An Approach for Evaluating Pressure Upgrades Using Reliability and Risk Analysis

March 21, 2006

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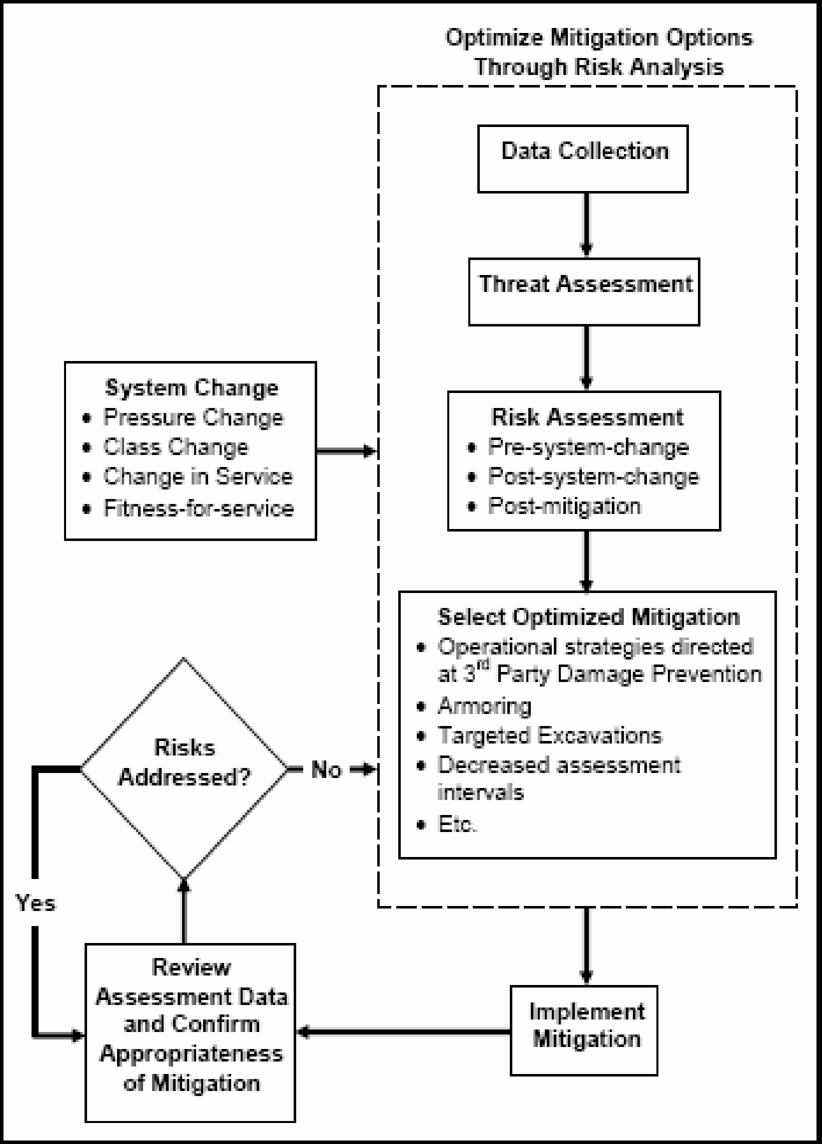
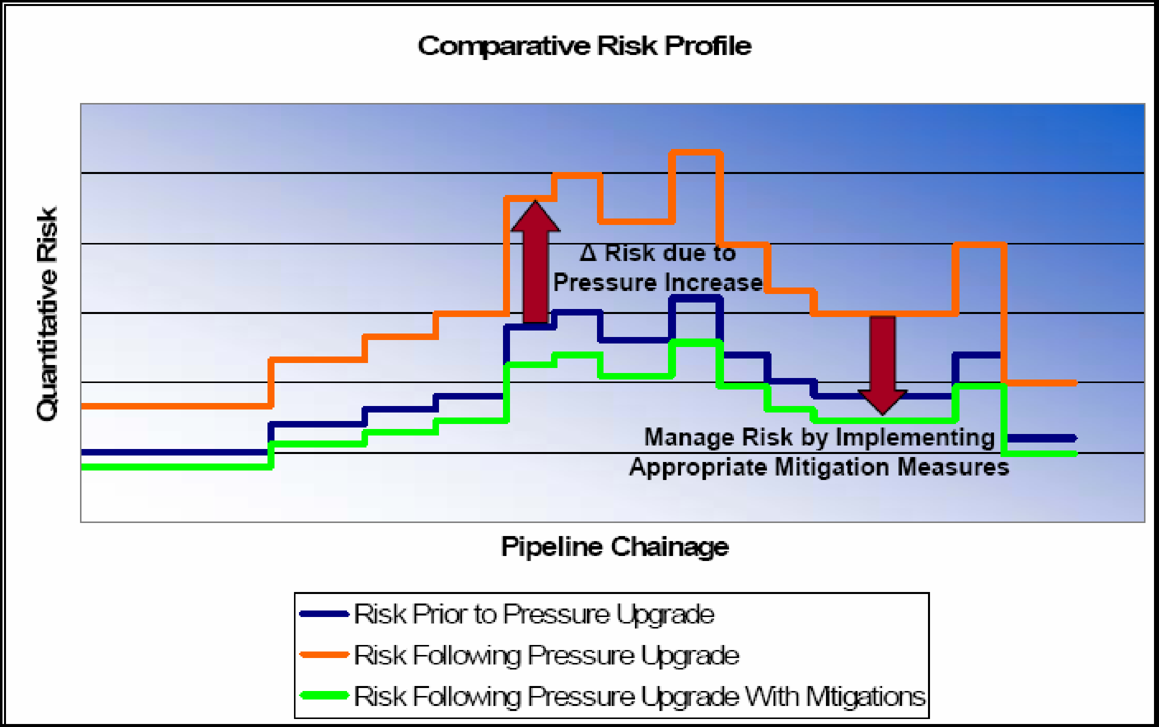
Background

- Canadian experience is to perform EAs to evaluate:
  - ➢Pressure Increases,
  - ➢Class Changes,
  - ➢Changes in service fluid
- QRA Techniques often used to:
  - ➢Evaluate risk implications, and,
  - ➢Select mitigation measures
- Replacement avoided in lieu of:
  - ➢Targeted excavations,
  - ➢↓ assessment intervals,
  - ➢↑ 3rd Party Prevention measures, etc.



General Concept – Assessment of Pressure Change

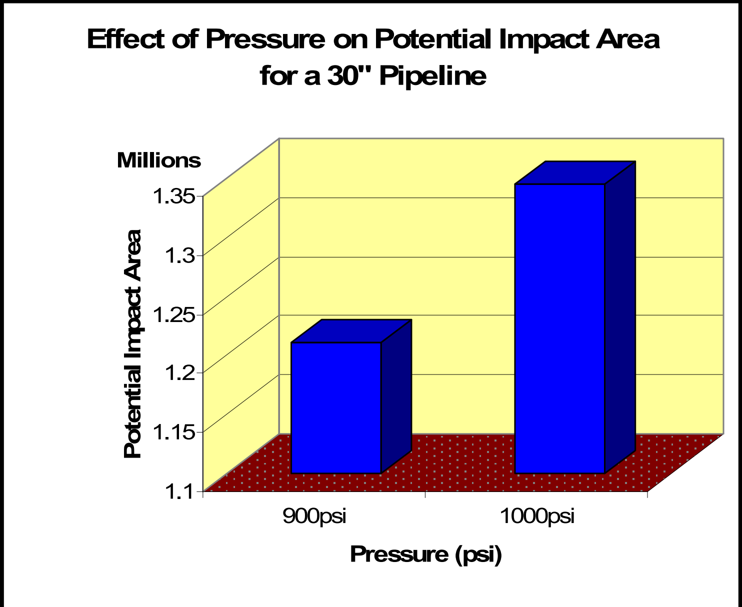


- Pressure increase drives increase in risk due to:
  - ↓ defect tolerance
  - ↑ in PIA ($R = 0.69 [P D^2]^{0.5}$)
- By quantifying Δ Risk, mitigation measures are selected
  - Risk is managed to a level ≤ level prior to pressure upgrade

Risk Implications of Pressure Change

Risk = [(Failure Likelihood) x (Consequences)]

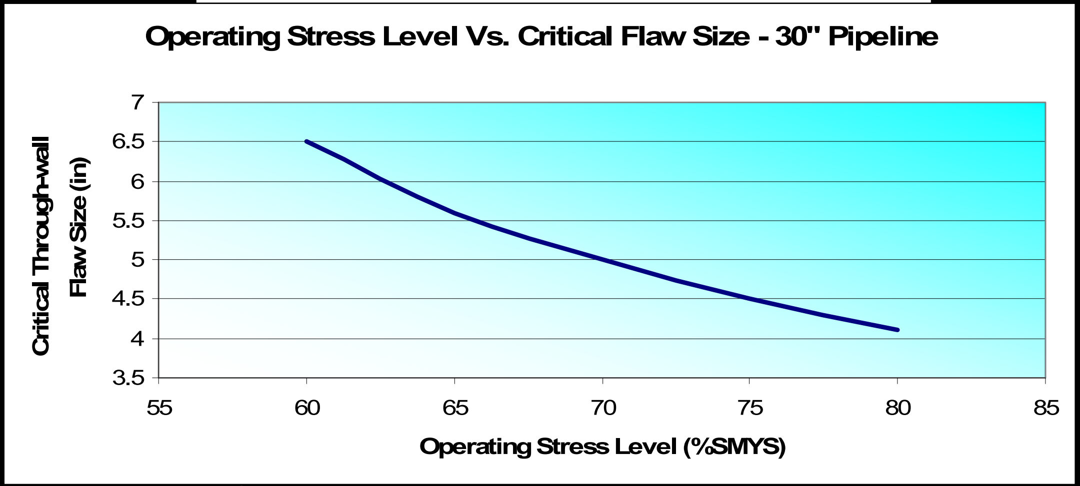
Pressure Change impacts risk in two ways:



1. ↑ Consequence
   - ($R = 0.69\,[P\,D^2]^{0.5}$)
   - Consequence α PIA
   - Consequence α Pressure

2. ↑ Failure Likelihood
   - ↑ P » ↓ Critical Flaw Size

   » ↑ Failure Likelihood



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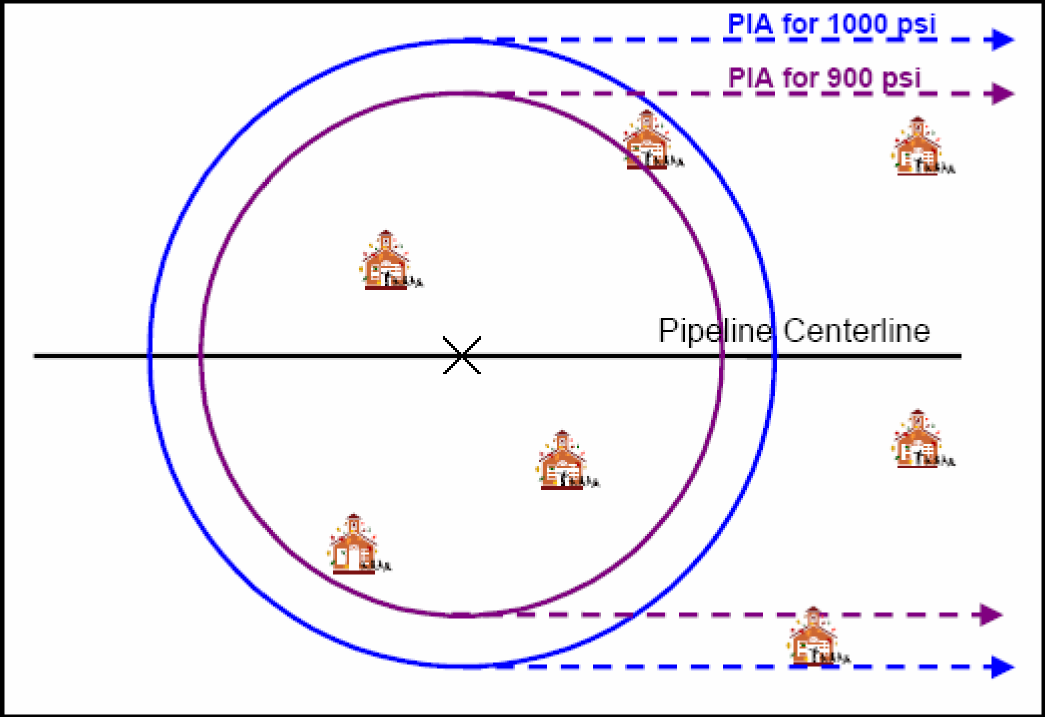
Quantification of Consequence Impacts

- PIA is calculated for both pressure cases
- Structure counts are performed
- Structure Occupancy Rates are applied
- Consequences are calculated for both pressure cases



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Quantification of Failure Likelihood Impacts

Reliability Approach

- In a Reliability-based approach:

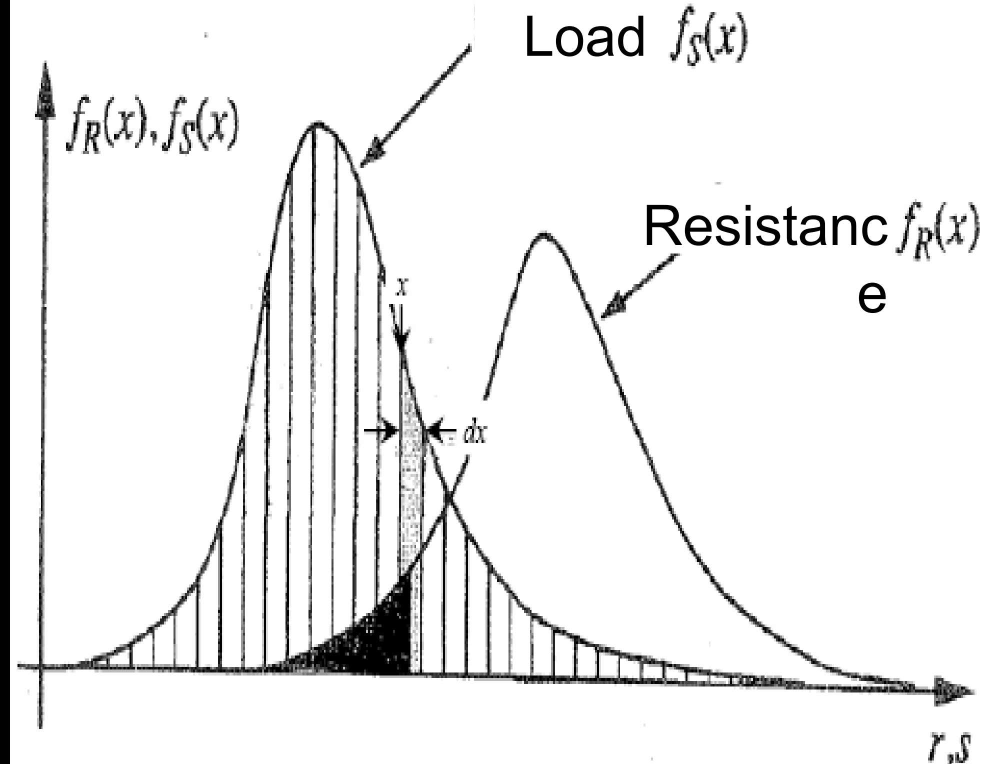
FAILURE OCCURS WHEN LOAD EXCEEDS RESISTANCE

POE = P(Load > Resistance)

= P (Resistance - Load) ≤ 0

= $P(P_{Burst} – MOP) \leq 0$

- Load and Resistance considered as joint probability density functions



$$POE = \int_{-\infty} F_R(x) . f_S(x) . dx$$

Reliability Tools

- FORM, SORM, Monte Carlo
  - Account for probability distributions of each parameter
  - Account for interrelationship of parameters
  - Failure Equation based on Limit State Equation
    - ASME B31G
    - EPRG Model (fatigue life of plain dents)
    - Tokyo Gas Equation (fatigue life of gouge-in-dent)
    - Maxey Q-Factor (immediate failure due to 3rd Party Damage)

Limit State Equation - Corrosion

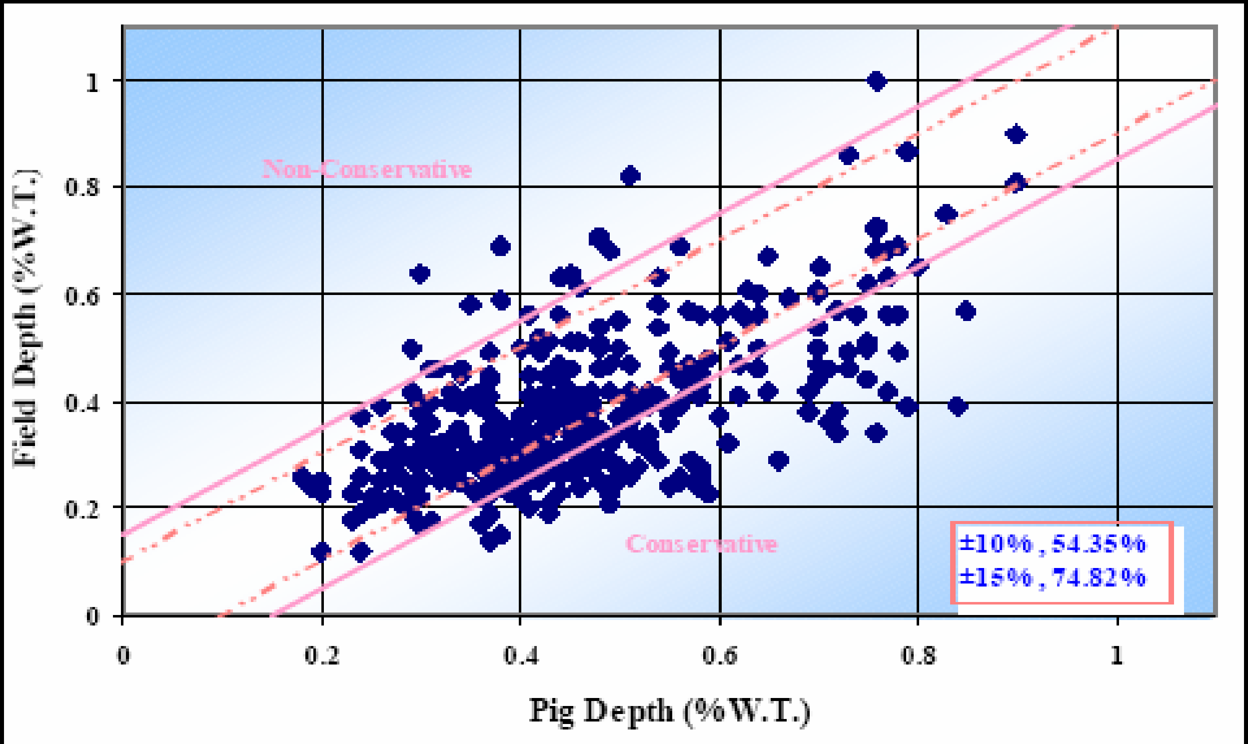
$$P_{burst} = \left(\frac{2t}{D}\right)\cdot(SMYS + 10{,}000)\cdot\left[\frac{1-0.85\frac{d}{t}}{1-0.85\frac{d}{t\cdot M_2}}\right]$$

Failure Equation - Corrosion

$$P_f = P\left\{\left[\left(\frac{2t}{D}\right)(SMYS+10{,}000)\left(\frac{1-0.85\frac{d}{t}}{1-0.85\frac{d}{t\cdot M_2}}\right)\right] - MOP\right\} \leq 0$$

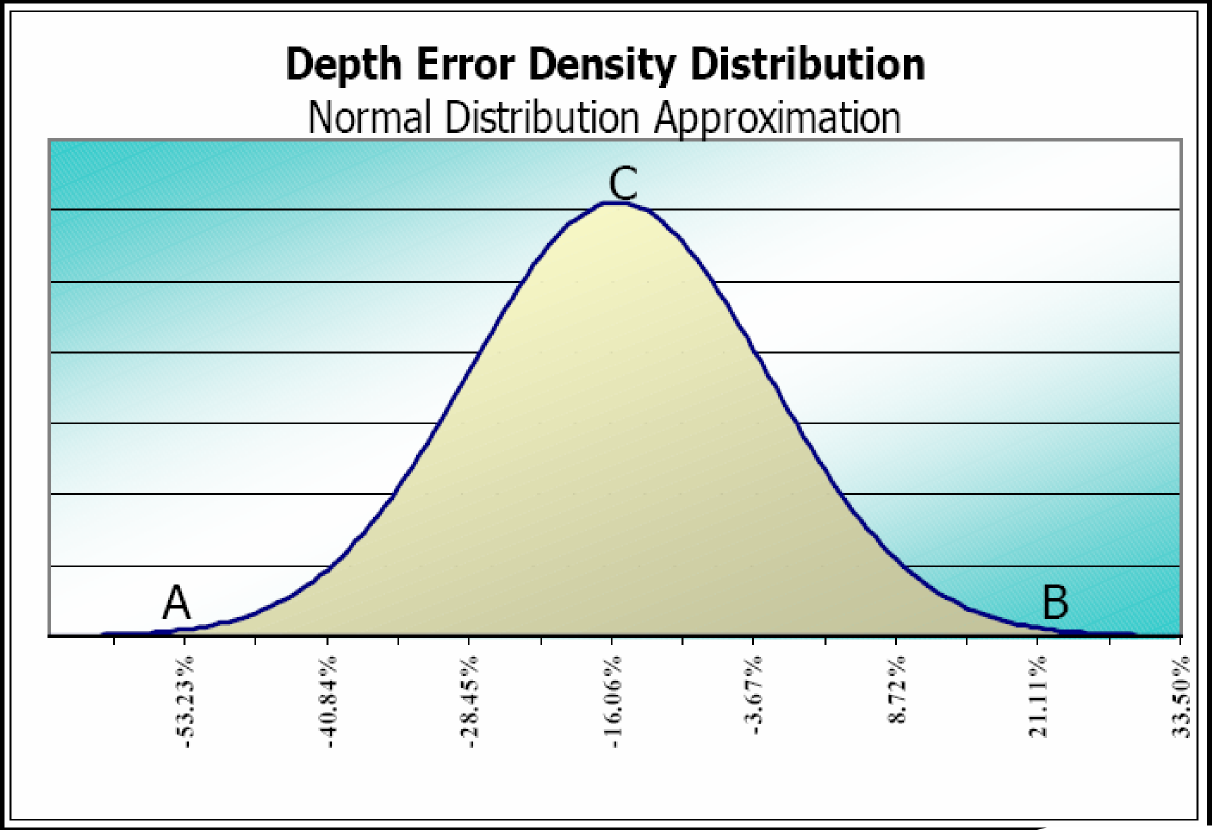
Sample Application of Reliability Method: *Threat of Failure Due to Corrosion*

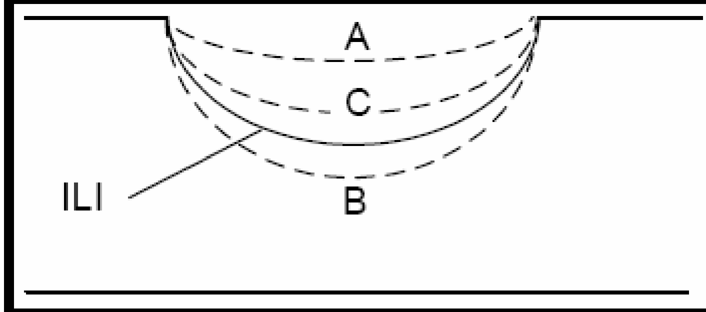
- **Uncertainty in Defect Size:**
  - Influenced by:
    - Time since inspection;
    - Defect Growth rate;
    - Sizing accuracy of inspection tool



Sample Application of Reliability Method: *Threat of Failure Due to Corrosion* (Continued)

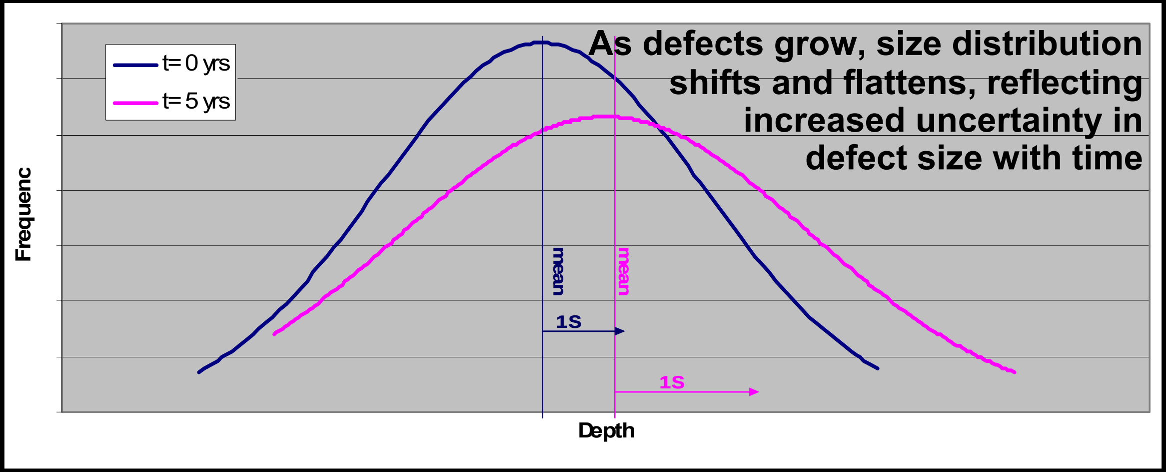
- **Defect Size Distribution *f*(*d*):**
  - Describes relationship between actual depth and ILI estimated depth

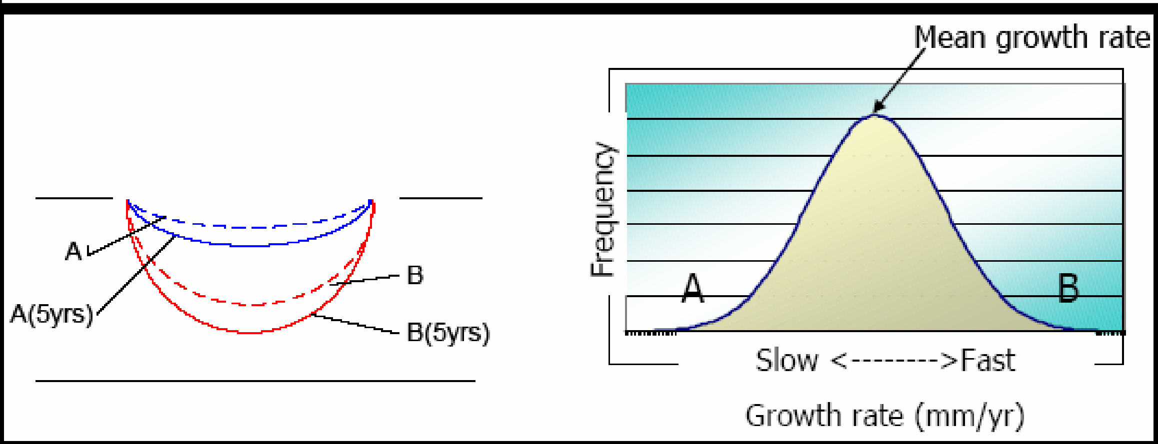




Sample Application of Reliability Method: *Threat of Failure Due to Corrosion* (Continued)

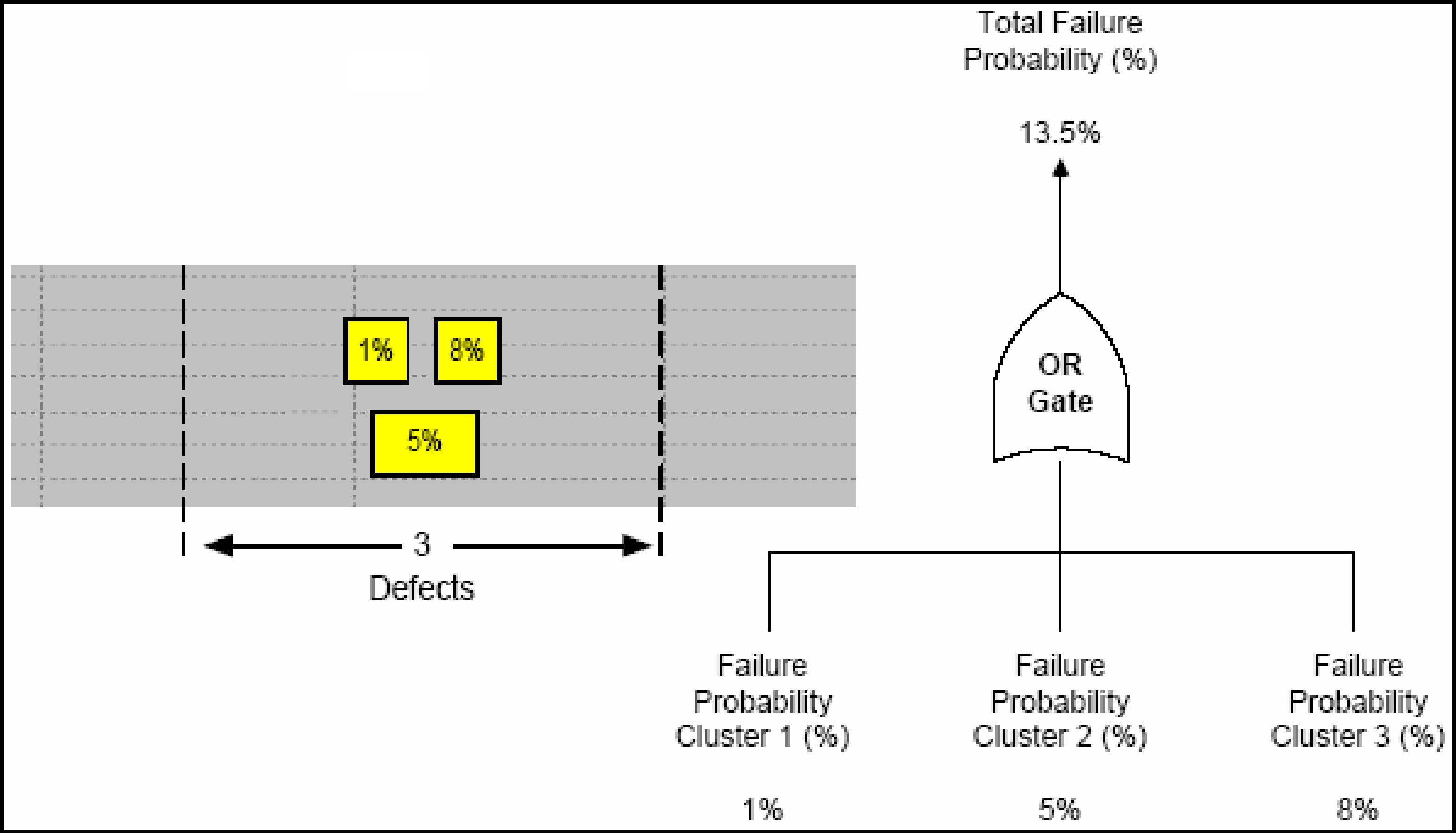
- **Defect Growth Rate Distribution *f*(*R*):**
  - Specific to each ILI feature:
  - ***f*(*R*) = *f*(*d*)/(*Growth Period*)**





Sample Application of Reliability Method: *Threat of Failure Due to Corrosion* (Continued)

- ***Interaction of Defects:***
  - OR-Gate: {1-[(1-P1) . (1-P2) … (1-Pn)]}



3rd Party Damage Approaches

- Two Scenarios:
  - Immediate failure at time of pipeline contact
  - Delayed failure: exposure of sub-critical defect to stress cycles
- Immediate Failure Scenario limit state function *h*(x):

$$\sigma_f = \bar{\sigma}\left(\frac{(Q - C_2)^{0.6}}{C_3}\right)$$

$$Q = C_{v,(2/3)}\left(\frac{R\,t}{D\,d_g\,c_g}\right)$$

- Delayed Failure Scenario limit state function *h*(x):

$$N_f = Z\left(\frac{d}{2R}\right)^{\alpha}\left(\frac{g}{t}\right)^{\beta}\left(\frac{\Delta\sigma}{2E}\right)^{\gamma}$$

3rd Party Damage Methodology - Immediate Failure Scenario

$$FF_{3PD} = H \times POE_{Given\ Hit}$$

Where,

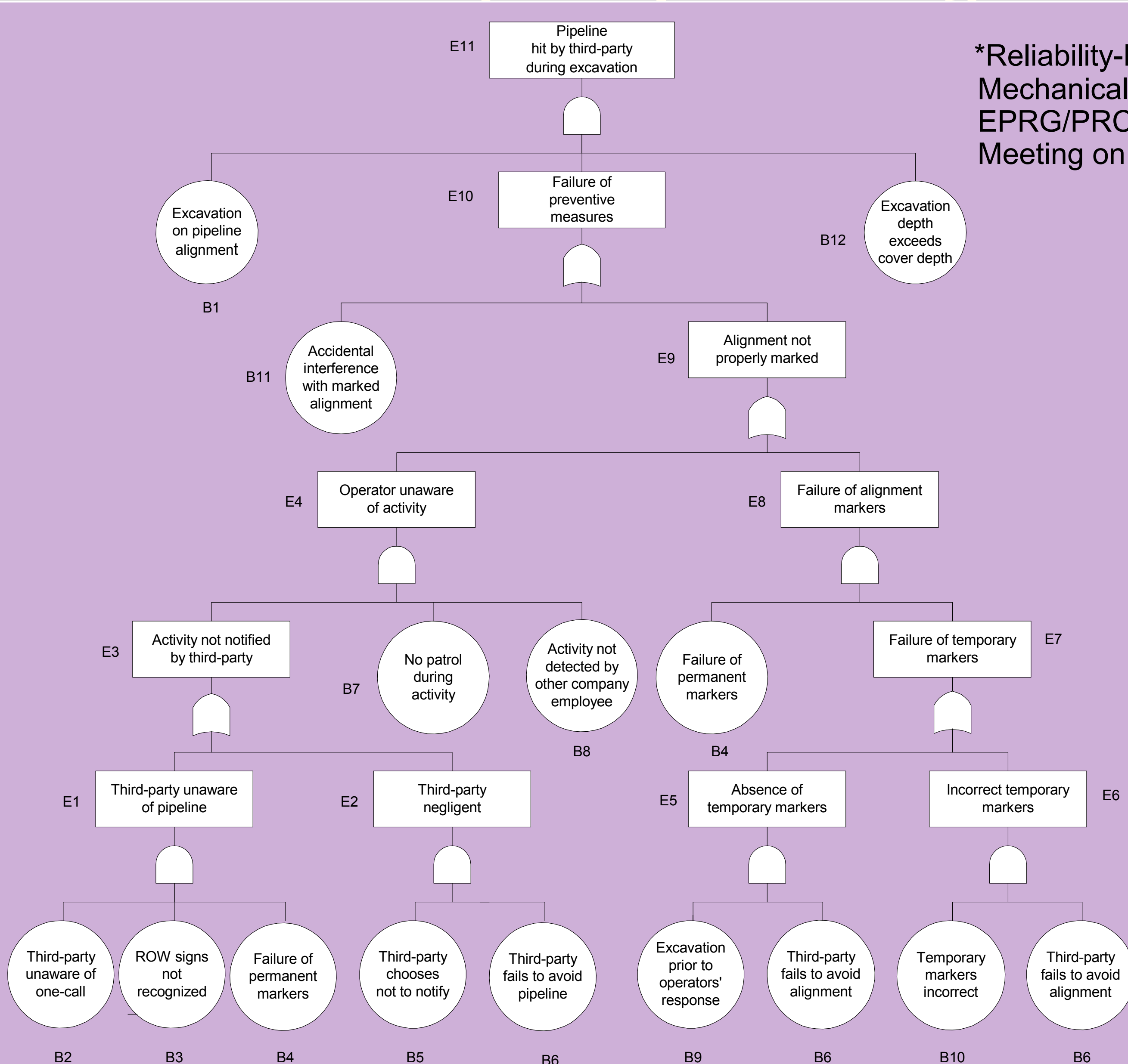
H = Hit Frequency (Event Tree Modeling)

$POE_{Given\ Hit}$ = POE, Given an Excavator Hit

Derived Either From:

- 3rd Party Damage Feature Size Distributions
- Damage Modeling

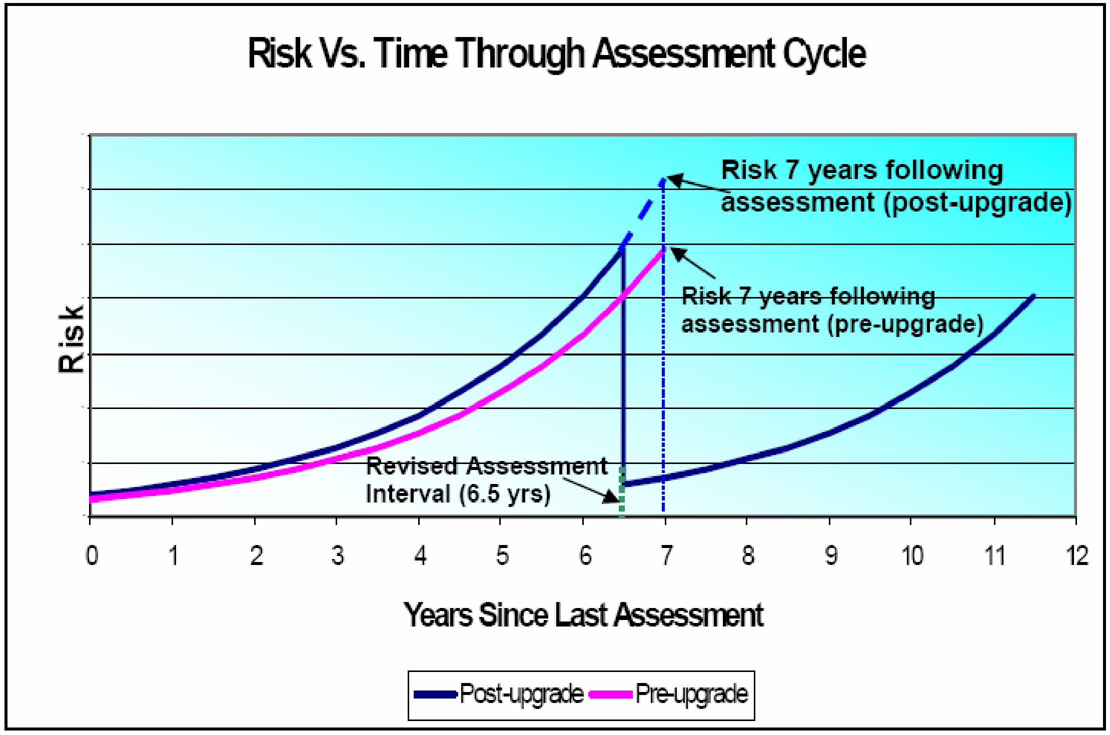
3rd Party Damage Methodology - Hit Frequency Modeling*



*Reliability-Based Prevention of Mechanical Damage, Proceedings of EPRG/PRCI 12th Biennial Joint Technical Meeting on Pipeline Research, May, 1999

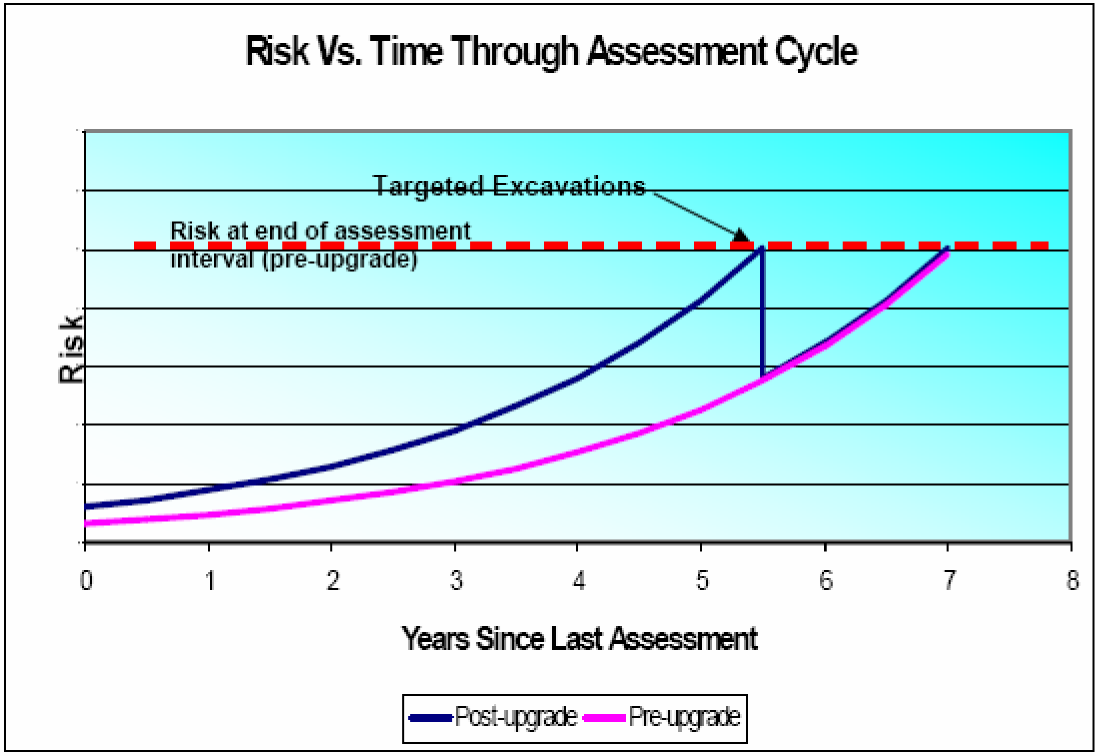
Risk Mitigation Strategies
Assessment Interval Modification

- ***Influence of time-dependent threats:*** ↑ Risk with time.
- Manage risk through Δ assessment interval
  - Goal: *Risk at end of new interval ≤ risk at end of the old interval prior to ↑ P*



Risk Mitigation Strategies
Targeted Excavations

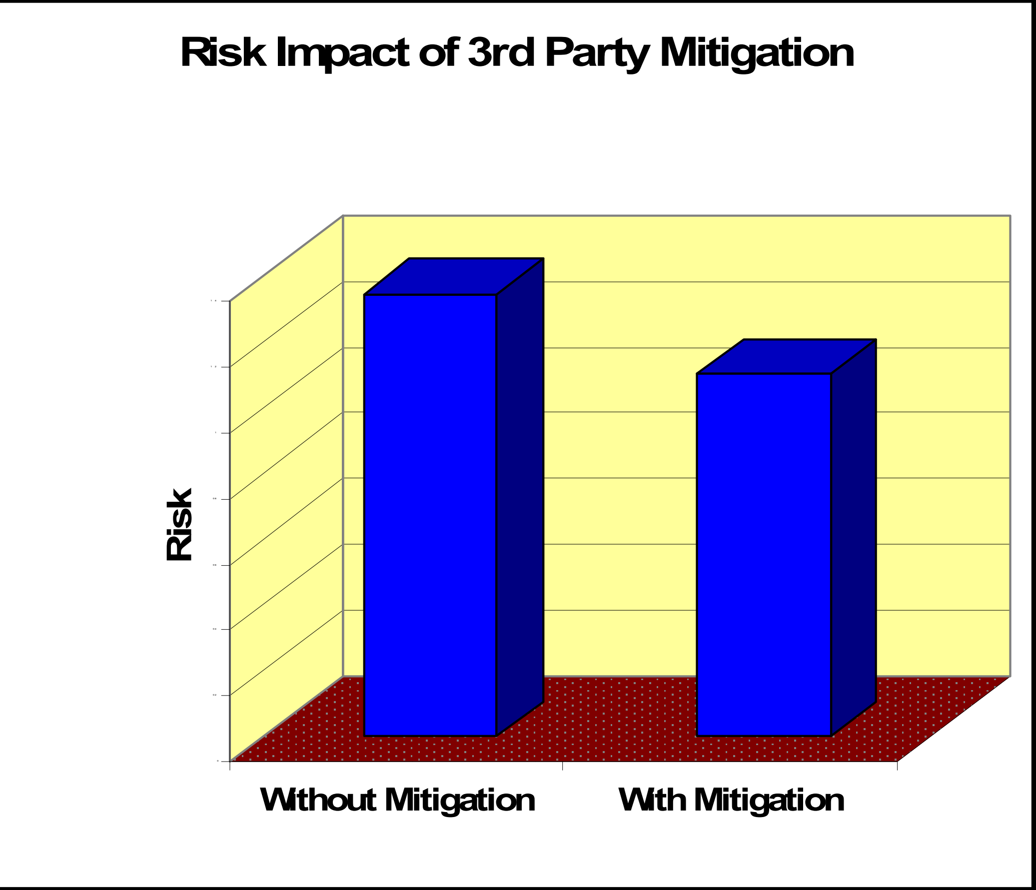
- Risk often dominated by presence of small number (1-3) of features after passage of time
- Manage risk via targeted excavations prior to end of assessment period
  - confirm the size of the features,
  - re-coat or otherwise repair those features



Risk Mitigation Strategies

Additional Measures to Prevent 3rd Party Damage

- Event Tree Modeling » Calculate risk-reduction benefits:
  - Increased signage
  - Installation of pipeline warning tape at crossings
  - Improved one-call response



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Summary

- Approach removes subjectivity from analysis:
  - Methods recognized and accepted in other critical end-use industries
    - nuclear industry
    - aviation industry
  - Employs results of industry-sponsored research (limit state functions)
  - Analysis is defendable without arm-waving
- 10s of millions of dollars in pipe replacement cost savings in Canada
- Focus is on desired results: *Managing risk through adoption of most cost effective risk mitigation solution*
- Consistent with current risk-management focus in DOT-regulated facilities
- Holistic approach - addresses risk along entire length of pipeline segment being subjected to pressure increase (not only confined to HCAs)