



Extremely Low Probability of Rupture Code: 2026 Update

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Agenda



- Background
- xLPR Version 3.0
 - What is the xLPR Framework?
 - Why are we replacing the Framework?
- Project Objectives
- Project Timeline
 - Current Status
- Future Plans

Extremely Low Probability of Rupture (xLPR) Code Overview

Probabilistic fracture mechanics (PFM) software tool for nuclear power plant piping integrity risk analysis

- > **Joint effort** by the NRC's Office of Nuclear Regulatory Research and the Electric Power Research Institute (EPRI), now in second major version (2.4) with a third major version being developed (v3.0)
- > Capable of **modeling** the effects of stress-corrosion **cracking** (SCC) and thermal fatigue
- > Used by NRC and EPRI staff and contractors to **risk-inform** industrywide emerging **piping integrity** issues via probabilistic approaches



Global Settings Dashboard

Version 2.2

Sampling Approach

Epistemic (Outer Loop)		Aleatory (Inner Loop)	
Set up epistemic sample size and random seed		Set up aleatory random seed <small>Click on 'Monte Carlo' tab when window opens</small>	
Sample Size (Display only)	<input type="text" value="40"/>	Sample Size (Display only)	<input type="text" value="2"/>
Related Epistemic Sampling Inputs (Display Only)		Related Aleatory Sampling Inputs (Display Only)	
Importance Sampling	<input type="text" value="Internal"/>	Importance Sampling	<input type="text" value="None"/>
Adaptive Sampling	<input type="text" value="No"/>	Adaptive Sampling	<input type="text" value="No"/>
Discretization	<input type="text" value="No"/>	Discretization	<input type="text" value="No"/>
Number of Strata*	<input type="text" value="1"/>	Number of Strata*	<input type="text" value="10"/>
<small>*Number of strata must be an integer greater than 1 and less than the epistemic sample size</small>		<small>*Number of strata must be an integer greater than 1 and less than the aleatory sample size</small>	
<input type="button" value="Refresh All Inputs"/>		<input type="button" value="Run xLPR Model"/>	

External Navigation

Inputs

Opens the Microsoft Excel workbook, "xLPR-2.2 Input Set.xlsx". This workbook is the primary interface for entering the inputs for a simulation. If changes are made, the workbook must be saved in the same directory as this GoldSim file and with the same file name. For more detailed descriptions of the inputs, the user should consult Appendix B of the User Manual.

Preprocessor

Runs the "xLPR-2.2 Preprocessor.exe". This action retrieves the applicable LEAPOR and TIFFANY color-coded inputs from the "xLPR-2.2 Input Set.xlsx" workbook and displays them to the user in a new window. From that window, the user can then execute the LEAPOR and TIFFANY modules to generate the required look-up tables for the simulation. If the applicable LEAPOR and TIFFANY inputs are changed, the user should save the workbook and retrieve the data using the Reload Excel Data button in the Preprocessor before generating the look-up tables. For a detailed description of the Preprocessor operations, the user should consult Appendix D of the User Manual.

Look-up tables must be generated using the Preprocessor prior to running the simulation in GoldSim.

Results Options

<input type="button" value="Go to Results - Axial Cracks"/>	<input type="button" value="Go to Error Dashboard - Axial Cracks"/>
<input type="button" value="Go to Results - Circ. Cracks"/>	<input type="button" value="Go to Error Dashboard - Circ. Cracks"/>



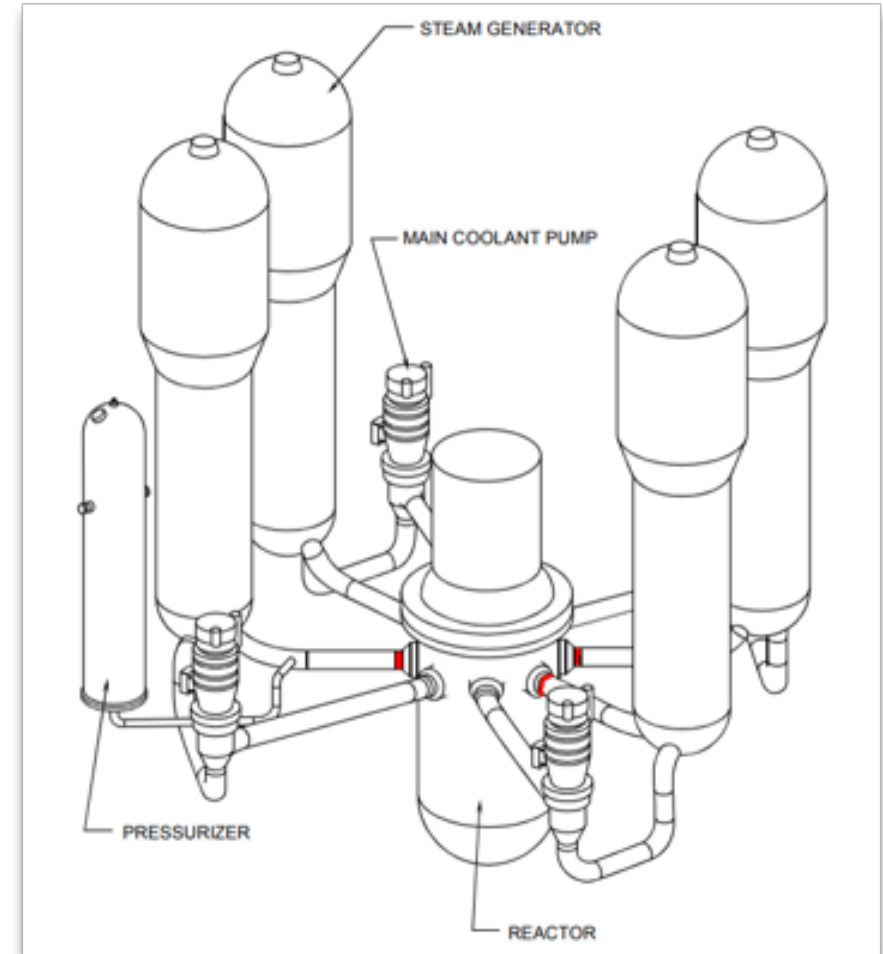
xLPR Use Cases

Latest NRC Use Cases

xLPR is used in support of NRR's LIC-504 analysis of the risk of the emergent French Stress Corrosion Cracking OE to the US PWR fleet (ML24162A131)

xLPR used to perform analyses in NRR review of Leak-before-Break (LBB) regulatory approach (ML21217A088 and ML22088A006)

xLPR used to reassess LOCA frequencies initially calculated in NUREG-1829 (ML24193A122)



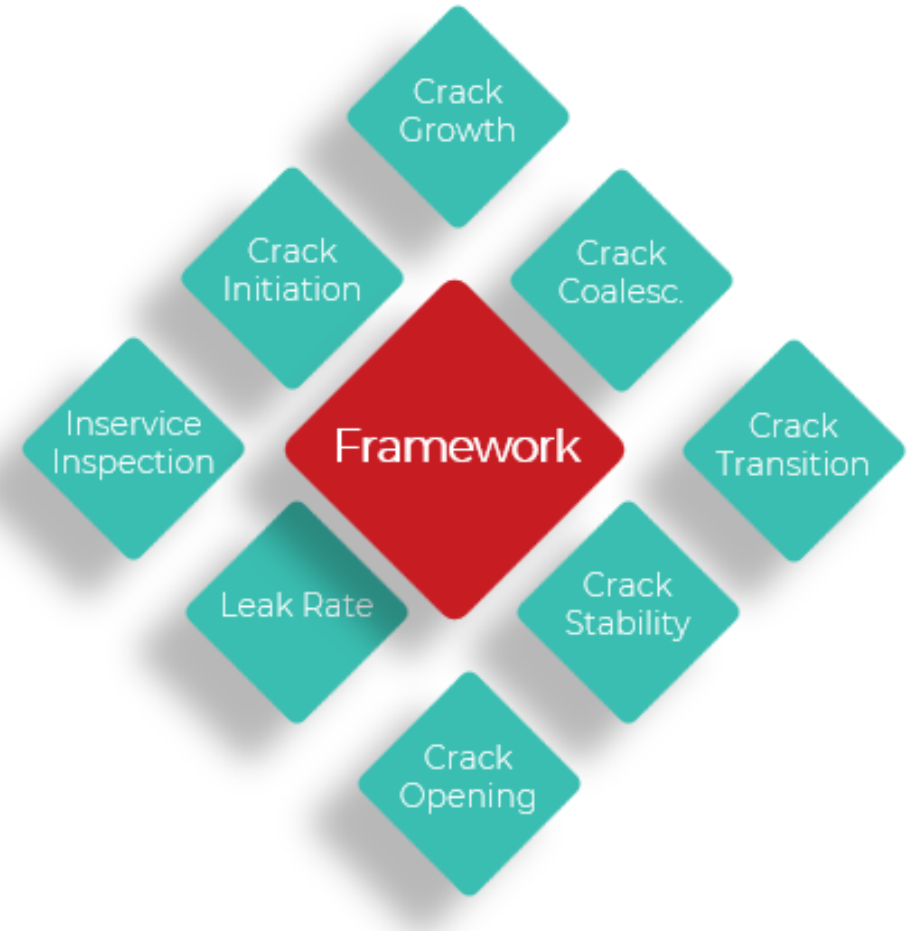
xLPR Modular Design

Framework

- Reads input parameters
- Performs sampling on probabilistic parameters
- Interfaces with FORTRAN modules containing physical models
- Collects module outputs

Modular Design

- Each FORTRAN module contains the physical models behind xLPR
 - Crack Initiation, Crack Growth, Inservice Inspection, etc
- Each module developed by technical experts
- Allows flexibility of future development



Known Framework Needs

Adaptability

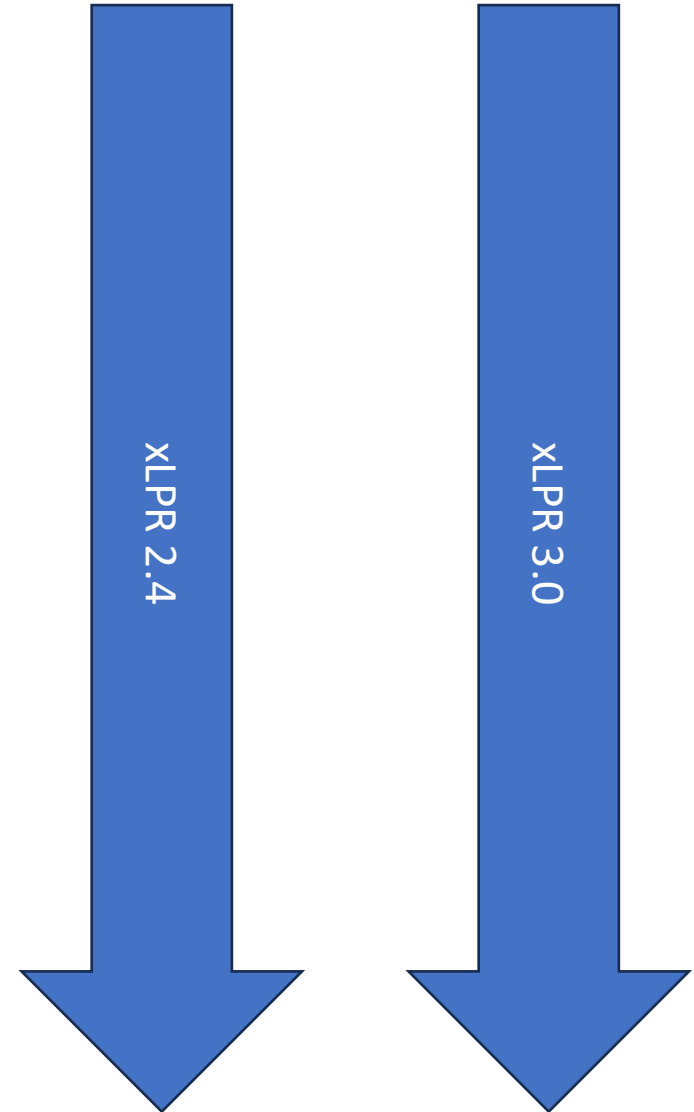
- Move away from requiring access to Commercial Off-the-Shelf (COTS) software
- Reduce the learning curve to making modifications
- Replace certain features that are proprietary and locked from users

Performance

- Currently there is limited parallelization capacity
 - 4 cores for free GoldSim version
 - 10 cores for subscription GoldSim
- Memory issues with large sample sizes
- 32-bit COTS application limits improvements to performance

xLPR 3.0 Project Timeline

- Framework replacement project started August 2024
 - Contracted with Information Systems Laboratory
- Concurrent with development of xLPR V2.4
- Framework replacement used xLPR 2.3 as a baseline for conversion



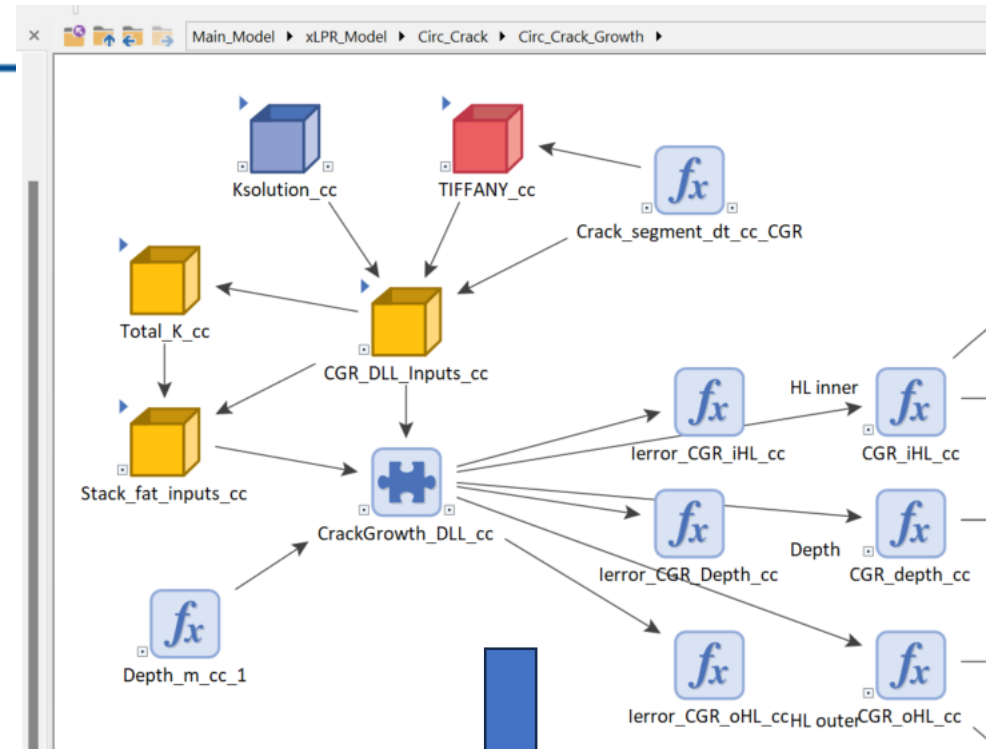
Language Selection

- Go has a syntax similar to C++ and Java and is simpler to learn
- Go eliminates aspects of C++ that are problematic and emphasizes features that improve maintainability
- The Go language is designed to limit dependencies that make code hard to modify
- Go was designed to simplify parallel computing and make threads more efficient
- Go compiles to an executable that incorporates Fortran routines and simplifies distribution



Framework Conversion

- 4000+ unique elements in the GoldSim framework need to be converted into Go code
- Create new interfaces between the Go Framework and the compiled FORTRAN DLLs
- Confirming consistency of outputs from DLLs compared to xLPR 2.3

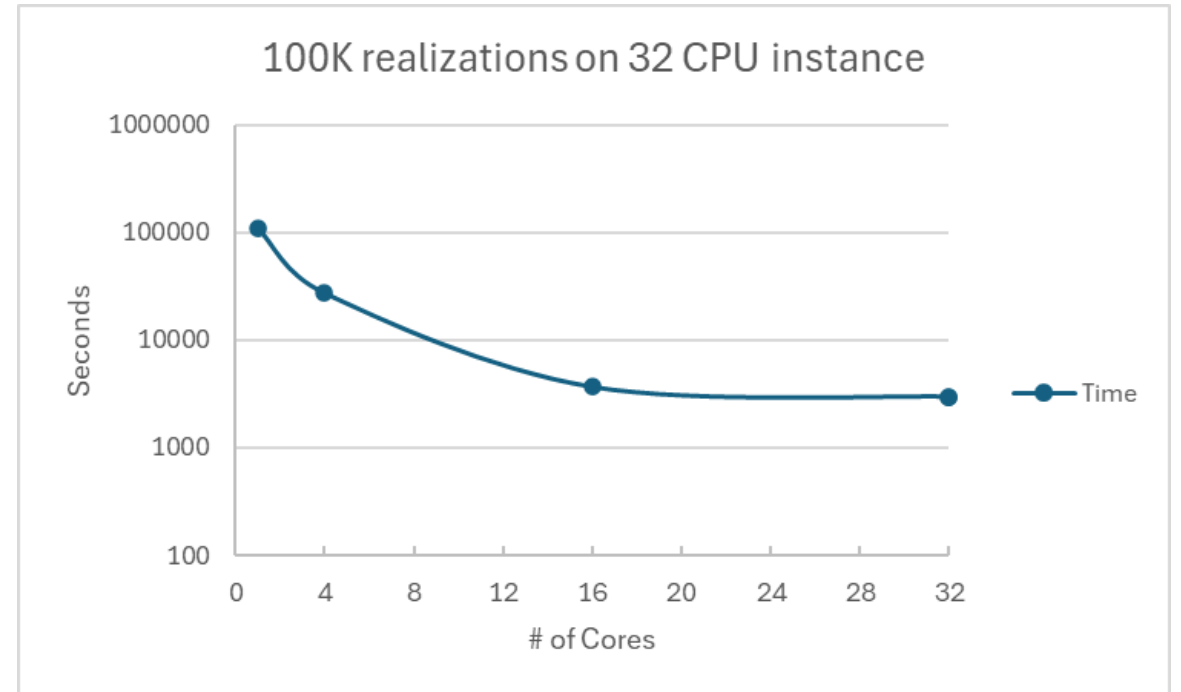


```
13 // GOLDSIM: CrackGrowth_DLL_cc; Pos 1309
14 //
15 // A [fc.FortranFnWrapper] that computes the crack growth of all initiated cracks.
16 type CrackGrowthCCcalc struct {
17     name          string
18     calculationType fc.FortranFnType
19 }
20
21 func (c CrackGrowthCCcalc) Name() string {
22     return c.name
23 }
24
25 // Returns the [fc.FortranFnType] of this [fc.FortranFnWrapper]
26 func (c CrackGrowthCCcalc) FortranFnType() fc.FortranFnType {
27     return c.calculationType
28 }
29
30 // Runs the growth subroutine from the CGR Fortran90 file.
31 func (c CrackGrowthCCcalc) DoStep(currentParams pc.ParamCollector) {
32     status := C.int(0)
33     outputs := make([]C.double, 211)
34     inputArray := c.getInputs(currentParams)
35     C.growth(&status, &inputArray[0], &outputs[0])
36     c.storeOutputs(outputs, currentParams)
37 }
```



Computational Performance

- xLPR 3.0 on single processor is ~2-3x faster than xLPR 2.3
- Parallelization does substantially reduce the time to completion.



Memory Usage Overview

- Took example simulation from prior NRC work on SCC in US PWR fleet
- xLPR v2.3: 100K realization simulation with initial flaw crack
- Memory issues required:
 - Reducing savepoints to only 4 20-year timepoints
 - Broken into ten 10K realization simulations
 - 8 hours each when utilizing GoldSim DPS



Technical Letter Report
TLR-RES/DE/REB-2024-08

Probabilistic Fracture Mechanics Analysis of French Stress Corrosion Cracking Operating Experience Applied to the US Fleet using the Extremely Low Probability of Rupture Code

Date:

June 04, 2024

Prepared in response to Task 6 in User Need Request NRR-2021-008, by:

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Washington, DC 20555-0001



Memory Usage Overview

- Completed in <8 hours in xLPR 3.0 with 16 threads
- Full linear time histories of important outputs
- 13 GB of output data in xLPR 3.0
 - ~20GB of output data from GoldSim 2.3



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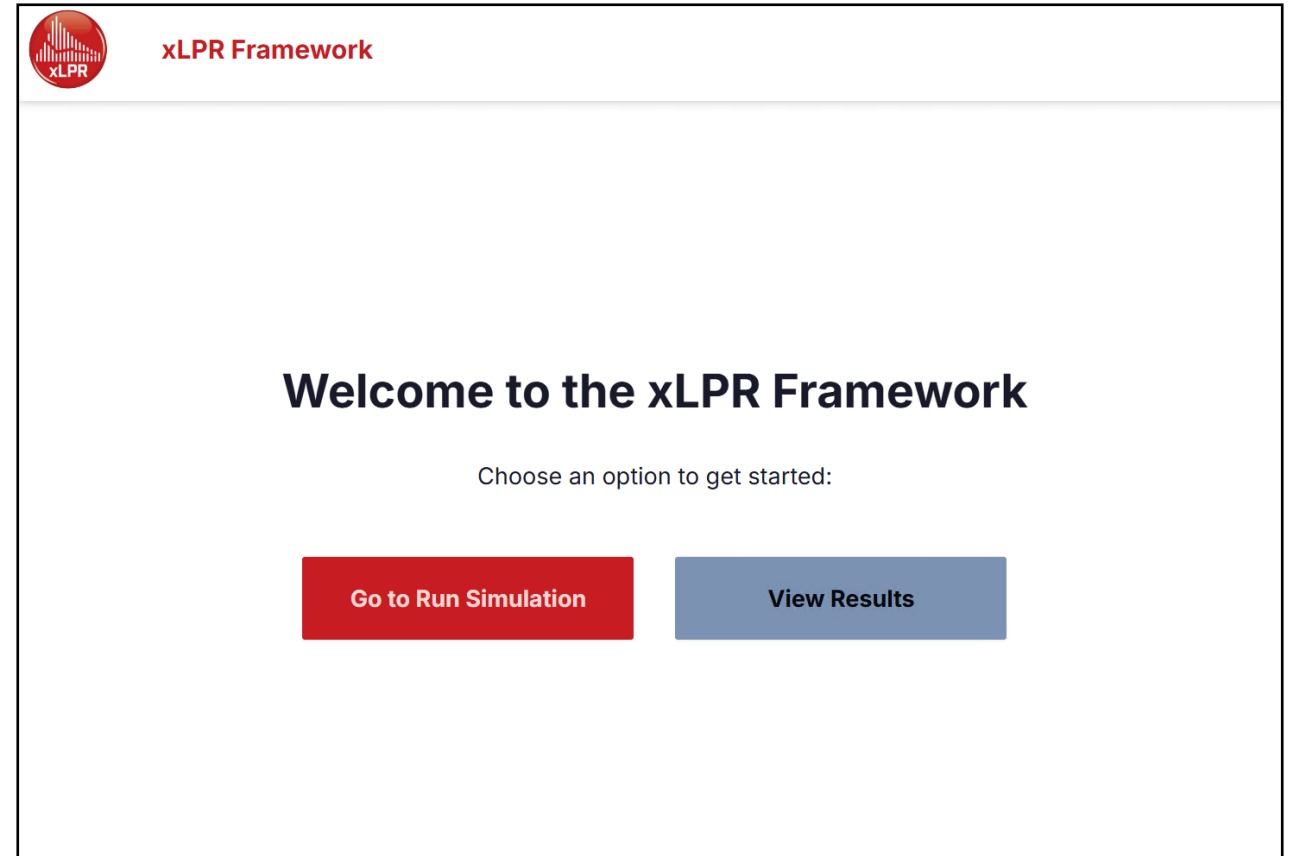
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v3.0 vs v2.0 Capabilities

- Faster operation in serial
- Much easier parallelization
 - More cores available
- Ability to collect sampled values from realizations with ruptures
- Ability to run a specific realization
- Improved memory performance
- In-progress results dashboard




Summary

xLPR 3.0 anticipated for release
in early Fall 2026

xlpr@nrc.gov or xlpr@epri.com
for further information



Demonstration



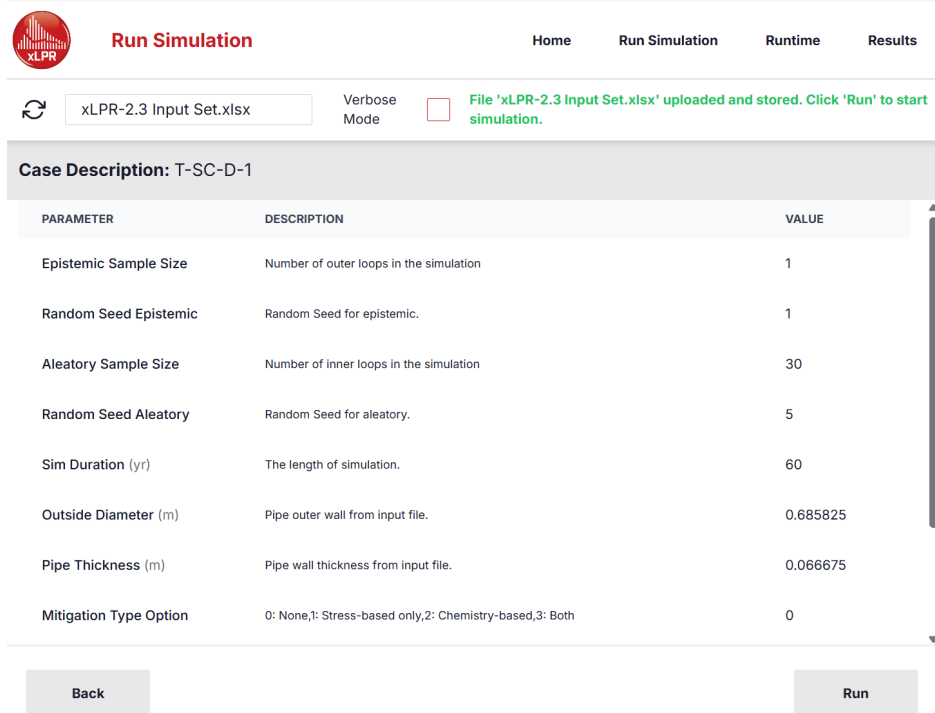
xLPR Framework

Welcome to the xLPR Framework

Choose an option to get started:

[Go to Run Simulation](#) [View Results](#)

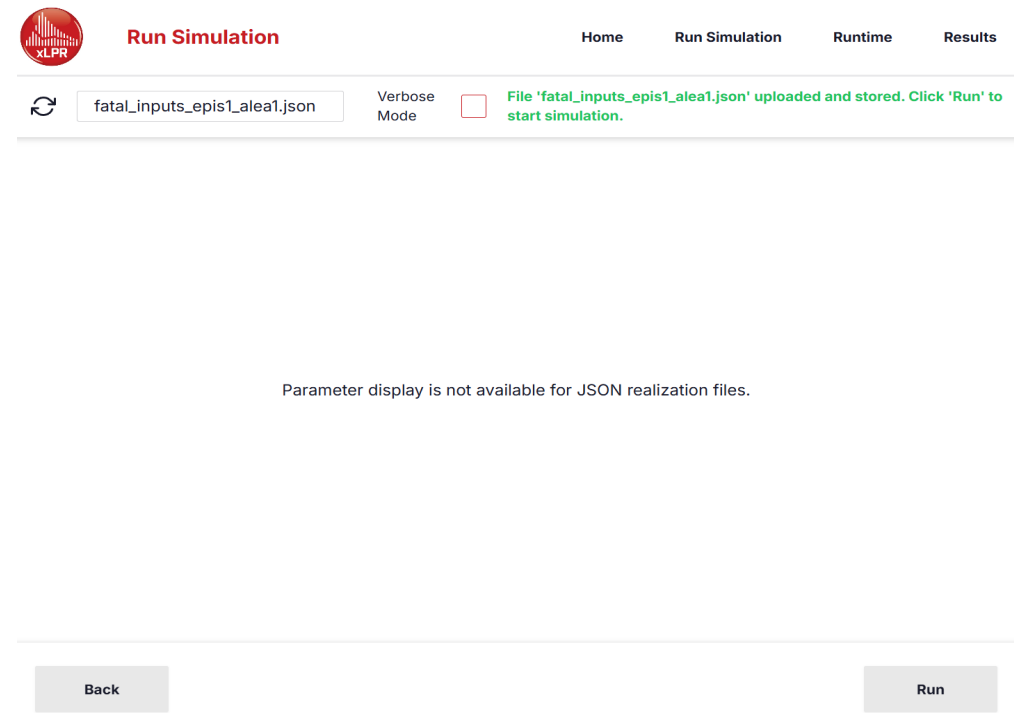
Graphical User Interface



The screenshot shows the xLPR GUI with the 'Run Simulation' tab selected. The file 'xLPR-2.3 Input Set.xlsx' is uploaded. A message states: 'File 'xLPR-2.3 Input Set.xlsx' uploaded and stored. Click 'Run' to start simulation.' Below this, the 'Case Description: T-SC-D-1' is shown, followed by a table of parameters.

PARAMETER	DESCRIPTION	VALUE
Epistemic Sample Size	Number of outer loops in the simulation	1
Random Seed Epistemic	Random Seed for epistemic.	1
Aleatory Sample Size	Number of inner loops in the simulation	30
Random Seed Aleatory	Random Seed for aleatory.	5
Sim Duration (yr)	The length of simulation.	60
Outside Diameter (m)	Pipe outer wall from input file.	0.685825
Pipe Thickness (m)	Pipe wall thickness from input file.	0.066675
Mitigation Type Option	0: None,1: Stress-based only,2: Chemistry-based,3: Both	0

Buttons for 'Back' and 'Run' are visible at the bottom.

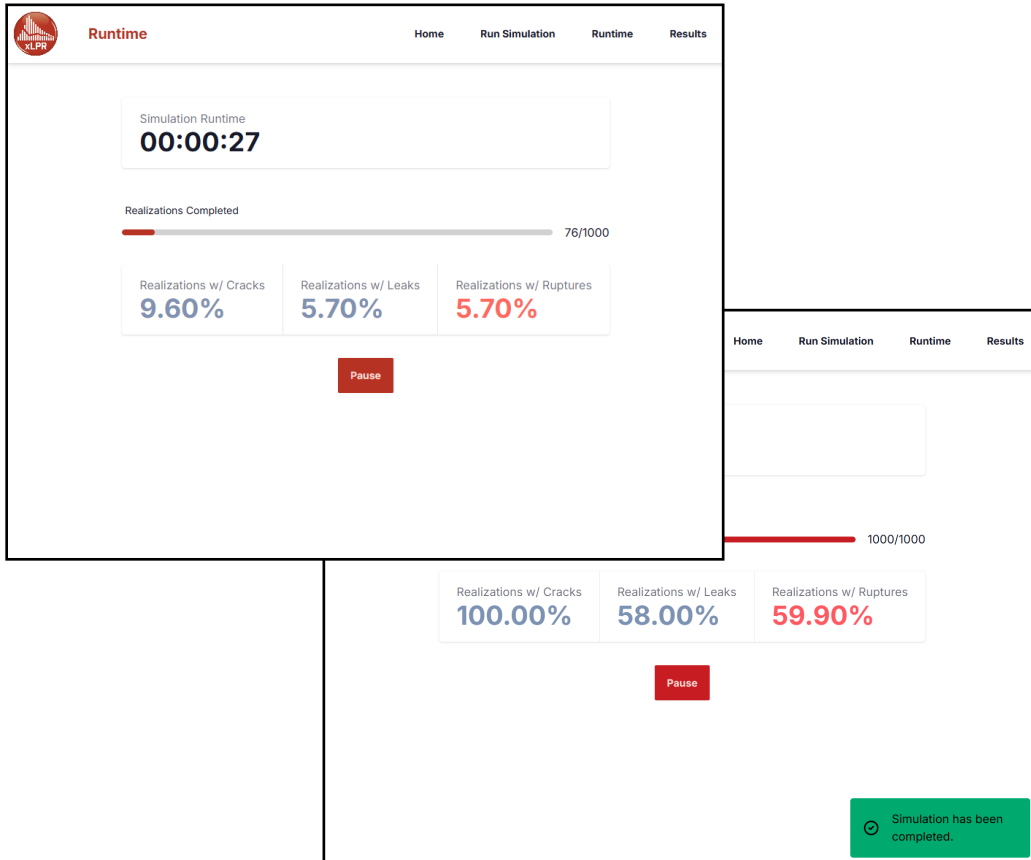


The screenshot shows the xLPR GUI with the 'Run Simulation' tab selected. The file 'fatal_inputs_epis1_alea1.json' is uploaded. A message states: 'File 'fatal_inputs_epis1_alea1.json' uploaded and stored. Click 'Run' to start simulation.' Below this, a message reads: 'Parameter display is not available for JSON realization files.' Buttons for 'Back' and 'Run' are visible at the bottom.

- The user can select to upload either an Excel input file or a JSON realization file.
- JSON realization files that are created for realizations that fail from previous simulation runs (found in the 'fatal' folder).
 - Parameter display is not available for these file types since only one selected realization will run
- Case description and selected parameter details from an input sheet will be shown once the file is uploaded. The user can review this information before choosing to run the simulation



Runtime View



- Once the user selects to run the simulation, they will navigate to the Runtime page
- This page tracks real time data from the simulation:
 - Total simulation runtime
 - Number of realizations completed
 - Total percentage of realizations with cracks, leaks, and ruptures
- Pause button is used to pause or resume the simulation
- User can navigate to other areas of the application while simulation is running and return to runtime page to view statistics.
 - The simulation completed notification will display on all pages when the simulation has finished.

Results Page



Results

Home Run Simulation Runtime Results

Parameters

Upload HDF5 File

- LeakNotDetected
- OccRuptNocrackNo
- OccRuptNocrackSeis
- OccurrenceCrack
- OccurrenceCrackAC
- OccurrenceCrackCCw
- OccurrenceLeak
- OccurrenceLeakAC
- OccurrenceLeakCCw
- OccurrenceLeakISI
- OccurrenceRupture
- OccurrenceRuptureAC
- OccurrenceRuptureCC
- OccurrenceRuptureISI
- OccurrenceRuptureLRDisi
- OccurrenceRuptureLrd

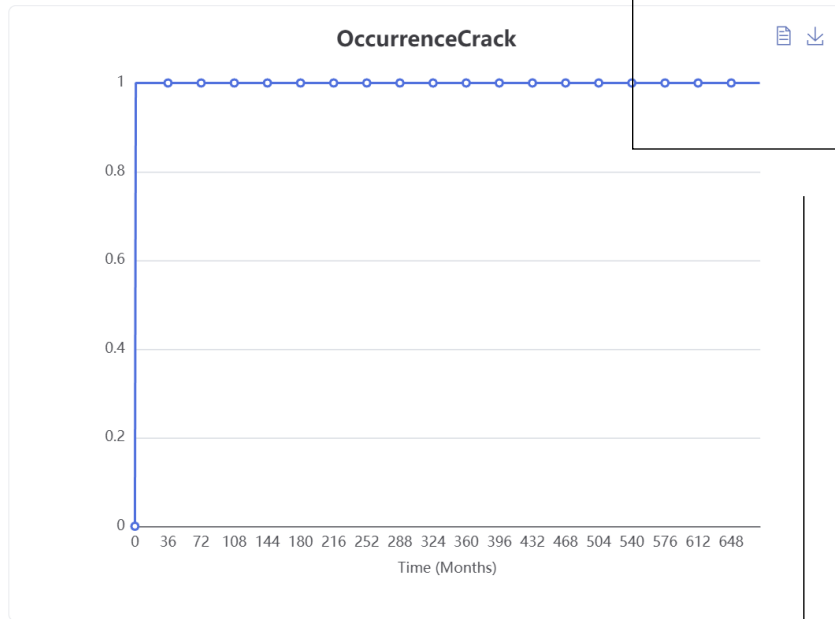
Epistemic Aleatory

1

1

Plot

Plot Results



- Once the simulation has been completed, a HDF5-formatted results file will be loaded on the results page for plotting.
 - This will load the available parameters from the HDF5 file into a list for selection.
 - Once the user selects a parameter from the list, the plot will be displayed in the plot results area
- A specific realization is selected using the selection list at the top of the Plot Results area.
- The plot that is being displayed can be downloaded in PNG format using the download button in the top right corner
- A table view of the plot can also be selected in the same area

