Bruce Young and Jennifer O'Brian
Battelle Energy Resources
September 28, 2016
Teleconference

https://primis.phmsa.dot.gov/matrix/PrjHome.rdm?prj=390

# The Comprehensive Study to Understand Longitudinal ERW Seam Failures Project

Contract No. DTPH56-11-T-000003
Battelle Project No. 100004552



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# Objective

1. Provide an overview of the project focusing on ***technical accomplishments*** used to advance the state of the art in analytical modeling for axial crack-like defects in oil and gas pipeline.

2. Demonstrate the capabilities of PipeAssess$^{TM}$ which implements these analytical models to provide the owners, operators, and regulators advanced, easy-to-use tools to make decisions on safe operation, repair/replace, and re-inspection intervals.

# Project Review Papers

- B. A. Young, S. Nanney, B. L. Leis, and J. M. Smith, “Overview of a Comprehensive Study to Understand Longitudinal ERW Seam Failures” IPC2014-33226, ASME-IPC 2014, Calgary, Alberta, Canada, September 2014

- B. A. Young, S. Nanney, and J. M. O’Brian, “Review of Phase II for the Comprehensive Study to Understand Longitudinal ERW Seam Failures”, ASME International, IPC 2016, IPC2016-64142, Calgary, Alberta, Canada, September 2016

# Outline

- Project Drivers
- Phase I Overview
- Phase II
  - Task 1 – Improve Hydrotesting Protocols for ERW/FW Seams
  - Task 2 – Enhance Defect Detection and Sizing
  - Task 3 – Defect Characterization: Type, Size, Shape
  - Task 4 – Model Refinement / V&V
- Details of PipeAssess$^{TM}$ (Phase II, Task 5)
- Future Concepts
- Demonstration of PipeAssess$^{TM}$

# Drivers for the Project

- Stemmed from the Carmichael, MS rupture in 2007
- NTSB P-09-01 Recommended Comprehensive Study
  - ERW pipe properties
  - Assess the means to assure the integrity - so they do not fail in service.
- Battelle, KAI, and DNV–Columbus teamed to conduct a comprehensive study to understand longitudinal seam failures in electric resistance welded (ERW) and flash-welded pipes.
- Project started in August 2011
- Phase I completed in January 2014
- Phase II completed in August 2017

# Phase I, Task Organization

**Task 1** History and current practice

- failure history of ERW and FW seams,
- the effectiveness of ILI and hydrotesting, and
- experience with predictive modeling

**Task 2** Experiments designed to better characterize and quantify the resistance of such seams and their response to pressure.

- the validity of predictive models of pipeline failure, and~~,~~
- the viability of ILI and ITD inspection tools.

**Task 3** Focused on selective seam weld corrosion (SSWC).

- literature review and analysis of the results,
- field-deployable method to quantify the susceptibility of a seam to this failure mechanism, and
- guidelines developed to mitigate this mechanism

**Task 4 Summary and Recommendations**

# Phase I, Results

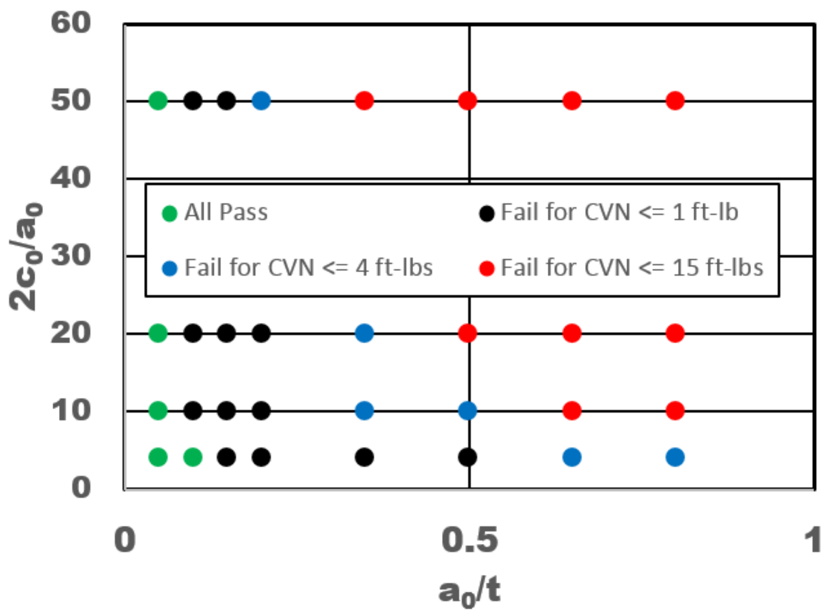
- 17 Public Reports in Phase I (https://primis.phmsa.dot.gov/matrix/PrjHome.rdm?prj=390)
- 11 Specific Recommendations
  - Six (6) on Condition Assessment via ILI or Hydrotesting
  - Three (3) on Predictive Models
  - One (1) on Local Mechanical and Fracture Properties
  - One (1) on Aging Pipelines
- 2 Presentations: 2014 PRCI Research Exchange Meeting
- 5 Presentations: 2014 ASME IPC

# Outline

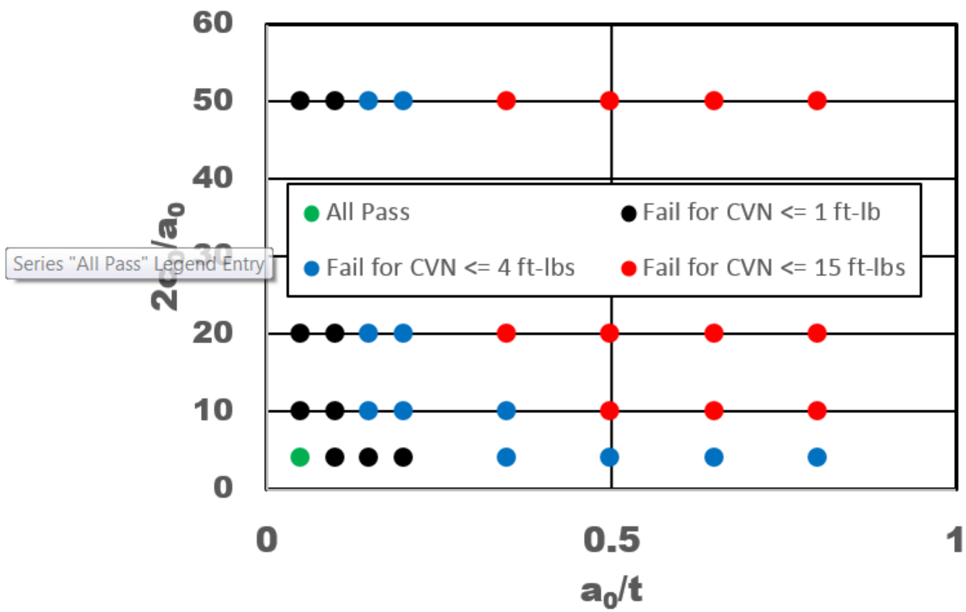
- Phase II
  - Task 1 – Improve Hydrotesting Protocols for ERW/FW Seams
  - Task 2 – Enhance Defect Detection and Sizing
  - Task 3 – Defect Characterization: Type, Size, Shape
  - Task 4 – Model Refinement / V&V
  - Task 5 – Integrity Management Software

  - Each Task produced a report
  - Phase II completed in August 2017

# Task 1 – Hydrotest Protocols




**X42 Base Case (110% SMYS @ 60 min + 90% SMYS @ 24 hr)**




**X80 Base Case (110% SMYS @ 60 min + 90% SMYS @ 24 hr)**

Details can be found in the following paper:

R. J. Olson, B. L. Leis, and B. A. Young, “Findings from an Investigation of Hydrotest Protocols”, ASME International, IPC 2016, IPC2016-64146, Calgary, Alberta, Canada, September 2016

# Task 2, ILI & ITDM

- 90+ cracks deeper than 25% NWT collected
  - Traditional ITDM and IWEX used
- Largest cracks installed in Battelle's Ø16" ILI pull rig
  - EMAT and transverse MFL used
- 19 crack sets identified for validation
  - 2 cracks false positives via MPI and Shear Wave
  - 17 crack sets underwent metallography

Seam Weld Anomaly (SWA) #1

*SWA #1 leaking during lab hydrotest*

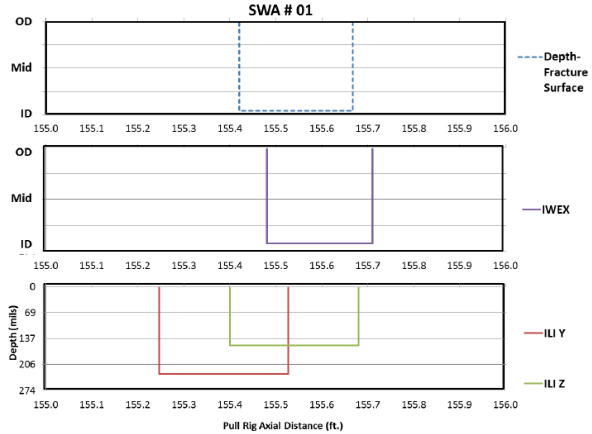
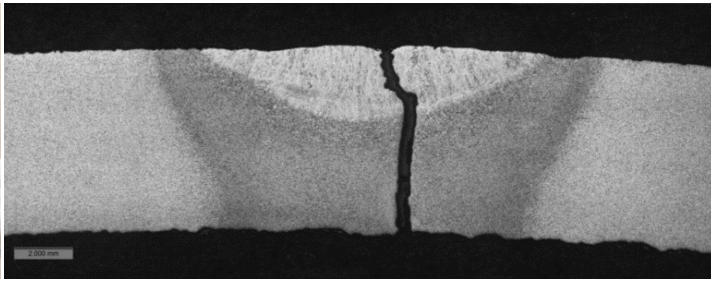



**Figure 7. Depth profile and inspection results of SWA #1**

*SWA #1 axial profile showing 99% NWT depth*

*Inspection call comparisons of SWA #1*



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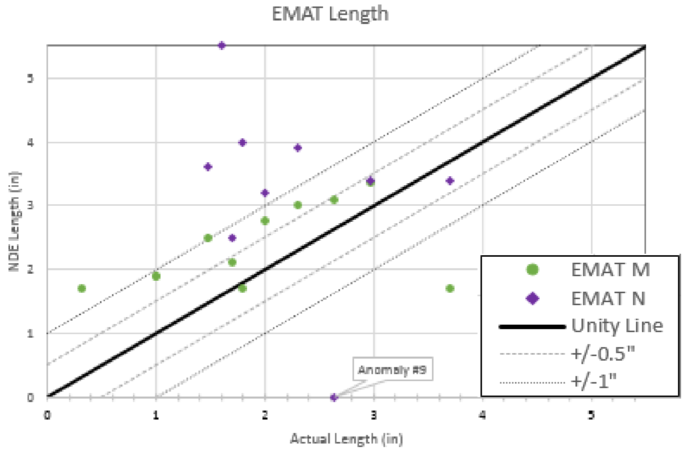
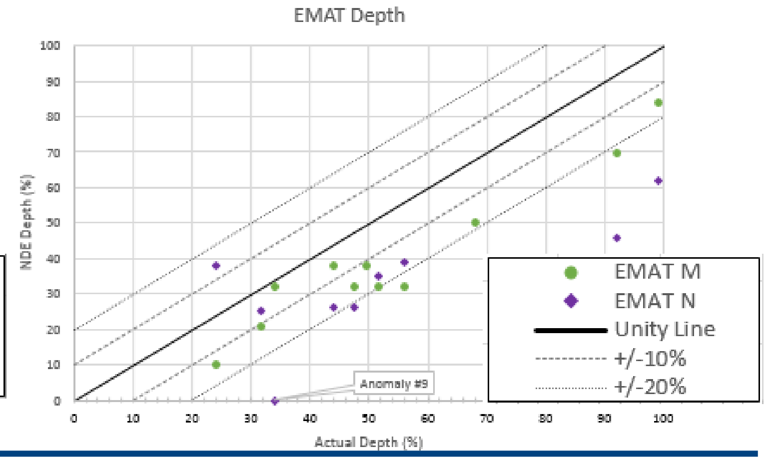
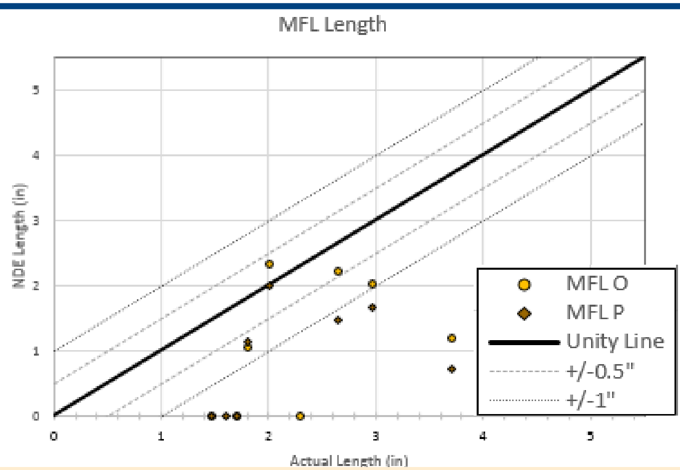
# Task 2, ILI & ITDM

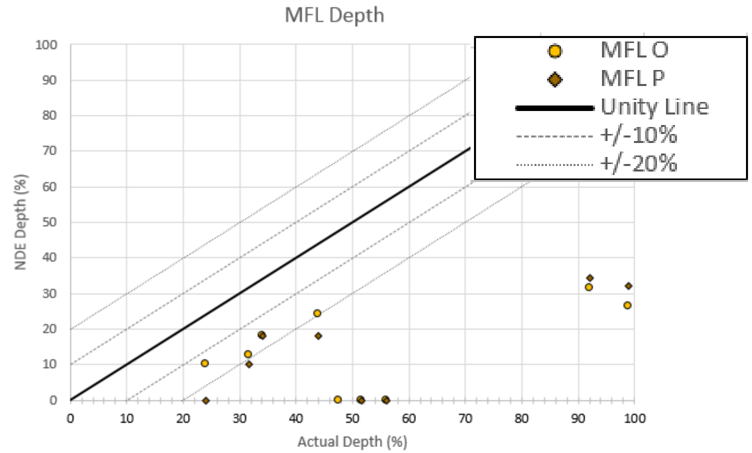
EMAT




MFL

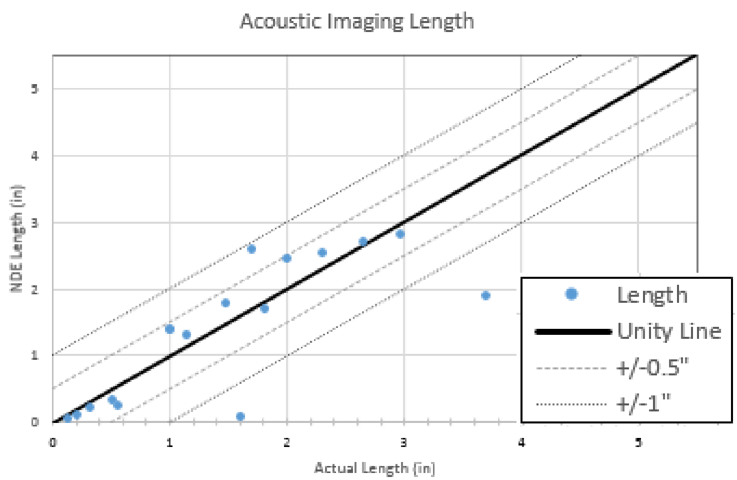


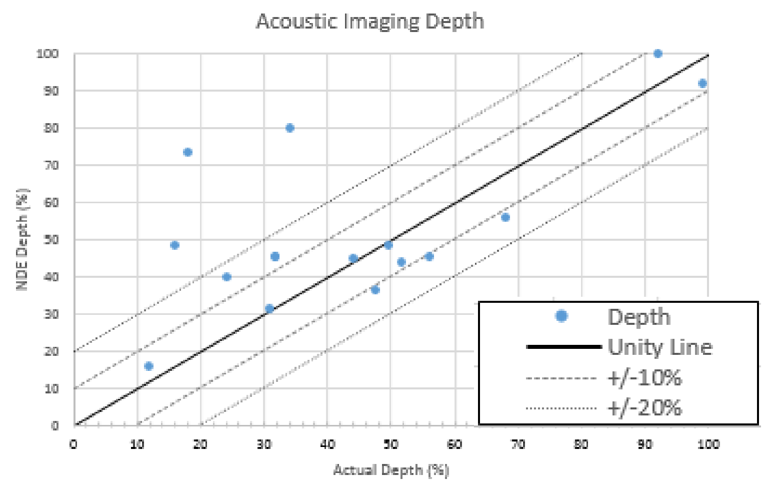




- ➢ EMAT & transverse MFL PODs exceed or on target with system specification
- ➢ EMAT tends to oversize length & undersize depth
- ➢ Transverse MFL offers complementary role to EMAT crack sizing

  (e.g. screen for innocuous features like excess trim, identify long seam & pipe fab process, etc)

# Task 2, ILI & ITDM




- Acoustic Imaging length calls can be accurate
  13 of 16 simple anomalies' lengths within +/- 0.5".
  Two of the remaining were undersized
- Acoustic Imaging depth generally reliable
  13 of 16 simple anomalies' depths within +/-18%.
  Remaining three oversized



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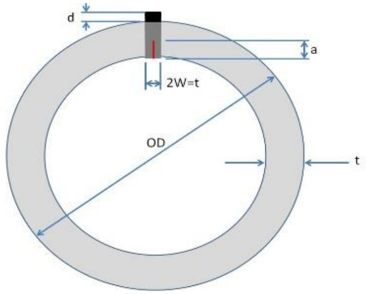
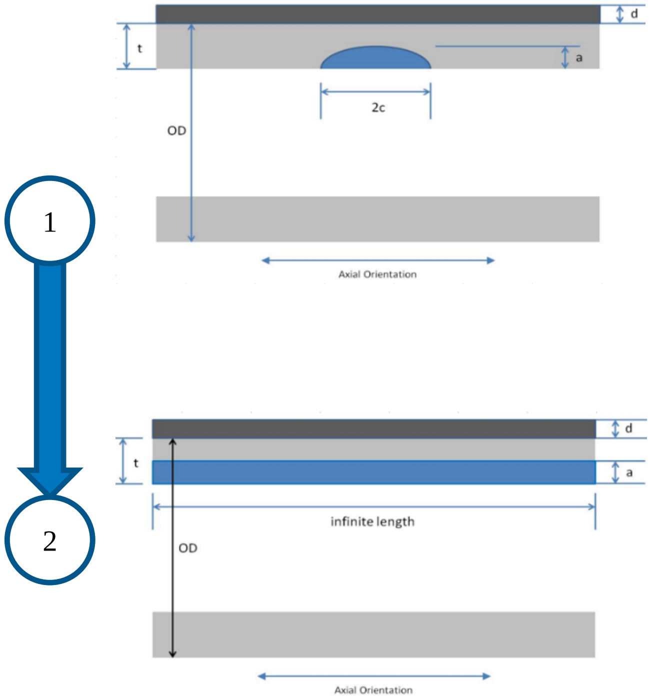
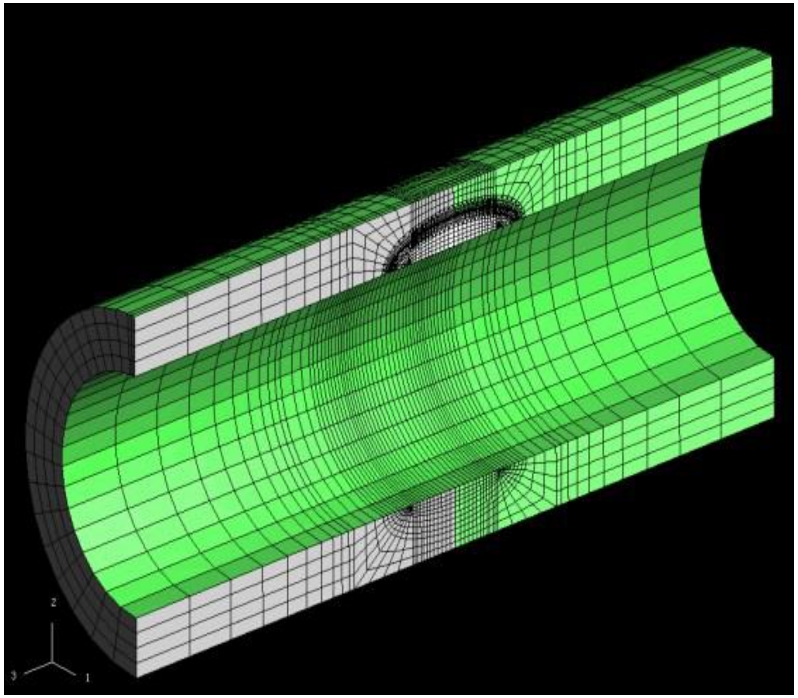
# Task 3, Defect Characterization

- Analytical modeling of failure requires detailed characterization of flaws
- Defect Characterization: Type, Size, Shape
- Required to complete Tasks 1, 4, and 5
- Major shapes (hook, stitching, SSWC,…etc.)
- Characterized shapes by calculating linear elastic stress intensity values (K)

# Task 3, Defect Characterization





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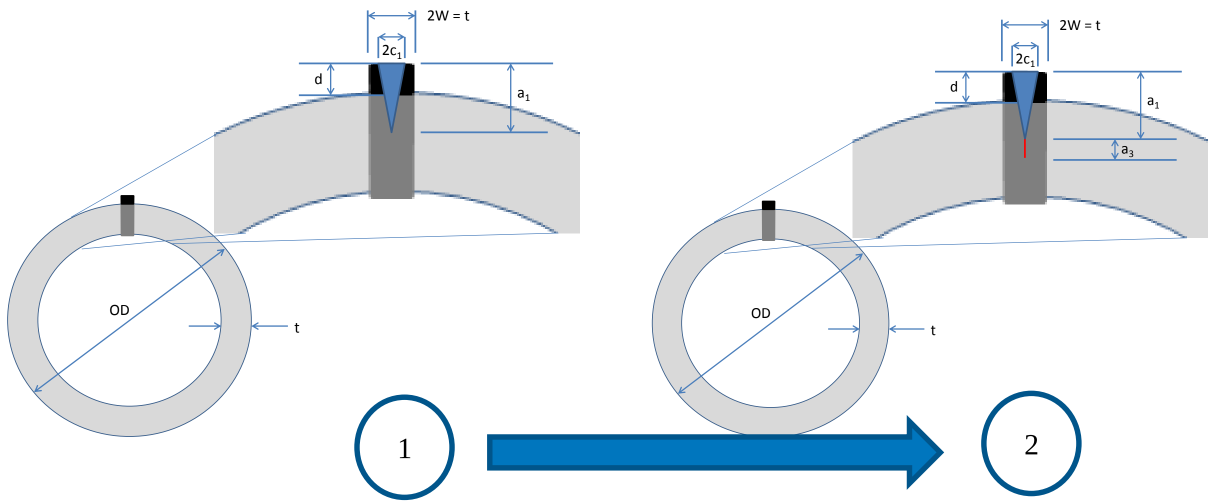
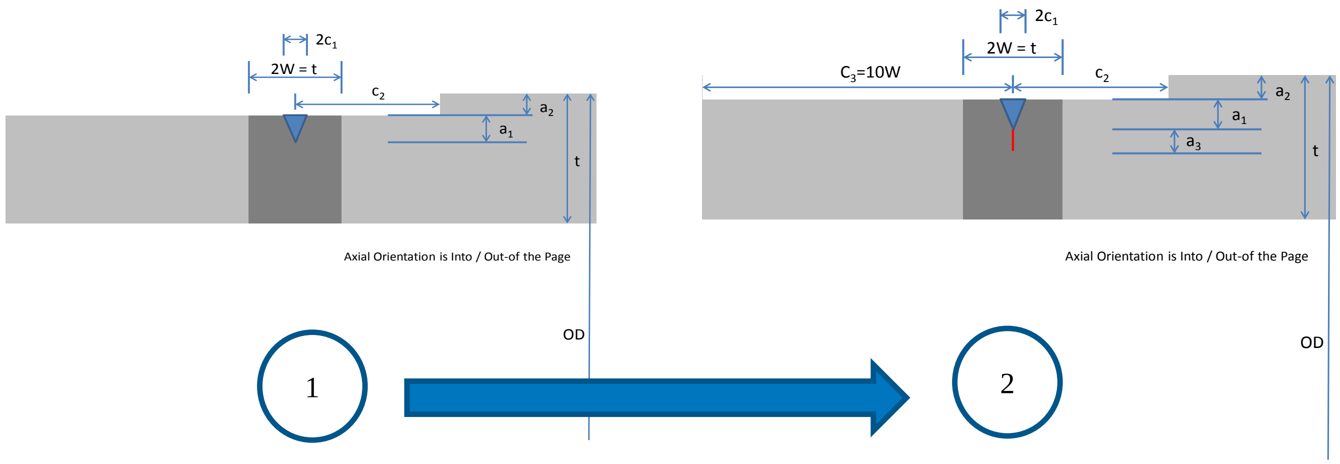
# Task 3, Defect Characterization



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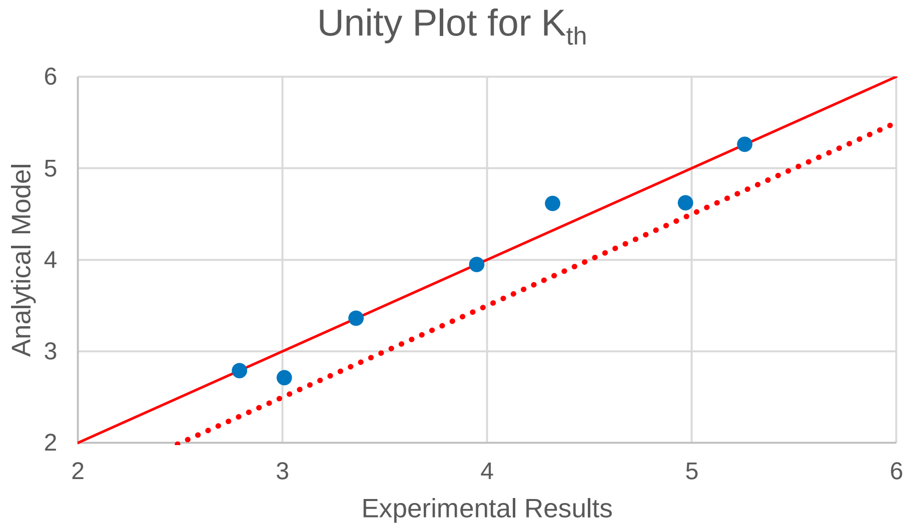
# Task 4, Model Refinement

- Explicit Models Developed / Implemented
- Fracture
  - Plastic Collapse, Tearing, and Brittle Fracture
  - Hook Cracks – growth perpendicular to hoop stress
- Crack Growth / Retardation
  - Paris Law with threshold values
  - Walker model to account for stress-ratio effects
  - Willenborg model to account for overloads
- Account for explicit hydrotests
- Account for semi-explicit (block loading) fatigue cycles

# Task 4, Model Refinement

- Threshold Values




$$K_{th} = R(m_1 SMYS + b_1) + m_2 SMYS + b_2 - \delta$$

$$\delta = \begin{cases} 1 \; for \; weld \\ 0 \; for \; base \end{cases}$$



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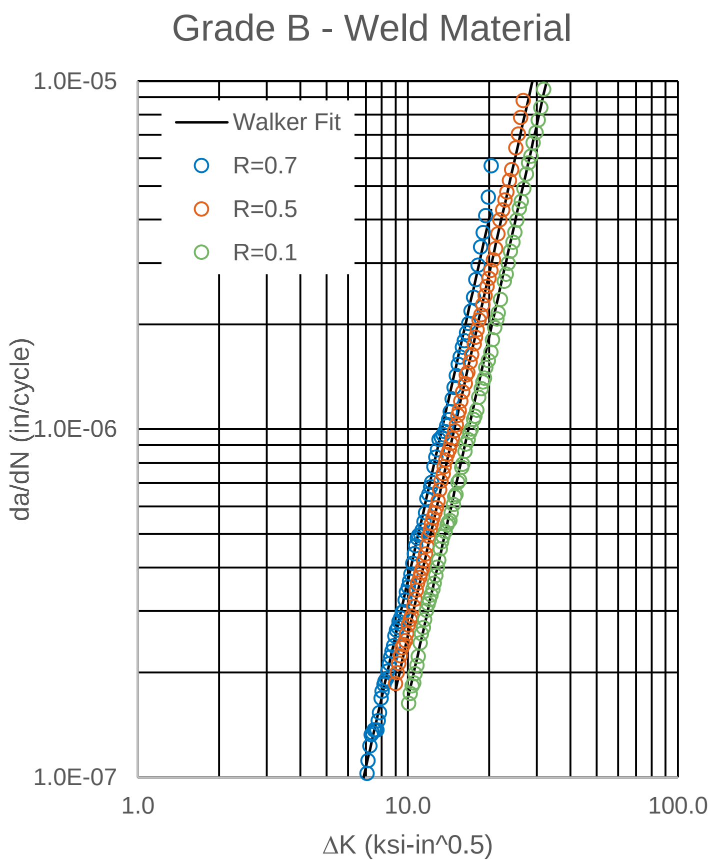
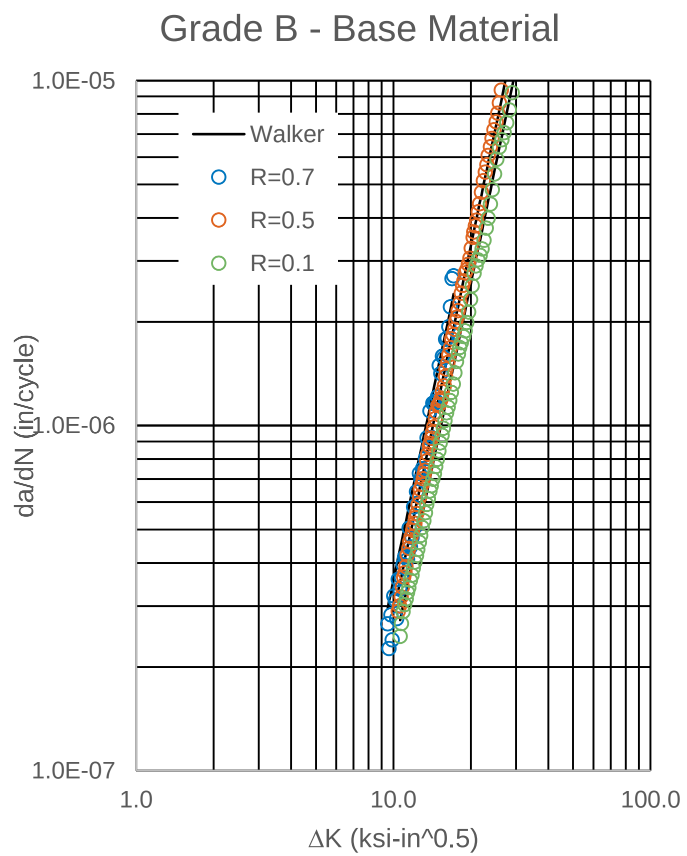
# Task 4, Model Refinement

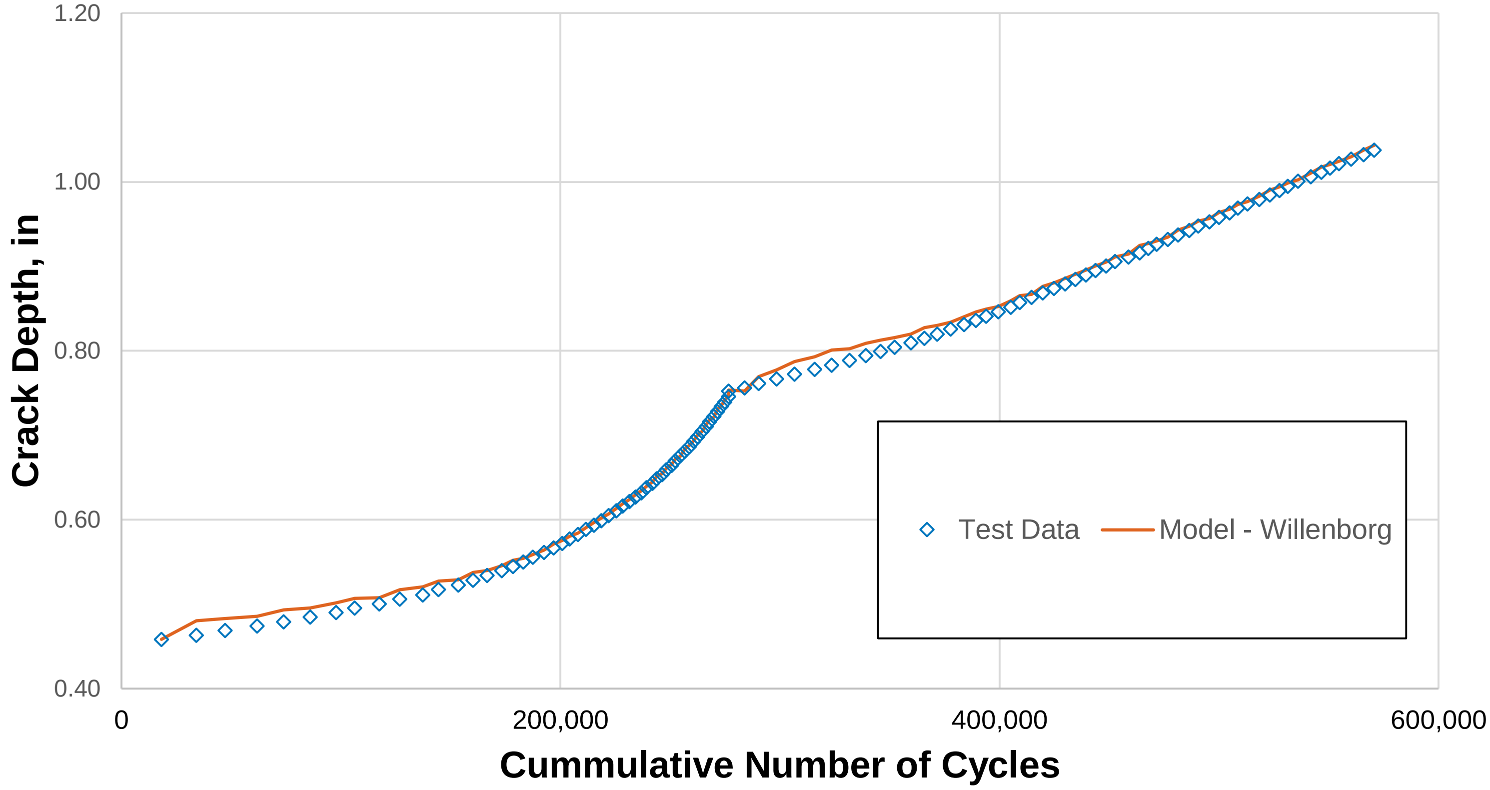
- Walker Model

$$\frac{da}{dN} = C\left[\frac{\Delta K}{(1-R)^{(1-m)}}\right]^n$$



# Task 4, Model Refinement



# Task 4, Current Status

- Models have been Implemented
  - Fracture (Brittle, Ductile, Plastic Collapse…)
  - Fatigue Crack Growth
    - Walker with Threshold Concept
    - Willenborg
  - Creep (Stress-Induced) Crack Growth
- Lab-Scale Testing Complete
- Full-Scale Testing being planned

# TASK 5 PipeAssess PI$^{TM}$ Overview

- Overall, this software is designed to directly determine:
  - critical crack size for a given operating pressure, applied as either a constant pressure or cyclic load, or
  - failure pressure for a given flaw size.
- Crack growth mechanisms can either be
  - time-dependent (i.e. Fatigue Crack Growth or Creep)
  - time-independent (Tearing), or
  - both
- PipeAssess$^{TM}$ can be used to evaluate remaining life of pipe and similar cylindrical pressure vessels with pre-existing axial crack-like defects. Note that this program does not initiate cracks from defect-free material; an initial flaw size is required input. (i.e. Flaw Tolerant Approach)

# Overview Continued

- The fracture mechanics theory for both time independent and time-dependent crack growth are theoretically consistent with:
  - NG-18 report 193
  - NG-18 report 194
- The founding principles revolve around long-established and respected J-tearing theory within elastic–plastic material behavior and Paris Law behavior for fatigue. The time-dependent nature (i.e. creep) of a simulated hydrotest is also captured

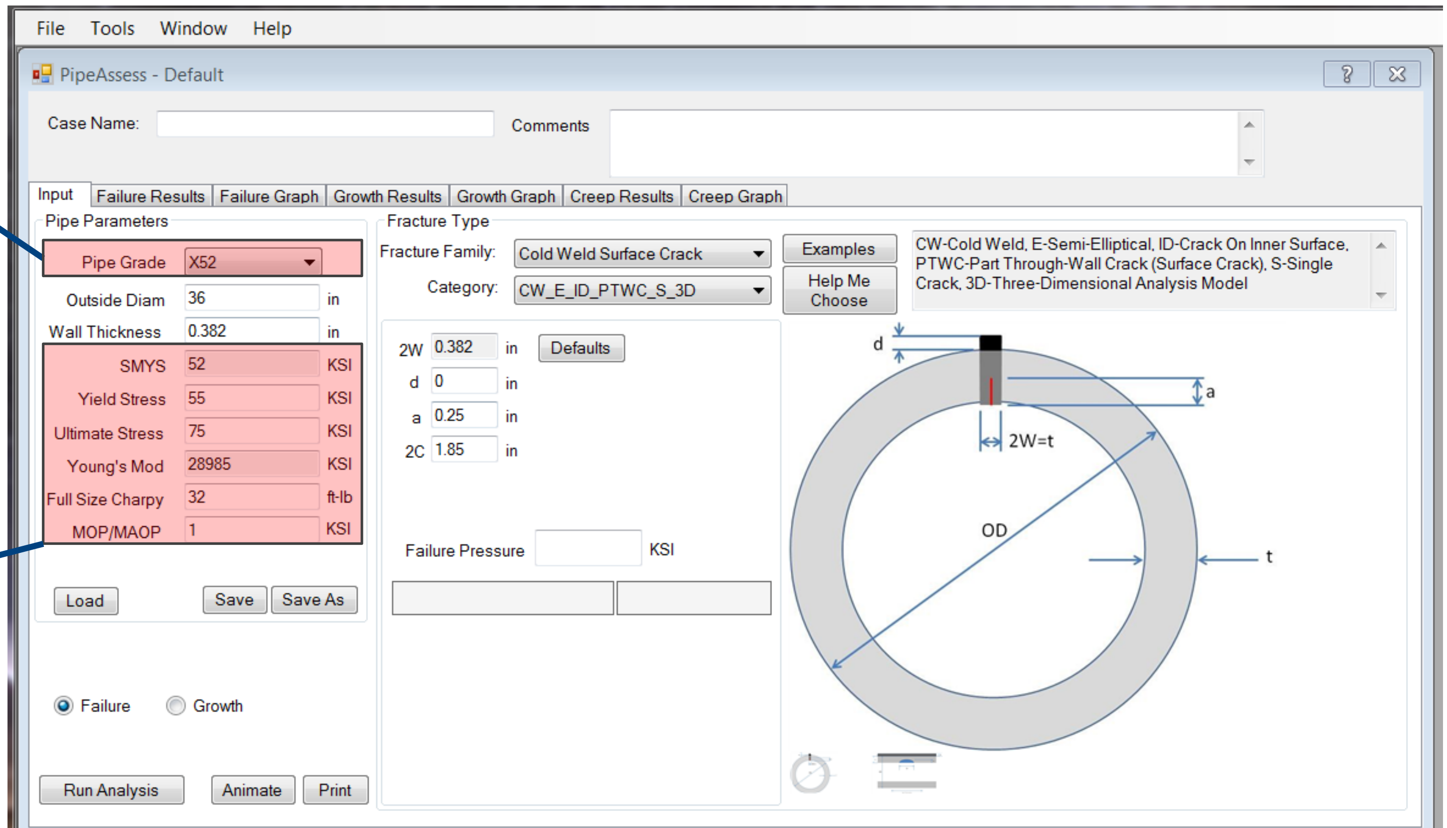
# Overview Continued

- As the modeling appropriately accounts for the differing material behavior for brittle, quasi-brittle, and ductile steels; varying types of material property values are valid inputs.
- The PipeAssess™ software is not limited to only ductile crack growth. Three failure modes are assessed for each case and the value from the limiting failing mechanism is provided to the user. This includes failure by:
  - ductile tearing,
  - net section collapse, and
  - ultimate material limit.

# Material Properties – User Input

**IMPORTANT** ***It is strongly recommended to use material properties local to the crack, wherever possible.*** This is especially critical for cracks located in an ERW bondline or heat affected zone, where typically the metal has drastically different properties than the base metal.

Required Input:
Material Properties



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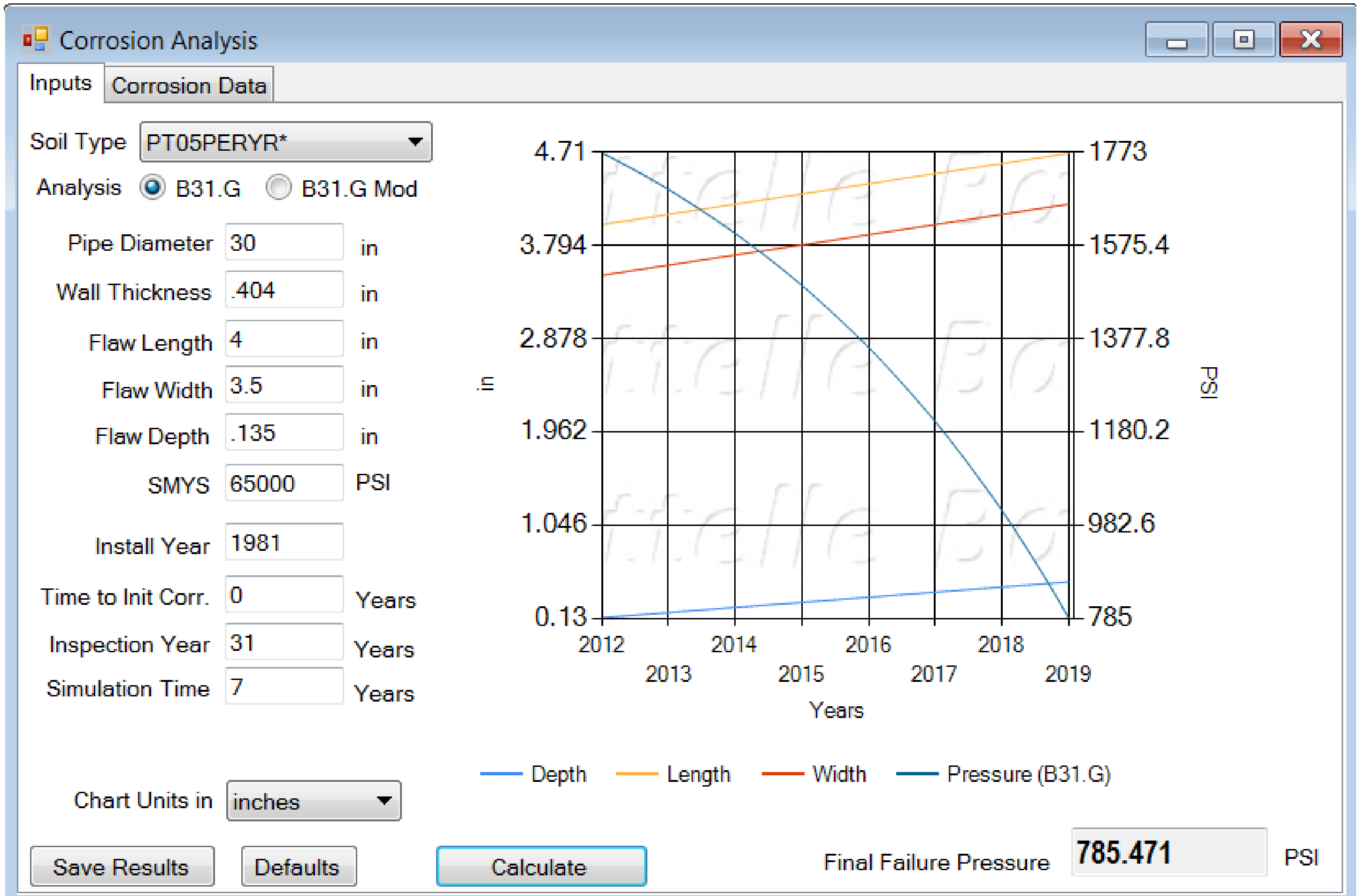
# Summary

- User Inputs
  - Pipe geometry and material properties
  - Crack Geometry
  - Fatigue Loading as a function of time
  - Hydrotest Loading profile
- Software Calculates
  - Instantaneous failure pressure for given crack size
  - Family of failure curves for various combinations of depths and lengths
  - For Fatigue / Hydrotests
    - Crack Growth as a function of operational time
    - Failure Pressure as a function of operational time

# Beyond the Basic PipeAssess™

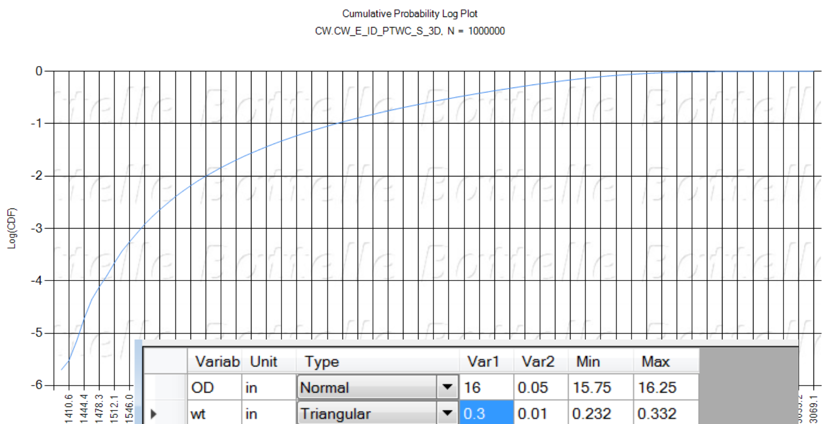
# PipeAssess PI™ Enhancements

**External Corrosion added with Internal R&D Funding**



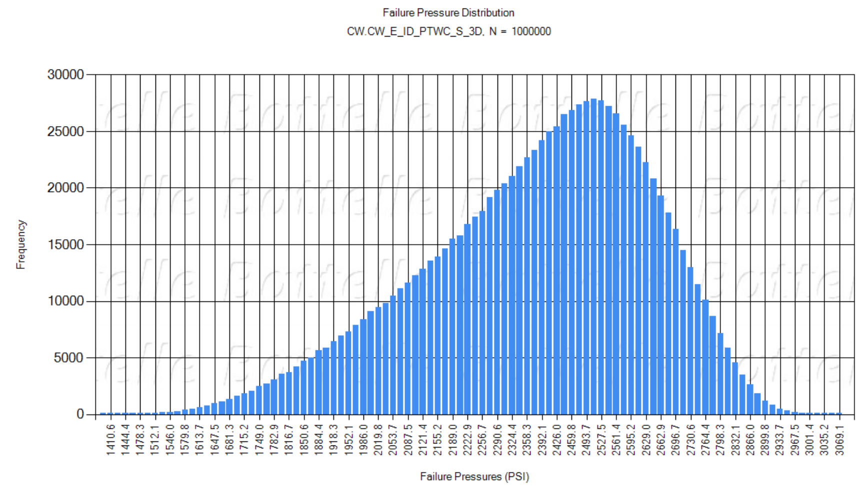
# PipeAssess PI™ Enhancements

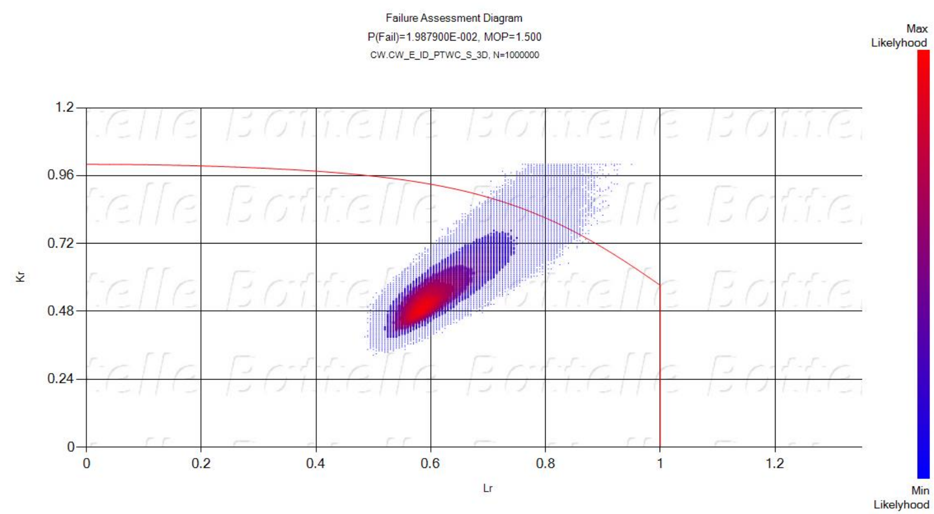
**Probabilistic Modeling added with Internal R&D Funding**




| | Variab | Unit | Type | Var1 | Var2 | Min | Max |
|---|---|---|---|---|---|---|---|
| | OD | in | Normal | 16 | 0.05 | 15.75 | 16.25 |
| ▸ | wt | in | Triangular | 0.3 | 0.01 | 0.232 | 0.332 |
| | E | ksi | Deterministic | 29000 | 200 | 28000 | 30000 |
| | SMYS | ksi | Uniform | 42 | 1 | 35 | 47 |
| | YS | ksi | Uniform | 55 | 1 | 50 | 60 |
| | UTS | ksi | Normal | 75 | 1.5 | 67.5 | 82.5 |
| | CVN | ft-lbs | Uniform | 15 | 0.75 | 11.25 | 18.75 |
| | d | in | Normal | 0.1 | 0.01 | 0 | 0.2 |
| | a | in | Normal | 0.141 | 0.01 | 0.091 | 0.191 |
| | 2c | in | Normal | 1.41 | 0.05 | 1.16 | 1.66 |

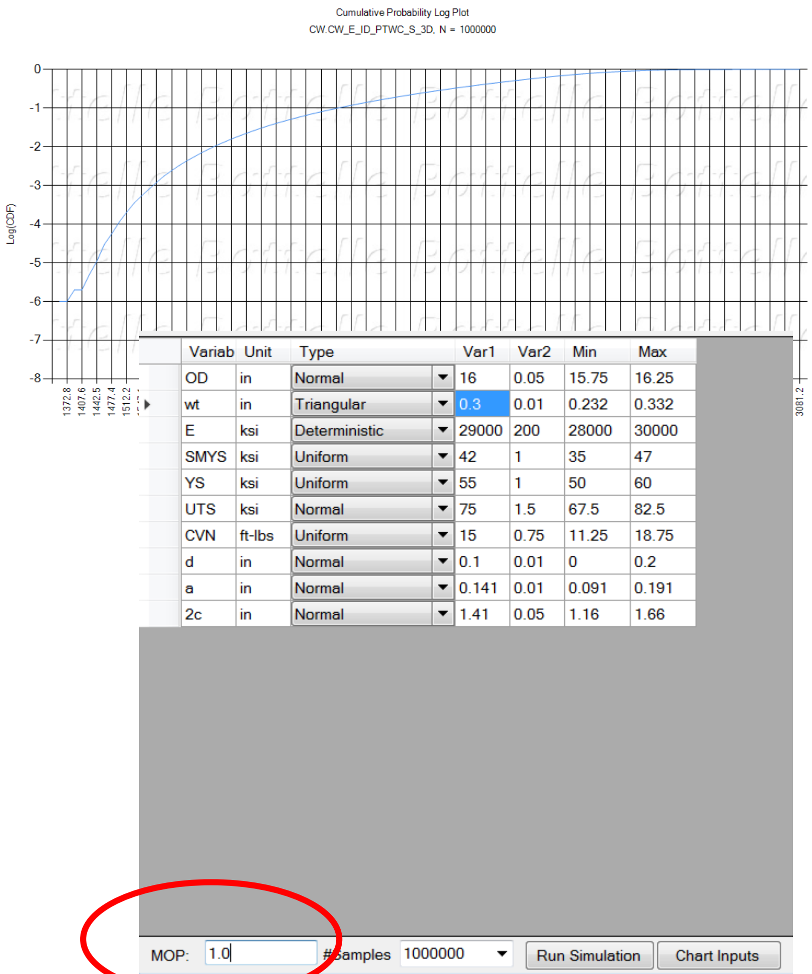
MOP: 1.5 #Samples 1000000 Run Simulation Chart Inputs



# PipeAssess PI™ Enhancements

**External Corrosion and Probabilistic Modeling Added with Internal R&D Funding**

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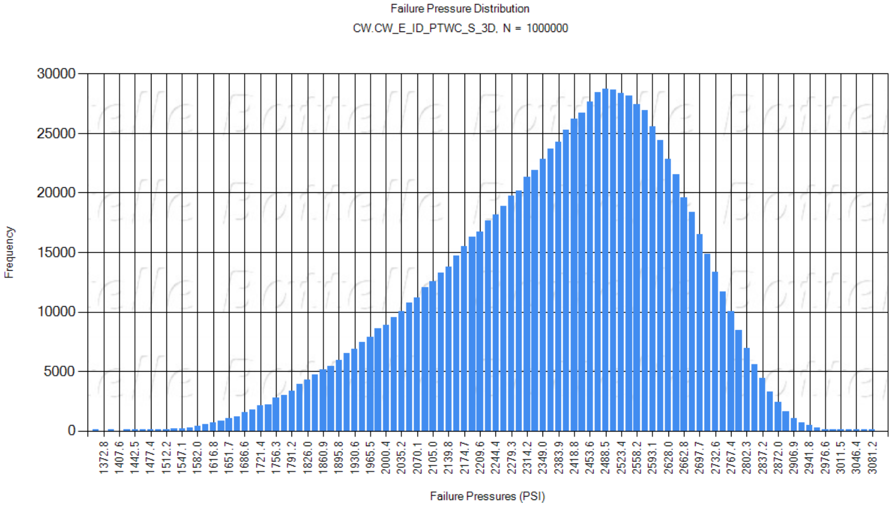


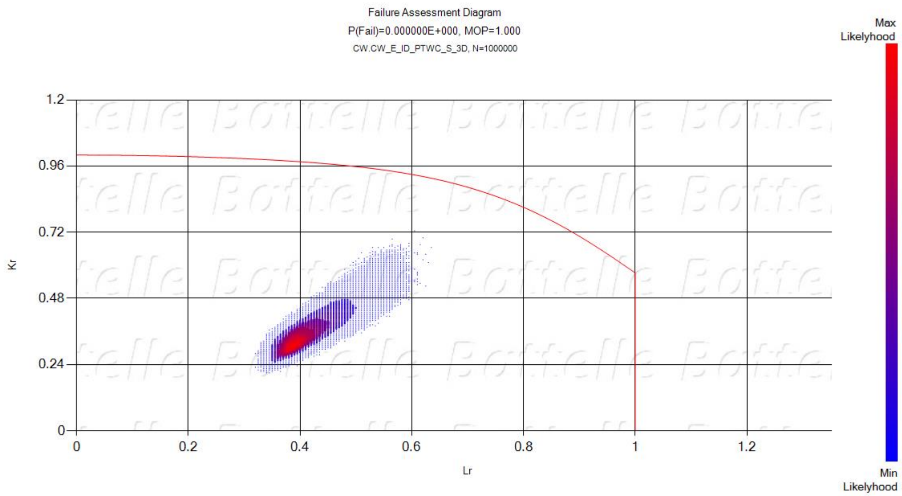




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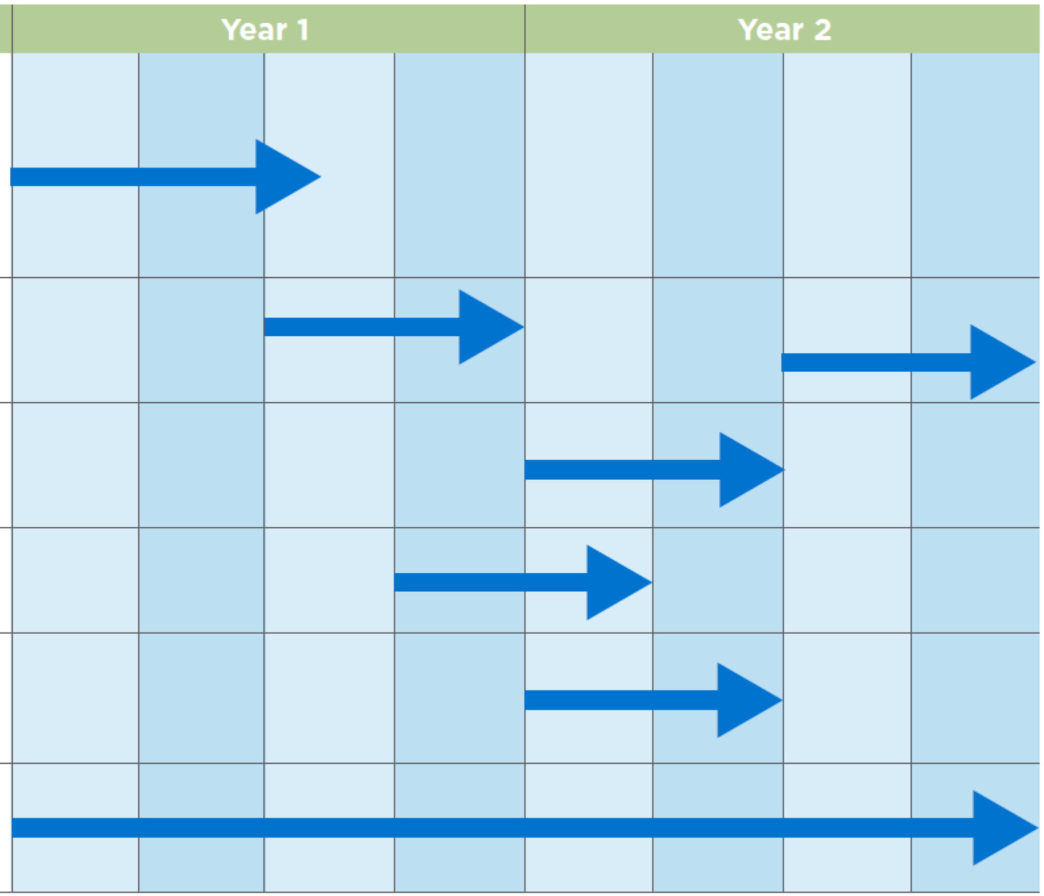
# PipeAssess PI™ Enhancements

**Technical Roadmap for PipeAssess PI beyond base software for DOT PHMSA**




### Addition of Degradation Models - Set #1
- Add External Corrosion Model
- Add Empirical Internal Corrosion Model
- Add Corrosion Failure Modes
- Add Denting Models
- Add Initiation Models

### Preprocessor Development**
- Bernoulli Analyses to Obtain Pressure Cycles
- GIS File - Layer Interpretation

### FEA Updates
- Through-Walls Cracks
- Hook Cracks

### Addition of Degradation Models - Set #2**
- Add Stress Corrosion Cracking Models

### Post Processing
- Develop Priority Scheme
- Display Statistical Results

### Verification and Validation
- Comparison to known Solutions
- Comparison to Experimental and Field Data

# Licensing Considerations

Battelle is Licensing PipeAssess$^{TM}$

- A Yearly Subscription Fee (per seat)
- A Joint Industry Program for those interested in funding additional capabilities – benefits: 10 seats for 10 years

  - cost: 60K/year for 2 years ($120K commitment)

# Call for Pipe



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