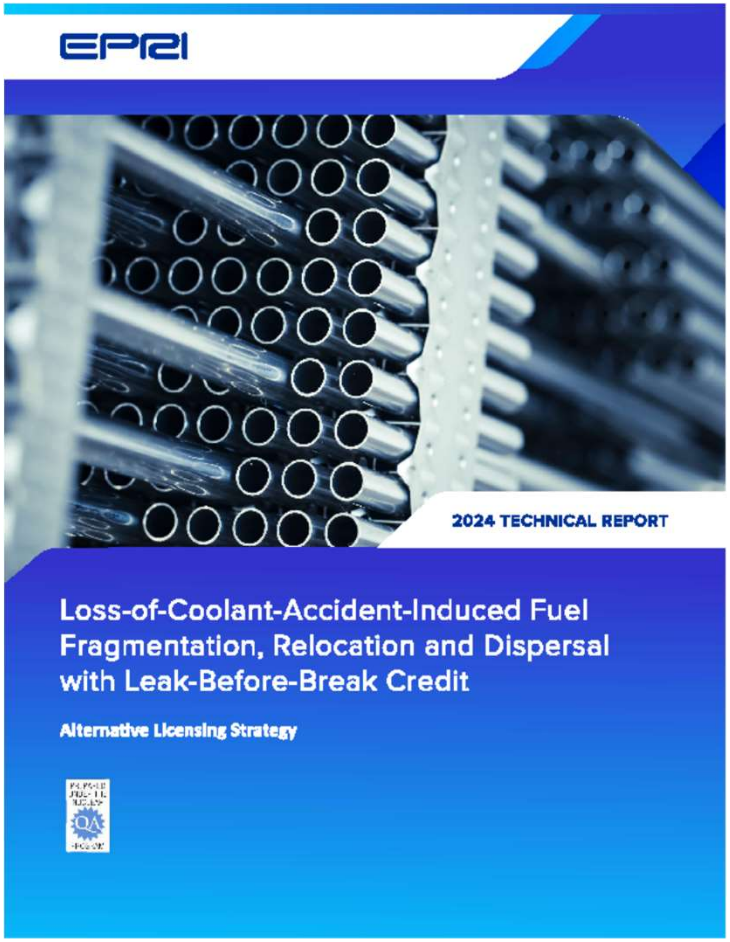
June 6, 2023

ALS Submittal Introduction



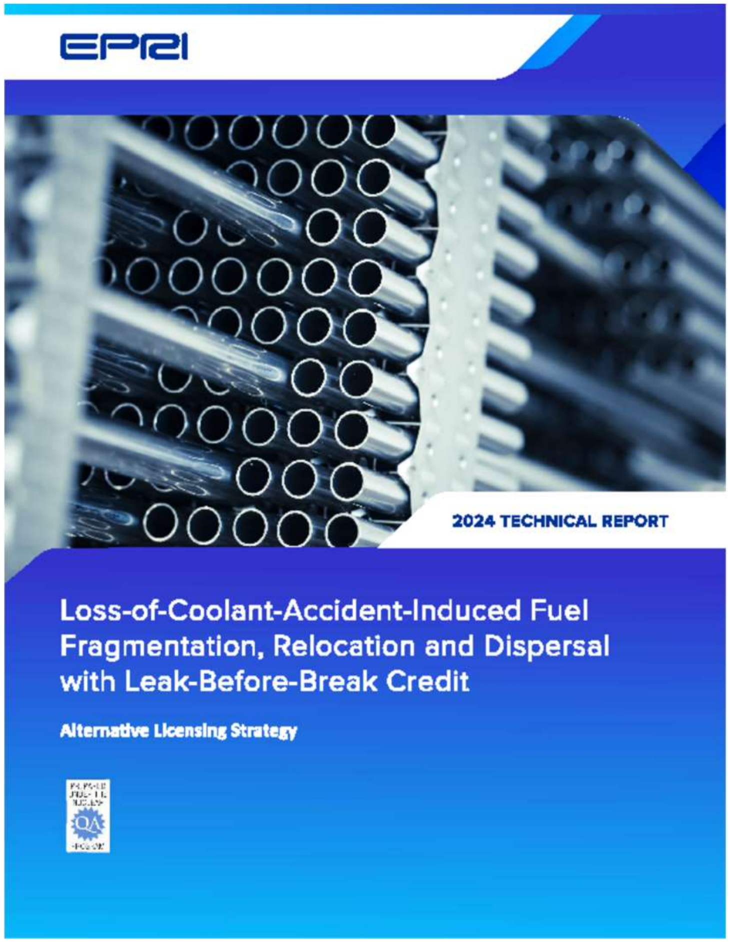
Key Features - LBB

- Introduction
  - Safety Benefits
    - Reduced Fuel Cycle Impacts including High Level Waste and other Radiological Impacts
    - Support Nuclear Plant Low Carbon Emissions
    - Reduced industry and NRC demand on scarce specialized resources
- Regulatory Guidance
  - Current Guidance and potential changes to Regulations
  - Defense-in-Depth
- Methodology
- Leak-Before-Break



Key Features

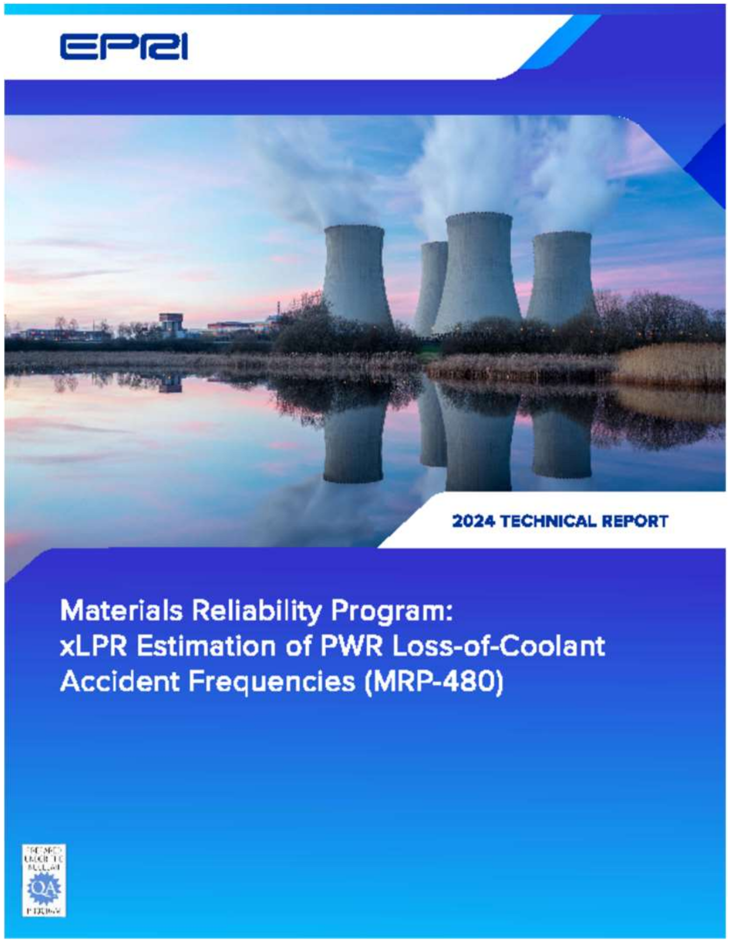
- Piping Ruptures
- Non-Piping Ruptures
- Summary and Conclusions
  - Initial Application – Westinghouse NSSS Systems using Westinghouse fuel
    - Extensions to other PWRs with appropriate small break and intermediate break LOCA analysis
    - Other NSSS systems
    - Other fuel designs
    - Other vendor’s analysis methods
  - Appendix A Requirements to Apply ALS to Specific Plants



EPRI

Key Features - xLPR

- Introduction
- xLPR Probabilistic Fracture Mechanics
  - Evaluated Case Matrix – Full case matrix involves non-primary coolant piping which is not applicable to ALS scope
  - Benchmarking and validation
- Comparison to NUREG-1829
- Time between detectable leakage and LOCA
- Evaluation of applicable degradation mechanisms
- Conclusion

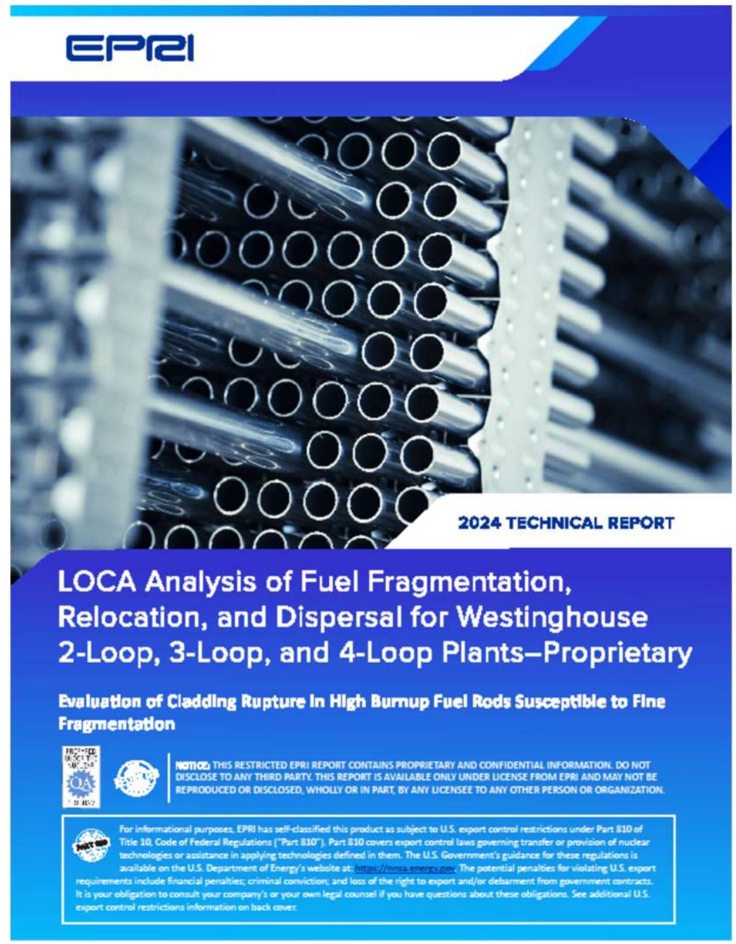


Key Features - LOCA

- Overview of Cladding Rupture Analysis
- Methodology
- Bounding Model development
- Cladding Rupture Results
  - 2-Loop
  - 3-Loop
  - 4-Loop
- Summary and Implementation
  - Evaluation of Limitations and Conditions
  - Plant-Specific Implementation Requirements

Relies on previously submitted Methodology Report:

WCAP-18850-P, “Adaptation of the FULL SPECTRUM LOCA (FSLOCA) Evaluation Methodology to Perform Analysis of Cladding Rupture for High Burnup Fuel,” February 2024.



EPRI

Use of the xLPR Code for Developing LOCA Frequency Estimates

Overview and Key Analysis Results

Craig Harrington and Nate Glunt
EPRI Materials Reliability Program (MRP)

Markus Burkardt and Gideon Schmidt
Dominion Engineering, Inc. (DEI)

NRC Public Meeting
November 8, 2023

Outline

- Background
- Scope
- Summary of xLPR Analysis Cases
- Key Results
  - LOCA frequency compared to NUREG-1829
  - Time between detectable leakage and LOCA
- Conclusions

List of Acronyms

ACRS	Advisory Committee on Reactor Safeguards
ALS	Alternative licensing strategy
CE	Combustion Engineering
CL	Cold leg
DMW	Dissimilar metal weld
DN	Diametre nominal
FFRD	Fuel fragmentation, relocation and dispersal
HL	Hot leg
ISI	In-service inspection
LBB	Leak-before-break
LBLOCA	Large-break loss-of-coolant accident
LRD	Leak rate detection
LOCA	Loss-of-coolant accident
MDM	Materials Degradation Matrix
NPS	Nominal pipe size
NRC TLR	US Nuclear Regulatory Commission Technical Letter Report
PWR	Pressurized water reactor
PWSCC	Primary water stress corrosion cracking
PZR	Pressurizer
RCP	Reactor coolant pump
RCS	Reactor coolant system
RVIN	Reactor vessel inlet nozzle
RVON	Reactor vessel outlet nozzle
SGIN	Steam generator inlet nozzle
SGON	Steam generator outlet nozzle
WRS	Weld residual stress
xLPR	Extremely Low Probability of Rupture

Previous NRC Interactions

Date	Event	NRC ADAMS Accession Number
06/14/2022	NRC Public Meeting to Discuss Use of the Extremely Low Probability Rupture Code for LOCA Frequency Estimates	ML22166A345
01/19/2023	NRC Public Meeting to Discuss Use of the Extremely Low Probability Rupture Code for LOCA Frequency Estimates	ML23019A148
05/18/2023	ACRS Fuels, Materials, and Structure Subcommittee Meeting	ML23164A190

Background and Scope

Background

- xLPR is a state-of-the-art **probabilistic fracture mechanics code** jointly developed by the NRC's Office of Nuclear Regulatory Research and the Electric Power Research Institute (EPRI)
  - Provides new quantitative capabilities to analyze the risks (e.g., leakage or rupture) associated with nuclear power plant piping systems subject to active degradation mechanisms
- NUREG-1829, Vol. 1 estimates Loss-of-Coolant Accident (LOCA) frequencies
  - Evaluated the technical adequacy of redefining the design-basis break size (largest pipe break to which 10 CFR 50.46 applies) to a smaller size
  - Estimated LOCA frequencies through an expert elicitation process

Scope & the Fuels Alternative Licensing Strategy

- As part of research into an alternative fuel licensing strategy (ALS) for fuel fragmentation, relocation, and dispersal (FFRD), it was suggested to apply xLPR to:
  - Validate NUREG-1829 LOCA frequency estimates for use in high burnup fuel licensing
    - Demonstrating LOCAs / ruptures are sufficiently low frequency
  - Evaluate probability that leakage as a precursor to a LOCA / rupture will be detected in sufficient time to allow for reactor shutdown and reduce decay heat levels before a LOCA / reactor coolant system (RCS) piping rupture occurs
    - Demonstrating further defense in depth

Line Size Considerations

- NUREG-1829 gives estimates of LOCA frequencies based on expert elicitation (Table 1)
- The expert elicitation considered LOCA-sensitive piping systems and associated degradation mechanisms (Table 3.5)

Table 1 Total BWR and PWR LOCA Frequencies
(After Overconfidence Adjustment using Error-Factor Scheme)

Plant Type	LOCA Size (gpm)	Eff. Break Size (inch)	Current-day Estimate (per cal. yr) (25 yr fleet average operation)				End-of-Plant-License Estimate (per cal. yr) (40 yr fleet average operation)			
			5^{th} Per.	Median	Mean	95^{th} Per.	5^{th} Per.	Median	Mean	95^{th} Per.
BWR	>100	½	3.3E-05	3.0E-04	6.5E-04	2.3E-03	2.8E-05	2.6E-04	6.2E-04	2.2E-03
	>1,500	1 7/8	3.0E-06	5.0E-05	1.3E-04	4.8E-04	2.5E-06	4.5E-05	1.2E-04	4.8E-04
	>5,000	3 ¼	6.0E-07	9.7E-06	2.9E-05	1.1E-04	5.4E-07	9.8E-06	3.2E-05	1.3E-04
	>25K	7	8.6E-08	2.2E-06	7.3E-06	2.9E-05	7.8E-08	2.3E-06	9.4E-06	3.7E-05
	>100K	18	7.7E-09	2.9E-07	1.5E-06	5.9E-06	6.8E-09	3.1E-07	2.1E-06	7.9E-06
	>500K	41	6.3E-12	2.9E-10	6.3E-09	1.8E-08	7.5E-12	4.0E-10	1.0E-08	2.8E-08
PWR	>100	½	6.9E-04	3.9E-03	7.3E-03	2.3E-02	4.0E-04	2.6E-03	5.2E-03	1.8E-02
	>1,500	1 5/8	7.6E-06	1.4E-04	6.4E-04	2.4E-03	8.3E-06	1.6E-04	7.8E-04	2.9E-03
	>5,000	3	2.1E-07	3.4E-06	1.6E-05	6.1E-05	4.8E-07	7.6E-06	3.6E-05	1.4E-04
	>25K	7	1.4E-08	3.1E-07	1.6E-06	6.1E-06	2.8E-08	6.6E-07	3.6E-06	1.4E-05
	>100K	14	4.1E-10	1.2E-08	2.0E-07	5.8E-07	1.0E-09	2.8E-08	4.8E-07	1.4E-06
	>500K	31	3.5E-11	1.2E-09	2.9E-08	8.1E-08	8.7E-11	2.9E-09	7.5E-08	2.1E-07

Table 3.5 PWR LOCA-Sensitive Piping Systems

System	Piping Matls.	Piping Size (in)	Safe End Matls.	Welds	Sig. Degrad. Mechs.	Sig. Loads.	Mitigation/ Maint.
RCP: Hot Leg	304 SS, 316 SS, C-SS, SSC-CS CS – SW	30 - 44	A600, 304 SS, 316 SS, CS	A82 304 SS, 316 SS, CS	TF, SCC, MA, FDR, UA	P, S, T, RS, DW, O, SUP	ISI w TSL, REM
RCP: Cold Leg/Crossover Leg	304 SS, 316 SS, C- SS, SSC-CS, CS – SW	22 - 34	A600, 304 SS, 316 SS, CS	A82 304 SS, 316 SS, CS	TF, SCC, MA, FDR, UA	P, S, T, RS, DW, O, SUP	ISI w TSL, REM
Surge line	304 SS, 316 SS, C-SS	10 - 14	A600, 304 SS, 316 SS,	A82 304 SS, 316 SS	TF, SCC, MA, FDR, UA	P, S, T, RS, DW, O, TFL, TS	TSMIT, ISI w TSL, REM
SIS: ACCUM	304 SS, 316 SS, C-SS	10 - 12	A600, 304 SS, 316 SS,	A82 304 SS, 316 SS	TF, SCC, MA, FS, FDR, UA (FAC)	P, S, T, RS, DW, O	ISI w TSL, REM
SIS: DVI	304 SS, 316 SS	2 – 6	A600, 304 SS, 316 SS,	A82 304 SS, 316 SS	TF, SCC, MA, FS, FDR, UA (FAC)	P, S, T, RS, DW, O	ISI w TSL, REM
Drain line	304 SS, 316 SS, CS	< 2"			MF, TF, GC, LC, FDR, UA	P, S, T, RS, DW, O, V, TFL	ISI w TSL, REM
CVCS	304 SS, 316 SS	2 – 8	A600 (B&W and	A82	SCC, TF, MF, FDR, UA	P, S, T, RS, DW, O, V	ISI w TSL, REM

The goal of the current study is to analyze piping welds > NPS 14 (> DN 350) in support of alternative licensing strategy (ALS) for FFRD

Summary of xLPR Analysis Cases

Summary of xLPR Analysis Cases

- xLPR analysis cases were developed applying Primary Water Stress Corrosion Cracking (PWSCC) and/or fatigue *(driven by plant transients and not local thermal fluctuations or vibration)* as the material degradation mechanisms
- Analysis cases either modeled flaws as present at the start of the simulation or used initiation models to calculate the time to flaw initiation
  - All flaws at initiation were modeled as flaws of engineering scale
- Sensitivity studies were performed to determine the impact of changes to analysis inputs
  - Sensitivity studies modeled alternate inputs for parameters such as geometry, loading, weld residual stress profiles, or initial flaw sizes

Summary of xLPR Analysis Cases

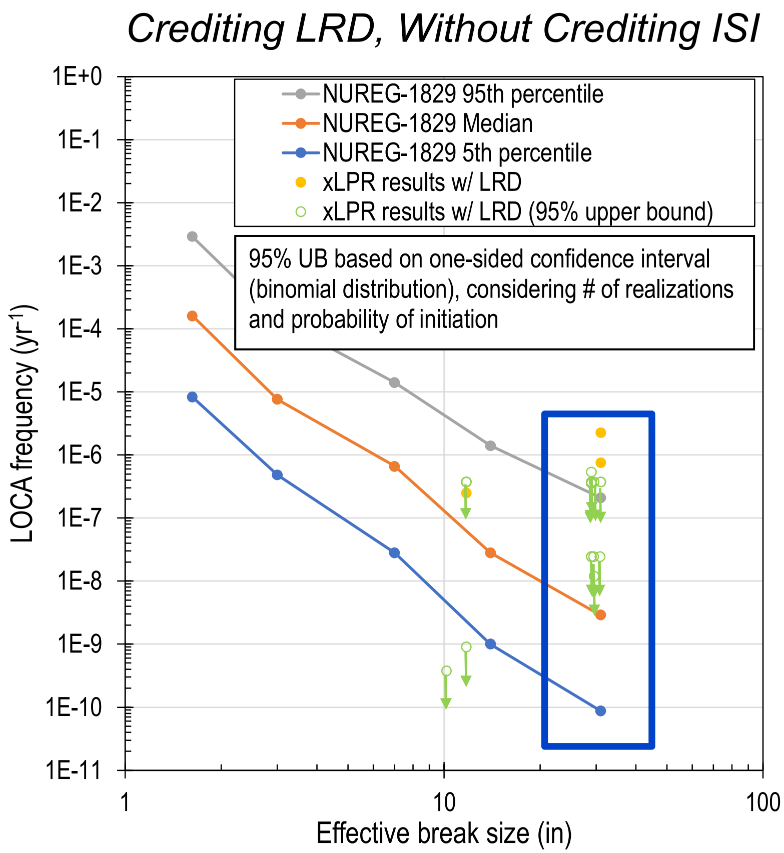
- The results of recent NRC analyses are used where possible and supplemented with additional xLPR analysis cases as needed
  - TLR-RES/DE/REB-2021-09 (ML21217A088)
    - Referred to herein as "xLPR piping system analysis"
    - Documented xLPR analysis of representative reactor vessel outlet and inlet nozzle welds in a Westinghouse four-loop PWR
    - Includes extensive set of sensitivity studies
  - TLR-RES/DE/REB-2021-14 R1 (ML22088A006)
    - Referred to herein as "xLPR generalization study"
    - Documented xLPR analysis of other piping systems containing Alloy 82/182 dissimilar metal piping butt welds which had received prior LBB approvals from the NRC staff
    - Includes reduced set of sensitivity studies per analyzed component, as informed by "xLPR piping system analysis"
  - Shorthand numbering #.#.##.### is used to refer to specific xLPR analysis cases
- Results of Interest for ALS
  - Time between 1 gpm detectable leakage and rupture or LBLOCA ("lapse time")
  - P(Rupture|Initiation) ≈ P(Rupture|Initial Flaw) × P(Initiation)
  - Average 80-year rupture (LOCA) frequency = P(Rupture) / 80 yrs

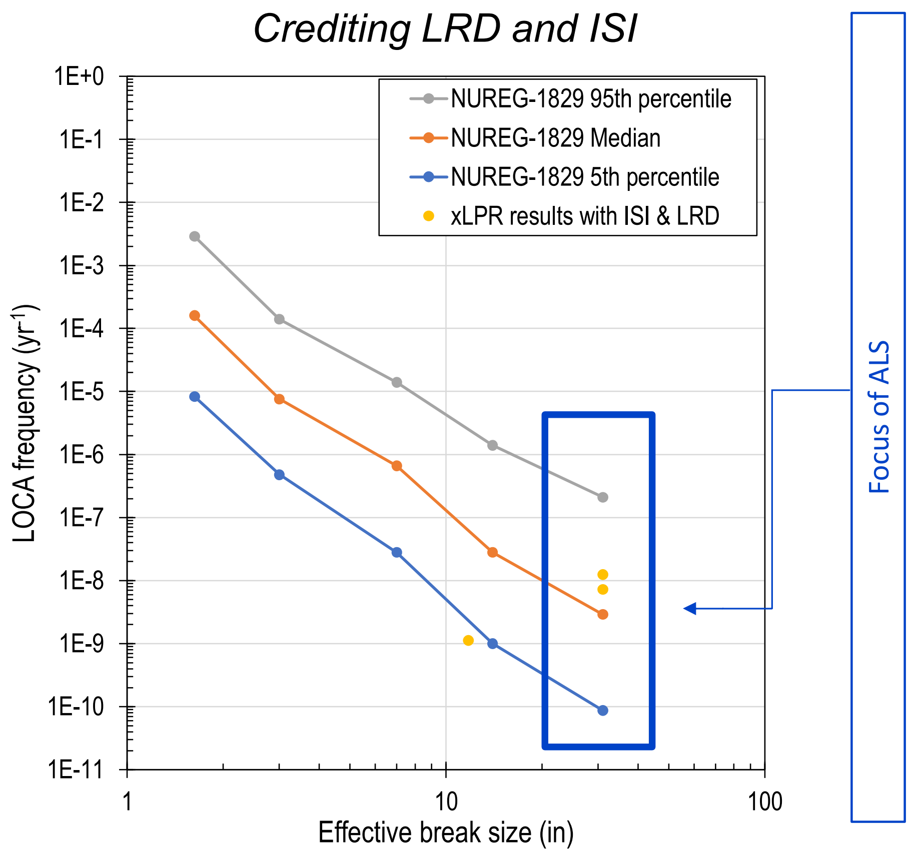
LOCA Frequency Compared to NUREG-1829

LOCA Frequency Compared to NUREG-1829 Table 1

- NUREG-1829 LOCA frequencies used for comparison are:
  - Based on expert elicitation
  - From Table 1
    - Median, 5^{th} percentile, and 95^{th} percentile
    - Total PWR LOCA frequencies after overconfidence adjustment using error-factor scheme
    - 40 yr fleet average values
    - Consider typical ISI with LRD resolution as required by tech spec limits
  - Results are presented on a per plant basis, for each distinct LOCA category
  - Considers piping and non-piping passive system contributions

LOCA Frequency Compared to NUREG-1829 Table 1





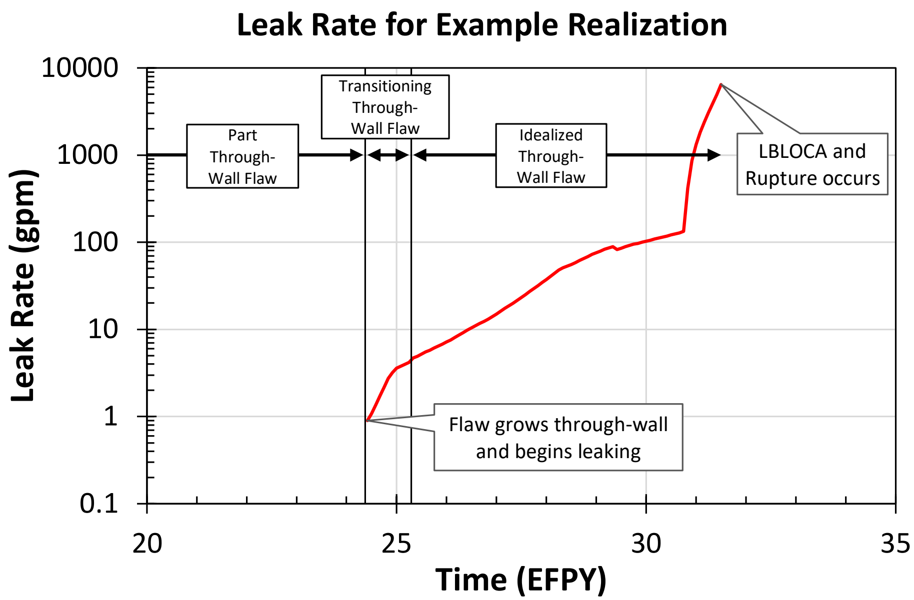
When considering ISI and LRD, LOCA frequencies estimated from xLPR are on a similar order of magnitude as median NUREG-1829 LOCA frequency estimates

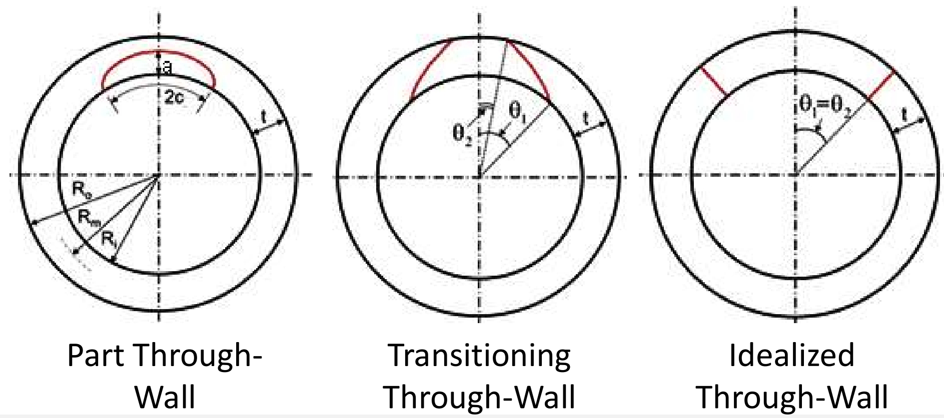
Time Between Detectable Leakage and Large-Break LOCA

Time from Detectable Leakage to LBLOCA

For a Single xLPR Analysis Case Realization

- Results shown depict example leak rate time history for one realization modeled in xLPR
  - Component modeled: Unmitigated Alloy 82/182 reactor vessel outlet nozzle dissimilar metal weld
  - Key modeling options selected:
    - Initial flaw model (i.e., initiation at time = 0)
    - PWSCC growth only
    - One circumferential crack
    - No inservice inspection, leak rate detection, mitigation, or seismic effects
    - LBLOCA = 5,000 gpm leak rate

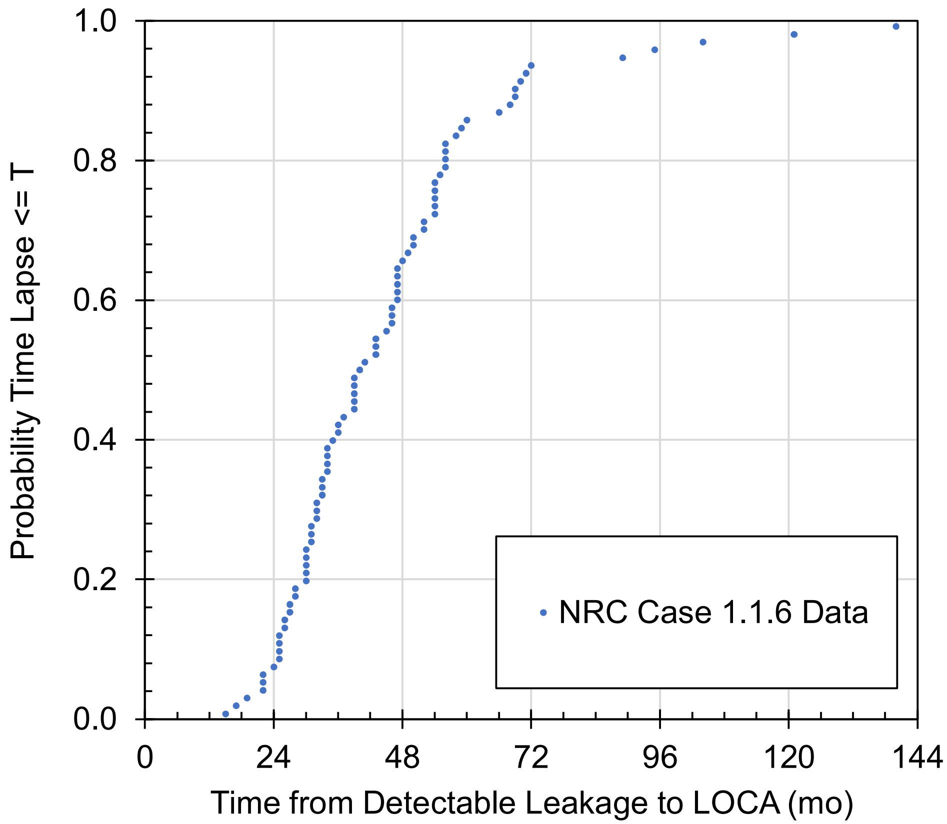




Distributions of Time from Detectable Leakage to LBLOCA

For a Single xLPR Analysis Case

- Results for one xLPR analysis case produce a distribution of lapse times
- Each data point corresponds to one realization which resulted in LBLOCA (without crediting ISI or LRD)
  - Note that lapse time results greater than 12 years are truncated in NRC TLRs
- The distribution of results for each xLPR analysis was considered as part of the overall assessment
- These results do not credit ISI or LRD



Investigation of Limiting Cases

- Considering the distributions of times from detectable leakage to LBLOCA/rupture for each xLPR analysis cases, limiting cases were identified for further review
- Performed further investigation for limiting cases exhibiting either:
  - Minimum time between detectable leakage and rupture < 3 months
  - Nonzero occurrence of rupture with LRD
- All limiting cases were sensitivity studies, which were:
  - Defined to inform understanding of the base case results by investigating inputs known to have influence on xLPR results
  - Less constrained by maintaining fidelity to realistic plant conditions
- Some of these limiting cases were then re-run with:
  - Refined time-stepping
  - Updated input model parameters

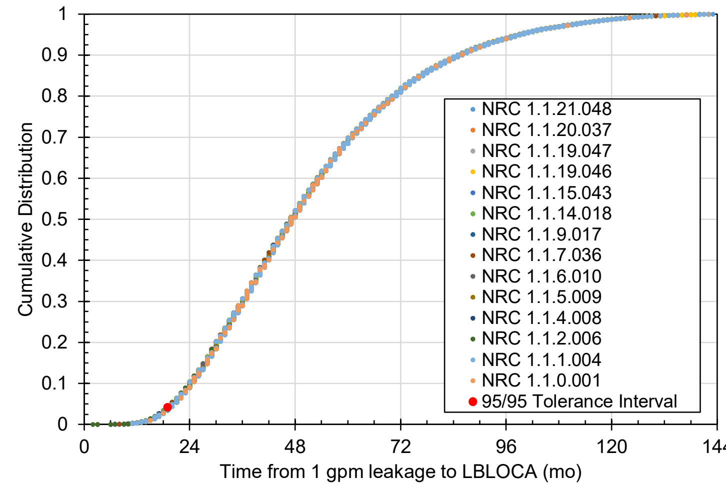
Summary of Time from Detectable Leakage to LBLOCA

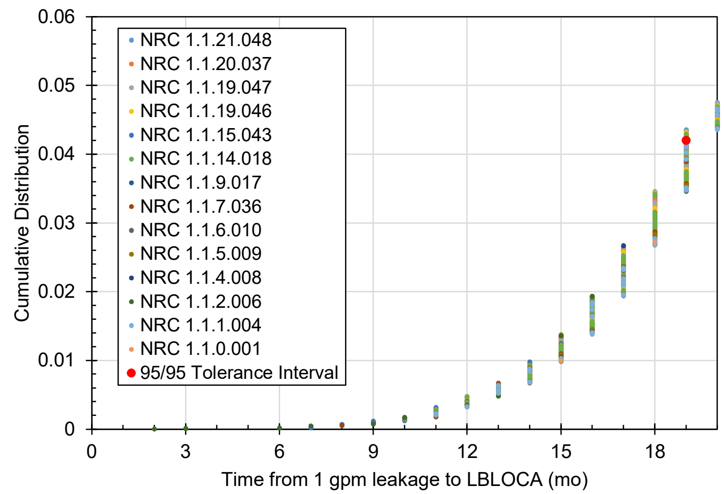
- Considers full population of cases with realizations resulting in LBLOCA
- Summary below reflects results including re-runs of cases (as noted on prior slide)

Component	Summary of Time from Detectable Leakage to LOCA
Reactor Vessel Outlet Nozzle (RVON)	Data for all realizations resulting in LOCA (~27,000 realizations) were evaluated further. [See following slides]
Reactor Vessel Inlet Nozzle (RVIN)	This component is at cold leg temperature. xLPR results showed no occurrence of crack, leak, LBLOCA, or rupture.
Reactor Coolant Pump Nozzle (RCP)	This component is at cold leg temperature. xLPR results in cases modeling flaw initiation showed no occurrence of leakage (and therefore no significant probability of LBLOCA). Cases modeling initial flaws did have ruptures, but the minimum time from detectable leakage to LOCA was 25 months.
Steam Generator Inlet Nozzle (SGIN)	All SGINs in the US PWR fleet have been mitigated, and xLPR results showed no leaks or ruptures in mitigated components. (Includes results from re-runs of two cases with a more realistic initial flaw size, based on suggestions in the xLPR Generalization Study)
Steam Generator Outlet Nozzle (SGON)	There are two realizations where the time from detectable leakage to LBLOCA is zero months. When ISI is credited, these scenarios are highly unlikely. [See following slides]

Time from Detectable Leakage to LBLOCA: RVON

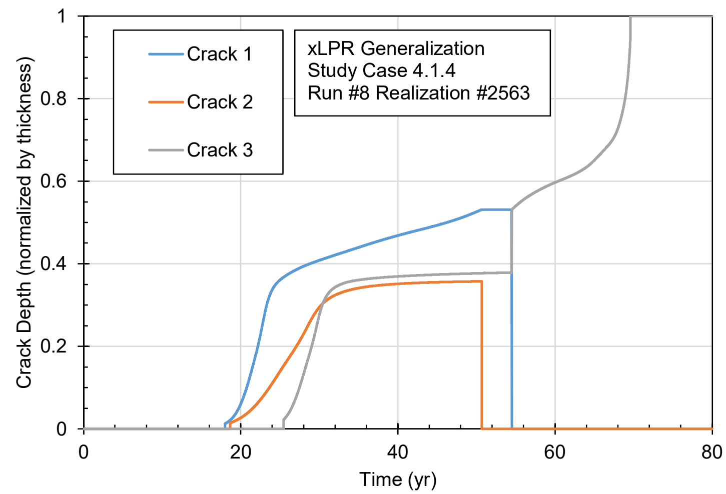
- The distribution of time from detectable leakage to LBLOCA for all ~27,000 realizations is shown in the upper right figure
  - Distribution of times is near-lognormal
- A 95/95 one-sided tolerance interval is defined such that *"there is a 95% probability that the constructed limit is less than 95% of the population of interest for the surveillance interval selected"*
- For this distribution of times, the 95/95 one-sided tolerance interval lower bound is 19 months
  - Calculated considering the assurance-to-quality (A/Q) criterion described in Chapter 24 of NUREG-1475R1
- The lower tail of the distribution is shown in the lower right figure, depicting the data that would fall outside of the 95/95 one-sided tolerance interval lower bound
  - Only 4 realizations had a time lapse of less than 6 months
- Results shown do not credit LRD or ISI
  - No LBLOCAs are modeled to occur if LRD and ISI are credited

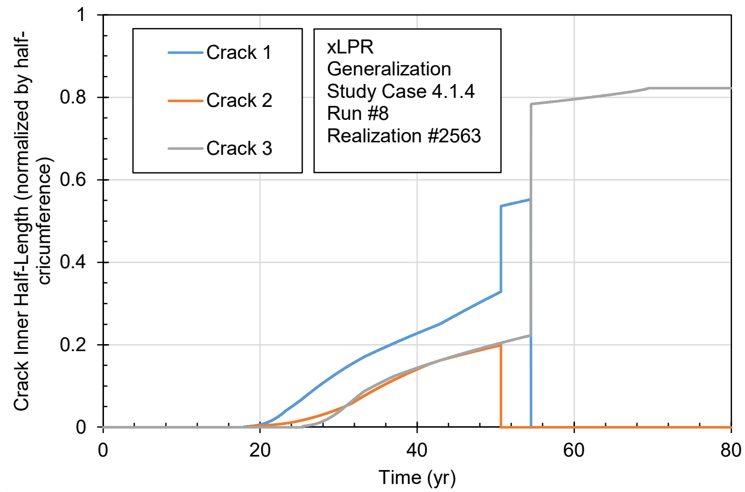




Time from Detectable Leakage to LBLOCA: SGON

- There is one case modeling an unmitigated SGON, xLPR Generalization Study Case 4.1.4
  - This case had 54 realizations out of 100,000 that resulted in LBLOCA
  - Of these realizations, there are two realizations where the leak rate goes from <1 gpm to >5000 gpm in a single time step
    - Time from 1 gpm detectable leakage to LBLOCA is 0 months
- In both realizations, this is caused by multiple large flaws coalescing
  - Leads to extremely high leak rates once the flaw grows through-wall
- These scenarios are highly unlikely when ISI is credited
  - The probability of non-detection is on the order of 1E-5 or less
    - Flaws are present with depths exceeding 10% through-wall for multiple inspection intervals
  - When considering these two realizations among the population of 100,000 realizations and simulation time of 80 years, the annual occurrence of this scenario is on the order of 1E-12 yr^{-1}
- Only one US PWR has an unmitigated SGON





Conclusions

Conclusions

- When crediting ISI and LRD, occurrence of rupture results are on a similar order of magnitude as NUREG-1829 LOCA frequency estimates
  - The only nonzero results were for cases including modeling not representative of plant conditions and operations
  - For cases with zero ruptures w/ LRD, a 95% upper bound based on a one-sided confidence interval is considered for comparison
- For components relevant to the ALS, LBLOCA:
  - Does not occur for the RVIN, RCP, and mitigated SGINs
  - Occurs when not crediting ISI or LRD for RVONs
    - Distribution of times between detectable leakage and LBLOCA is characterized by a 95/95 one-sided tolerance interval lower bound of 19 months
    - Does not occur when crediting ISI and LRD
  - When crediting ISI, LBLOCA scenarios are highly unlikely for unmitigated SGINs
- These results demonstrate that there is sufficient time between detectable leakage and LBLOCA to shutdown the reactor and prevent LBLOCA
- The results further demonstrate the significant benefits of ISI and LRD
- The final report will include applicability criteria for these conclusions


Together…Shaping the Future of Energy®

Alternative Licensing Strategy

To Address Loss-of-Coolant-Accident-Induced Fuel Fragmentation, Relocation and Dispersal

Storm Kauffman, MPR

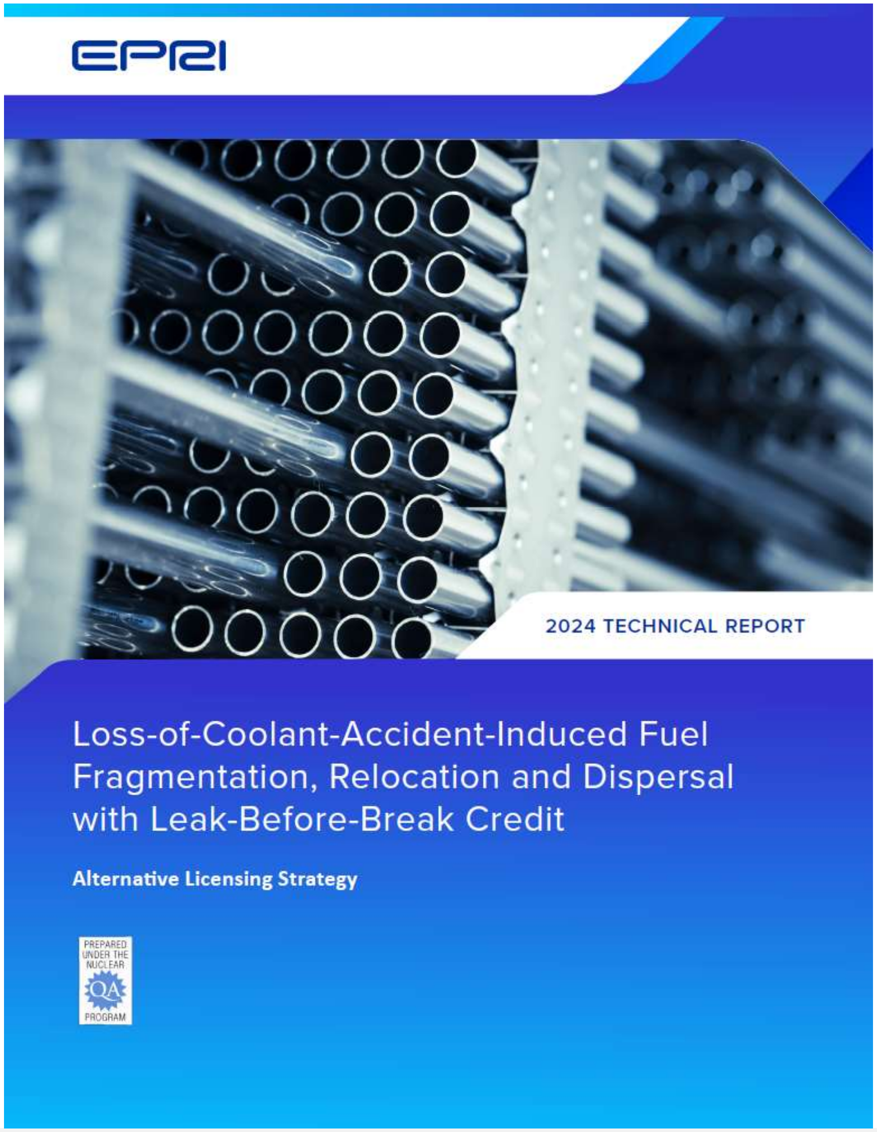
NRC Public Meeting
June 6, 2024

Outline of Presentation

EPRI 3002028673 [ML24121A207]: *Loss-of-Coolant-Accident-Induced Fuel Fragmentation, Relocation and Dispersal with Leak-Before-Break Credit – Alternative Licensing Strategy*

Presentation outline:

- Overview: the Alternative Licensing Strategy (ALS)
  - Purpose
  - Advantages
  - Basis
  - Coverage of the reactor coolant system (RCS)
  - Regulations and guidance
  - Defense-in-Depth (DiD)
- ALS Precedents
- Leak detection and response
- Non-piping assessment
- Summary



Overview:
Alternative Licensing Strategy (ALS)

Alternative Licensing Strategy Purpose

Purpose:

Provide technical justification to exclude consideration of fuel fragmentation, relocation, and dispersal (FFRD) from the core cooling evaluation for a loss of coolant accident (LOCA) in a pressurized water reactor (PWR) to allow increasing the fuel burnup limit.

Problem Statement

FFRD involves multiple phenomena potentially induced in high burnup (HBU) fuel by large-break (LB) LOCAs. The usual approach of validating methodology against empirical data does not support desired schedule.

Proposed Approach

Based on precedents and on existing regulations and guidance define a methodology that shows that:

1) Burst of clad of high burnup fuel is not credible for LB-LOCAs
2) Smaller LOCAs do not cause clad burst

Advantages of the ALS as Basis for Burnup Extension

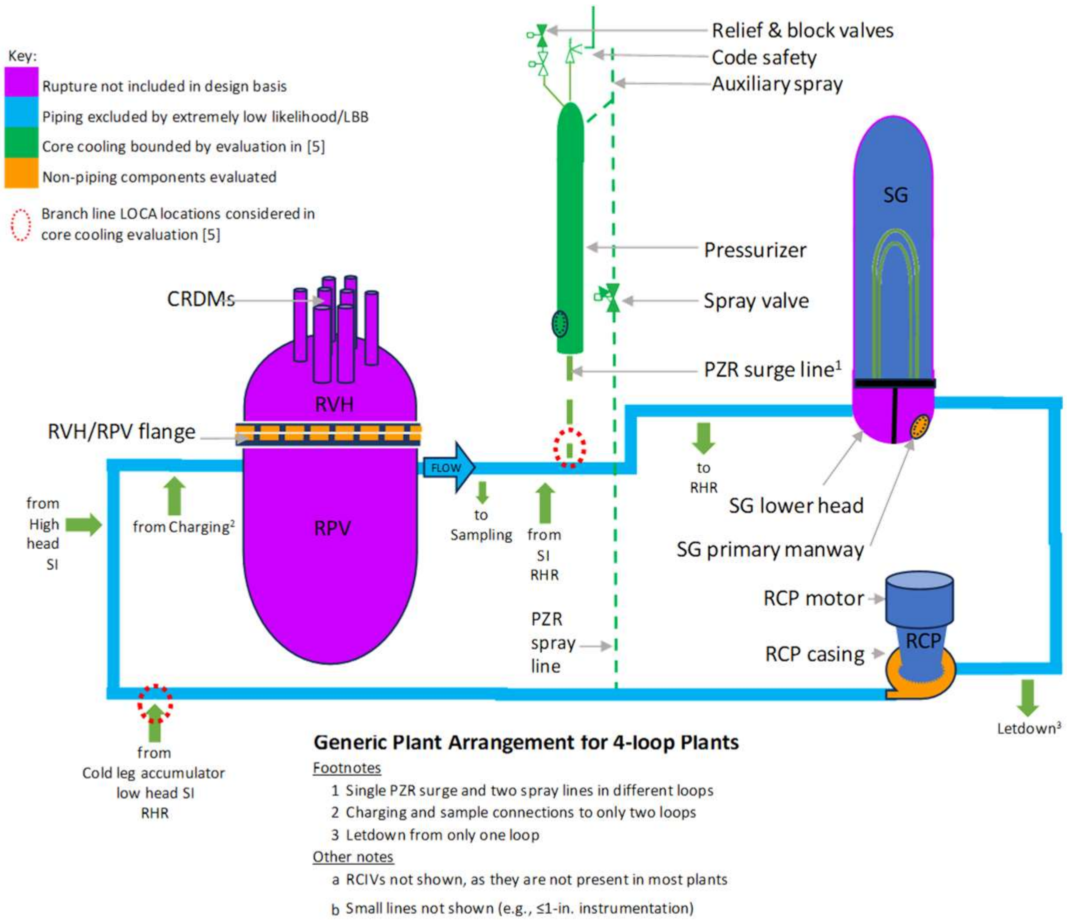
- Considers risk insights
- Minimizes licensee and NRC effort
  - Standard, generally applicable approach
  - Consistent with NRC Alternative 5 of regulatory basis document [ML23032A504] for increased enrichment rulemaking, but more limited
- Allows NRC to establish criteria now by avoiding need for
  - Additional experimental data
  - Qualification of analytical models of consequences (i.e., fuel dispersal)

Basis for the ALS

- LB-LOCA-induced FFRD not credible
  - Rupture of piping of RCS main loop extremely unlikely
    - Main loop piping already approved for LBB
    - NUREG-1829 frequency less than 10^{-6}/year threshold for screening
    - Supported by xLPR probabilistic fracture mechanics evaluation of piping
      - Extremely unlikely to 80-year plant life
      - Ample time (months) to detect precursor leakage and respond
    - Reactor coolant leakage is a focus area
      - Multiple means of detection by plant operating staff and others
      - Per Tech Specs (TS): shut down, cool down, and depressurization removes driving force needed to cause either LB-LOCA or fuel dispersal
- Smaller LOCAs, though more likely, shown to not cause clad burst
  - Fuel vendor LOCA analysis methodology and results in separate documents

ALS Methodology Coverage of RCS

- Piping:
  - Small/intermediate breaks: no HBU fuel clad burst based on vendor-specific LOCA analysis
  - Large piping (RCS main loop):
    - Extremely low probability of failure (NUREG-1829), as confirmed by xLPR evaluation
    - Ample time for operator recognition and response
- Non-piping – existing evaluations (e.g., license renewal/life extension) reviewed
  - ALS consistent with existing design basis
    - Screened
    - Bolted
    - Component bodies
    - Active component failures
  - No need for changes or further analyses



Regulations & Guidance: Large-break (LB) LOCAs

- Reactor coolant pressure boundary (RCPB) integrity is priority
  - Ductile materials
  - Structural analysis per ASME Code Section III
  - Procedural constraints to avoid adverse conditions
  - Inservice inspection (ISI) to detect unexpected degradation in advance
  - Plant performance indicator
- Piping LB-LOCA
  - Set of conservative assumptions: single active failure, worst initial conditions, etc.
  - Defined in 10 CFR 50.46

Defense-in-Depth (DiD)

- LB-LOCA has extremely low likelihood per NUREG-1829, as confirmed by xLPR analysis
  - Uses modern uncertainty propagation to provide upper/lower limit results
- If leak develops, ample time available for operations staff to detect leakage and respond
  - Multiple means of detection
  - Operators on all shifts, plant management, maintenance personnel would have time to detect leakage
  - TS LCO requires shut down at 1 gpm
    - Considerable time before rupture
    - In actual practice, 0.05 gpm or less detectable and plant shut down long before leakage reaches 1 gpm
- Once in Mode 5 {or 4}, LB-LOCA and FFRD risk is negligible
  - RCS subcooled and no pressurizer bubble
    - Insufficient energy to drive RCPB crack to rupture
    - Insufficient energy to separate pipe ends
    - No blowdown; coolant may drain to nozzles but fuel remains covered
  - Even if a RCPB rupture could occur, cladding burst would not occur
    - Negligible heat up: decay heat drops off with time
    - Internal fuel rod pressure reduced
    - Configuration is essentially the same as post LOCA long term cooling

Technical Specification Mode Definitions

Mode	k_{eff}	% rated power	Average RCS temp (˚F)
3	<0.99	NA	≥350
4	<0.99	NA	$350>T_{avg}>200$
5	<0.99	NA	≤200
RCS pressure below pressure limit for temp.			

EPRI

ALS Methodology Precedents

LBB – Refined Guidance

53 FR 11311, April 6, 1988

> "Until recently, severe failure for piping has been defined as the instantaneous double-ended guillotine leak regardless of the standards applied to piping. Under leak-before break technology, it has become possible to exclude the double-ended guillotine break from the dynamic structural design basis because it is unrealistic and overly conservative in certain situations. Piping which meets NRC's acceptance criteria now need only postulate stipulated 'leakage cracks' as severe failure."

- SECY-88-325, 4/13/1989, 54 FR 18149, Published 5/2/89

Policy Statement on Additional Applications of Leak-Before-Break Technology

> "Additionally, other breaches in the fluid system boundary, such as failed manways or valve bonnets, must be examined to determine whether they control EQ profiles."

ALS

- Is consistent with modified LBB applicability established in 1988-89
  - Containment, ECCS, and EQ functional and performance requirements are unchanged
  - Non-piping LOCAs (e.g., bolted closures, pump casings) are assessed

LBB Applied to Exclude LOCA Effects

WCAP-16498-NP, March 2008

17x17 Next Generation Fuel (17x17 NGF) Reference Core Report

- "Currently, all Westinghouse designed US PWR primary coolant main loop piping has been excluded from consideration for dynamic effects associated with postulated pipe rupture…. all current fuel qualification analyses are performed on the basis of postulated rupture of branch lines connected to the primary coolant loop.
- "The primary success criteria for the baffle bolting program are the same as those documented in SRP Section 4.2 discussed above: i.e., no fuel fragmentation, 10 CFR 50.46 criteria continue to be met, and control rod insertability is maintained. These analyses were also based on LBB exclusion of the main coolant loop piping.
- "…only the branch line breaks not covered by LBB are considered in the licensing basis."

ALS

- Is consistent in use of LBB for NGF fuel in excluding effects of LB-LOCA from the design basis
  - No fuel fragmentation caused by blowdown hydraulic loads for all fuel vs. no fuel dispersal for HBU rods
  - 10 CFR 50.46 limits must be met after exclusion applied

LBB – Summary of Extended Applicability

Application Approved	Year	Action	Description	Timing of Effect	Technical Area	SSCs Affected
USI A-2	1986	Approved	DEGB loads could alter plant geometry	Blow down	Mechanical	RPV
Pipe Whip / Jet Impingement	1986	Approved	Remove of pipe whip restraints	Blow down	Mechanical	Piping supports
Control rod insertion	2008	Approved	Exclude LB-LOCA blowdown forces	Blow down	Mechanical Nuclear	Control rods
NGF structural	2008	Approved	No fuel fragmentation Meet 50.46 Control rod insertability	Blow down	Fuels Thermal Mechanical	Fuel
GSI-191 sump blockage	2010	Rejected	Eliminate debris generated by LB-LOCA	Post blow down	Many	ECCS: recirculation
Baffle-former-bolt breakage	1998	Approved	No fuel fragmentation Meet 50.46 Control rod insertability	Blow down	Fuels Thermal Mechanical	Core
ECCS cross-connect valve	2003-2007	Approved	Eliminate pipe whip that could fail both trains of ECCS	Post blow down	Mechanical	ECCS: low pressure injection
FFRD dispersal	2024	TBD	Not consider FFRD for excluded breaks	Prior to reflood	Fuels Thermal Mechanical	Fuel

ALS

- Considers past precedents for application of LBB
  - Exclusion of fuel dispersal from HBU fuel does not affect the requirement for ECCS to mitigate the full spectrum of break sizes and locations. It does eliminate the need to posit fuel fragment dispersal of the highest burnup rods during LOCAs.
  - The EPRI ALS explicitly considers other possible failures such as valve bonnets, flanges, manways that could be large enough to possibly cause FFRD.

Leak Detection and Response

Leakage Technical Specifications

- TS 3.4.13 Limiting Condition for Operation (LCO)
  - No more than 1 gpm unidentified RCS leakage
  - Operators would act *before* reaching 1 gpm
    - If not addressed, continued leakage will lead to annunciated alarm and implementing abnormal or emergency procedures

3.4 REACTOR COOLANT SYSTEM (RCS)

3.4.13 RCS Operational LEAKAGE

LCO 3.4.13 RCS operational LEAKAGE shall be limited to:

a. No pressure boundary LEAKAGE,

b. 1 gpm unidentified LEAKAGE,

c. 10 gpm identified LEAKAGE, and

d. 150 gallons per day primary to secondary LEAKAGE through any one steam generator (SG).

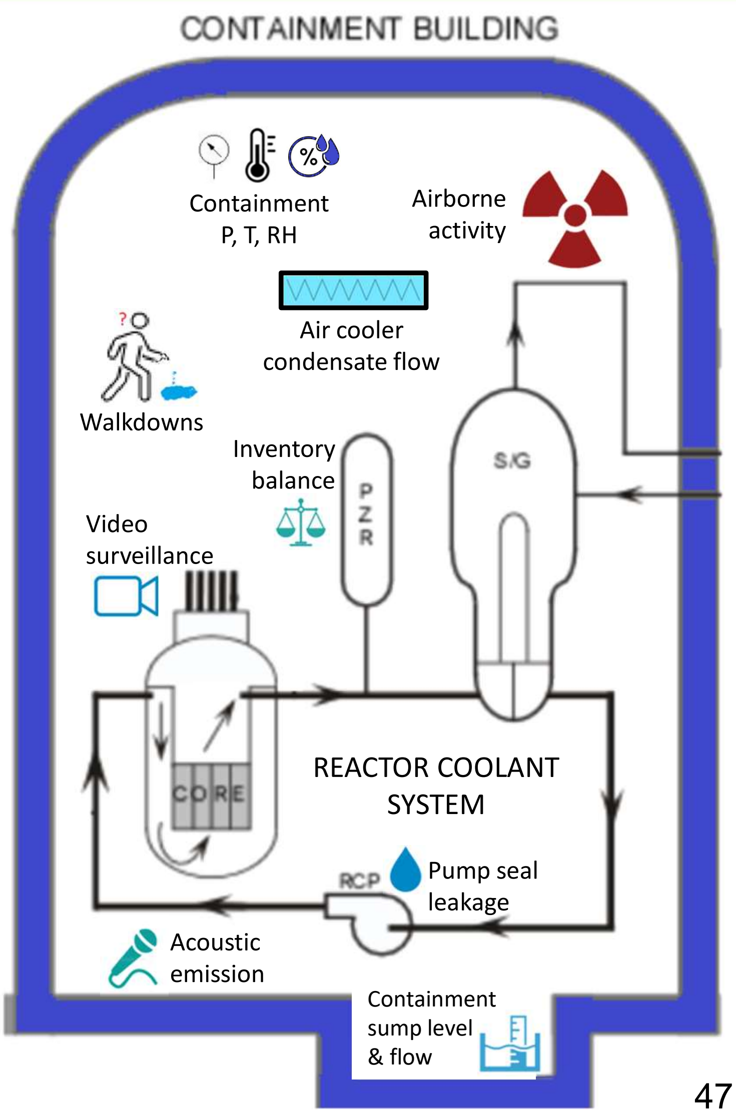
APPLICABILITY: MODES 1, 2, 3, and 4.

ACTIONS

CONDITION	REQUIRED ACTION	COMPLETION TIME
A. RCS operational LEAKAGE not within limits for reasons other than pressure boundary LEAKAGE or primary to secondary LEAKAGE.	A.1 Reduce LEAKAGE to within limits.	4 hours
B. Required Action and associated Completion Time of Condition A not met. <u>OR</u> Pressure boundary LEAKAGE exists. <u>OR</u> Primary to secondary LEAKAGE not within limit.	B.1 Be in MODE 3. <u>AND</u> B.2 Be in MODE 5.	6 hours 36 hours

Leak Detection

- Regulatory Guide 1.45, “Guidance on Monitoring and Responding to Reactor Coolant System Leakage”*
  - Unidentified leak rate > 0.05 gpm detection/quantification
  - Response time (excluding transport time) of no more than 1 hour for leak rate of 1 gpm
  - Leakage Monitoring Parameters
    - Inventory balance
    - Containment sump level or flow
    - Airborne particulate activity
    - Air cooler condensate flow
    - Airborne gaseous activity
    - Containment pressure, temperature, humidity
    - Acoustic emission
    - Video surveillance
    - Pump seal leakage
    - Makeup flow rate
    - Walkdowns



*Most PWRs were licensed to and still apply Revision 0

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RCS Unidentified Leakage Action Levels

- WCAP-16465-NP, “Standard RCS Leakage Action Levels and Response Guidelines for PWRs,” 9/06
  - Specifies three action level tiers based on RCS leak rate; lower tier triggers set to focus attention on detection of very small leaks
    - Tier 1:
      - One 7-day rolling average daily unidentified rate > 0.1 gpm
      - Nine consecutive daily unidentified rate > baseline mean
    - Tier 2:
      - Two consecutive daily unidentified rate > 0.15 gpm
      - Two of 3 daily unidentified rates > mean +2σ
      - 30-day total unidentified leakage > 5,000 gal. (0.116 gpm average over 30 days)
    - Tier 3:
      - One daily unidentified rate > 0.3 gpm or > mean +2σ
      - Long term (operating cycle) total unidentified leakage > 50,000 gal.
  - Summarizes operating experience
    - Detected as small as 0.01 gpm while operating
    - Only two RCS piping welds have had leaks
  - If annunciated alarm occurs, plant abnormal/emergency procedures apply

Non-piping Assessment

Assessment of Non-Piping Failures

- 10 CFR 50.46 requires core cooling analysis of range of LOCAs caused by piping failure
- As DiD, the ALS also considers potential for non-piping failure to cause FFRD
  - Considered as part of life extension/license renewal
  - ALS consistent with existing design basis
  - No need for changes or further analyses identified

Operating Experience – Assess for Relevance

- Licensee Event Reports
  - No events identified that showed gaps in the ALS framework
  - Addressed by industry actions

Summary

Summary: Alternative Licensing Strategy

- Addresses LB-LOCA with potential to cause FFRD:
  - Extremely low likelihood of occurrence based on NUREG-1829
    - Below 10^{-6} per year, considering piping and component failures
    - Consistent with threshold for screening licensing basis events
- LBB for PWR RCS main loop piping already authorized
  - xLPR confirms extremely low likelihood
  - xLPR shows long time for operator detection/response before rupture
- Non-piping components
  - Design features preclude failures potentially leading to clad burst
- Core cooling analyses for LOCAs smaller than RCS main loop
  - No clad burst for HBU rods
- Operating experience
  - ALS considers risk insights
- Criteria for implementation at individual plants

ALS

- Is consistent with NRC precedents & guidance
  - No existing regulations nor guidance specifically for FFRD
  - PWR RCS main loop piping already approved for LBB
  - Exclude events with extremely low probability of failure such as reactor vessel asymmetric loading
  - LBB accepted to exclude fuel fragmentation caused by blowdown hydraulic forces for broken baffle bolts
  - IE rulemaking basis FFRD alternative


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