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Validation of Extreme Low Probability of Rupture Software

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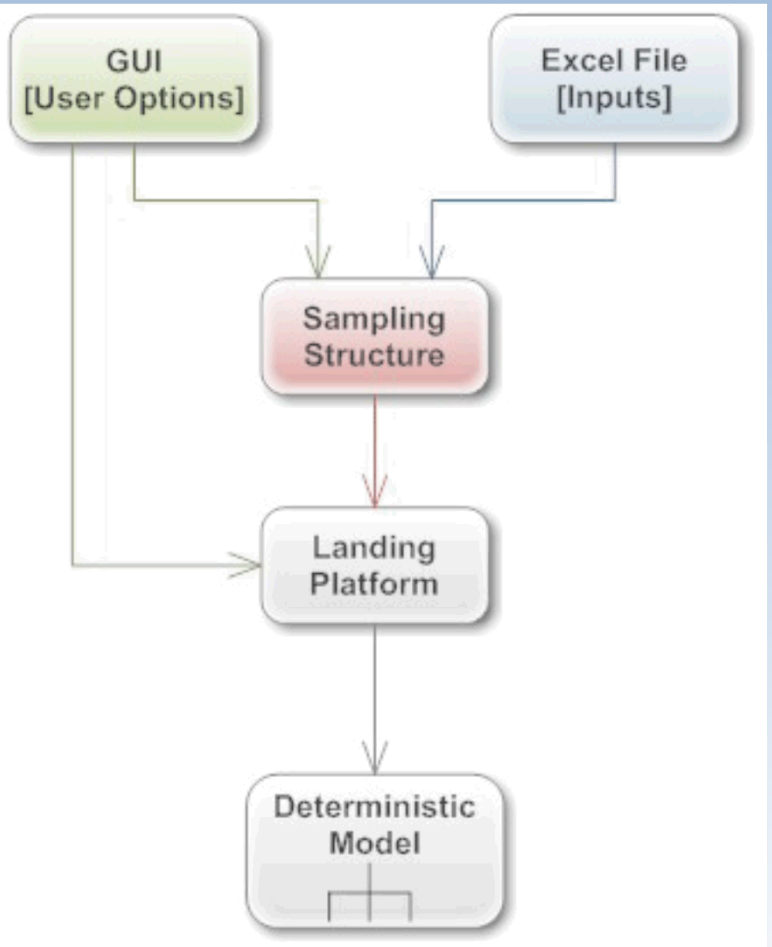
About xLPR

- From the Nuclear Regulatory Commission:
  - "Title 10 of the Code of Federal Regulations Part 50, Appendix A, General Design Criteria (GDC) 4, *"Environmental and Dynamic Effects Design Bases,"* requires that primary piping systems exhibit an extremely low probability of rupture in order to exclude dynamic effects associated with postulated pipe ruptures from the design basis."



Focus Area Inputs

- Variation with uncertainty
  - Epistemic: variability from imperfect knowledge
  - Aleatory: unknowable variability
- Variation with random seed
- Axial vs. Circumferential cracks
  - Scenarios 2 & 3

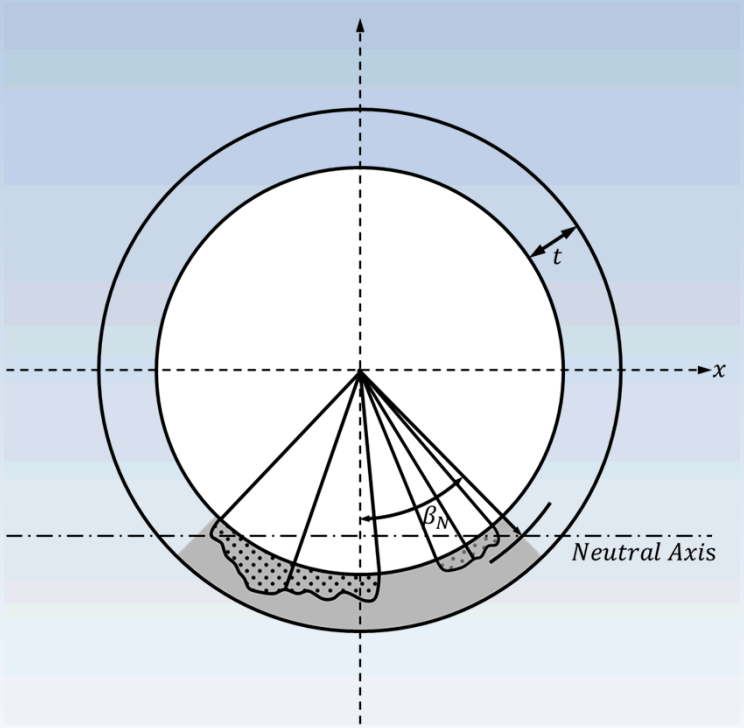
Scenarios

Scenario	Flaw initiation	PWSCC Growth only	Fatigue Growth only	PWSCC and Fatigue Growth	Flaw orientation: circumferential	Flaw orientation: circumferential + axial	Stress Mitigation (WOL, MSIP)	Stress Mitigation (inlay)	Chemical mitigation: Zn	Chemical mitigation: H	Chemical mitigation: Zn and H	Mitigation timing: 20 yrs	Mitigation timing: 40 yrs	Probability of rupture
1. Risk analysis due to fatigue	Initial flaw as an input		✓		✓									L
2. Fully unmitigated PWSCC circ.	PWSCC initiation	✓			✓									H
3. Fully unmitigated PWSCC axial	PWSCC initiation	✓				✓								VH
4. Fully mitigated PWSCC 20yrs	PWSCC initiation	✓				✓	✓					✓		VL
5. Fully mitigated PWSCC 40yrs	PWSCC initiation	✓				✓	✓						✓	L
6. Chemical mitigation PWSCC, Zn	PWSCC initiation	✓				✓			✓			✓		M
7. Chemical mitigation PWSCC, H	PWSCC initiation	✓				✓				✓		✓		M
8. Chemical mitigation PWSCC, Zn&H	PWSCC initiation	✓				✓			✓	✓		✓		M
9. Inlay mitigation	PWSCC initiation	✓				✓		✓					✓	M
10. Full mitigation, fatigue, PWSCC	PWSCC and fatigue initiation			✓		✓	✓				✓	✓		VL
11 Fatigue initiation only	Fatigue initiation		✓			✓								VL

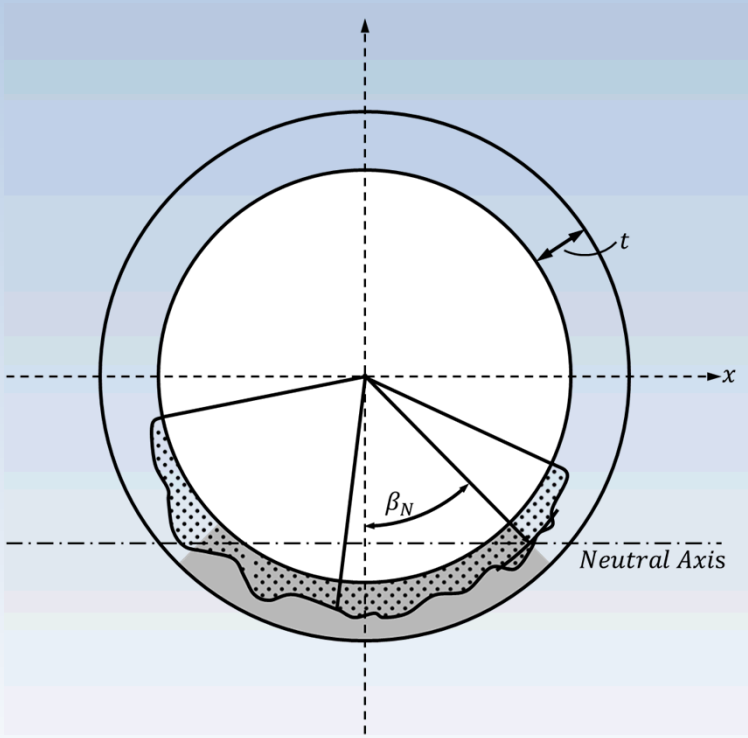
Focus A (100 epistemic, 25 aleatory)

- **Circumferential cracks 2 and 4, aleatory 13, epistemic 22**

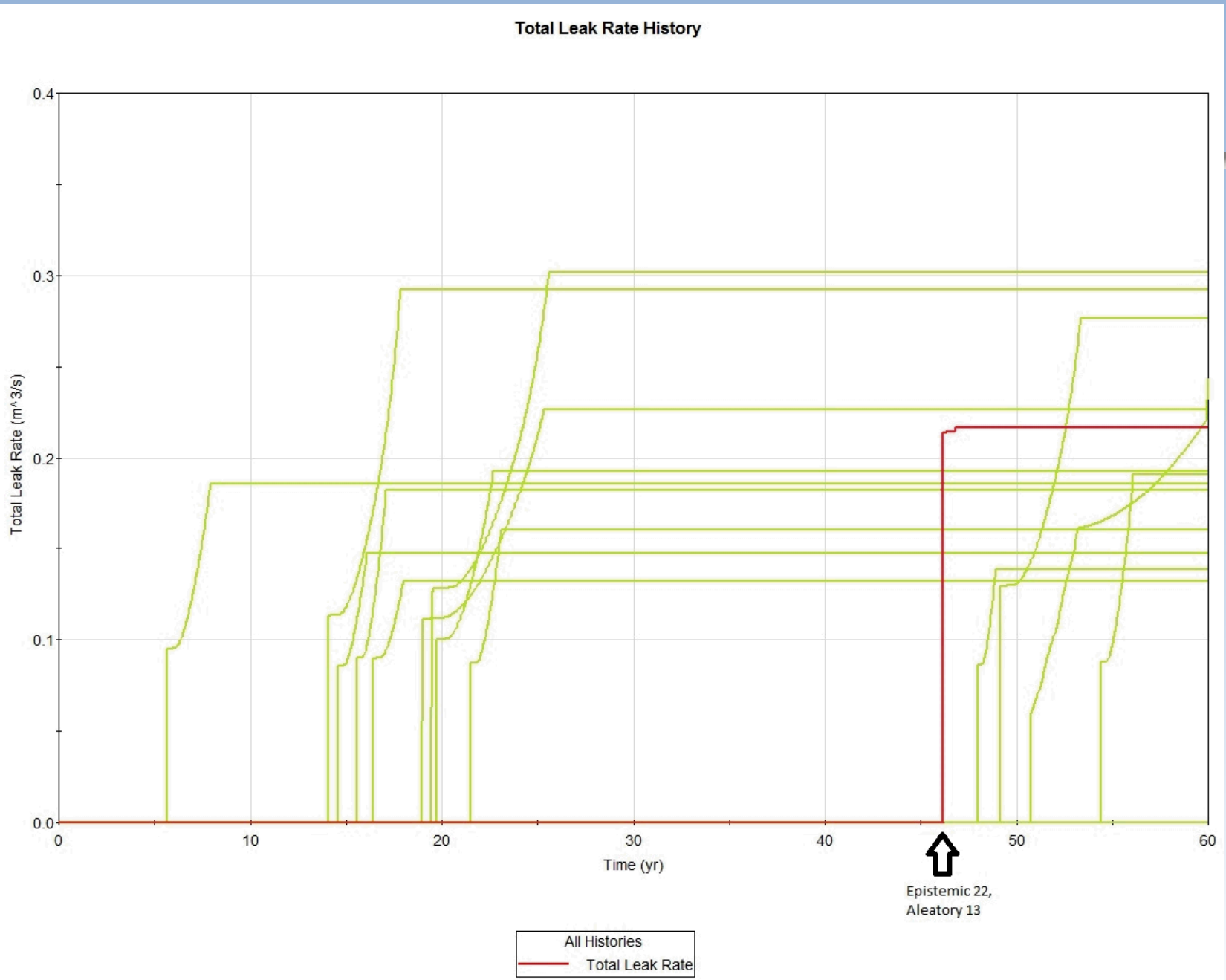
Time (years)	Crack Type
46	-1
46.083333	4
46.166667	4
46.25	4
46.333333	4
46.416667	4
46.5	4
46.583333	4
46.666667	4
46.75	4
46.833333	4
46.916667	200



Cracks 2 and 4 prior to coalescence



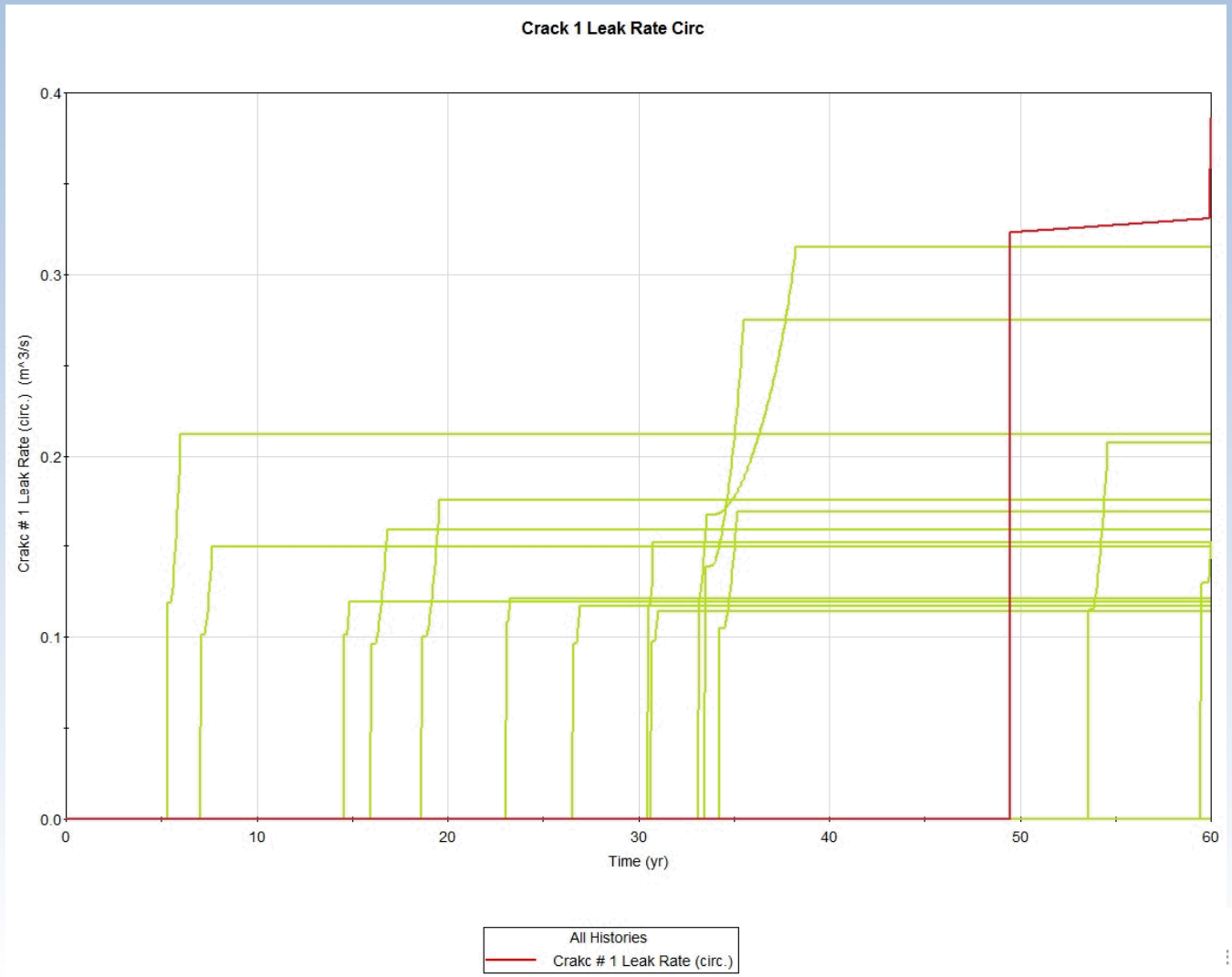
[Combined] Crack 4 after coalescence


Total Leak Rate History
Total Leak Rate (m^3/s)
0.4
0.3
0.2
0.1
0.0
0
10
20
30
40
50
60
Time (yr)
Epistemic 22,
Aleatory 13
All Histories
Total Leak Rate

Focus B (also 100 epistemic, 25 aleatory)

- **Circumferential crack 1, aleatory 21, epistemic 42**
  - Data:

Time (years)	Crack Type	Leak Rate (m^3/s)
49.33	-1	0
49.42	-1	0
49.50	-2	0.323
49.58	-2	0.3231
49.67	-2	0.3231
49.75	-2	0.3232
49.83	-2	0.3233
49.92	-2	0.3233



Focus C (also 100 epistemic, 25 aleatory)

- **Crack 1, realization 1, H#10**
  - Data:

Time (years)	Crack Type	Crack # 1 Leak Rate	Crack # 1 depth	Crack #1 Inner Half Length	Crack #1 Outer Half Length
40.666667	-3	0.4415	1	0.7285	0.7285
40.75	-3	0.4415	1	0.8333	0.8333
40.833333	-3	0.0007843	1	1	1.14
40.916667	-3	0.0007843	1	1	1.14
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59.833333	-3	0.0007843	1	1	1.14
59.916667	-3	0.0007843	1	1	1.14
60	-3	0.001088	1	1	1.14