
ASSESSMENT OF THE INTEGRITY OF PIPELINES SUBJECT TO CORROSION-FATIGUE AND PITTING CORROSION

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Objectives

ζ Why Physics based probabilistic model?

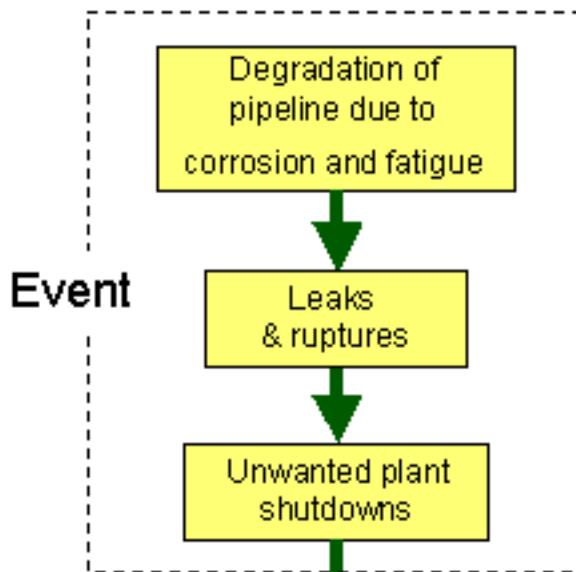
- ψ PoF (Physics of Failure) models capture material degradation and failure mechanism and can be extrapolated to different levels.
- ψ Probabilistic models can adequately represent all of the factors that contribute to variability (e.g. material properties , Inspection devices accuracy, human errors, etc.)

Uncertainty is Certain!

Problem Statement



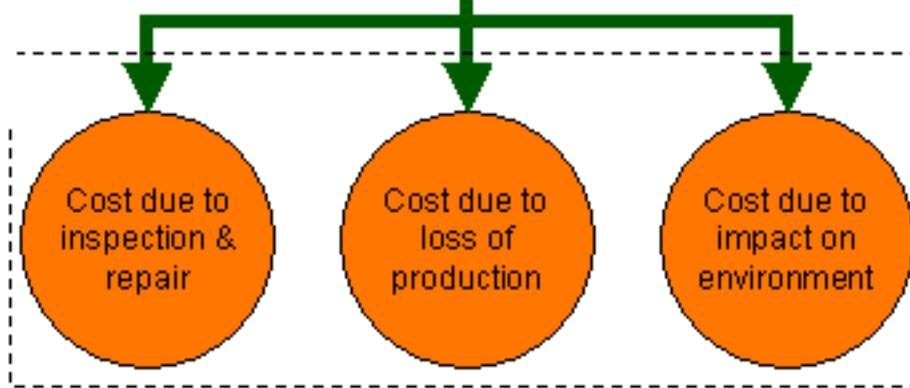
Pitting and Fatigue leading to Pipe Failure - Ductile Iron



Corrosion Inside the Pipe

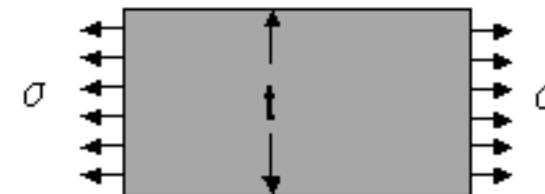
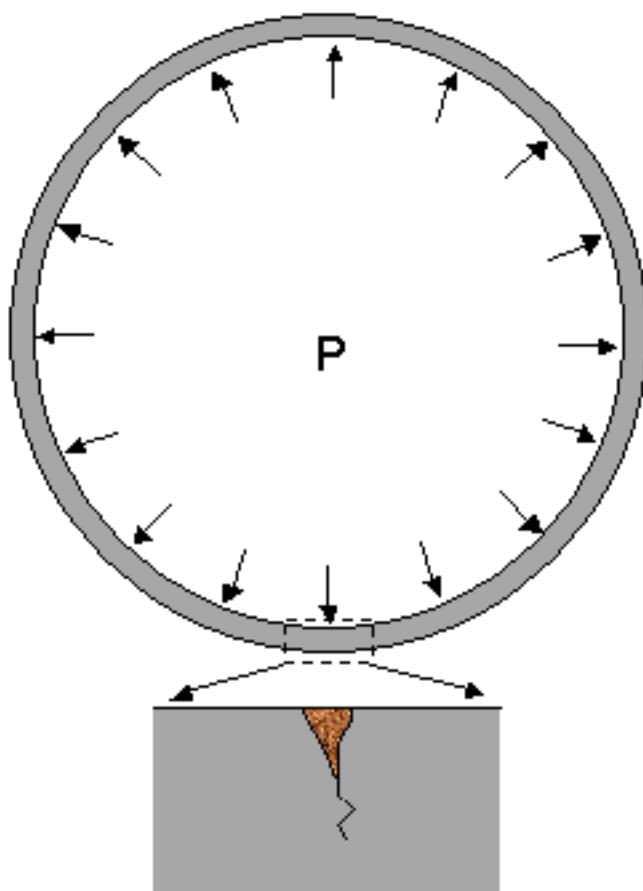
Consequences

Problem:
Cost of corrective maintenance

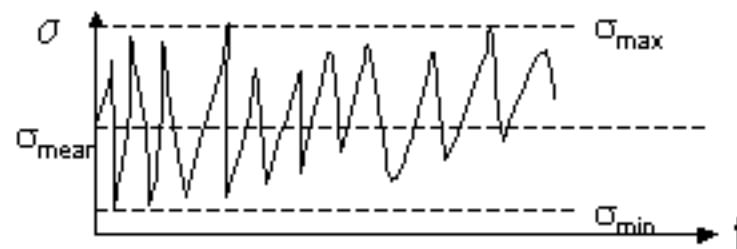
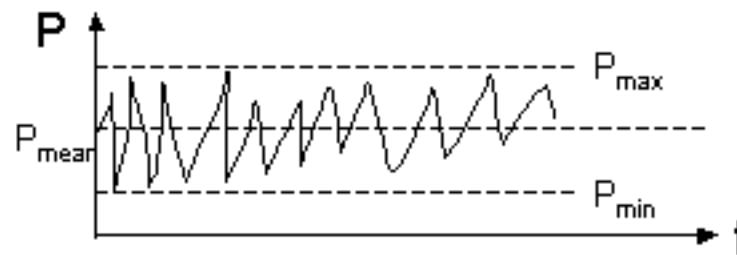


Solution:
Predictive maintenance

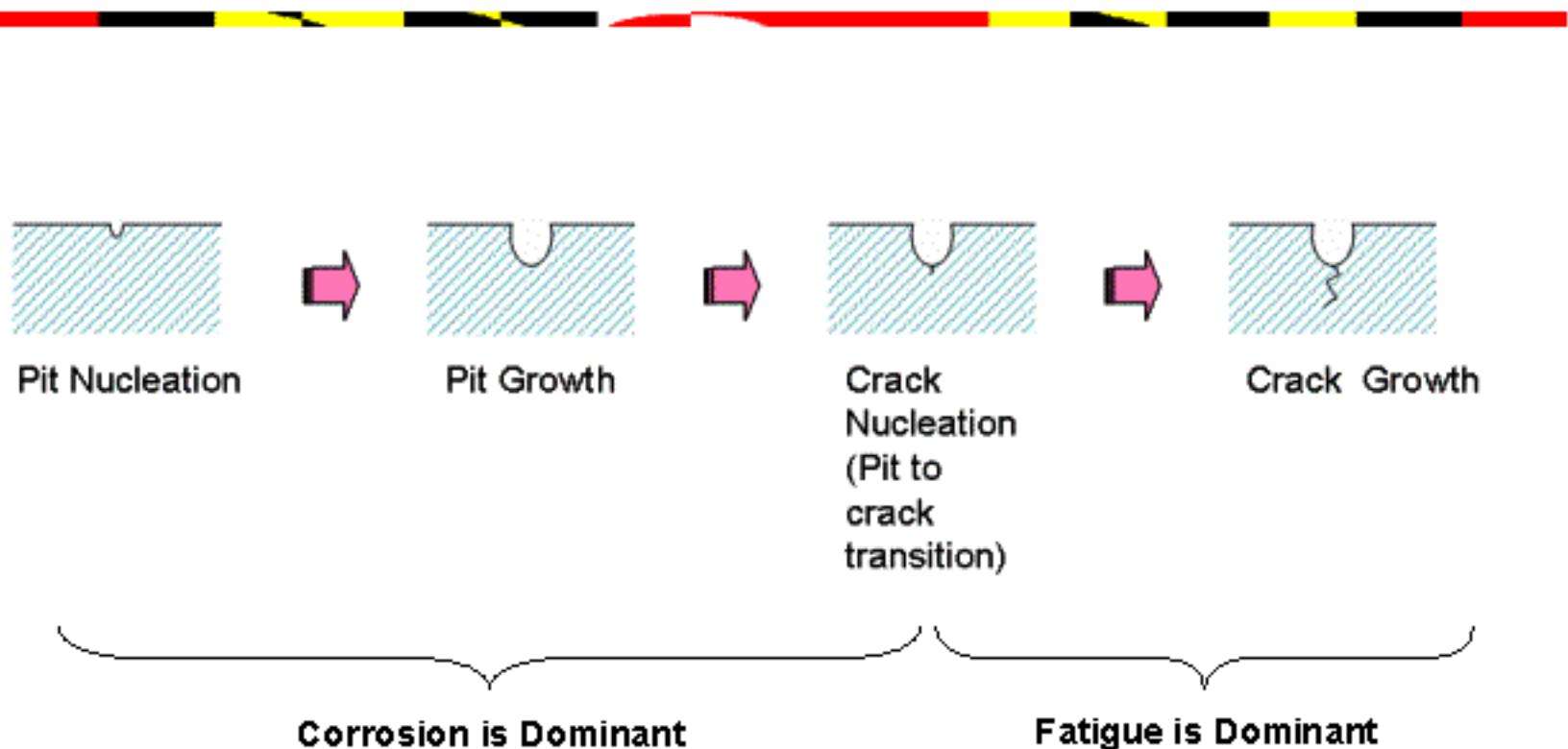
Corrosion-Fatigue in Pipes



$$\sigma = \frac{PD}{2t}; \frac{t}{D} \ll 1; D = \text{diameter}, t = \text{thickness}$$



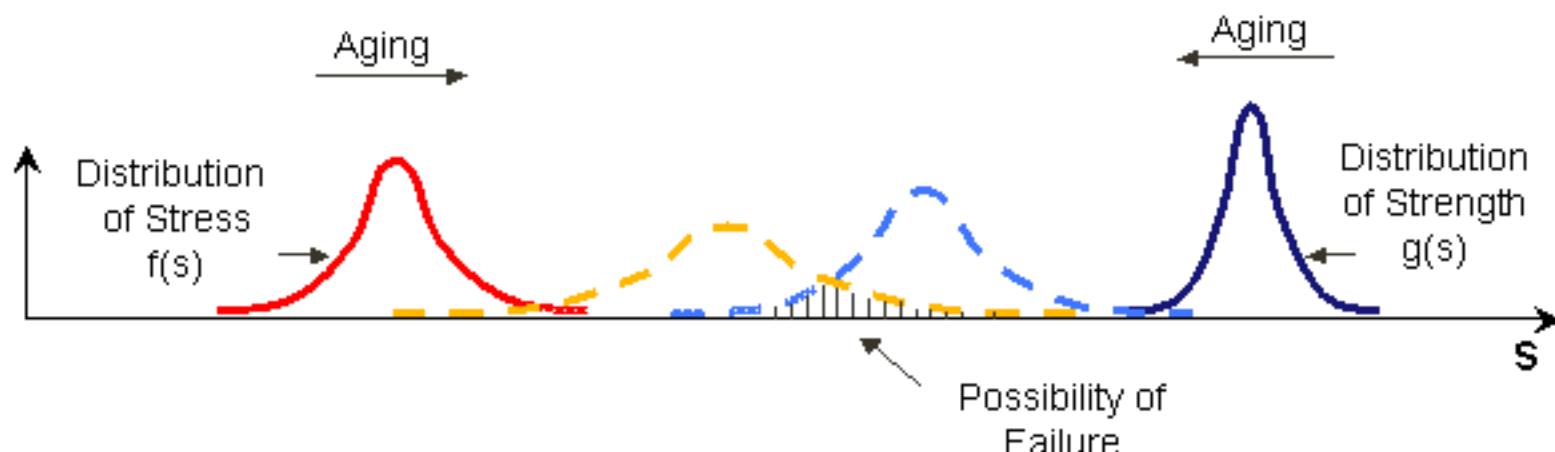
Modeling Approach



The criterion for transition :

$$\left(\frac{da}{dt} \right)_{\text{crack}} \geq \left(\frac{da}{dt} \right)_{\text{pit}}$$

Stress-Strength Interference Reliability Models

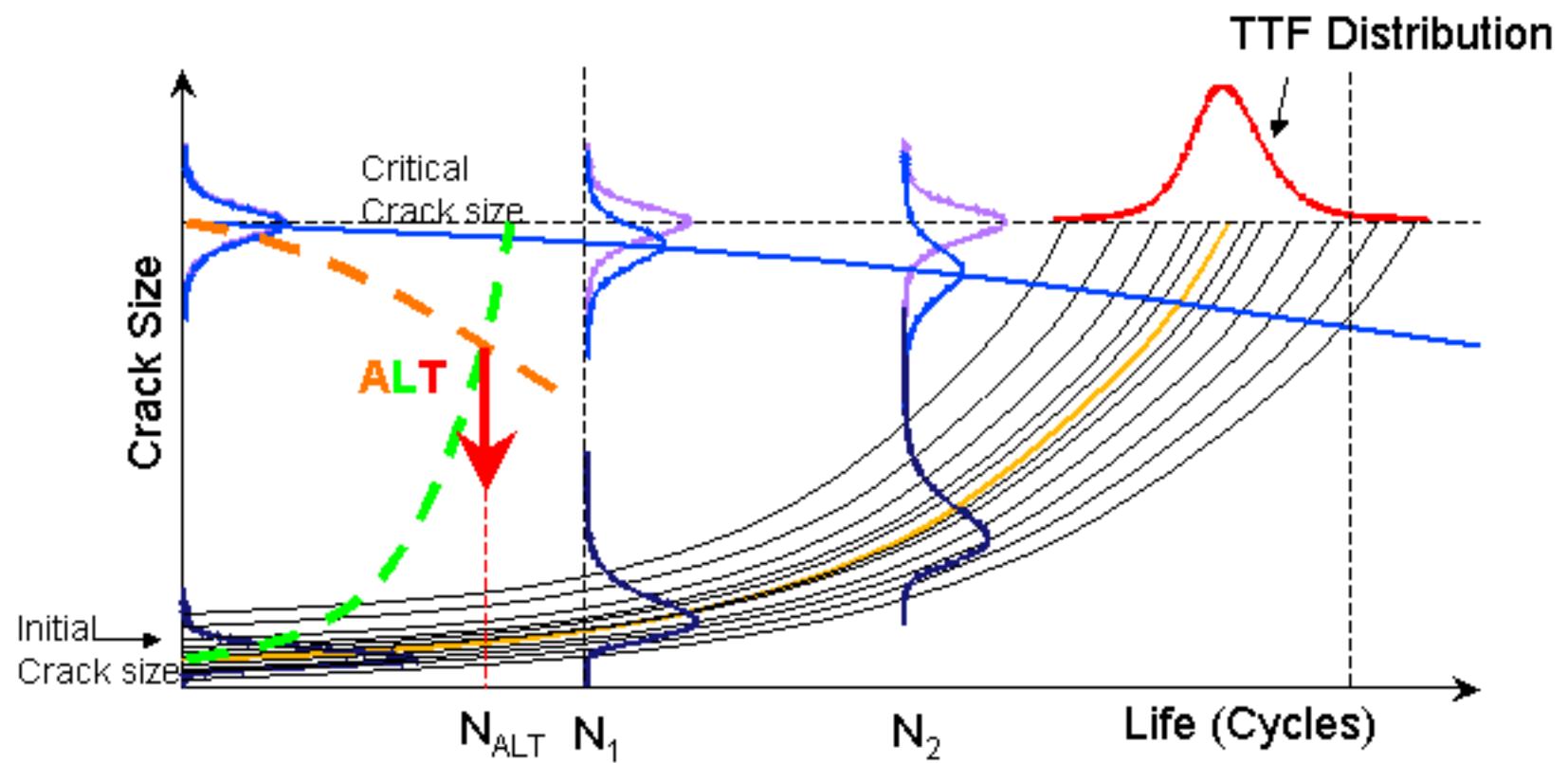


$$P(\text{Stress} > \text{Strength}) = \int_0^{\infty} \left\{ \int_0^s g(x) dx \right\} f(s) ds$$

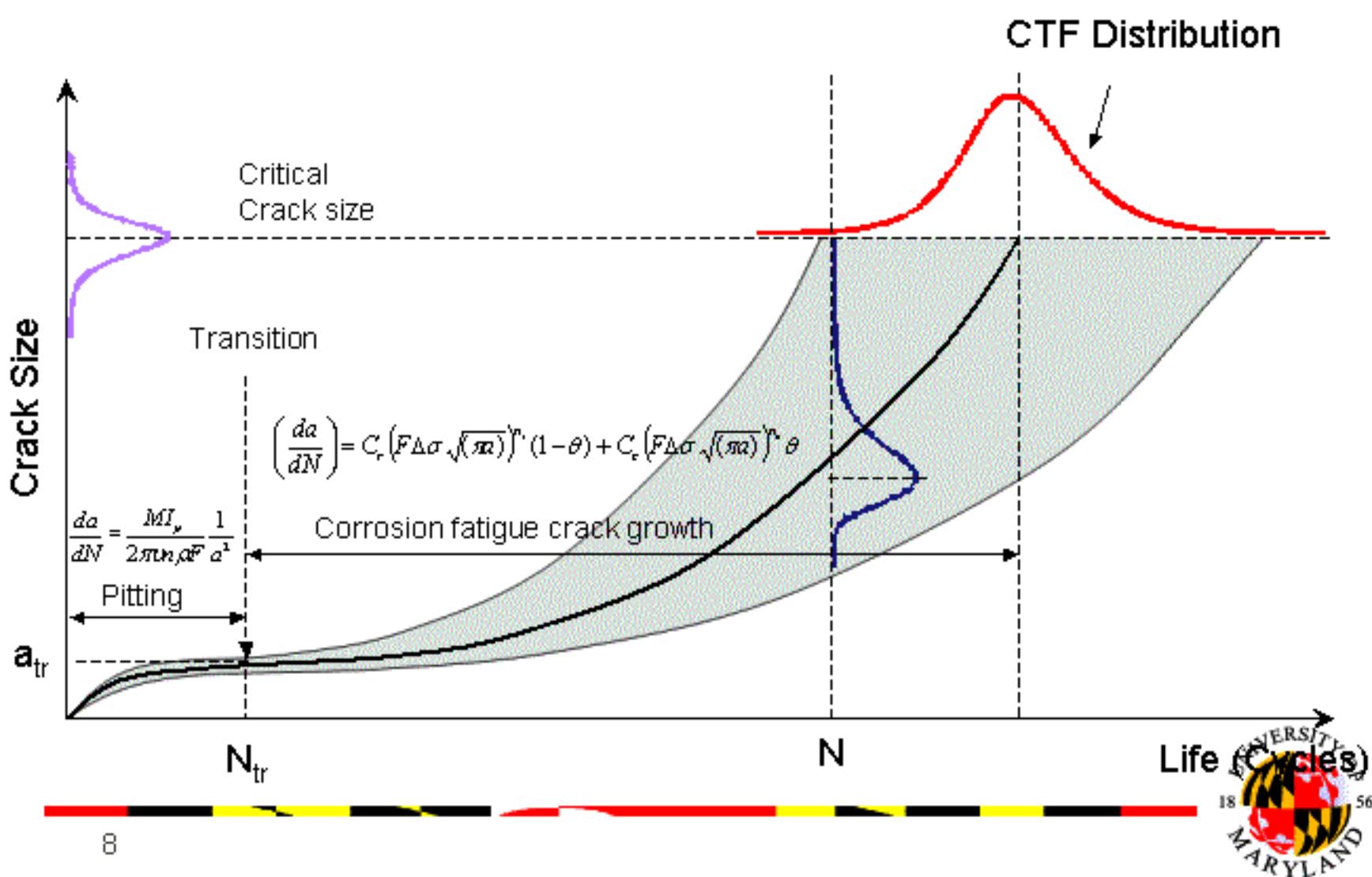
Examples:

- Damage-Endurance Model
- Challenge-Tolerance Model
- Performance-Requirement Model

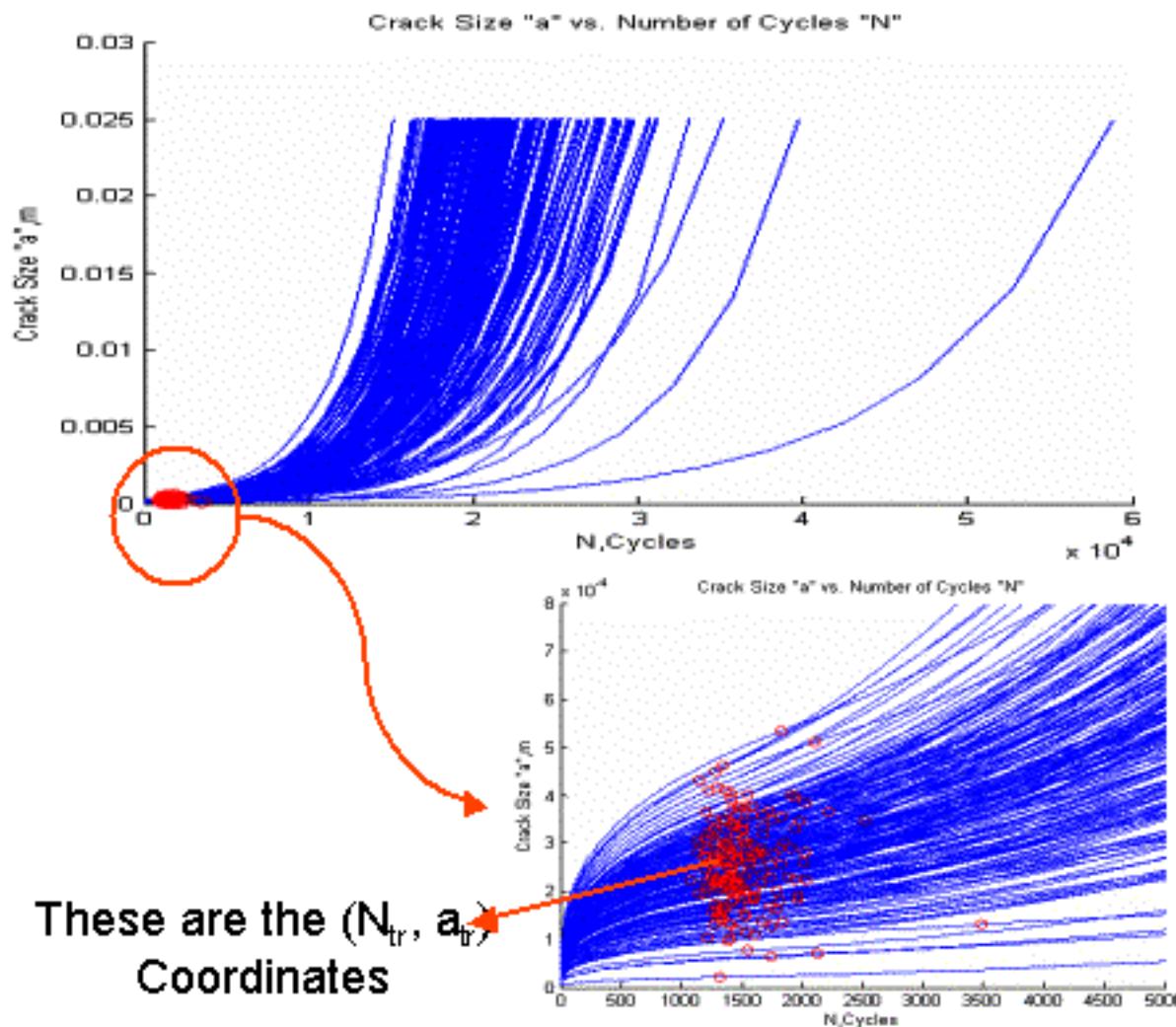
Probabilistic Fracture Mechanics Approach to Fatigue



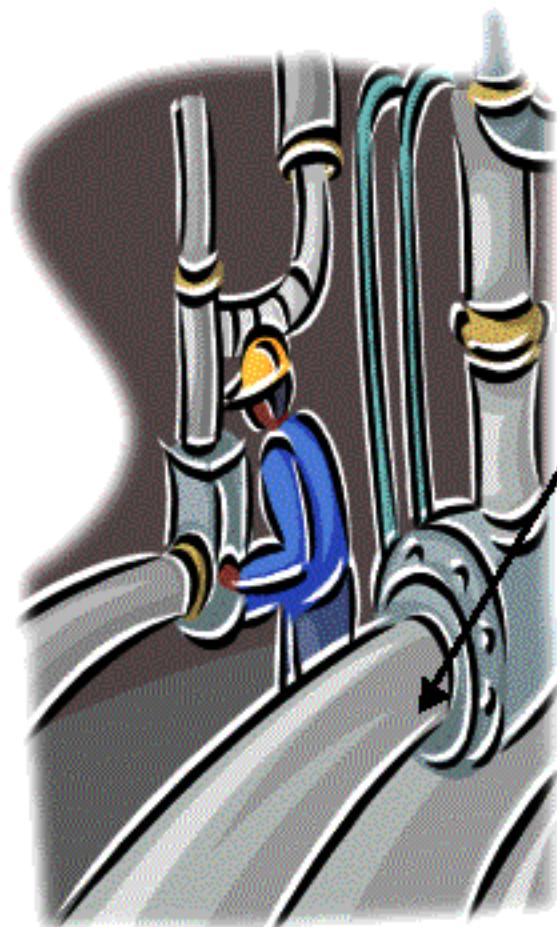
Modeling Outline



Simulation Results



Empirical Model Development



Find the correlation of A & B with the physical parameters of the pipeline:

- Loading Stress “ σ ”
- Loading Frequency “ v ”
- Temperature “ T ”
- Flow Characteristic “C” (e.g., l_p , $[Cl^-]$, pH, ...)

$$Damage, D = f(v_i, t_i | \Theta)$$

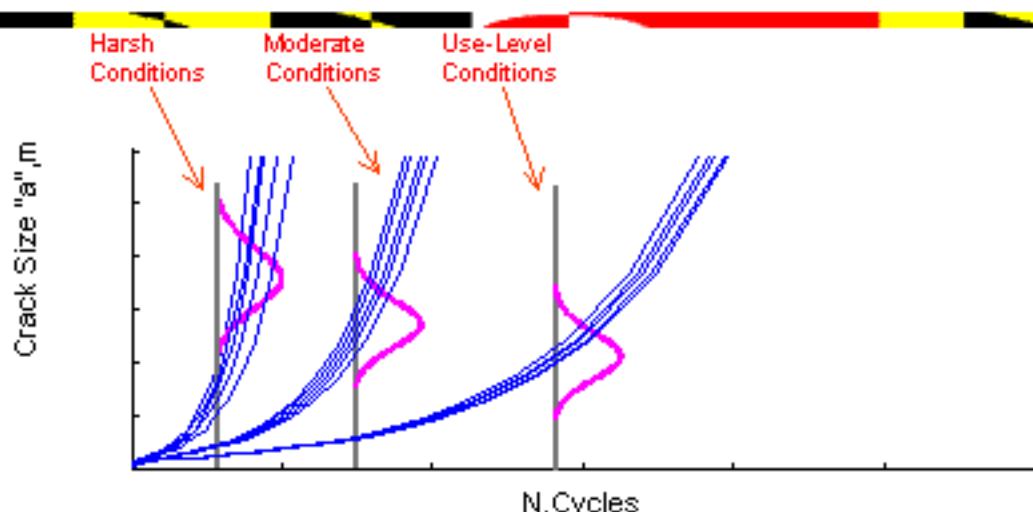
$D \approx$ e.g. crack size, a

$v_i \approx$ variables (e.g. T , σ , v , $[Cl^-]$, ...)

$t_i \approx$ index of time (e.g. N , ...)

$\Theta \approx$ vector of model constants (e.g. $\varepsilon_1, A, B, \dots$)

The Proposed crack size vs. stress, cycle, etc.



$$L(a_i) = LN(\mu_i, \sigma_i)$$

$$\mu_i = \ln[f(s_i, T_i, v_i, I_p, N_i)]$$

$$a = \left[A \cdot s_i^{0.182} \cdot v_i^{-0.288} \cdot I_p^{0.248} \cdot N_i^{1/3} + B \cdot s_i^{3.24} \cdot v_i^{-0.377} \cdot I_p^{0.421} \cdot N_i^2 \cdot e^{(4 \times 10^{-10} \cdot s_i^{2.062} \cdot v_i^{0.024} \cdot N_i)} \right]$$

where a =crack size v =load frequency s =stress amplitude I_p =Current intensity N =cycle Number

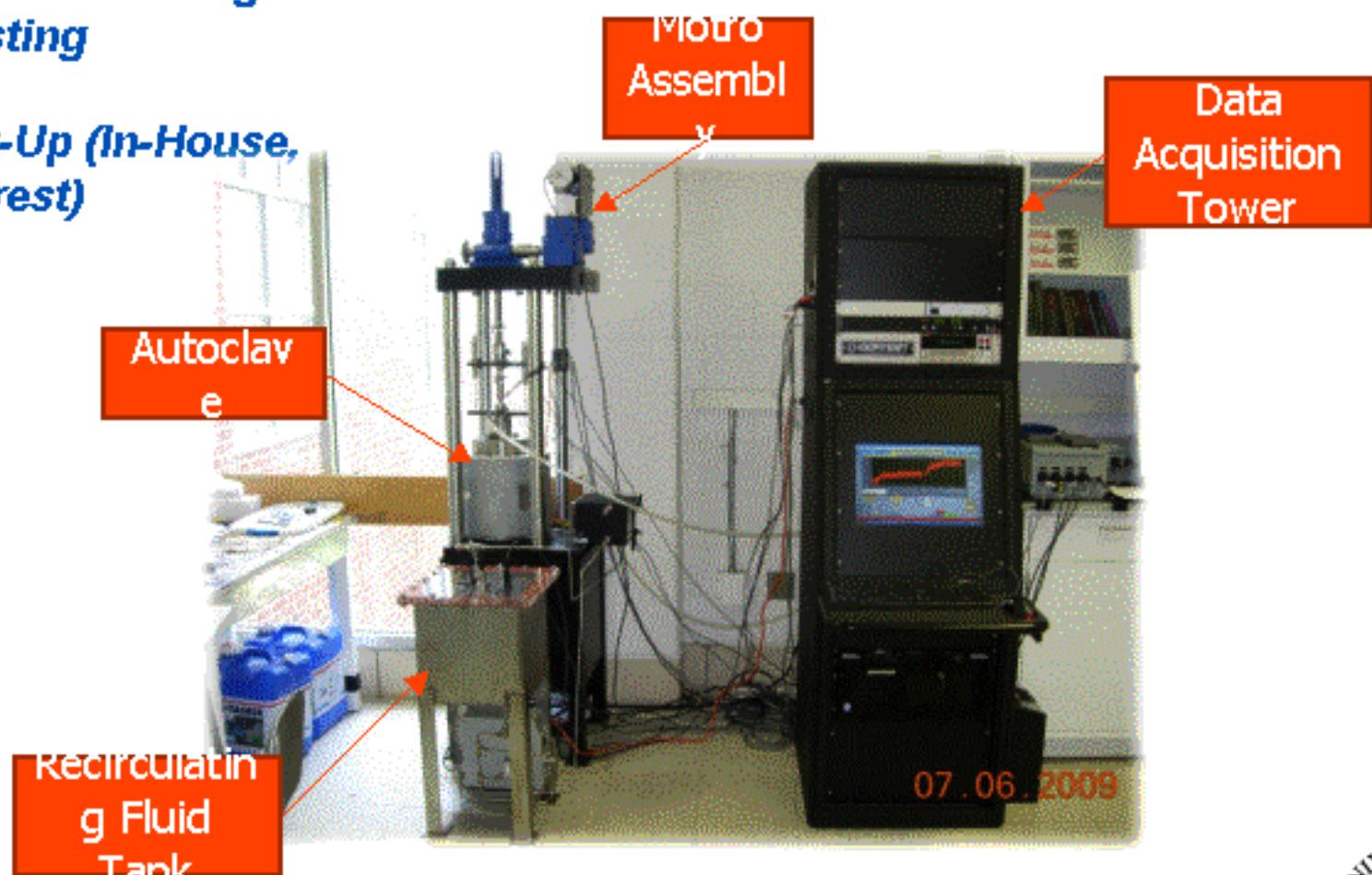
$$L(a) = f(a) = \frac{1}{\sigma \cdot a \sqrt{2\pi}} \exp \left[-\frac{1}{2\sigma^2} (\ln a - \ln (A \cdot s^{0.182} \cdot v^{-0.288} \cdot I_p^{0.248} \cdot N^{1/3} + B \cdot s^{3.24} \cdot v^{-0.377} \cdot I_p^{0.421} \cdot N^2 \cdot e^{(4 \times 10^{-10} \cdot s^{2.062} \cdot v^{0.024} \cdot N)}))^2 \right]$$



Data Collection

Corrosion-Fatigue
Testing

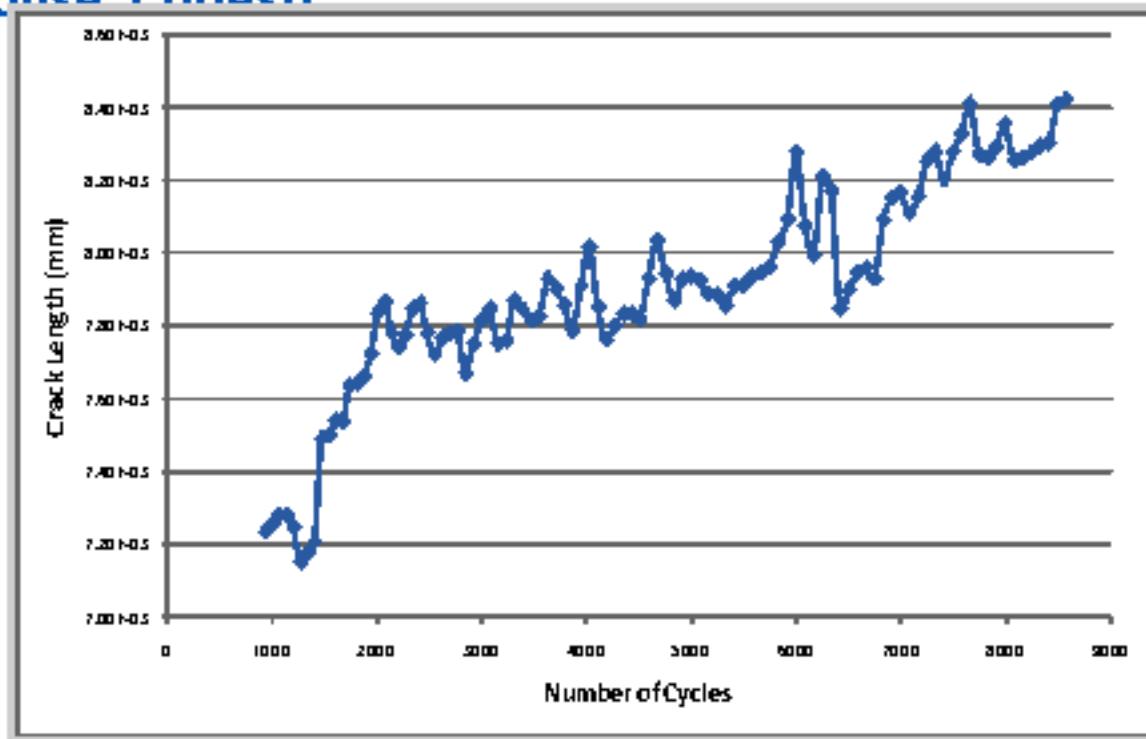
Set-Up (In-House,
Corest)



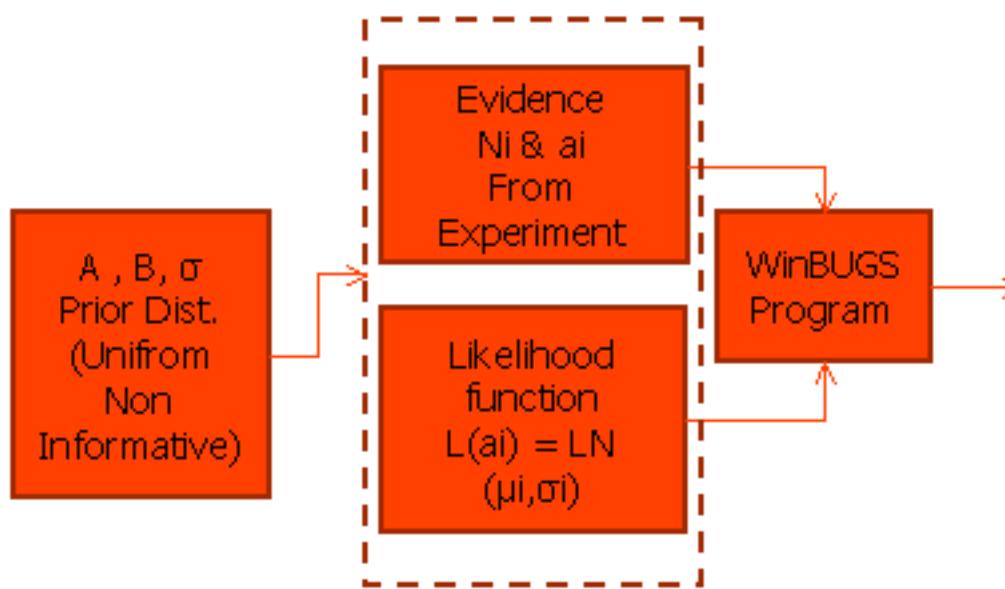
Data Collection

Corrosion-Fatigue
Testing

Data (In-House, Corten)

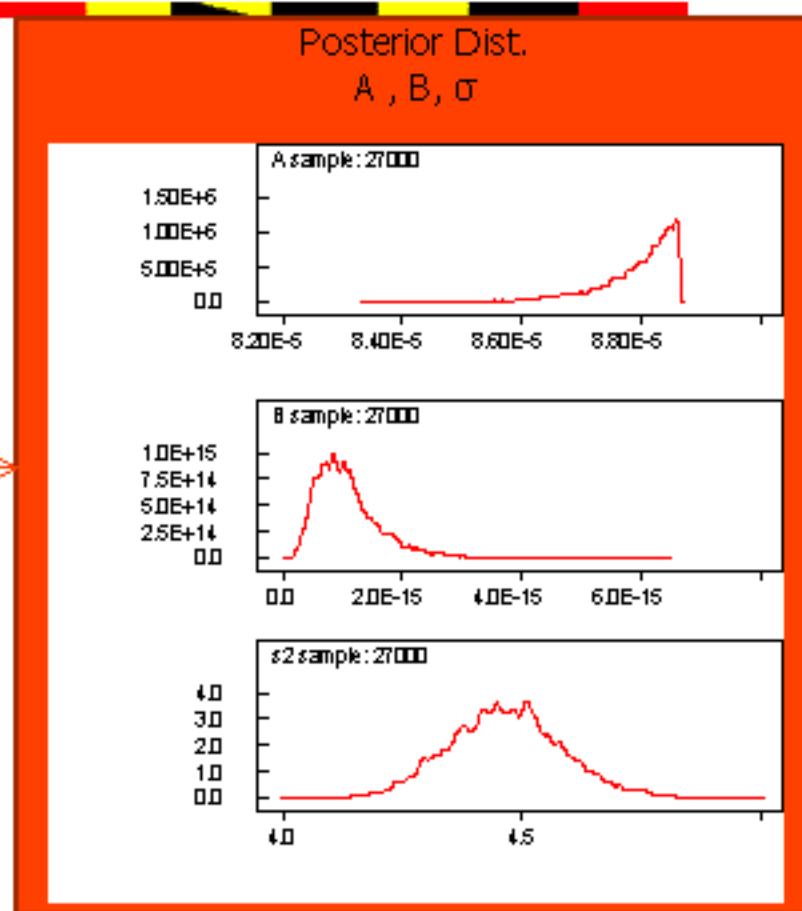


Parameter Estimation



Marginal A & B Longnormal Distribution

$$\begin{aligned}
 A &\left\{ \begin{array}{l} \mu_A = -9.34 \\ \sigma_A = 7.41 \times 10^{-3} \end{array} \right. \\
 B &\left\{ \begin{array}{l} \mu_B = -34.524 \\ \sigma_B = 0.4686 \end{array} \right. \\
 s_2 &\left\{ \begin{array}{l} \mu_{s_2} = 4.468 \\ \sigma_{s_2} = 1188 \end{array} \right.
 \end{aligned}$$

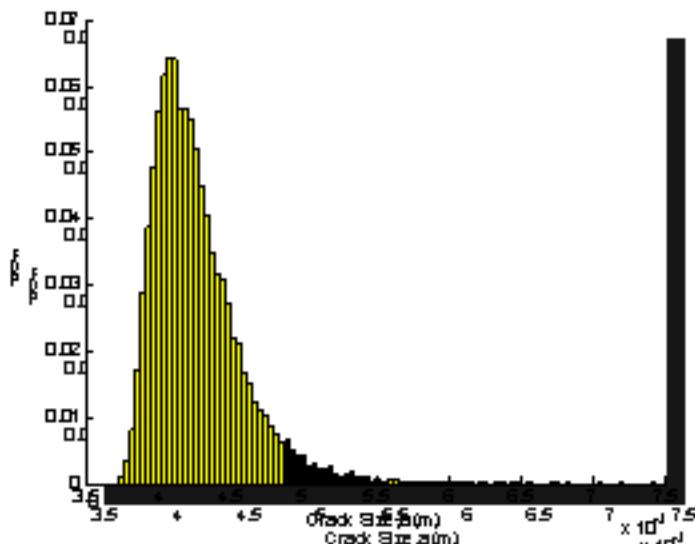


Probability Risk Assessment Application



Run
simulation

Using proposed
Empirical Model



- "a_i" Lognormal distribution:
 $\mu = -5.47$; $\sigma = 0.06$

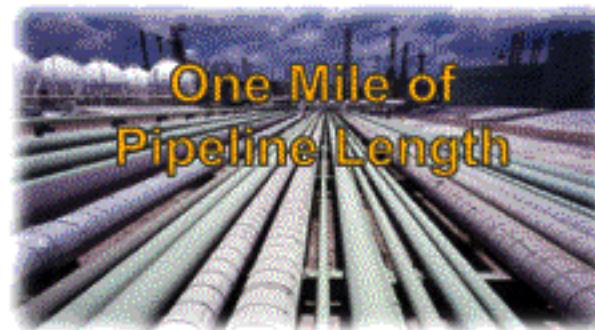
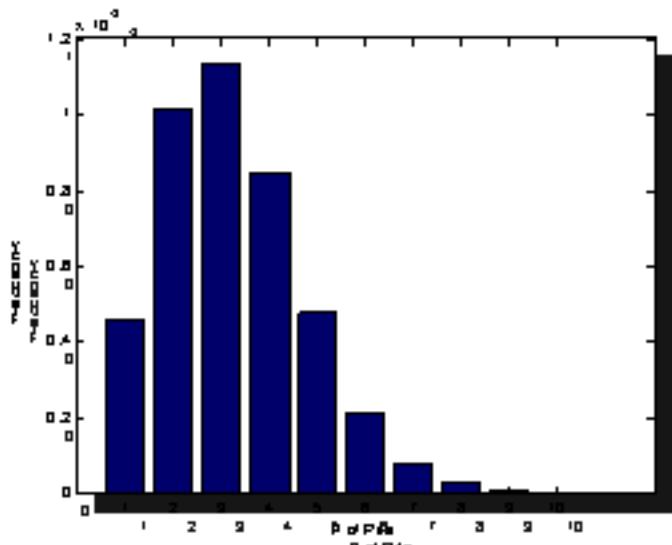
Probability Risk Assessment Application

A harsh pipeline environment:

- Higher Loading Stress



Frequency of Exceedance for Each Observed Number of Pits in the Refinery Pipeline.



The new frequency of exceedance for the bulk pipeline is estimated to be 548 pits/25 yrs life of pipeline!!!! → Drastically Increased

Conclusions

- ❑ A simple physics based empirical model has been proposed that could be globally applied to wide rage of applications in pipes.
 - ❑ The proposed model captured two main degradation processes: firstly the pitting initiation site for cracking and secondly the dominating fatigue crack growth part.
 - ❑ The physical parameters in the proposed model reflect corrosion under aquatic environment
 - ❑ Generic data helped in model development, and Experimental data validated the proposed empirical model through a Bayesian approach.
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