Sandia National Laboratories

PROBABILISTIC FRACTURE MECHANICS TOOLKIT FOR HYDROGEN BLENDS IN NATURAL GAS INFRASTRUCTURE

HyBlend U.S. DEPARTMENT OF ENERGY

HELPR Hydrogen Extremely Low Probability of Rupture

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Overview:

As part of the Pipeline Blending CRADA (a HyBlend™ project), a modular probabilistic fracture mechanics platform coined Hydrogen Extremely Low Probability of Rupture (HELPR) is being developed to assess structural integrity of natural gas infrastructure for transmission and distribution of gaseous hydrogen

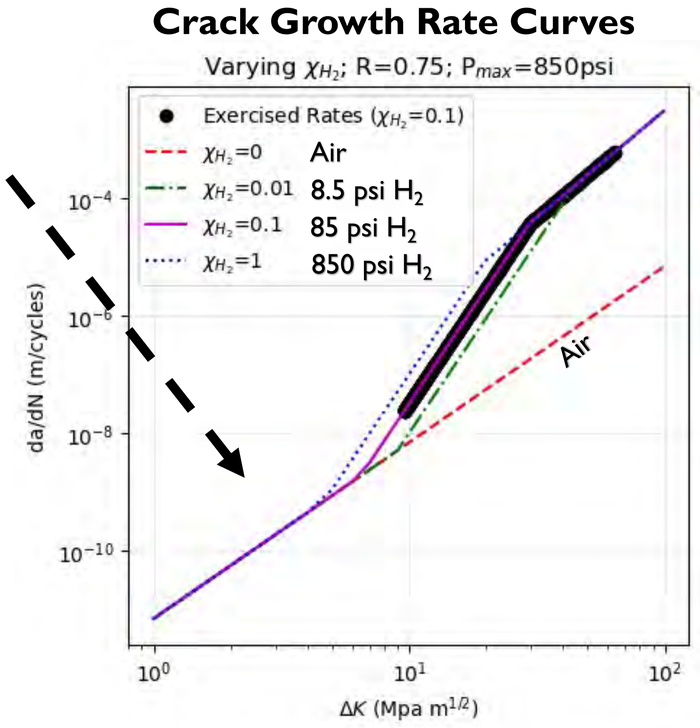
Fracture Mechanics and Fatigue Analysis

Demonstration parameters *(deterministic)*:

- Pipe diameter: 36 in
- Wall thickness: 0.4 in
- Yield strength: 52 ksi
- Fracture resistance: 50 ksi $in^{1/2}$
- Max pressure 850 psi
- Min pressure 638 psi
- R = 0.75
- Cyclic loading (1 cycle/day)
- H_2 vol. fraction: 0.1 (85 psi H_2)
- Flaw depth: 25% through wall (a/t)
- Flaw length: 1.57 in

- Crack growth rates determined using **ASME B31.12 bounding curves** with hydrogen correction term
- Stress intensities calculated using analytical Anderson solutions with work towards API approach and high fidelity flaw modeling
- Reduced-order physics models allow for low cost computations
- Predicts unstable crack size a(crit) and # of pressure cycles to reach

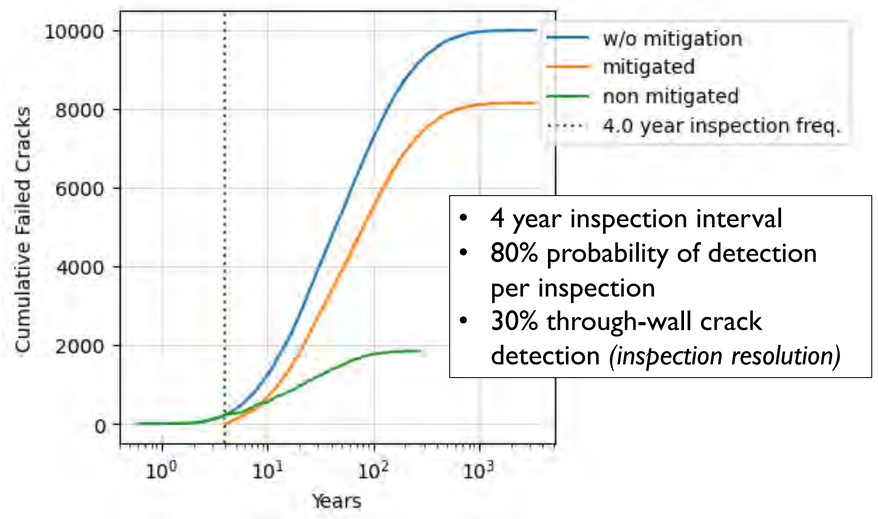
Crack Growth Rate Curves



Failure Assessment Diagram

- Capabilities under development include Failure Assessment Diagrams (**FAD**) to account for multiple failure modes and assessing the impact of inspection schedules

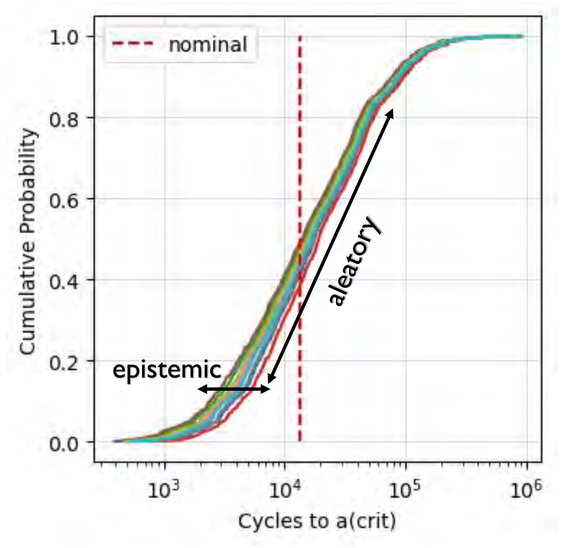
Inspection / Mitigation Assessment



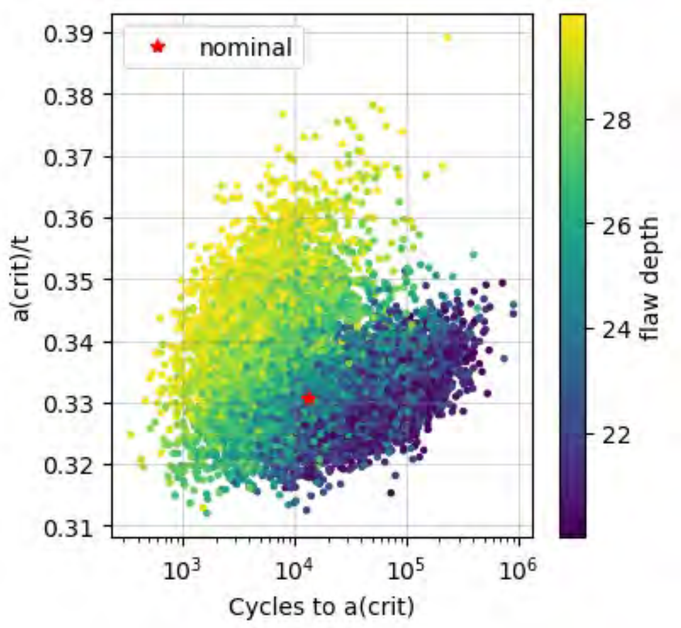
- 4 year inspection interval
- 80% probability of detection per inspection
- 30% through-wall crack detection *(inspection resolution)*

Probabilistic Modeling

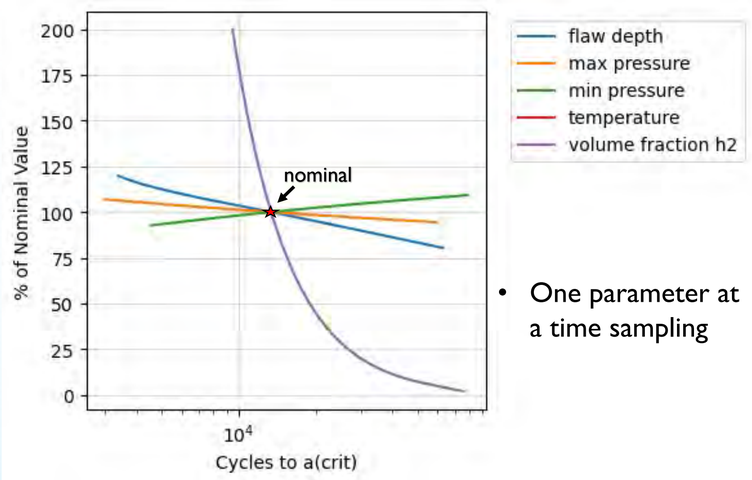
Aleatory & Epistemic Uncertainty



Probabilistic Fatigue Predictions



Sensitivity Studies



- One parameter at a time sampling

Probabilistic parameters *(others remain deterministic)*:

- Max pressure: N(850, 2) psi (*)
- Min pressure: N(638, 2) psi (*)
- Temperature: U(285, 300) K
- H_2 vol. fraction: U(0, .2)
- Flaw depth: U(20, 30) %
- 10,000 samples

(*) Epistemic in mix type figure

- Random sampling of probabilistic characterizations of pipeline structure and operation parameters to characterize uncertainty in predictions
- Supports aleatory (random variability) and epistemic (lack of knowledge) uncertainty characterizations
- Enables sensitivity analysis of uncertain inputs and their impacts on predicted quantities
- Allows for uncertainty and margin informed decision making instead of historical safety factors

Goal:

Inform stakeholders on the structural and operational implications of converting natural gas infrastructure to hydrogen service based on known influence of gaseous hydrogen embrittlement on modern and vintage pipeline steels

U.S. DEPARTMENT OF ENERGY

NNSA National Nuclear Security Administration

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