# Alternative Licensing Strategy - Overview

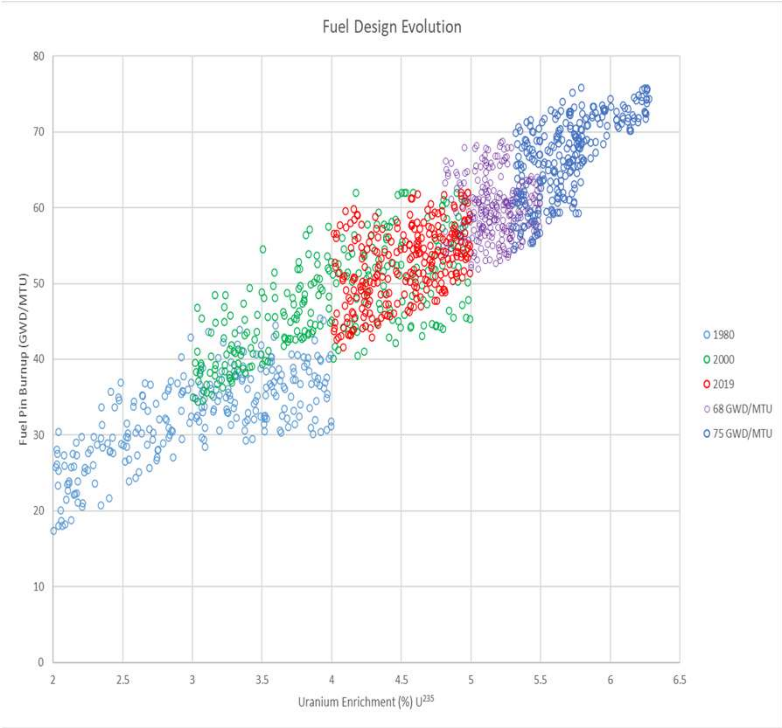
## Risk Informed Analysis of Loss of Coolant Accident Induced Fuel Fragmentation, Relocation, and Dispersal


Fred Smith
EPRI - Technical Executive


NRC Pre-submittal Meeting
June 2, 2021
Webcast

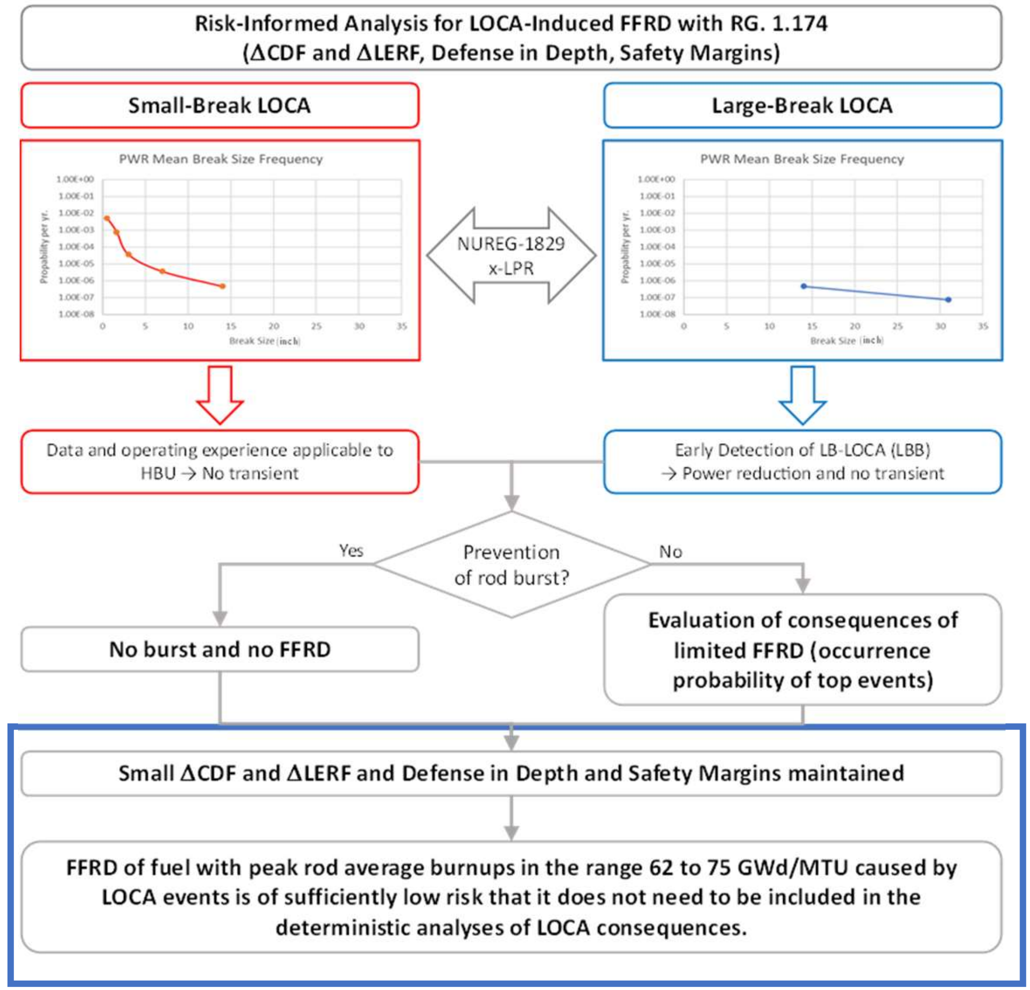
# Issue Statement

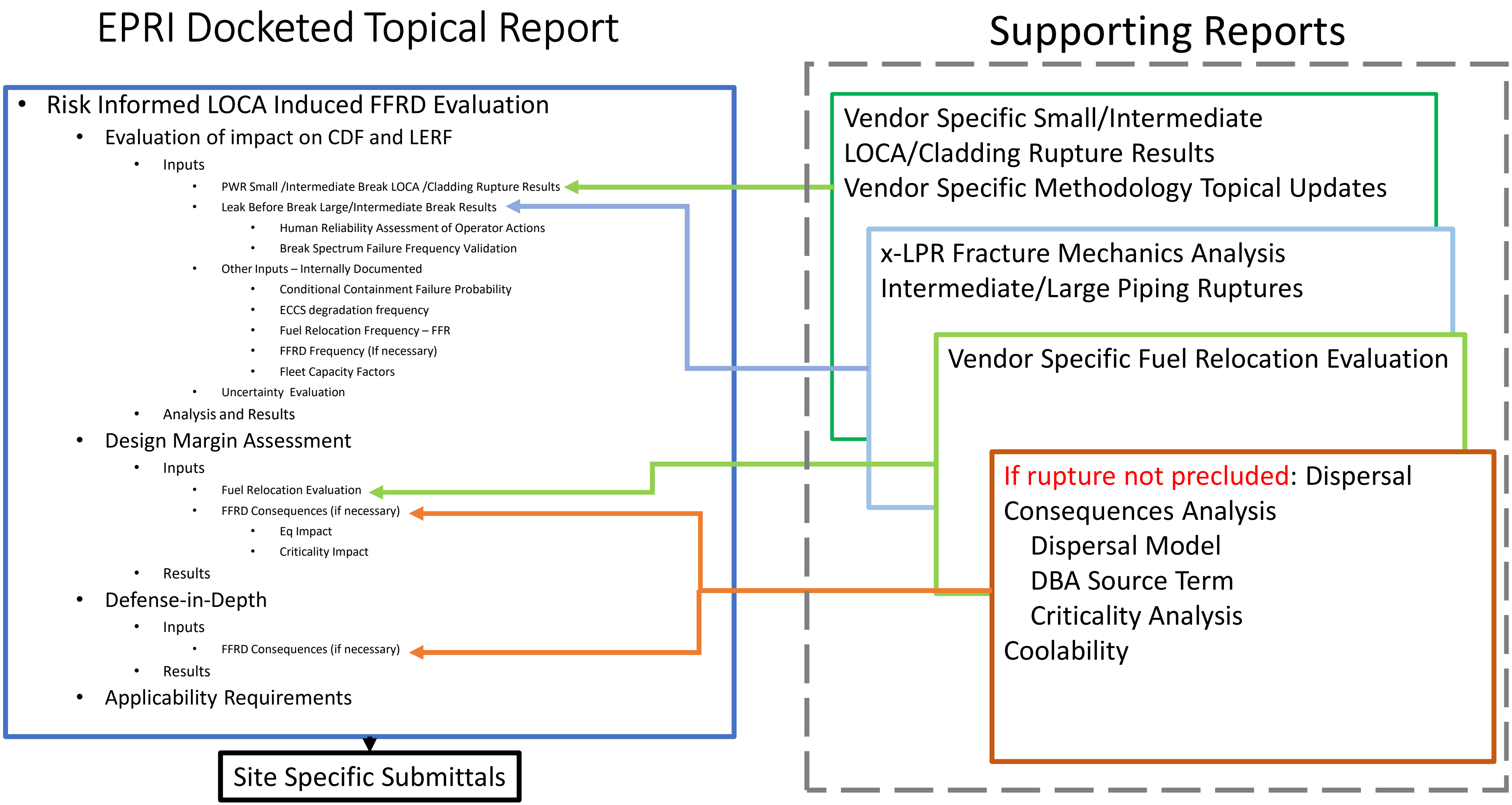
- Enhancements to fuel safety, reliability, efficiency and economics are critical to the industry, now and into the future
- Evolutionary fuel designs and materials have enabled increases in discharge burnup limits and uranium enrichments over the past several decades
  - Burnup limit currently at 62 GWd/MTU (rod average)
  - Enrichment limit currently at 5 weight percent U-235
- Generic issue for increasing burnup limit Fuel Fragmentation, Relocation, and Dispersal (FFRD) with fuel rod burst/rupture during design basis accidents (Ref: SECY-15-0148)



# Risk Informed Analysis of LOCA induced FFRD

- Based on existing process – RG-1.174
- Small increase in Core Damage Frequency ($<10^{-6}$) and Large Early Release Fraction ($<10^{-7}$)
    - Small Break – No cladding rupture for high burnup fuel
    - Large Break – Credit Plant Shutdown (Leak Before Break) prior to LOCA
    - Ensure overlap addresses Intermediate Break
    - Feasibility evaluations show lower risk than the target criteria by factor of 10 (regulatory margin)
- Defense in Depth/Safety Margins
    - Seven Principles for Defense in Depth addressed
    - Maintained with combination of SB-LOCA analysis results and Leak Before Break mitigation for LB-LOCA
    - Evaluation of fuel dispersal impacts provides a backup strategy




EPRI Docketed Topical Report
Supporting Reports
Risk Informed LOCA Induced FFRD Evaluation
Evaluation of impact on CDF and LERF
Inputs
PWR Small /Intermediate Break LOCA /Cladding Rupture Results
Leak Before Break Large/Intermediate Break Results
Human Reliability Assessment of Operator Actions
Break Spectrum Failure Frequency Validation
Other Inputs – Internally Documented
Conditional Containment Failure Probability
ECCS degradation frequency
Fuel Relocation Frequency – FFR
FFRD Frequency (If necessary)
Fleet Capacity Factors
Uncertainty Evaluation
Analysis and Results
Design Margin Assessment
Inputs
Fuel Relocation Evaluation
FFRD Consequences (if necessary)
Eq Impact
Criticality Impact
Results
Defense-in-Depth
Inputs
FFRD Consequences (if necessary)
Results
Applicability Requirements
Site Specific Submittals
Vendor Specific Small/Intermediate LOCA/Cladding Rupture Results
Vendor Specific Methodology Topical Updates
x-LPR Fracture Mechanics Analysis
Intermediate/Large Piping Ruptures
Vendor Specific Fuel Relocation Evaluation
If rupture not precluded: Dispersal Consequences Analysis
Dispersal Model
DBA Source Term
Criticality Analysis
Coolability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# Westinghouse Approach for SBLOCA Rupture Calculations to Support EPRI Alternative Licensing Strategy

Jeffrey Kobelak
Fellow Engineer
Westinghouse Electric Company
June 2021

Westinghouse

# Background
# FULL SPECTRUM LOCA

- The **FULL SPECTRUM**™ LOCA (**FSLOCA**™) evaluation model (EM) is the latest advancement in Westinghouse analysis technology
  - WCOBRA/TRAC-TF2 is the T/H system code licensed as part of the FSLOCA EM
  - PAD5 code provides steady-state fuel rod calculations
- The FSLOCA EM is NRC-approved to analyze the full spectrum of break sizes using a single best-estimate code
  - Currently approved for Westinghouse-designed 3-Loop and 4-Loop plants
- The methodology demonstrates with high probability that the acceptance criteria will not be exceeded in a design basis LOCA scenario

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# Background
# Incremental Burnup Extension

- Incremental burnup extension for Westinghouse (and Combustion Engineering) fuel designs was submitted to the NRC in December 2020
  - Increases fuel rod average burnup limit to ~68 GWd/MTU

- Various WCOBRA/TRAC-TF2 code models were updated for analysis of higher burnup fuel

- Method was developed to assess cladding rupture for higher burnup fuel on the core periphery under LOCA conditions using WCOBRA/TRAC-TF2

**Code and method used for SBLOCA rupture calculations to support EPRI will build on FSLOCA EM and Incremental BU submittals**

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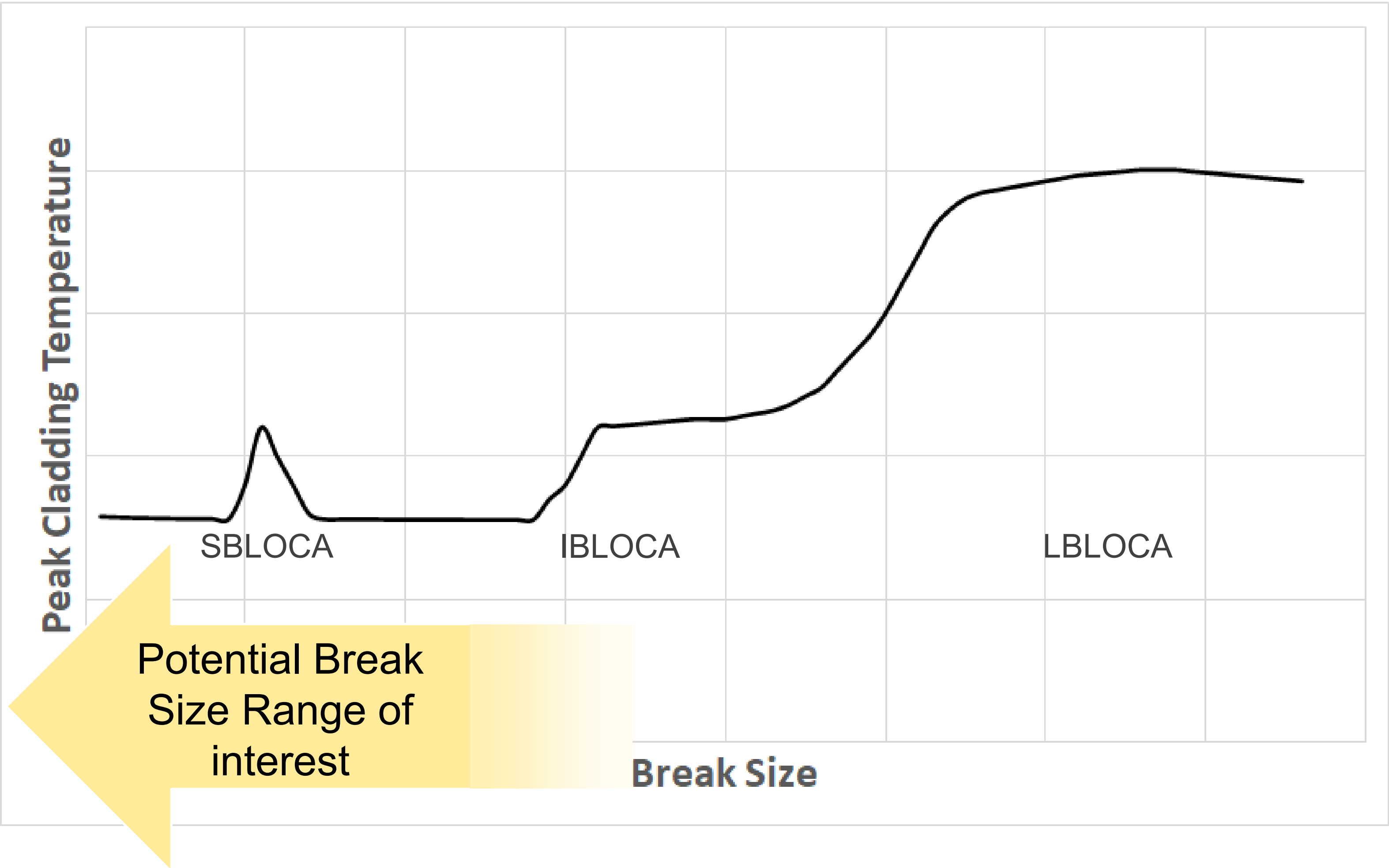
# Illustration of LOCA Cladding Temperature Response versus Break Size

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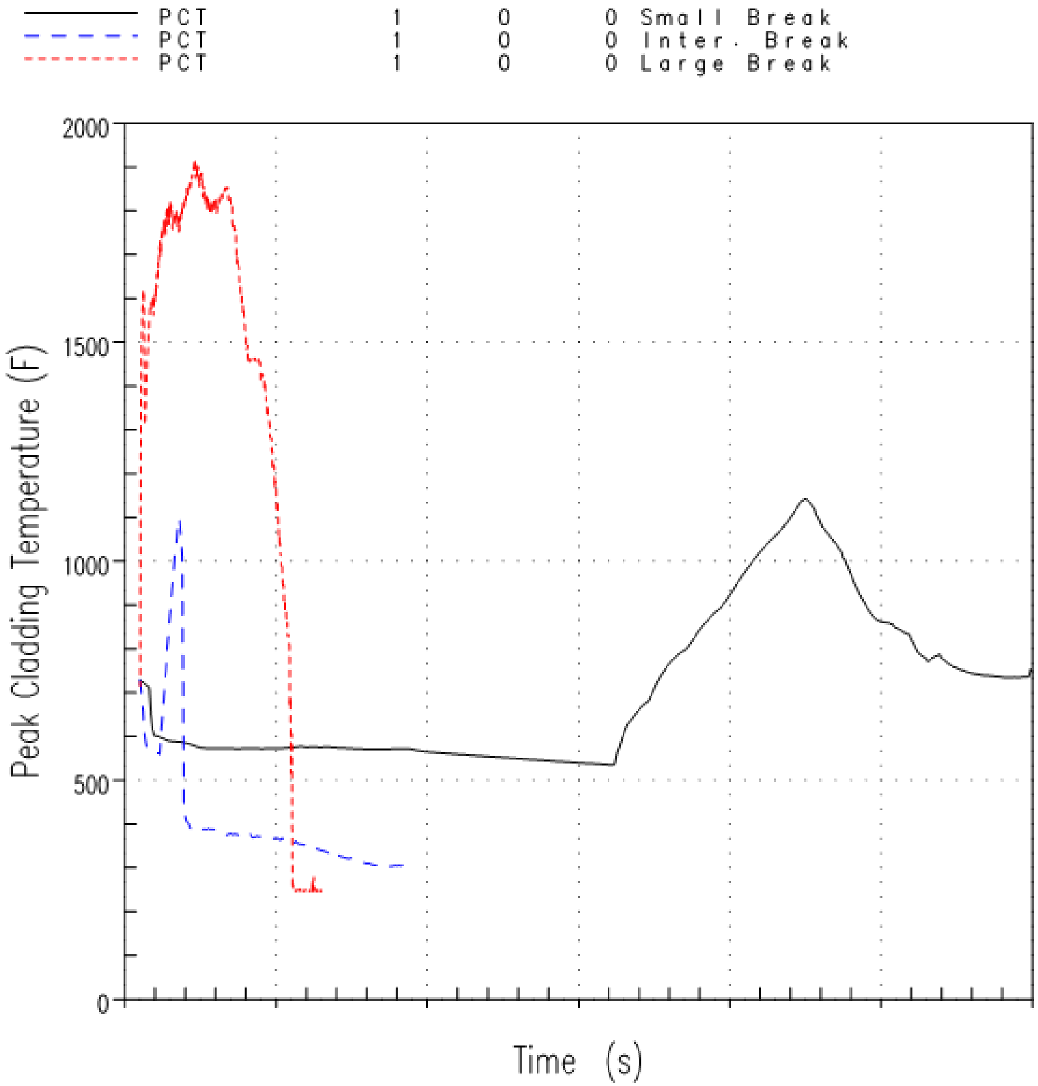
# EPRI Alternate Licensing Strategy Preliminary Scoping Calculations

- FSLOCA EM is well-aligned with EPRI alternate licensing strategy
- Westinghouse has completed exploratory work indicating that burst may be precluded for high burnup fuel under SBLOCA and IBLOCA conditions
- Approach and results will be formalized to support EPRI submittal to NRC



# EPRI Alternate Licensing Strategy Westinghouse Plan

- **Step 1**: Establish bounding nuclear design envelope
  - Nuclear designs will cover various fuel designs, fuel arrays, and operating strategies
- **Step 2**: Develop bounding fuel rod design data
  - Include conservatism to ensure that plant-specific operation falls within analysis envelope
- **Step 3**: Generate bounding PWR / ECCS model
  - Updates will be made to a relatively limiting model to address PWR and ECCS design differences with first-order impact on LOCA transient results

**Applicability of various envelopes would have to be confirmed for implementation, or plant-specific calculations would be required**

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# EPRI Alternate Licensing Strategy Westinghouse Plan

- **Step 4**: Address phenomena related to high burnup fuel rod response within the FSLOCA methodology / WCOBRA/TRAC-TF2 code as appropriate
  - Transient fission gas release
  - Potential for pre-burst axial fuel relocation

- **Step 5**: Execute cladding rupture calculations
  - Objective is to demonstrate no cladding rupture occurs for breaks smaller than threshold defined by EPRI

# Expected Ranges of Applicability

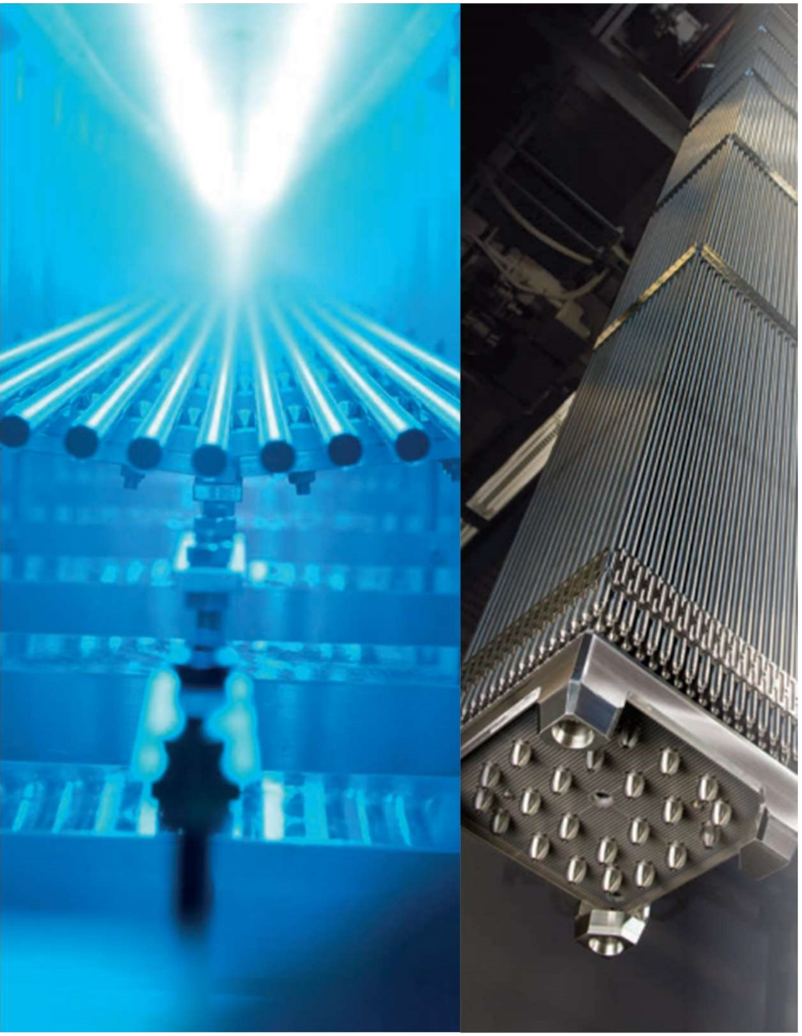
- Westinghouse-designed 2-Loop, 3-Loop, & 4-Loop PWRs
  - 2-Loop extension of the FSLOCA EM has been completed and will be available to the NRC in advance of any EPRI submittal
- Westinghouse 14x14 and 17x17 fuel assembly designs, at a minimum
  - Extension to other designs / classes could be accomplished via supplement
- Westinghouse cladding and fuel materials intended for high burnup operation

Westinghouse

# NRC meeting – EPRI FFRD Strategy

John H. Strumpell, General Manager, US Fuel R&D

Web Conference, June 2, 2022



# Framatome Supports the Industry FFRD Solution 100%

**Framatome is partnering with the industry initiative led by NEI and EPRI to develop an alternative licensing strategy to address FFRD in PWR reactors**

- Framatome views the alternative licensing approach as a precedent setting, constructive approach that will fully support safe, competitive energy production
- Framatome will leverage licensed SBLOCA codes and methods to evaluate the effects of FFRD for fuel with burnups greater than 62 GWd/mTU

**Specific details of EPRI support will link to Framatome proprietary methods and is being disclosed through official channels**

# xLPR Analysis of Intermediate/Large Piping Ruptures

## LOCA Frequency Estimates and Time Between Leakage and Rupture

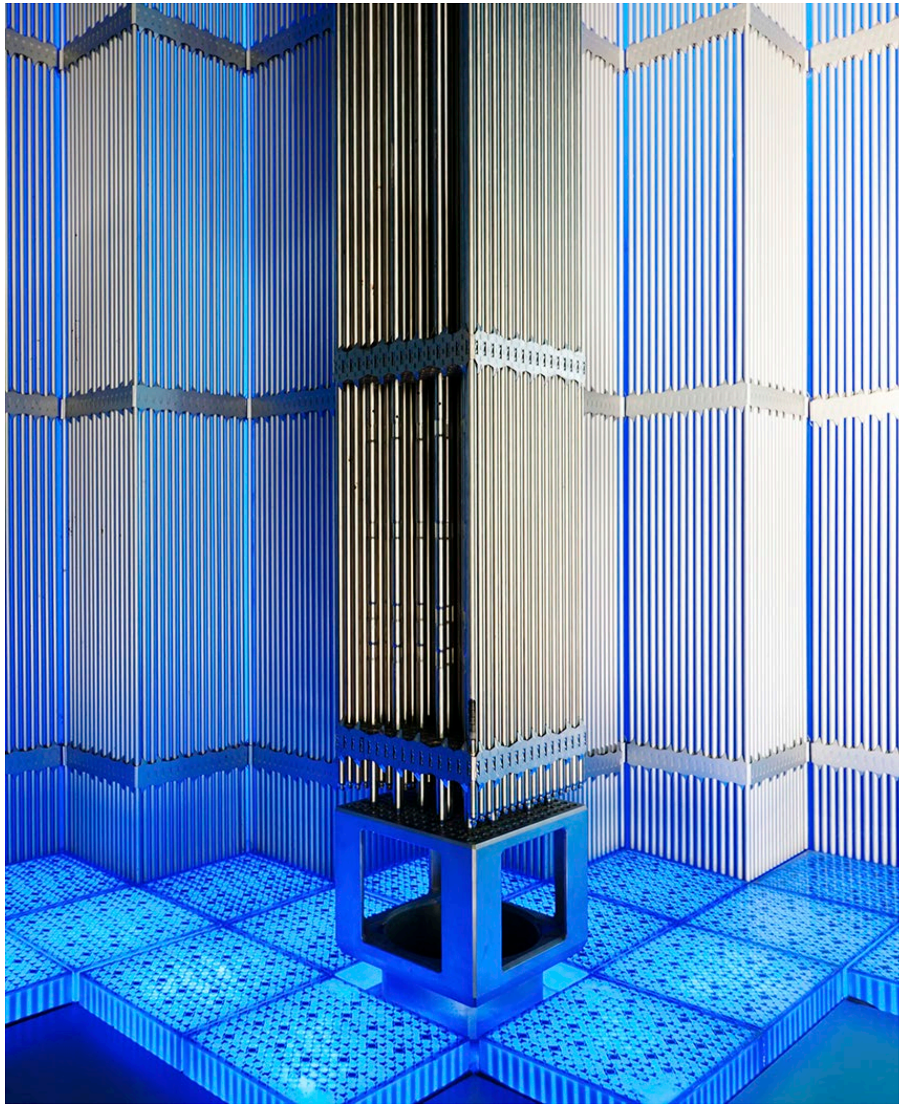
Craig Harrington
Technical Executive

Nate Glunt
Senior Technical Leader

NRC Public Meeting -EPRI Report on FFRD Licensing Strategy
June 2, 2021

# Introduction

- *"The approach would be supported by the application of the Extremely Low Probability of Rupture (xLPR) leak-before-break (LBB) analysis tool, developed jointly by EPRI and the NRC Office of Nuclear Regulatory Research for Large Break- (LB) LOCAs. This tool could be used within this generic methodology to inform the probability of LB-LOCAs and that LB-LOCAs may be detected in sufficient time to allow for reactor shutdown before a reactor coolant system (RCS) piping rupture occurs. This approach facilitates the demonstration of no fuel rod burst (that is, no FFRD) and estimates the changes in CDF."*
  - From: *Alternative Licensing Approaches for Higher Burnup Fuel: A Scoping Study on Deterministic and Risk- Informed Alternatives Supporting Fuel Discharge Burnup Extension.* EPRI, Palo Alto, CA: 2020. 3002018457.



# xLPR Work Scope

- **Objective:** Perform Probabilistic Fracture Mechanics (PFM) evaluation using xLPR to calculate the probabilities of Loss-of-Coolant-Accidents (LOCAs) as a function of line size
  - Use xLPR to benchmark NUREG-1829, Vol. 1, *“Estimating Loss-of-Coolant Accident (LOCA) Frequencies Through the Elicitation Process”*
    - Validate (or replace) NUREG-1829 LOCA frequency estimates for use in high burnup fuel licensing
  - Evaluate the time between detectable leakage and rupture to further inform the fuels licensing effort
- **Approach:** Project to be performed in phases
  - Phase 1 consists of a PFM evaluation of two line sizes as a proof-of-concept and to develop methodology for possible expansion to other line sizes
  - Phase 2 will expand the study to a variety of line sizes

# Phase 1 Proof-of-Concept Study

- Focus on the following:
  1. Methodology for using xLPR to evaluate the probability of LOCAs as a function of line size
  2. Estimation of the frequency of LOCA events
  3. Statistics on time between detectable leakage and unstable pipe rupture
- Two lines for initial evaluations were selected considering:
  - xLPR computational abilities
  - NUREG-1829 LOCA frequency insights *(smaller lines have higher frequency of rupture)*
  - Line size *(mid-range of greatest interest)*
  - Input availability
  - Degradation mechanisms *(i.e., fatigue and primary water stress corrosion cracking (PWSCC))*
- Scope is limited to Pressurized Water Reactors (PWRs)

# Lines Selected for Evaluation

- Emphasis was placed on lines in the 6-10 in. (DN 150-250) range, as this range is of particular interest for FFRD
- Available input sources reviewed to identify lines for which xLPR inputs were readily available
  - Licensee submittals in NRC ADAMS
  - EPRI reports
  - xLPR documentation
- It was determined that of the two lines evaluated, one should be susceptible to PWSCC and the other only susceptible to fatigue since the population of dissimilar-metal welds is small

## Stainless Steel Weld

- NPS 6 (DN 150)
- NUREG-1829 category:
  - Direct Volume Injection
- Represented by Westinghouse Safety Injection
- Population includes both hot leg and cold leg temperature locations

## Alloy 82/182 Weld

- NPS 12 (DN 300) SCH 140 or 160, resulting in ~10 in. (250 mm) ID
- NUREG-1829 Category:
  - High Pressure Safety Injection
- Represented by CE Safety Injection/Accumulator
- Cold leg temperature
  - Unmitigated at most plants

# Summary of Cases Evaluated

- Base cases for each line include
  - Initial postulated flaws
  - Fatigue and PWSCC crack growth (where applicable)
  - Seismic occurrences
  - 80-years of service life
  - Inservice inspection and leak rate detection not initially credited, but included in base case inputs

- Sensitivity cases were defined considering both inputs known to have influence on xLPR results and assumptions made during input development
  - Geometry
  - Increased loading
  - Increased earthquake probability
  - Crack initiation
  - Alternate WRS Profile
  - Multiple initial flaws
  - Mitigation

# Initial Results

- Runs are nearing completion for the two lines selected for Phase 1
- Loading and WRS sensitivity cases have shown the highest importance
- As expected, LOCA frequencies are higher for lines susceptible to PWSCC
  - When fatigue is the only active degradation mechanism the frequency of occurrence of leakage/rupture is extremely low
- Results show rupture frequencies on similar order of magnitude or lower than NUREG-1829 LOCA frequencies
  - Results are conservative as inservice inspection and leak rate detection were not credited
- Time between detectable leakage and rupture data also show notable margin (>1 year) between leak rates of 1 and 10 gpm and rupture

# Summary

- xLPR is being used to estimate probabilities of rupture, for comparison with LOCA frequency estimates presented in NUREG-1829
  - Initial analysis cases
    - Stainless Steel Weld – NPS 6 (DN 150)
    - Alloy 82/182 Weld – NPS 12 (DN 300) *w/ ID of ~10 in. (250 mm)*
- Results suggest the NUREG-1829 LOCA frequencies are conservative
  - It is noted that NUREG-1829 expert elicitation considered degradation mechanisms in addition to those modeled in these xLPR analyses
- A methodology has been established that is able *(with some refinements)* to evaluate LOCA probabilities and time between leakage and rupture for other PWR lines

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# Risk-Informed Analysis of LOCA-Induced Fuel Fragmentation, Relocation and Dispersal

## Risk Assessment for High Burnup Fuel

Storm Kauffman
MPR Associates, Inc.

NRC Pre-Application Meeting
June 2, 2021

# Outline

- Objective
- Topical Report
- Risk-Informed LOCA-Induced FFRD Methodology
- Technical Basis for Methodology
- Human Reliability Analysis
- Defense in Depth and Safety Margins
- Conclusion – Key Takeaways

# Objective for Industry Initiative

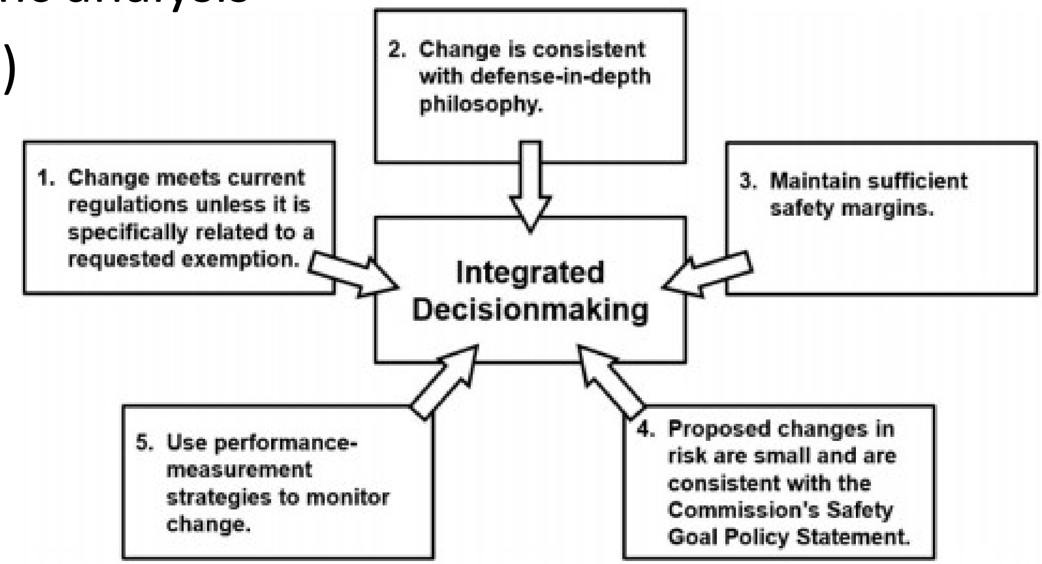
**Demonstrate that fuel fragmentation, relocation, and dispersal of fuel with peak rod average burnups in the range 62 to 75 GWd/MTU caused by LOCA events is of sufficiently low risk that it does not need to be included in the design-basis analyses of LOCA consequences, as currently performed to satisfy 10 CFR 50.46**

Not intended to justify:

- Changes to safety-related Systems, Structures and Components requirements
- Relaxation of conditions for operation

# Topical Report

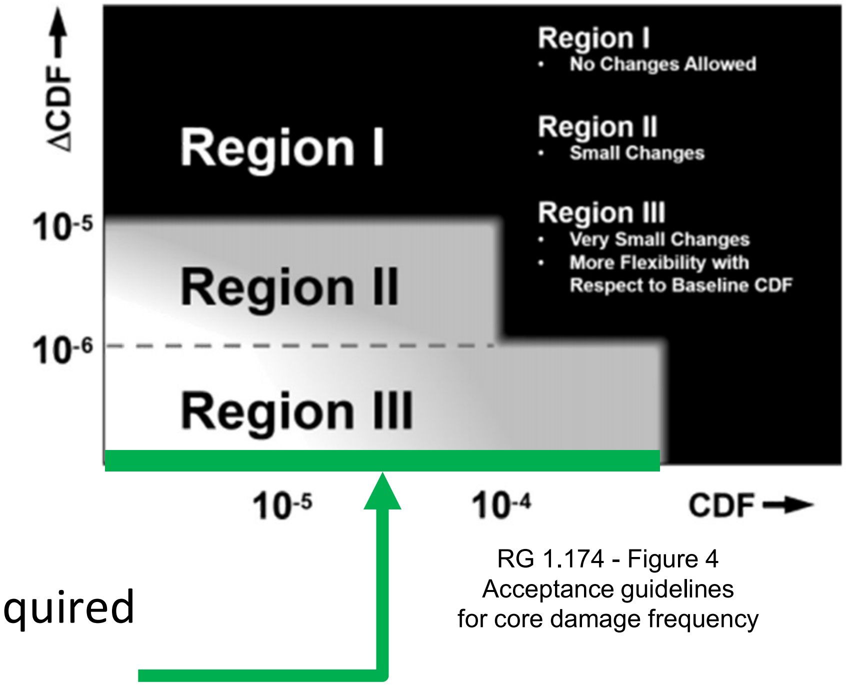
- Topical Report to be submitted to NRC
  - Assess justification for burnup limit extensions for PWRs
  - Minimize need for licensee-specific analysis
  - ΔCDF estimates (ΔLERF if needed)
  - Uncertainties
  - Defense-in-depth
  - Safety margins




RG 1.174 - Figure 2.
Principles of risk-informed integrated decision making

# Risk-Informed LOCA-Induced FFRD Methodology

- RG 1.174 approach; address RG 1.200
- Supporting analyses
  - LOCA analyses to determine break size threshold for rod burst
  - xLPR to assess:
    - Initiating event frequency
    - Time for operator response
- Probabilistic Risk Assessment (PRA) goal
  - Determine Δ CDF for LOCAs with potential to induce FFRD
  - If ΔCDF < $10^{-7}$/ry, no calculation of total CDF is required
    - Individual plant CDF not a constraint
    - Determination of ΔLERF and containment failure probability analysis may not be required if ΔCDF is below RG 1.174 criteria




RG 1.174 - Figure 4
Acceptance guidelines
for core damage frequency



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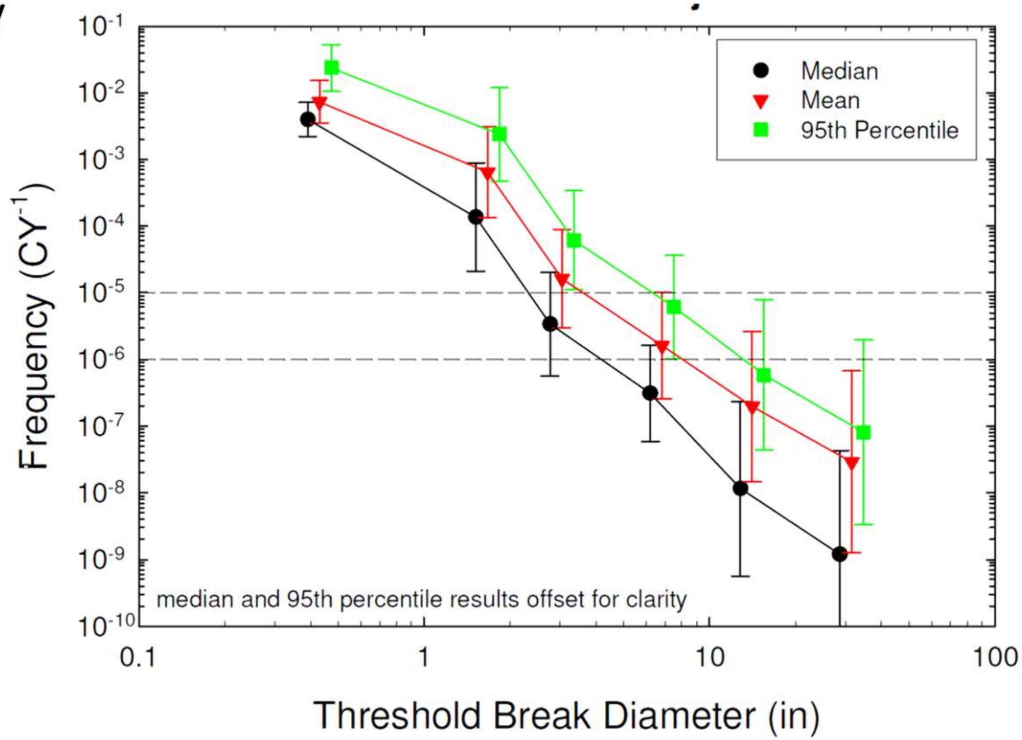
# Technical Basis for Methodology

- Larger breaks are very low frequency
  - xLPR predicts large breaks presaged by detectable leakage
  - Use xLPR to predict:
    - Frequency
    - Time from detectable rate before rupture occurs

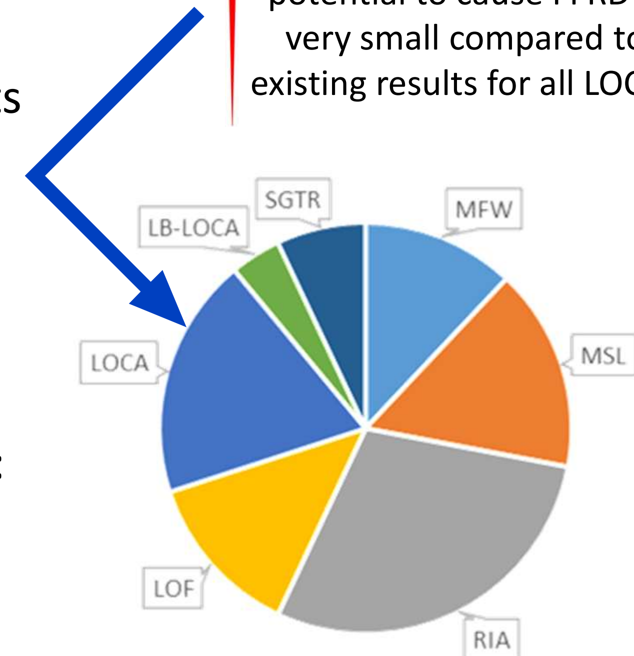



NUREG-1829, Vol 2, PWR part of Figure 1

# Technical Basis for Methodology

- LOCA-induced FFRD
  - Does not affect LOCA PRA of record for individual plants
  - LOCAs already included in individual plant PRA
    - A portion of these LOCAs is assessed for FFRD risk
  - ΔCDF for LOCAs is in addition to existing plant CDF:
    - Cannot reduce CDF
  - Details of PRA may differ from that of individual plants:
    - Event trees: simplified and different top events
    - Initiating event frequency (IEF) based on xLPR and NUREG-1829
    - Assess operator response by Human Reliability Analysis (HRA)

CDF from LOCAs with potential to cause FFRD is very small compared to existing results for all LOCAs




**LOCA risk contribution already in existing plant CDF**

# Human Reliability Analysis

- HRA methodology considers human error probability, dependency, time available for action, training, procedures, etc.
- Consistent with industry practice
  - Slow flaw progression allows time for operator recognition and response
  - Considerable time available for operator detection of leak
  - RG 1.45 criteria – multiple means to detect 1 gpm within one hour
  - Technical Specifications Limiting Condition for Operation for unidentified leakage
  - Plant procedures for troubleshooting/responding to increased unidentified leakage
  - Response to alarm indications of unidentified leakage

# Defense in Depth and Safety Margins

## Defense in Depth

- Maintain existing layers of defense
- Design features unaffected
- Preserve system redundancy, independence and diversity
- Assess defense against potential common cause failures
- Evaluate impact on effectiveness of the multiple fission product barriers
- Assess defense against human errors
- Retain existing plant's design criteria

## Safety Margins

- Maintain sufficient safety margin
- No reduction in required safety system performance specifications

**Address criteria of RG 1.174**

# Conclusion – Key Takeaways

- Proposed licensing basis change:

  *"Fuel fragmentation, relocation, and dispersal of fuel with peak rod average burnups in the range 62 to 75 GWd/MTU caused by LOCA events is of sufficiently low risk that it does not need to be included in the design-basis analyses of LOCA consequences, as currently performed to satisfy 10 CFR 50.46."*

- Risk-informed application of RG 1.174 to LOCA-induced FFRD
  - Low probability event – NUREG-1829 / xLPR
  - xLPR – validates time for operator detection of leak and response
  - Defense in depth maintained – requirements for safety equipment not relaxed
  - Safety margins maintained – requirements for safety margins not relaxed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# Alternative Licensing Strategy

## Submittal Schedule

Fred Smith
EPRI – Technical Executive

NRC Pre-Application Meeting
June 2, 2021

## EPRI Docketed Topical Report

- Risk Informed LOCA Induced FFRD Evaluation
  - Evaluation of impact on CDF and LERF
    - Inputs
      - PWR Small /Intermediate Break LOCA /Cladding Rupture Results
      - Leak Before Break Large/Intermediate Break Results
        - Human Reliability Assessment of Operator Actions
        - Break Spectrum Failure Frequency Validation
      - Other Inputs – Internally Documented
        - Conditional Containment Failure Probability
        - ECCS degradation frequency
        - Fuel Relocation Frequency – FFR
        - FFRD Frequency (If necessary)
        - Fleet Capacity Factors
      - Uncertainty Evaluation
    - Analysis and Results
  - Design Margin Assessment
    - Inputs
      - Fuel Relocation Evaluation
      - FFRD Consequences (if necessary)
        - Eq Impact
        - Criticality Impact
    - Results
  - Defense-in-Depth
    - Inputs
      - FFRD Consequences (if necessary)
    - Results
  - Applicability Requirements

Site Specific Submittals

## Supporting Reports

Vendor Specific Small/Intermediate LOCA/Cladding Rupture Results

Vendor Specific Methodology Topical Updates

x-LPR Fracture Mechanics Analysis

Intermediate/Large Piping Ruptures

Vendor Specific Fuel Relocation Evaluation

If rupture not precluded: Dispersal Consequences Analysis

Dispersal Model

DBA Source Term

Criticality Analysis

Coolability

# Planned Submittal

- Schedule 4th quarter 2022
  - Risk Informed LOCA induced FFRD Evaluation
    - Vendor Specific LOCA Evaluations
    - xLPR Fracture Mechanics Analysis
    - Consequence Analysis  - If cladding rupture is NOT precluded
  - Vendor Specific Methodology Updates

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