EVALUATING PIPE RUPTURE PROBABILITY IN PWSCC SUSCEPTIBLE WELDMENTS
(A Proposed Approach)

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International Workshop on LBB in RCS Components with Active Degradation Modes

January 9-11, 2008

Structural Integrity Associates, Inc.

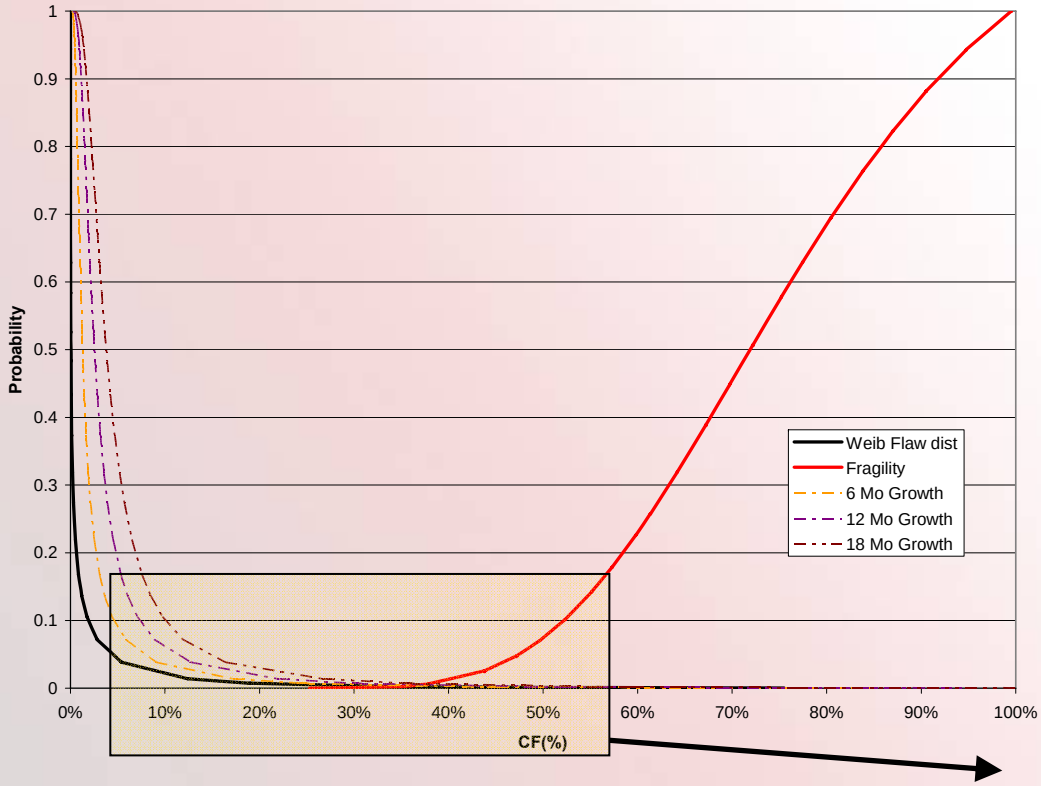
Outline of Presentation

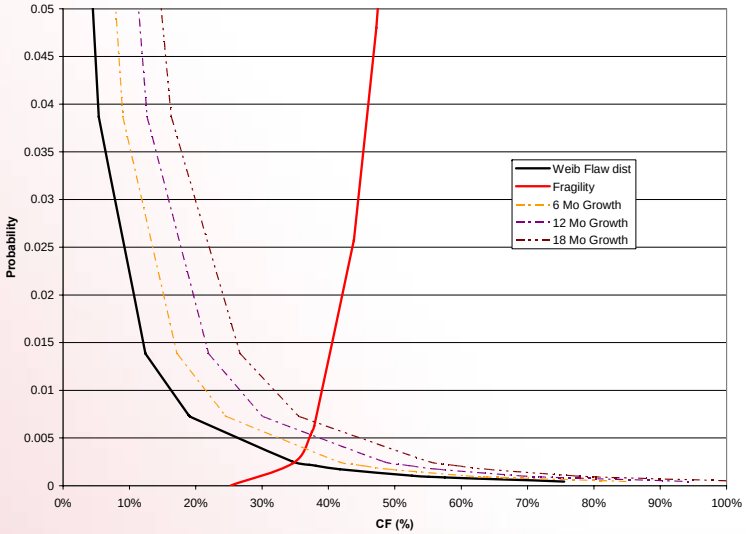
- Summary of Prior Work (MRP-216, Appendix E)
- What Constitutes LPR (Low Probability of Rupture) for purposes of Meeting GDC-4 Criteria?
- Additional Technology Needs for LPR Evaluations (WinPRAISE07)
  - Probabilistic Treatment of PWSCC Initiation and Growth
  - Probabilistic Treatment of Effect of Periodic Inspections
  - Probabilistic Treatment of Leak Detection
  - Probabilistic Evaluation of PWSCC Mitigation Techniques

Summary of MRP-216, Appendix E

- Probabilistic Analyses to Supplement Advanced FEA (Deterministic) Effort to Address Wolf Creek Indications
- Elements of Technical Approach:
  - Criticality Factor (% of cross section lost to crack)
  - Flaw Distribution
  - Fragility Curve
  - Crack Growth
  - Monte Carlo Analysis
- Results and Conclusions

Overview of Methodology





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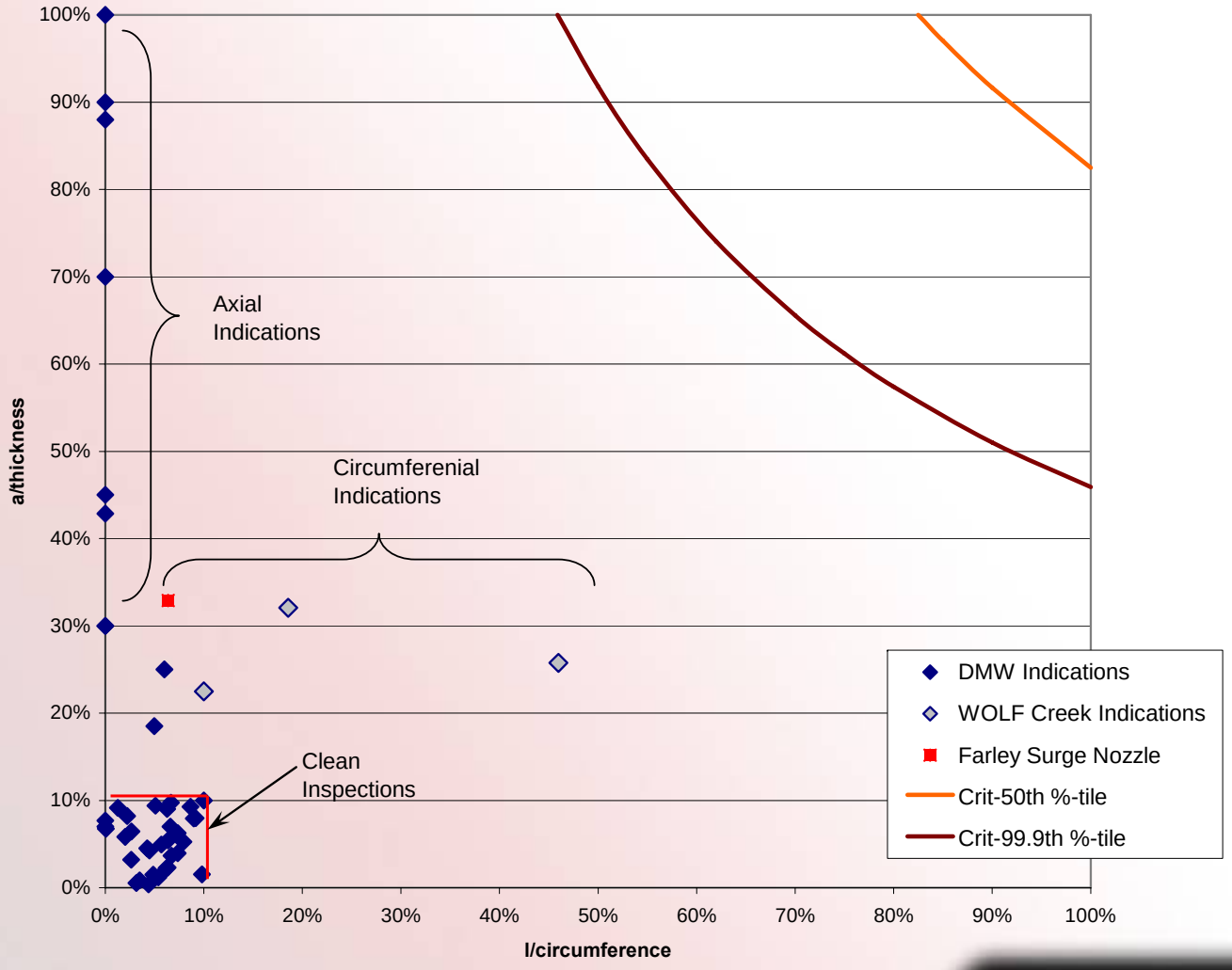
Pressurizer Inspection Data



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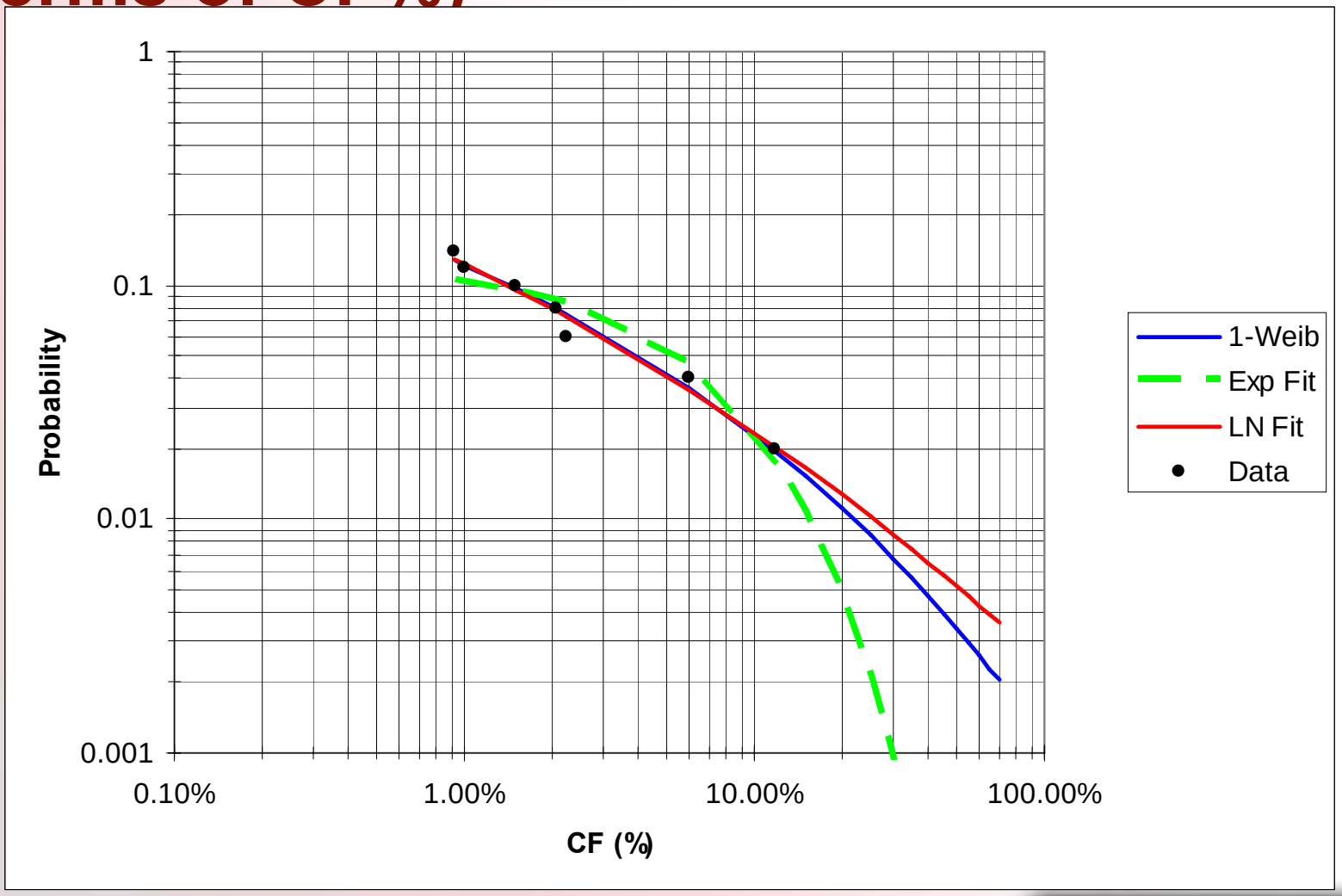
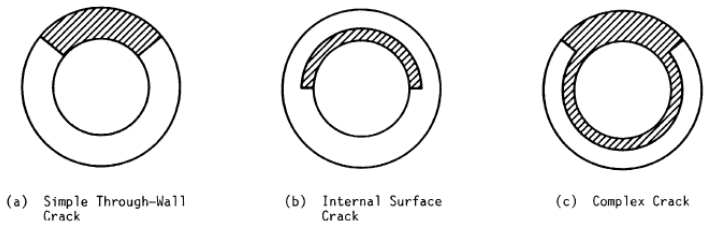
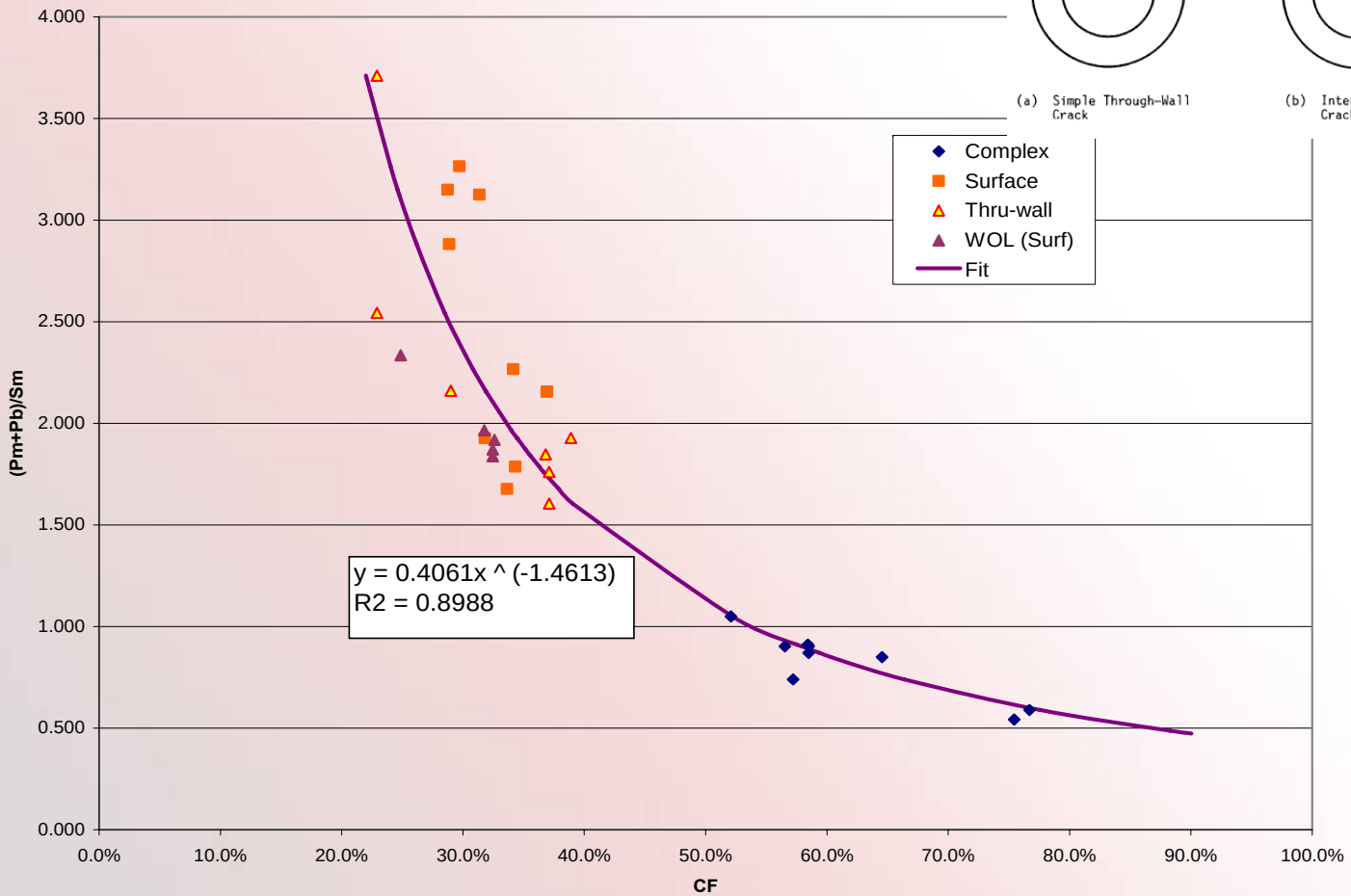
Flaw Distribution (Fall 2006 Snapshot in terms of CF%)



Degraded Piping Program (DP2) Full Scale Pipe Test Data





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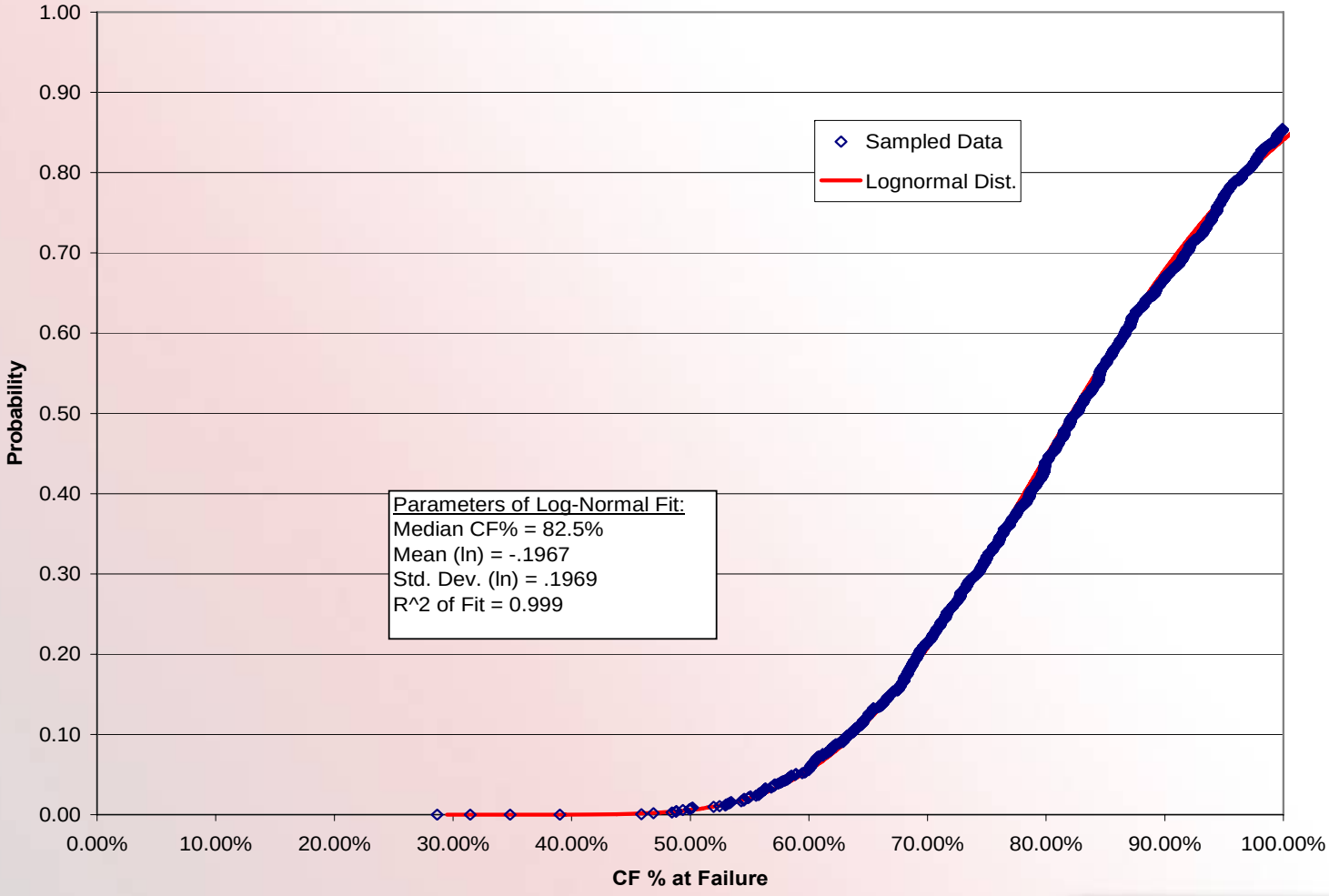
Fragility Curve (Derived from DP2 Test Data)



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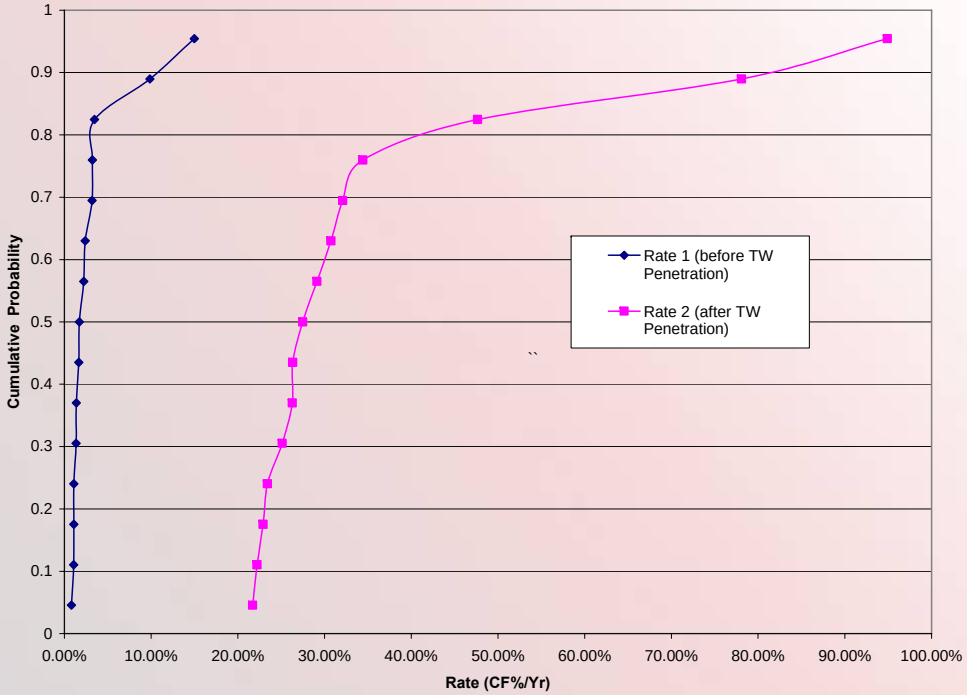
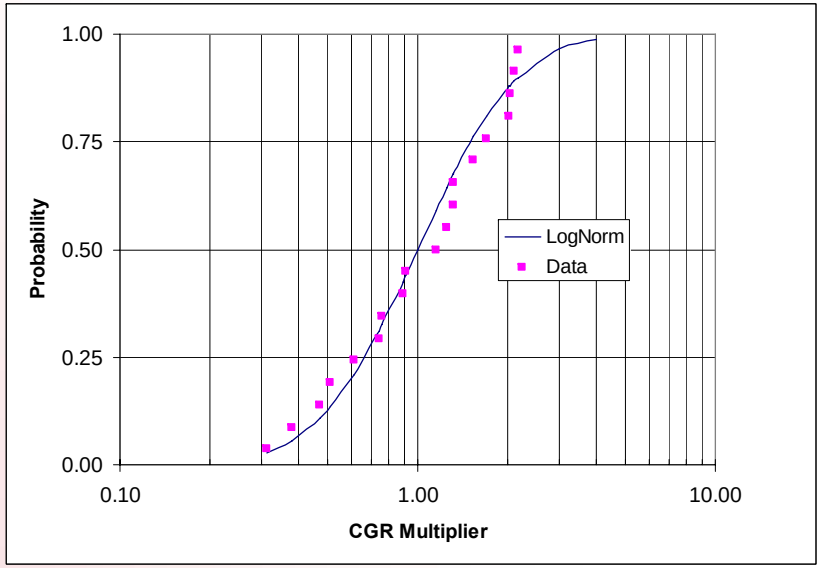
Crack Growth Probabilities (Estimated from Advanced FEA Cases)





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Summary of Results

Evaluation Period	Nozzle Failure Probabilities*		
	Weibull	Log-Normal	Exponential
Spring-07	0.0040	0.0047	0.0002
Fall-07	0.0042	0.0045	0.0007
Spring-08	0.0040	0.0040	0.0016

* - Per Remaining Uninspected Plant in Interval

MRP-216 Appendix E Conclusions

- Failure Probabilities (per plant, per six-month interval) do not increase significantly for nine Spring-08 Plants
- Absolute Failure Probabilities per plant year were greater than generally accepted LOCA Frequencies
- However:
  - Analyses were not intended to yield <u>absolute</u> probabilities for comparison to fixed licensing limits
  - Results assume no leakage or plant response to leakage
  - When factored by probability of non-LBB or failure to react to leakage (estimated at 1/500 from Advanced FEA study), acceptable probabilities of rupture result (3.2×10^{-6} to 8×10^{-6} per reactor-year)

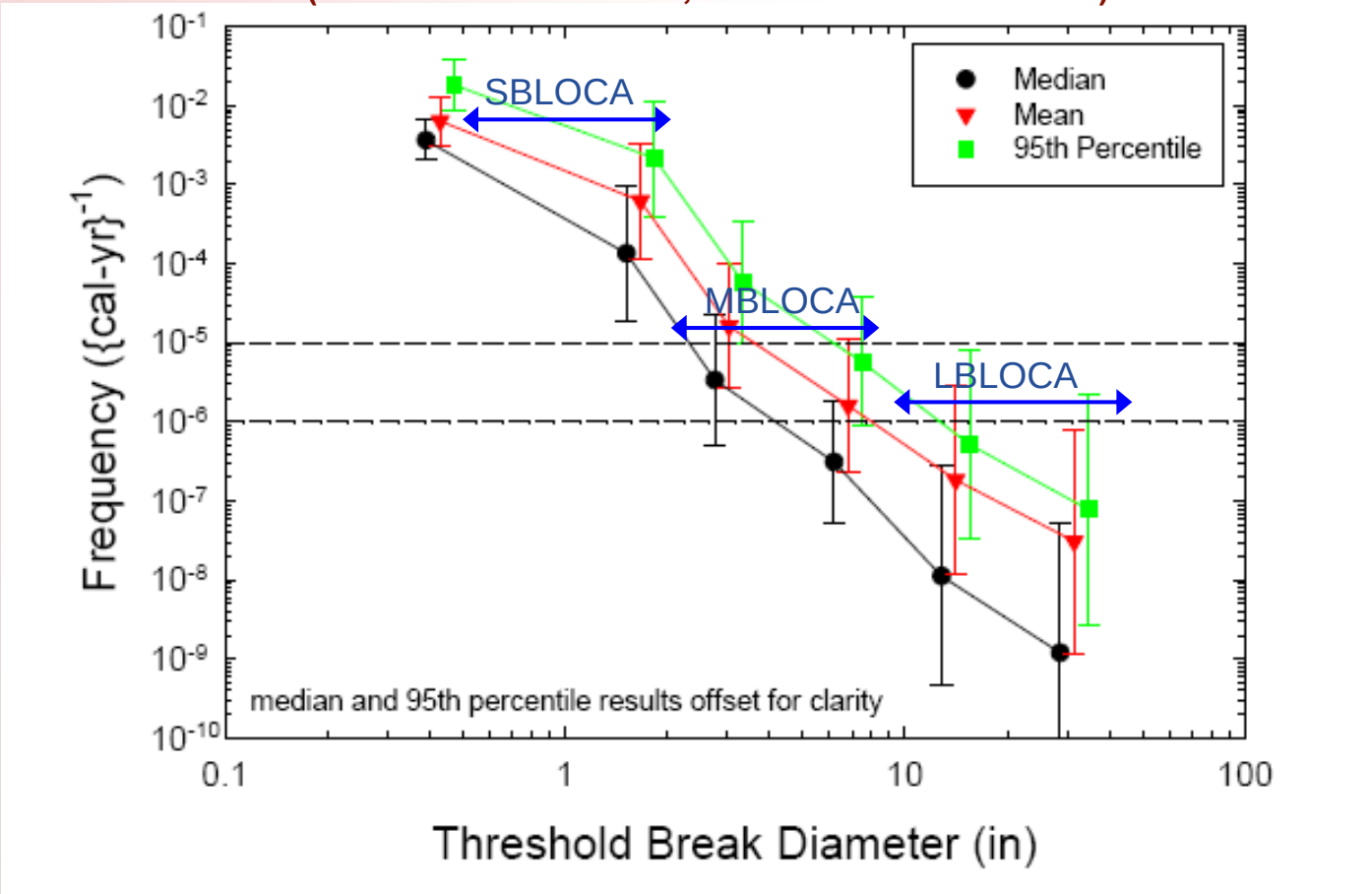
What is Needed to Extend this Approach for General LPR Evaluations *(of PWSCC susceptible locations)*

- **Establish acceptable probability of rupture for GDC-4 evaluations**
- **Mechanistic, time-dependent modeling**
  - **Crack initiation and growth modeling (calibrate WRT pressurizer nozzle inspections)**
  - **Leakage versus time with consideration of crack growth**
  - **Detection of leakage**
    - boric acid accumulation for small/incipient leaks
    - leakage detection system trending for larger leaks
  - **Effect of Inspections**
    - Inspection Frequency (MRP-139)
    - Inspection POD
  - **Ability to address mitigated welds and non-PWSCC susceptible locations**
  - **Ability to distinguish probabilities of leakage vs. rupture**

What Constitutes Low Probability of Rupture (LPR) for GDC-4?

Estimates of PWR LOCA Probabilities

(Chart = NUREG-1829; Arrows = NUREG-5750)



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WinPRAISE07 – Potential Tool for LPR Evaluations

- PRAISE code initially developed in 1980
  - NRC funded
  - probabilistic fatigue crack growth with ISI
- Expanded to include IGSCC, mid-1980s,
  - probabilistic initiation and growth of IGSCC
- Expanded to include probabilistic fatigue crack initiation, late 1990s
- WinPRAISE developed, late 1990s
  - Windows version for ease of use
  - self funded by EMT (D. Harris and D. Dedhia)
- WinPRAISE07 developed, 2006-07
  - probabilistic treatment of initiation and growth of PWSCC
  - fatigue crack initiation incorporated
  - currently owned by Structural Integrity Associates

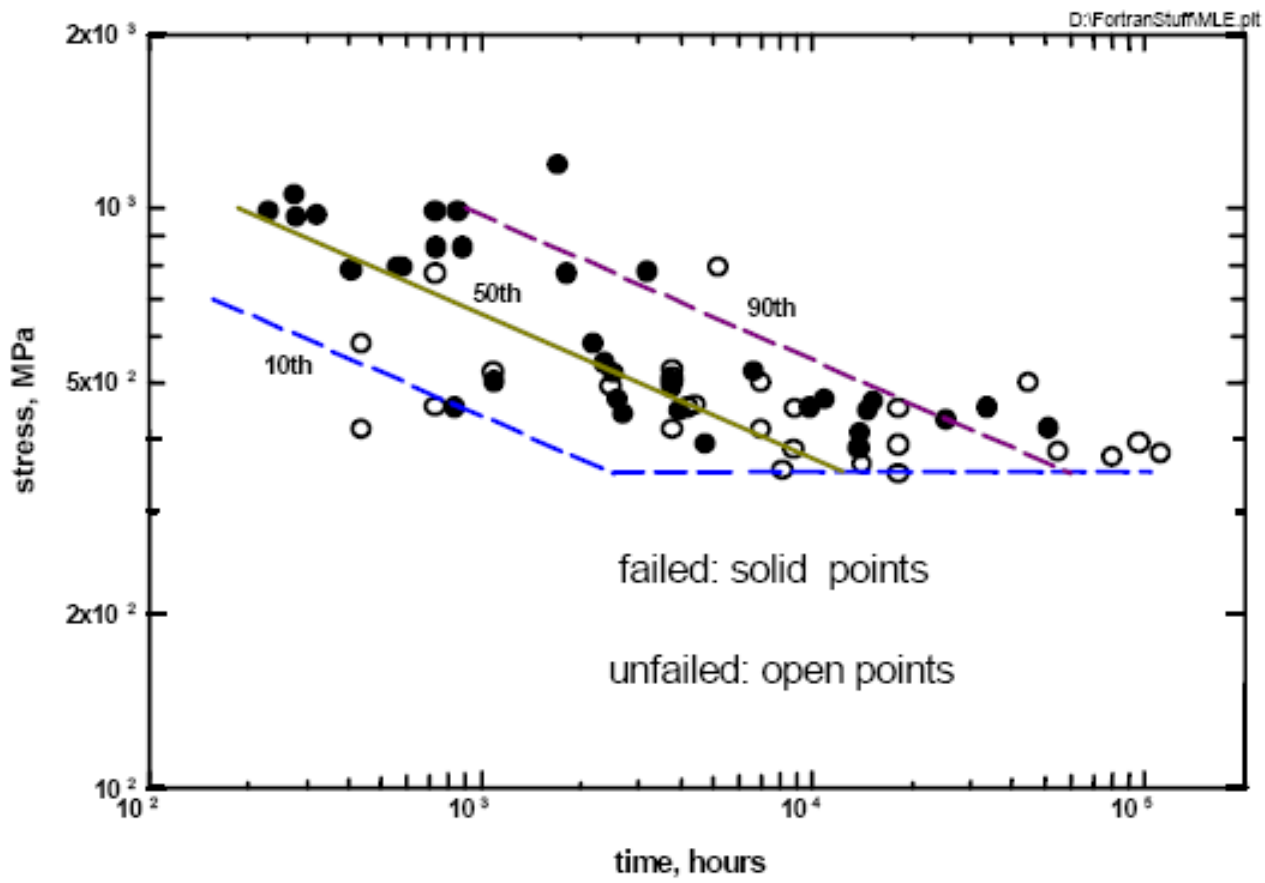
WinPRAISE07 –
Features for LPR Evaluation

- PWSCC Crack Initiation and Early Growth
- PWSCC Crack Growth
- Pre- and Inservice Inspections Addressed
- Leak Rate vs. Rupture Prediction
- Time Dependent Monte Carlo w/ Stratified Sampling
- Can Address Mid-Life Changes (i.e. Mitigation)

WinPRAISE07 Features – PWSCC Initiation and Early Growth

- Distribution vs. applied stress based on Amzallag (99 and 02)
- Crack Initiation Size
  - Depth Log-normally Distributed; (default: $\mu = 2$ mm, shape parameter = 0.5; or user input)
  - Flaw Shape -Log normally Distributed; (default: mean $b_o - a_o = 4.6$ mm, shape parameter = 0.68; or user input)
  - Multiple cracks initiated (in each 2 inches of circumference)

WinPRAISE07
A-182 Crack Initiation Distribution vs. Data



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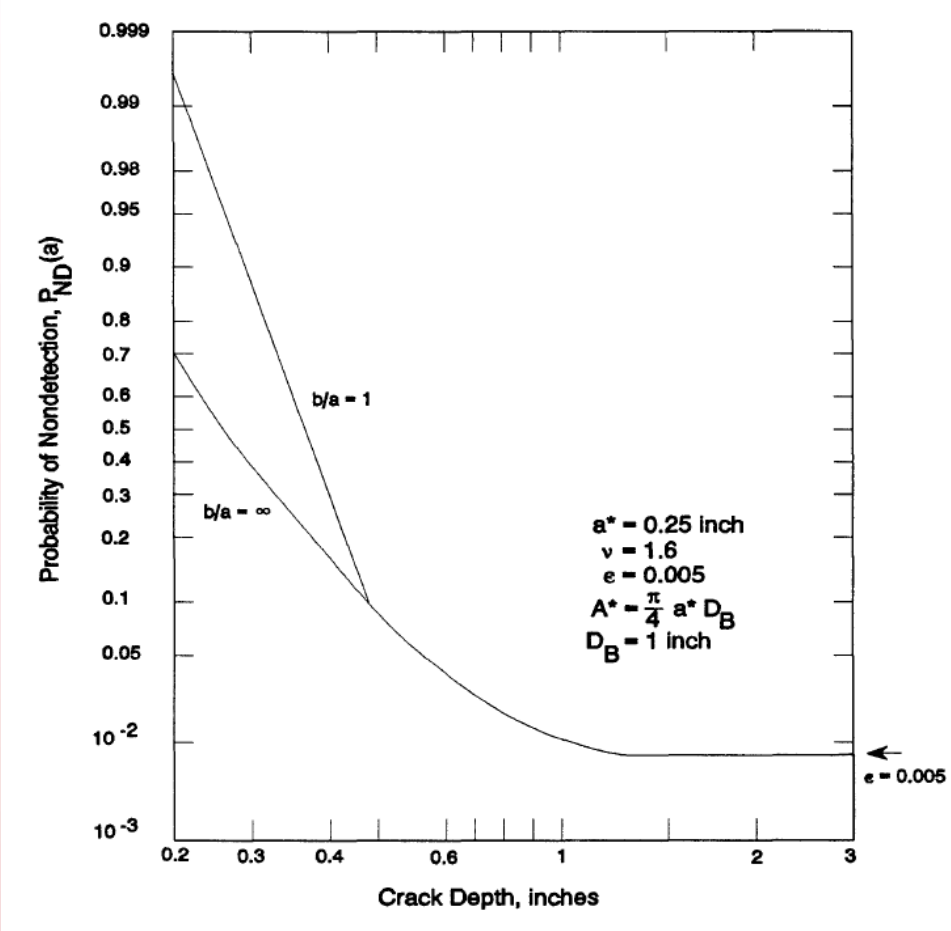
WinPRAISE07 Features – Pre- and Inservice Inspection

- **Detection Probability**

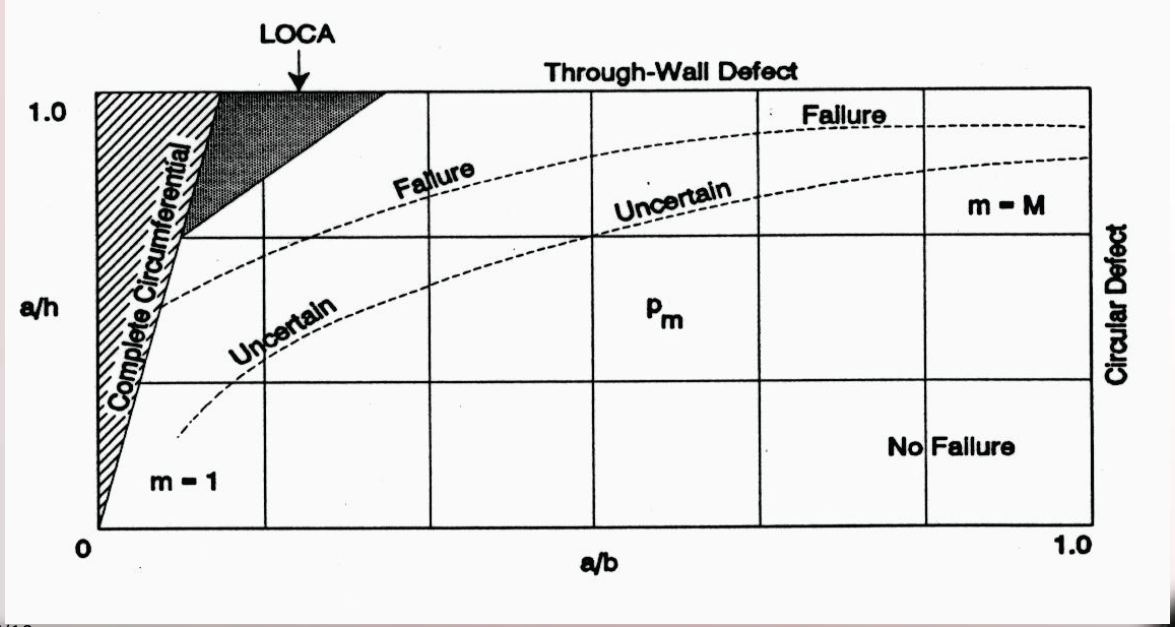
$$P_{ND}(A) = \varepsilon + \frac{1}{2}(1-\varepsilon)erfc(v \ln A / A^*)$$

- **Based on Crack Area (similar to CF%)**



WinPRAISE07 – Other Relevant Features

- Leak rate treated as random variable using SQUIRT methodology with appropriate crack morphology
- Stratified Monte-Carlo Sampling
  - Time dependent
  - Reduced run times



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Conclusions

- MRP-216, Appendix A – first cut at probability of failure evaluation for PWSCC
  - Fragility curve developed based on DP2 full scale pipe test data – function of CF%
  - Resulting failure probabilities reasonable for Spring-08 plants
- Need to establish baseline probabilities for application of GDC-4 LPR criterion
  - Should replace LBB with LPR in the lexicon
  - LBB is one means of demonstrating LPR
- WinPRAISE07 possesses many features that could be directly adapted to LPR evaluations