Extremely Low Probability of Rupture (xLPR) Project

Pilot Study Summary

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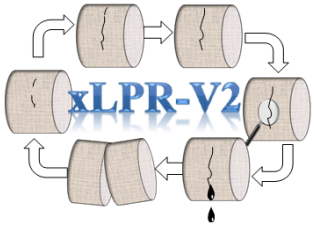
RES/DE/CIB

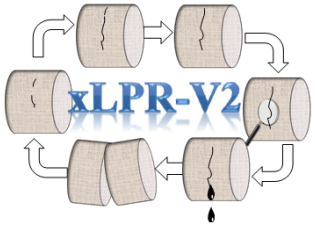
xLPR External Review Board Meeting
February 20, 2013

xLPR Pilot Study



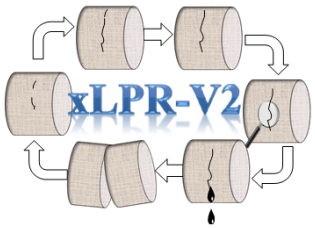
- **Objectives**
  - Develop and assess xLPR management structure
  - Determine the appropriate probabilistic framework
  - Assess the feasibility of developing a modular-based probabilistic fracture mechanics computer code
- **Focused on pressurizer surge nozzle DM weld with PWSCC**
- **Development of Version 1.0 code using comprehensive configuration management**
- **Developed detailed program plan (objective, schedule, deliverables, budget, communications) for Version 1.0 and Version 2.0 code**

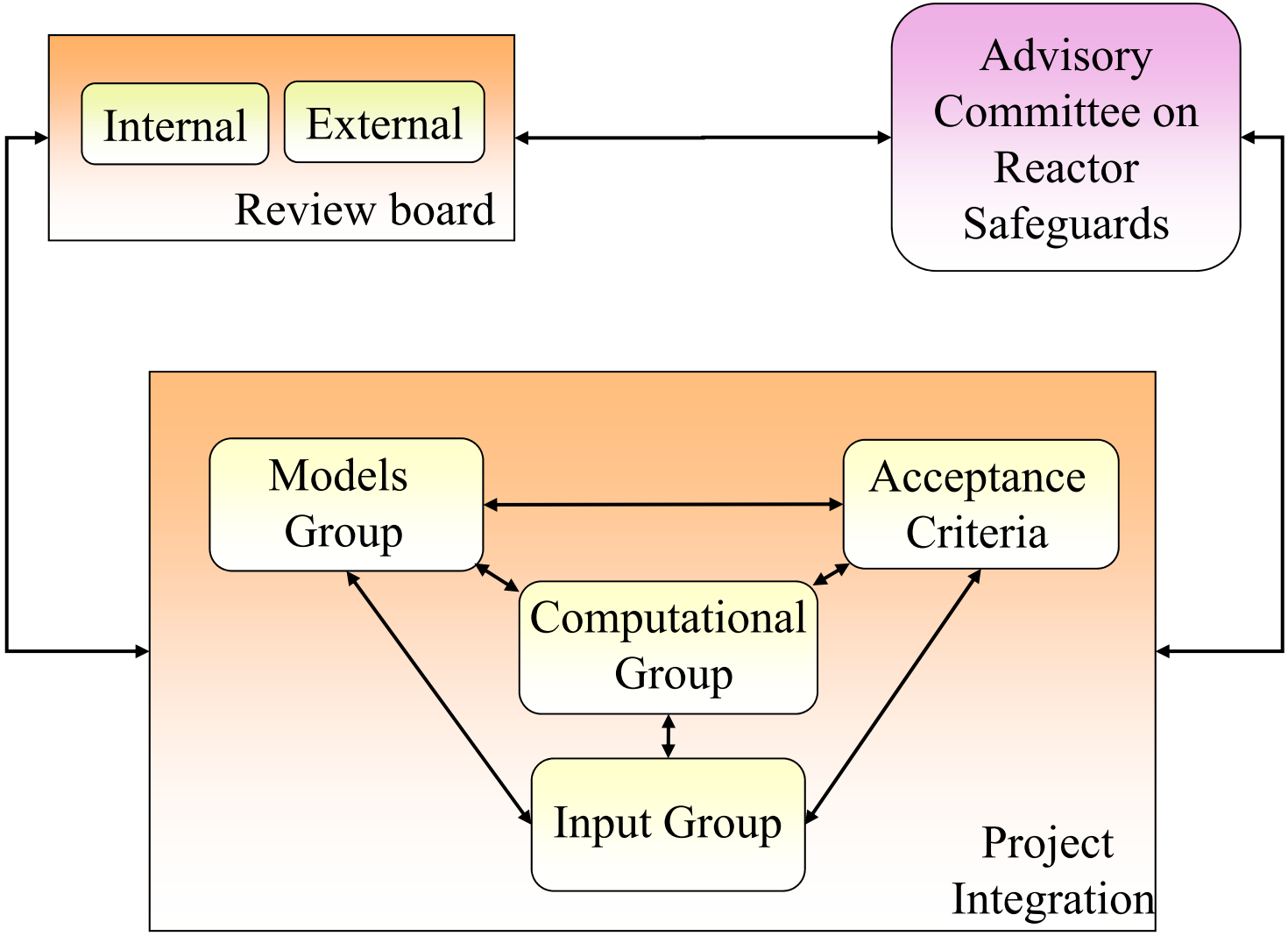
xLPR – Intended Use



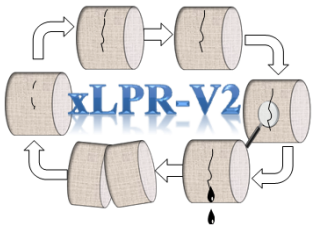
- **Version 1.0 – Pilot study – Surge nozzle DM weld**
  - To demonstrate feasibility
  - Determine appropriate probabilistic framework
  - Develop plan for future version
- **Version 2.0 – Primary piping**
  - Support LBB Regulation Guide development
  - Assess compliance with GDC-4
  - Prioritize future research efforts
- **Version 3.0 – Reactor coolant pressure boundary**
  - Combine piping with reactor vessel, steam generator, etc.
  - Analyze probability of failure for all coolant pressure boundary components

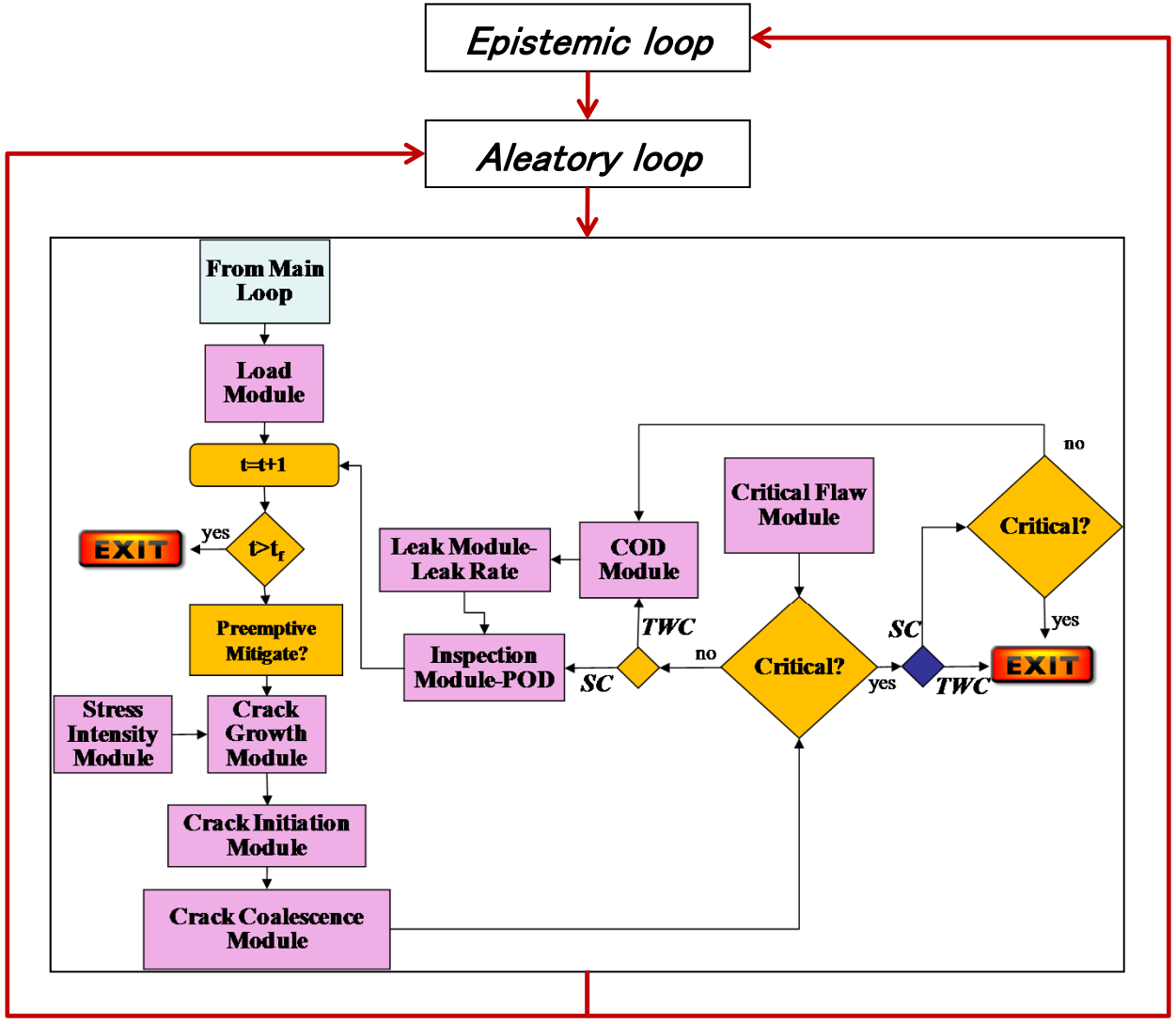
Pilot Study Code Group Structure





xLPR Pilot Study Process





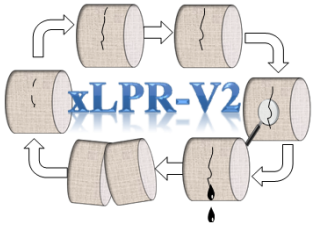
Purple boxes represent self-contained, independent modules

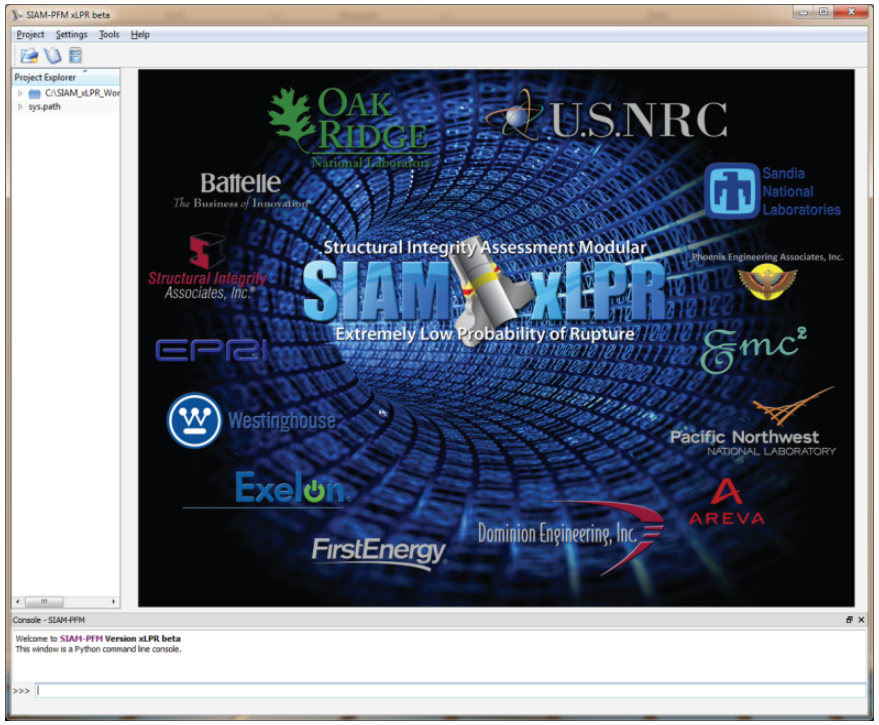
Epistemic – Lack of Knowledge uncertainty

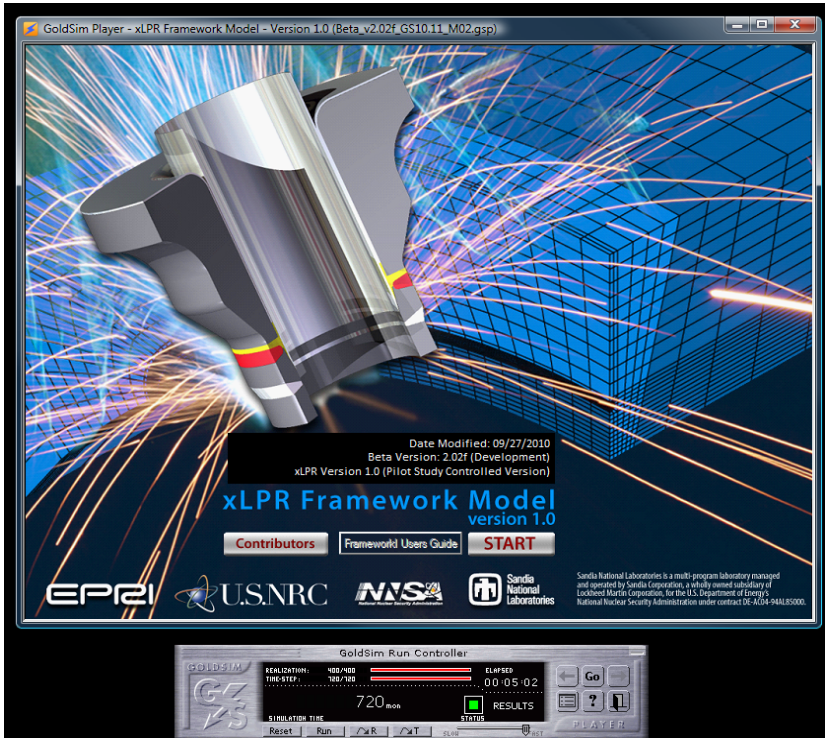
Aleatory – Irreducible uncertainty

Probability of leak/rupture

xLPR Version 1.0 Framework





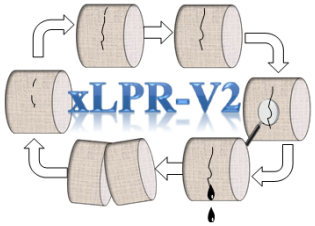


Fully Open Source

GoldSim Commercial Code

Two framework structures considered
Same calculation modules used
Both gave similar results

Pilot Study Uncertainty

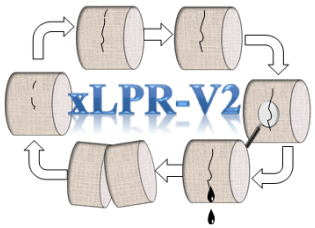


- **Uncertainties were classified by models/inputs group**
- **More discussion needed, but satisfactory for pilot study**

Epistemic (Lack of knowledge)	Aleatory (Irreducible)
• Loads • WRS • Crack growth (fweld) • Crack initiation parameters • POD parameters	• Crack size • POD detection • Material properties • Crack growth parameters (Q/R,c,P)

- **Currently uses LHS (epistemic) and MC (aleatory)**
- **Discrete probability distributions also available.**
- **Importance sampling was demonstrated**

Pilot Study Problems



Analysis	Description
Probabilistic Base Case ★	Probabilistic base case analysis using Monte Carlo sampling.
Sensitivity Study	
Stress Mitigation	Analyses evaluate different mitigation times, for the same stress-based mitigation.
Chemical Mitigation	Chemical effects of increasing the hydrogen concentration in the water on the crack growth module. Three hydrogen concentrations were evaluated.
Crack Initiation	Considers the crack initiation model uncertainty.
Safe End Evaluation ★	Considers stainless steel safe end weld, which causes a through-thickness bending stress that can reduce the tensile inner-diameter stress.

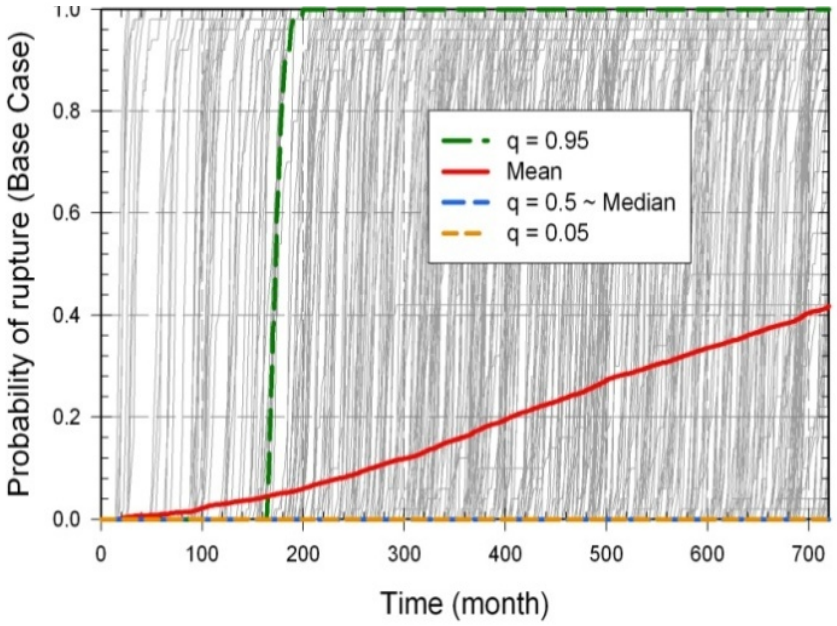
★ – with and without inspection and leak detection

★ – with and without mitigation, inspection and leak detection

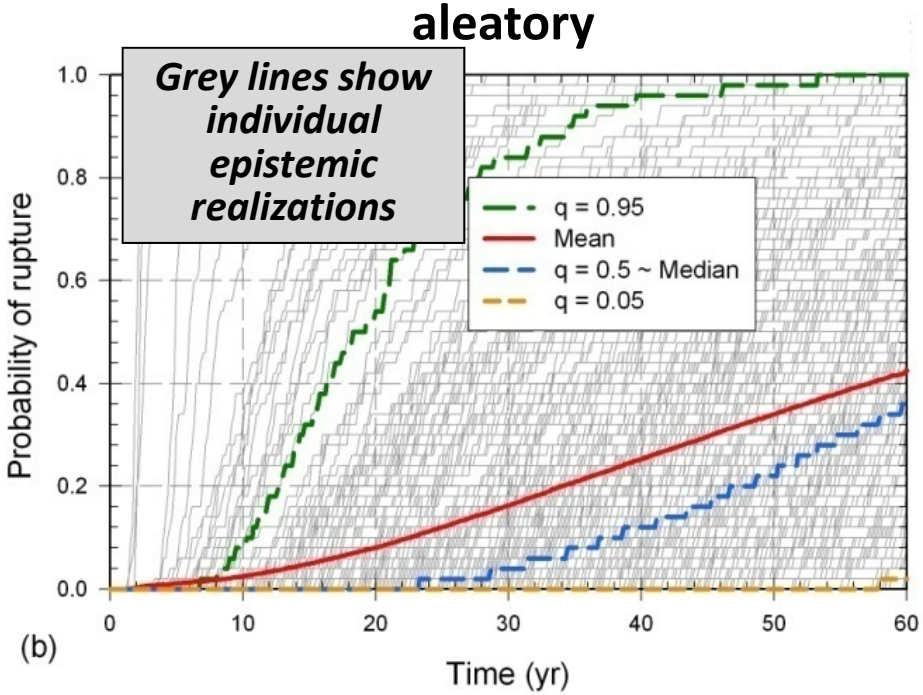
Base Case Results

No leak detection, no inspection, high WRS

Crack Initiation categorized as epistemic



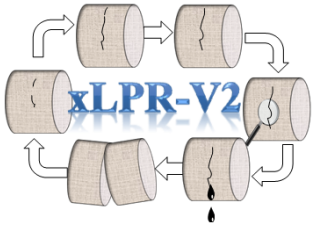
Crack Initiation categorized as aleatory

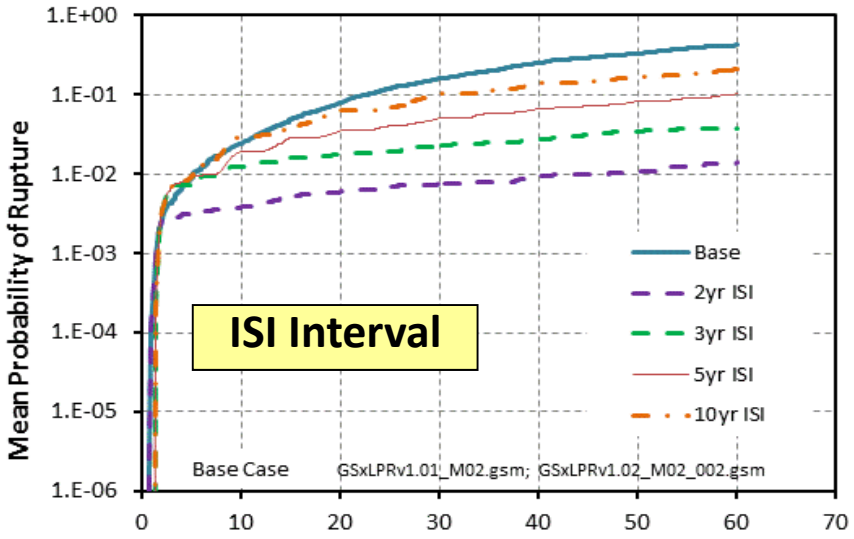


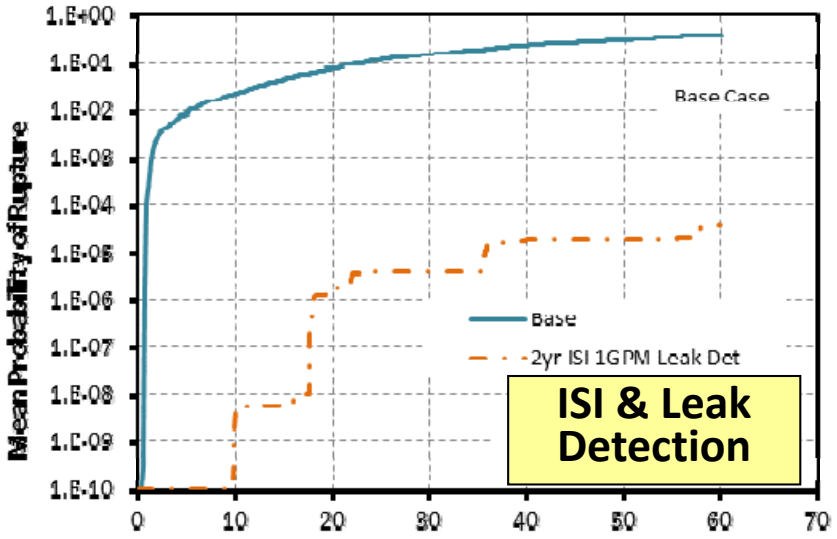
KEY POINTS

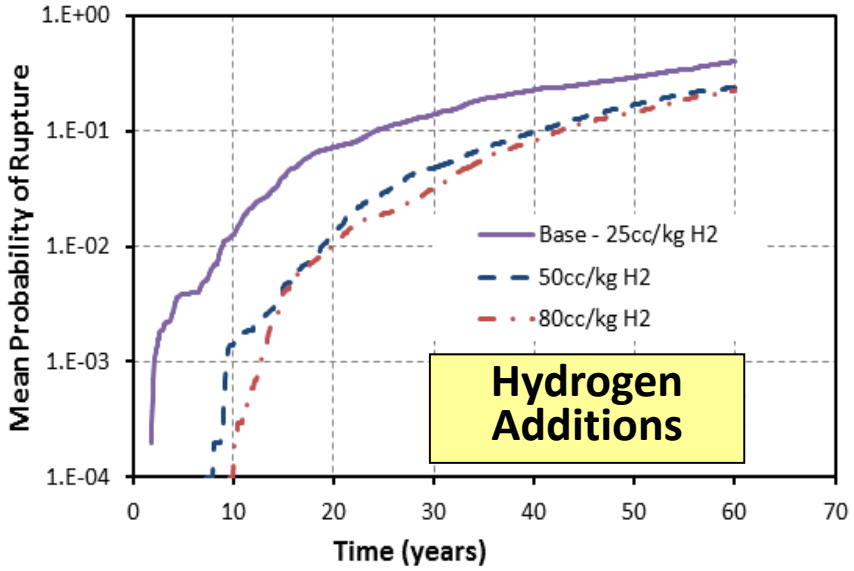
- **Classification of uncertainty affects bounds, does not affect mean value**
- **Classification of uncertainty is of primary importance with respect to crack initiation characterization**

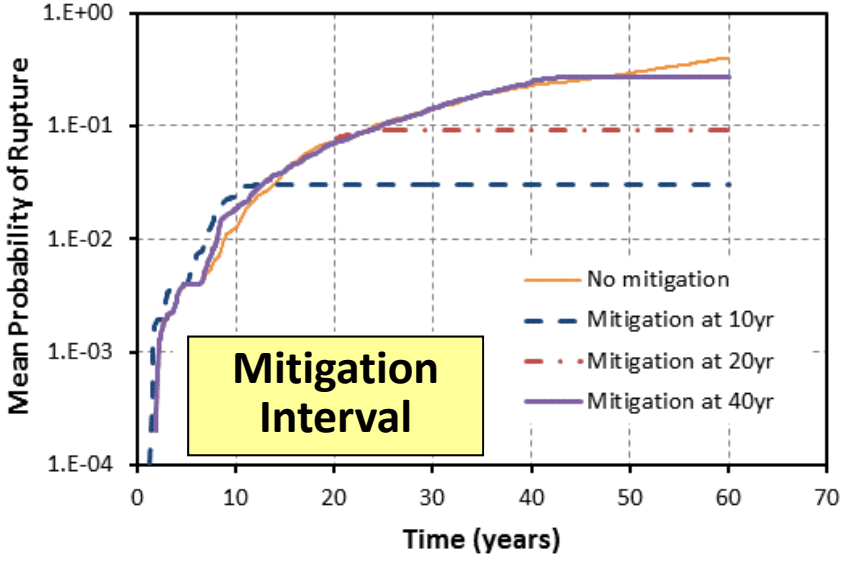
xLPR Pilot Study Results Illustrate Positive Effect of Mitigations



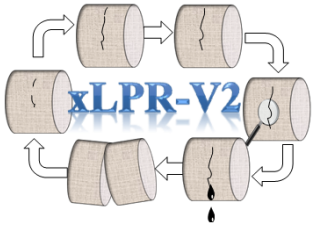








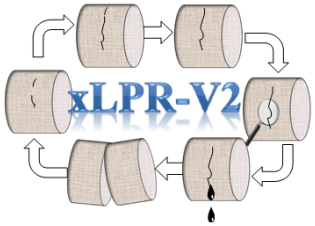
Pilot Study Results



- The project team demonstrated that it is feasible to develop a modular-based probabilistic fracture mechanics code within a cooperative agreement while properly accounting for the problem uncertainties
- V&V conducted successfully
- Identified potential efficiency gains in the program management structure
- Selected commercial software as the computational framework
  - Based on the framework code comparison, a cost analysis, and long term prospects

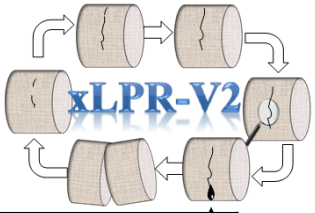
Lessons Learned & Key Gaps

Pilot Study Outcomes



- Organizational Issues – *PIB membership too large, no clear leader*
- Communication Issues – *Intergroup communication difficulty*
- Framework Issues – *GoldSim selected*
  - Inputs and Outputs – *Not user friendly and time consuming*
  - Uncertainty Classification and Analysis – *Large impact, need to consider carefully*
  - Improved Sampling Techniques – *Defining variables to importance sample is difficult*
  - Data Storage and Handling – *Time consuming and cumbersome*
  - Post Processing - *Not user friendly*
- Models Issues
  - Expertise – *Need correct experts*
  - Modeling Scope – *Needs to be expanded for LBB systems*
- Software QA & CM – *Needs to be expanded for future versions*

Available Pilot Study Reports



Report Title	Developer	Identifier
xLPR Pilot Study Final Report	NRC & EPRI	NUREG-2110 EPRI PID 1022860
GSxLPR and SIAMxLPR Comparison Report	CNWRA (Southwest Research Institute)	ML111510924
xLPR Version 1.0 Report, Technical Basis and Pilot Study Problem Results	xLPR Computational Group	ML110660292
xLPR Framework (GoldSim) Model User's Guide	Sandia National Laboratory	ML110700017
Structural Integrity Assessments Modular—Probabilistic Fracture Mechanics (SIAM-PFM): User's Guide for xLPR	Oak Ridge National Laboratory	ML110700023
Development, Analysis, and Evaluation of a Commercial Software Framework for the Study of Extremely Low Probability of Rupture (xLPR) Events at Nuclear Power Plants	Sandia National Laboratory	ML110700019
SIAM-xLPR Version 1.0 Framework Report	Oak Ridge National Laboratory	ML110700026
Models and Inputs Selected for Use in the xLPR Pilot Study	xLPR Models/Input Groups	EPRI PID 1022528