2019

PRCI Research Exchange Meeting

Presentations

March 5-6, 2019

Pipeline Research Council International
LEADING PIPELINE RESEARCH

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2019 PRCI RESEARCH EXCHANGE MEETING

Royal Sonesta Hotel Houston Galleria | 2222 West Loop South | Houston, Texas 77027 | +1 (713) 627-7600
March 5-6, 2019

Agenda

Tuesday, March 5, 2019

7:30 AM to 8:00 AM	**BREAKFAST & REGISTRATION | LEGENDS PREFUNCTION AREA, Lobby Level**				
8:00 AM to 9:00 AM	**OPENING PLENARY SESSION | LEGENDS 4-7, Lobby Level** Opening Remarks: Cliff Johnson, President of PRCI Keynote Speaker: Thornton May, Futurist & Author – "Data about Data: Mapping the Future of Knowing" Presentation of Distinguished Service Awards, In-kind Support Awards, and Distinguished Researcher Awards				
9:00 AM to 9:30 AM	**BREAK | LEGENDS PREFUNCTION AREA, Lobby Level**				
9:30 AM to 12:00 PM	**TRACK ONE: CORROSION** LEGENDS 4-7, Lobby Level			**TRACK TWO: LEAK DETECTION & RIGHT OF WAY** LEGENDS 1-3, Lobby Level	
	9:30 AM	Plausible Profiles (Psqr) Corrosion Assessment Model-Refinement and Further Validation *Shahani Kariyawasam, TransCanada*		9:30 AM	Application of Machine Learning to Improve Lead Detection Capabilities of Distributed Temperature Sensing (DTS) Systems *Maria Araujo, Southwest Research Institute*
	10:00 AM	Investigation of Biomethane Trace Elements Composition: A Tool to Better Know the Composition of the Gas Injected *Amelie Louvat, RICE GRTgaz*		10:00 AM	SmartBall Technology: An Innovative Multi-sensor Tool for Long Inspection of Oil and Gas Pipelines *Carine Lacroix, GRTgaz - RICE*
	10:30 AM	An Alternative Approach to the Assessment of Corrosion Anomalies within Pipelines *Ryan O'Kelley, Atteris LLC*		10:30 AM	Autonomous Aerial Detection of Liquid Hydrocarbons Leaks in Water Bodies *Maria Araujo, Southwest Research Institute*
	11:00 AM	Microchemical, Chemical, and Corrosion Samples *Mohita Sharma, University of Calgary*		11:00 AM	Pipeline Leak Rate Estimation *Mark Piazza, Colonial Pipeline Company*
				11:30 AM	Visualizing Buried Networks in Augmented Reality *Carine Lacroix, GRTgaz - RICE*
12:00 PM to 1:00 PM	**LUNCH | DISCOVERY CENTER, Lobby Level**				
1:00 PM to 3:00 PM	**TRACK ONE: CORROSION** LEGENDS 4-7, Lobby Level			**TRACK TWO: LEAK DETECTION & RIGHT OF WAY** LEGENDS 1-3, Lobby Level	
	1:00 PM	Clearing of Shorted Casings vs ILI Based Management – A Data Driven Approach to Preventing Failures and Managing Risk *Shahani Kariyawasam, TransCanada*		1:00 PM	CONOPs for LiDAR Operationalization for ROW Monitoring *Francois Rongere, PG&E*
	1:30 PM	Proposal of New HIC Test Solution with Good pH Stability for Fitness for Purpose Evaluation *Daisuke Mizuno, JFE Steel Corporation*		1:30 PM	Evaluation of Current ROW Threat Monitoring, Application, and Analysis Technology Project Update *Paul Adlakha, LOOKNorth, C-CORE*
				2:00 PM	Obstacle Detecting Technology for Horizontal Drilling *Carine Lacroix, GRTgaz - RICE*
				2:30 PM	Remote Monitoring of Geohazards for 800+ Kilometers of Pipeline and Right-of-Way Protection in Permafrost, Snow and Vegetation Using Radar Satellite Interferometry (InSAR) *Kris Covey, 3vGeomatics Inc. & Shin-ichi Sobue, Japan Aerospace Exploration Agency (JAXA)*
3:00 PM to 3:30 PM	**BREAK | LEGENDS PREFUNCTION AREA, Lobby Level**				
3:30 PM to 5:00 PM	**PIPELINE DATA HUB - GENERAL SESSION | LEGENDS 4-7, Lobby Level** Chairs: Walter Kresic, Enbridge and Cliff Johnson, PRCI Panelists: Sean Keane, Enbridge; Shahani Kariyawasam, TransCanada; and Jim Andrew, Flint Hills Resources; Gary Hines, PRCI				
5:00 PM to 6:30 PM	**RECEPTION | DISCOVERY CENTER, Lobby Level** Come and join PRCI members for an evening of drinks, hors d'oeuvres and networking.				

Wednesday, March 6, 2019

7:30 AM to 8:00 AM	**BREAKFAST & REGISTRATION | LEGENDS PREFUNCTION AREA, Lobby Level**			
8:00 AM to 10:00 AM	**TRACK ONE: ADDRESSING CRACKS & DENTS** LEGENDS 4-7, Lobby Level		**TRACK TWO: WELDING** LEGENDS 1-3, Lobby Level	
	8:00 AM	Implementation of the MAT-8 Fracture Model into a Probabilistic Crack Management Framework *Ted Anderson, TL Anderson Consulting*	8:00 AM	Enhanced Girth Weld Performance for Newly Constructed Grade X70 Pipelines *Robin Gordon, Microalloying International Inc.*
	8:30 AM	Full Scale Cyclic Fatigue Testing of Crack-in-Dent and Development of Frame Work for Life Prediction *Udayasankar Arumugam, Blade Energy Partners, Ltd.*	8:30 AM	Mechanical Properties of Vintage Girth Welds and Their Implications on Performance *Dan Jia, CRES*
	9:00 AM	Towards a Reliability-Based System-Wide Integrity Management Approach for Pipeline Dents *Nader Yoosef-Ghodsi, Enbridge*	9:00 AM	Fracture Resistance Testing of Dissimilar Girth Welds Using SE(T) Specimens *Eduardo Hippert, Petrobras and Claudio Ruggieri University of São Paulo, Brazil*
	9:30 AM	Leveraging Industry Data Sharing to Support Improved Crack Management Programs at a Liquids Operator *Steven Bott, Enbridge Liquids Pipelines*	9:30 AM	Tensile Strain Capacity of Girth Welds *Bo Wang, CRES*
10:00 AM to 10:30 AM	**BREAK | LEGENDS PREFUNCTION AREA, Lobby Level**			
10:30 AM to 1:00 PM	**TRACK ONE: IN-LINE INSPECTION & NONDESTRUCTIVE EXAMINATION** LEGENDS 4-7, Lobby Level		**TRACK TWO: DESIGN, MATERIALS & CONSTRUCTION** LEGENDS 1-3, Lobby Level	
	10:30 AM	A Comprehensive Assessment of Inspection Technologies for Characterizing ERW Seam Anomalies and Impact on Pipeline Integrity Management *Mark Piazza, Colonial Pipeline Company*	10:30 AM	Significance of Automatic Pipe Dimension Measurement of Line Pipe for Deep Offshore Pipe Lines ***(moved from Subsea track)*** *T.S Kathayat, Welspun*
	11:00 AM		11:00 AM	EPRG Approach to Assess Avoidance of Brittle Fracture in Presence of Ductile Initiation in DWT Tests *Marion Erdelen-Peppler, European Pipeline Research Group*
	11:30 AM	A Novel Method in Assessment of Corroded Steel Pipe in Water Lines Ali Alavinasab, Xylem	11:30 AM	Evaluation of Cracked In-service Welded 4" Stub End with LOR Flange *Otto Jan Huising, N.V. Nederlandse Gasunie*
	12:00 PM	Evaluating SCC in Pipelines with IWEX Harvey Haines, Applus RTD & Ben Hanson, Kinder Morgan	12:00 PM	Soil-pipe Interaction in Muskeg Soils for Design of Buried Energy Pipelines *Dharma Wijewickreme, University of British Columbia*
	12:30 PM	MAOP Verification of Facility Piping Peter Veloo, Exponent and Michael Rosenfeld, Kiefner & Associates	12:30 PM	Composite Crack Reinforcement *Chris Alexander, ADV Integrity, Inc.*
1:00 PM to 2:00 PM	**LUNCH | DISCOVERY CENTER, Lobby Level**			
2:00 PM to 4:00 PM	**TRACK ONE: SAFETY MANAGEMENT** LEGENDS 4-7, Lobby Level		**TRACK TWO: SUBSEA** LEGENDS 1-3, Lobby Level	
	2:00 PM	NDE - Technician Qualification - Industry Improvement Efforts *Michael Sens, Chevron & Andri Orphanides, API*	2:00 PM	Local Hard Zone Formation in Sour Service Pipeline Steels *Douglas P. Fairchild, ExxonMobil Upstream Engineering*
			2:30 PM	Flexible Riser Life Extension using Advanced inspection and Analysis *Arya Majed, INTECSEA*
	3:00 PM	Determining the Impact of Human Factors on the Performance of In-Service NDE *Jane Rau, Jtrain*	3:00 PM	Validation of an Ultrasonic Phased Array Tool for Inspection of Weld Overlay Cladding for Subsea Applications *Channa Nageswaran, TWI Ltd.*
	3:30 PM	Competency in the Pipeline Industry: An Industry Survey *Reena Saheny, PBOK*		

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March 5-6, 2019 | Houston, Texas

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(Print of Individual)

For attendance at

2012 PRCI Research Exchange Meeting

(Title of Technical Course/Event)

On

February 7-9, 2012 / Phoenix, Arizona USA (Date and Location) for 18.0 PDH (No. of Hours/PDH)

Cliff Johnson, President

PRCI Pipeline Research Council International

February 9, 2012

Date

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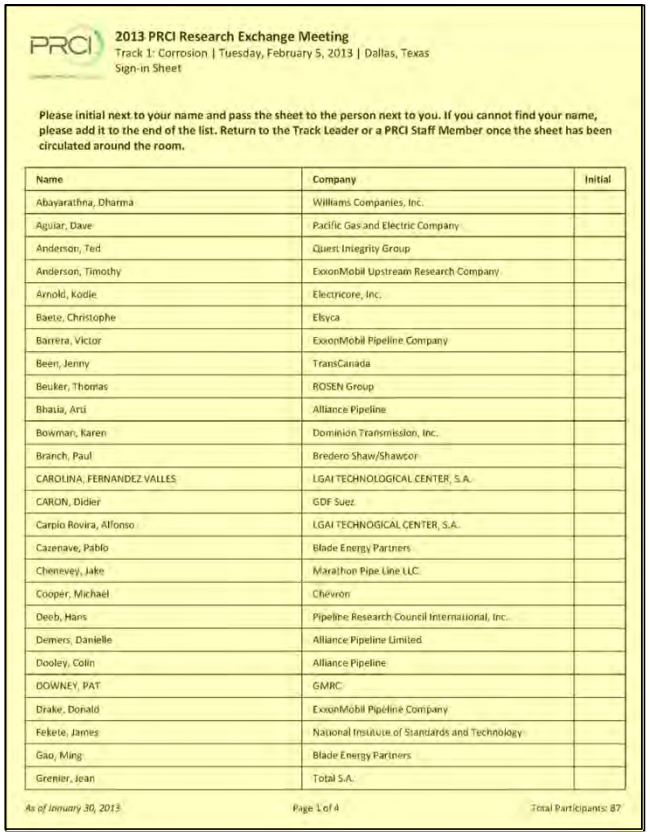

PRCI

2013 PRCI Research Exchange Meeting
Track 1: Corrosion | Tuesday, February 5, 2013 | Dallas, Texas
Sign-in Sheet

Please initial next to your name and pass the sheet to the person next to you. If you cannot find your name, please add it to the end of the list. Return to the Track Leader or a PRCI Staff Member once the sheet has been circulated around the room.

Name	Company	Initial
Abayarathna, Dharma	Williams Companies, Inc.	
Aguilar, Dave	Pacific Gas and Electric Company	
Anderson, Ted	Quest Integrity Group	
Anderson, Timothy	ExxonMobil Upstream Research Company	
Arnold, Kodie	Electricore, Inc.	
Baete, Christophe	Elsyca	
Barrera, Victor	ExxonMobil Pipeline Company	
Beer, Jenny	TransCanada	
Beuker, Thomas	ROSEN Group	
Bhatia, Arti	Alliance Pipeline	
Bowman, Karen	Dominion Transmission, Inc.	
Branch, Paul	Bredero Shaw/Shawcor	
CAROLINA, FERNANDEZ VALLES	LGAI TECHNOLOGICAL CENTER, S.A.	
CARON, Didier	GDF Suez	
Carpio Rovira, Alfonso	LGAI TECHNOLOGICAL CENTER, S.A.	
Cazenave, Pablo	Blade Energy Partners	
Chenevey, Jake	Marathon Pipe Line LLC	
Cooper, Michael	Chevron	
Deeb, Hans	Pipeline Research Council International, Inc.	
Demers, Danielle	Alliance Pipeline Limited	
Dooley, Colin	Alliance Pipeline	
DOWNEY, PAT	GMRC	
Drake, Donald	ExxonMobil Pipeline Company	
Fekete, James	National Institute of Standards and Technology	
Gao, Ming	Blade Energy Partners	
Grenier, Jean	Total S.A.	

As of January 30, 2013 Page 1 of 4 Total Participants: 87

Complimentary Day Self Parking

Your registration includes complimentary day self parking in the hotel's garage.

Stop by the registration desk each day to pick up a validation sticker.

2018 Year in Review

Learn About PRCI's Accomplishments in the Last Year!

Don't Forget Your Copy!

Save the Date! Upcoming Meetings

22nd APGA-EPRG-PRCI Joint Technical Meeting on Pipeline Research

- April 29 – May 3, 2019 | Brisbane, Australia

Spring 2019 Pipeline Technical Committee Meetings

- May 14-16, 2019 | St. Louis
- *Registration opening soon!*

Fall 2019 Pipeline Technical Committee Meetings

- October 22-24, 2019 | Charlotte

2020 PRCI Research Exchange Meeting & Winter Pipeline Technical Committee Meetings

- March 3-6, 2020 | San Diego

Please Contact Natalie Tessel if Your Company is Interested in Sponsoring any of These Meetings!

Pipeline Research Council International, Inc.

Welcome to the 2019 Research Exchange!

Cliff Johnson, President

March 5, 2019
Houston, Texas

LEADING PIPELINE RESEARCH

Welcome to the 13th Annual Research Exchange!

- Report Important Research Results and Outcomes for Completed Work
- Share your experiences and challenges
- Focus on How to Use the Results
- Tuesday Evening Networking Reception in the Discovery Center

Safety Moment

Distracted Driving

Keynote Speaker

Thornton A. May

Futurist, Author and Education, Co-Founder, The Digital Value Institute

Data about Data: Mapping the Future of Knowing

Housekeeping

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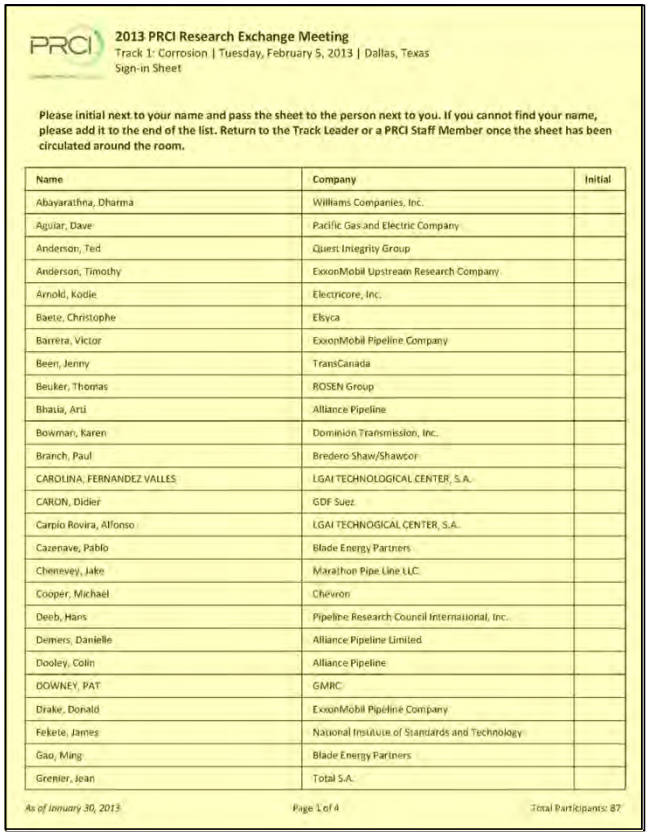

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Distinguished Service Award

For Distinguished Service to the Energy Pipeline Industry through a Sustained Commitment to PRCI and Noteworthy Contributions to the Achievement of its Mission, Goals, and Programs

Richard McNealy

Distinguished Service Award

For Distinguished Service to the Energy Pipeline Industry through a Sustained Commitment to PRCI and Noteworthy Contributions to the Achievement of its Mission, Goals, and Programs

Mark Piazza

Distinguished Service Award

For Distinguished Service to the Energy Pipeline Industry through a Sustained Commitment to PRCI and Noteworthy Contributions to the Achievement of its Mission, Goals, and Programs

Mures Zarea

In-Kind Support Award

For Companies that have Provided Significant Contributions and Support for Furthering PRCI Research

Colonial Pipeline Company

In-Kind Support Award

For Companies that have Provided Significant Contributions and Support for Furthering PRCI Research

ExxonMobil Pipeline

Distinguished Researcher Award

For Dedicated and Distinguished Service and Scientific Achievements that have Enhanced the Integrity, Reliability and Environmental Performance of Energy Pipelines Around the World

Chris Alexander

Distinguished Researcher Award

For Dedicated and Distinguished Service and Scientific Achievements that have Enhanced the Integrity, Reliability and Environmental Performance of Energy Pipelines Around the World

Shane Siebenaler

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Data about Data

Mapping the Future of Knowing

[5 March 2019]

thorntonamay@aol.com
TWITTER: @deanitla

Ida Ten Eyck O'Keeffe,
Variation on a Lighthouse Theme II, c. 1932
DMA "Escaping Georgia's Shadow"

I would like to begin…

…by saying “Thank You”

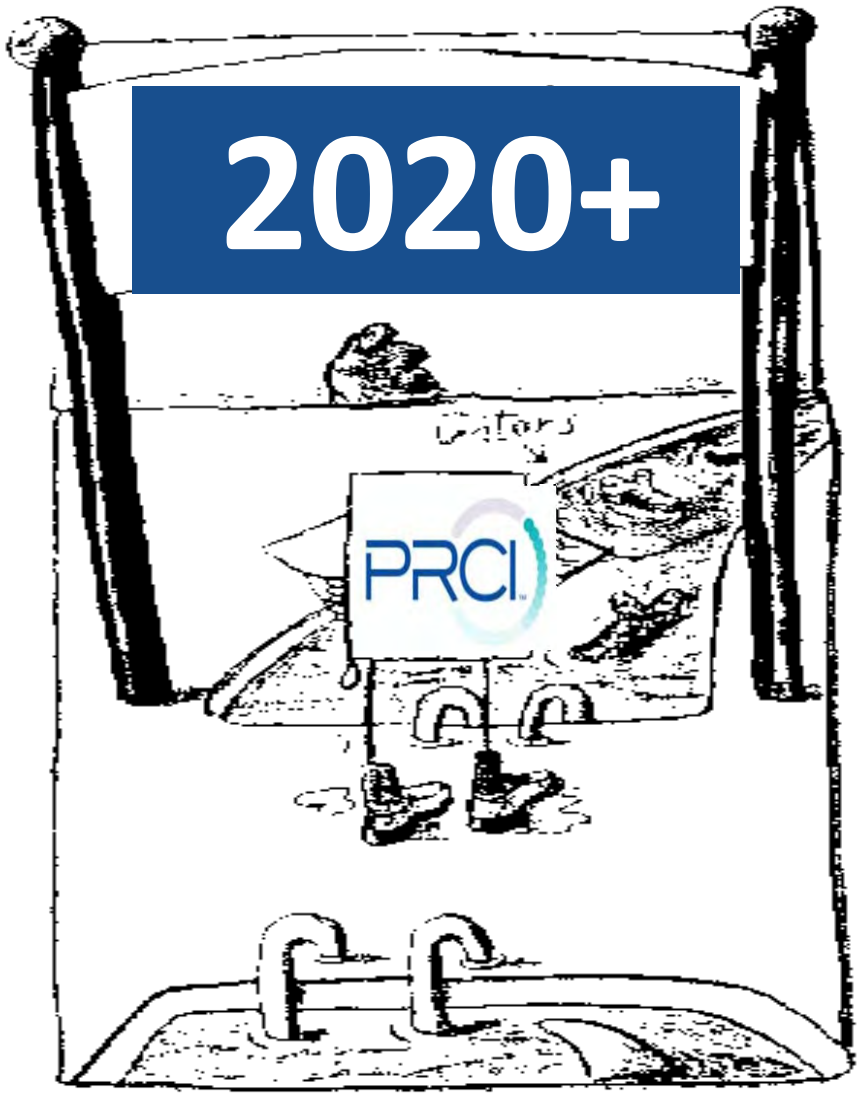
A Special Session

For a Special Audience

On a Critically Important Topic

At a Unique Moment in History

I am a Futurist!



I am…

Francis Bacon
[1561-1626]

An Empirical Futurist…

I Collect Data…
…by listening to People…

I collect data by asking people:

Where have they been?

Where are they now?

Where are they going?

MONDAY, NOVEMBER 16, 1998

TECHNOLOGY

Interview

CORPORATE SEERS

Who knows better what the future holds than those who make a living thinking about it?

By WILLIAM M. BULKELEY

MARIAN SALZMAN MARK MOONEY THORNTON MAY JIM TAYLOR

THEY GET PAID TO THINK ABOUT THE FUTURE. While most corporate workers are lucky if they can think about next week, there are others whose job is to keep an eye on where technology is taking the world. Their views vary widely, as do their responsibilities, but their roles are the same: to open minds.

To see what these thinkers are thinking, The Wall Street Journal put together an e-mail panel discussion of some designated future

tion. You will plug into a securities-transaction device and buy yourself stocks, securities, commodities or products on a "best price" basis from anywhere in the world at any time of the night or day.

MR. MAY: Paper checks exist in a unique eco-

that are now being described as Web communities or "fraternities of strangers" will give way, to the irritation of Webheads, to dominance by traditional society.

MR. O'LEARY: Not only will we know more people, we will probably know a lot more of the

My Data “Reeks of Human Juices”

Laurence Stephen Lowry, detail

SHE ISN'T TALKING

This Girl's Job Is Top Secret

BY ROBERTA MACKEY

Mary Waterfall loves her job so much she feels as though she should be paying Uncle Sam, instead of vice versa.

She meets "fantastically brilliant people."

Her co-workers, all with fascinating backgrounds, are the kind you'd normally never meet.

She sums it up: "I couldn't possibly design a better job for myself."

And nobody but Mary knows what the job is. In the language of Government security, it's top secret.

Even the Thornton E. Waterfalls, of Lincoln Road, know only that their daughter works in a Government security agency.

Home from Washington for the holidays, she has revealed to her family and friends only that she can't tell them a thing.

Since September, 1952, when Mary went to Washington, security has become second nature.

* * *

"YOU GET SO you don't even tell anybody what kind of toothpaste you use," she laughs. "You don't think about security; you just close off certain portions of your mind.

"In Washington," grins Mary, "everybody works for the Agriculture Department or the Post Office.

"The theory is that nobody is interested in those. A man you meet at a cocktail party may tell you with a perfectly straight face that he's with the Rural Electrification Commission — even though you've met him professionally in his real role as an FBI agent."

Reticent as she is about her work, Mary's a geyser of enthusiasm over life in the Capital.

"People think that London, Rome and Paris sound glamorous—Washington is twice as exciting! Every country sends its best people here."

* * *

SHE'S BEEN TO diplomatic receptions, and she doesn't particularly care about them. "Once you've seen one, you've seen them all," she says, "but you never quite believe it, so you keep on going.

"Nobody has much fun, but there are always beautiful gowns and interesting food."

Mary learned early — the hard way—not to ask questions about the hors d'oeuvres she ate at embassy parties.

She was completely carried away with some meatballs once and wishes she had never learned that they were a combination of snake meat and sundry other exotic native ingredients.

Mary Waterfall

Mary likes small, informal gatherings. "You learn much more about foreign countries," she points out.

"Eventually you pick up a few words in every language, and most of the foreigners talk with their hands anyway.

"The most terrific party I ever went to," Mary reminisces, "was a private dance at the Brazilian Embassy, when one of the military attaches was promoted.

"Brazilians like to dance better than anything else, and they had wonderful Brazilian music."

* * *

IT WASN'T hard to tear herself away for the holidays because "It's Christmas the year around in Washington. Somebody is always celebrating something."

She hasn't noticed the shortage of beaux supposedly plaguing Government girls. "I never saw so many men," she claims. "They're all either second lieutenants or four-star generals."

International friendships aren't as transient as they might seem. Although top diplomatic figures come and go as fast as governments change, the young career people stay for a specified tour of duty.

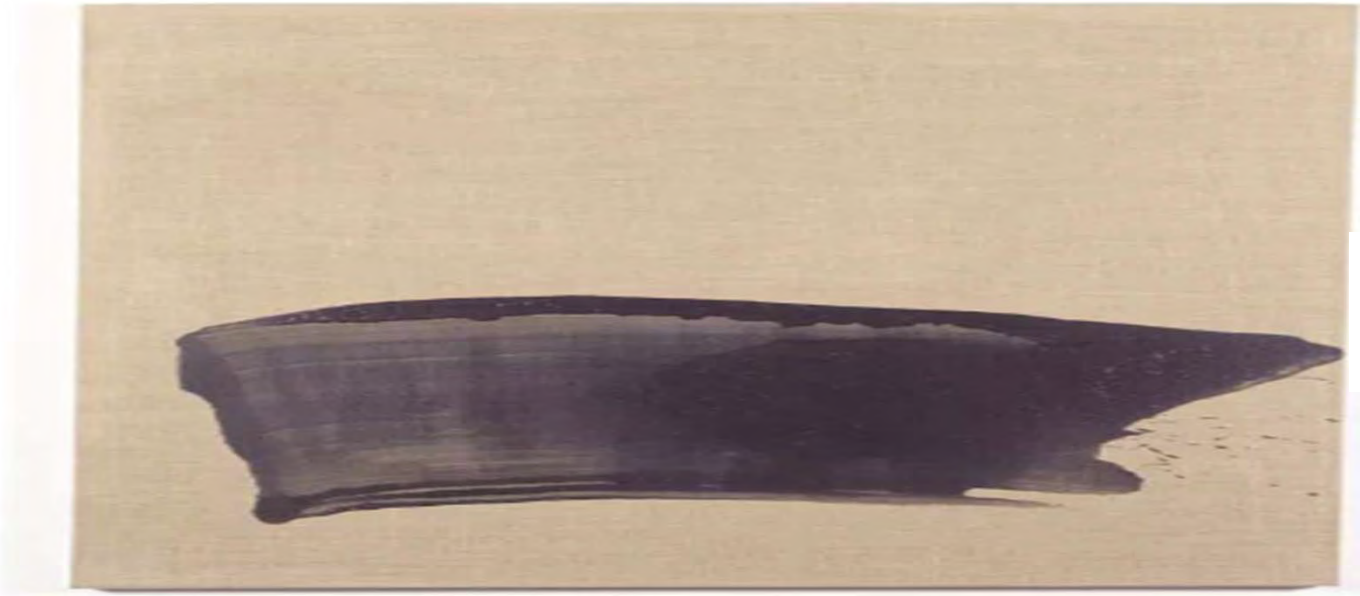
Mary's co-workers are young, too, so the circle grows continually.

Her job has one more crowning feature: Every time an important visitor comes to town, all Government workers get the afternoon off.

All Washingtonians work for the Government, and they've got to have somebody to line the streets for the parade!

My Mother Was a Spy...

Ultimate Truth about Thinking about the Future



Adrian Schär,
And Now What? [III]
[2017]

Your Network Will Keep You Safe

Action Items

Talk to your peers

Query the Solutions Community

Schedule “Conversations”
On Topics of Import

Render Explicit Your KK’s, KU’s & UU’s

Friedrich Hayek
Nobel Prize 1974

"Civilization advances
by conquering ignorance.

Ignorance is
best conquered
Not so much
by the addition
of new knowledge
as the broader distribution
of existing knowledge."

My Objective This Morning

[1] Get you ‘barking-dog’

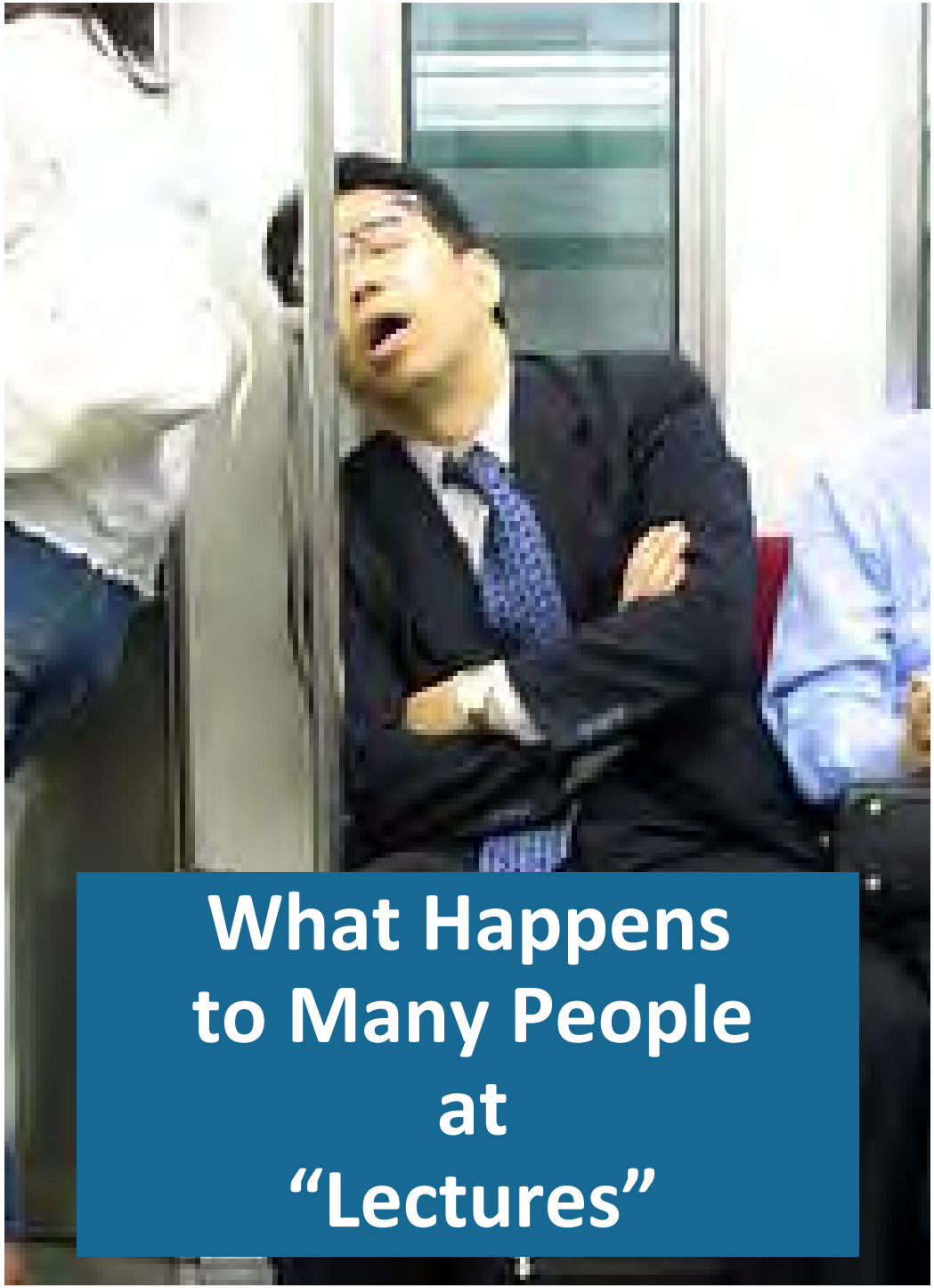
Excited about

Getting on the path to

Data Mastery

Session Data

This is not a *"lecture"!*

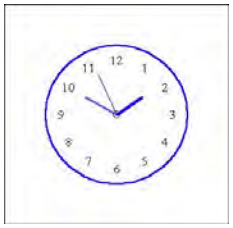


What Happens to Many People at "Lectures"

Your immediate Future Involves Several Quick Exercises…

Opening
Jump Ball Exercise

45 second exercise



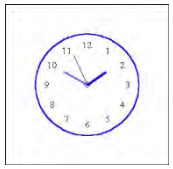
In Small Groups

Please select
the “one word”

Which best describes

How you feel about the future of the pipeline industry

Group Exercise



4 minute exercise

In your groups, please divide the History AND Future of the Pipeline Industry [Years 2004 through 2034]

into

‘eras’

[no less than 2, no more than 6]

Report Backs

What Patterns/Trends [if any]

do you perceive
in your responses?

Patrick Caulfield

When Doing the Last Exercise…

Did you spend more time Thinking about the Years BEFORE 2019…

Or the Years AFTER 2019?

Observation

Most Organizations Don't Spend Enough Time Thinking about the Future

???

A.M.O.

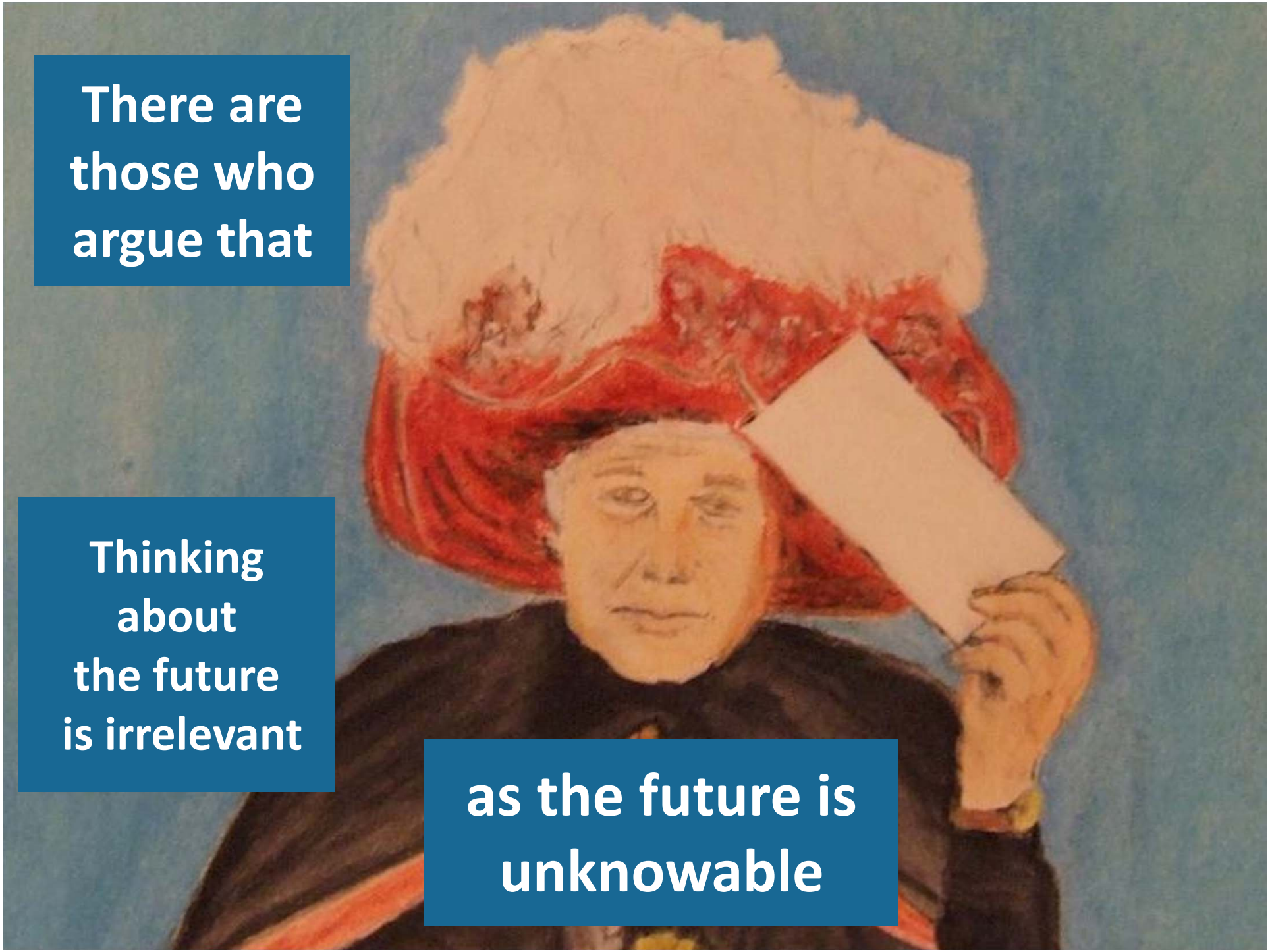
Next Tech

Now Tech

Old Tech

2019

Source: Thornton May, *CIO Habitat Report*


There are those who argue that
Thinking about the future is irrelevant
as the future is unknowable

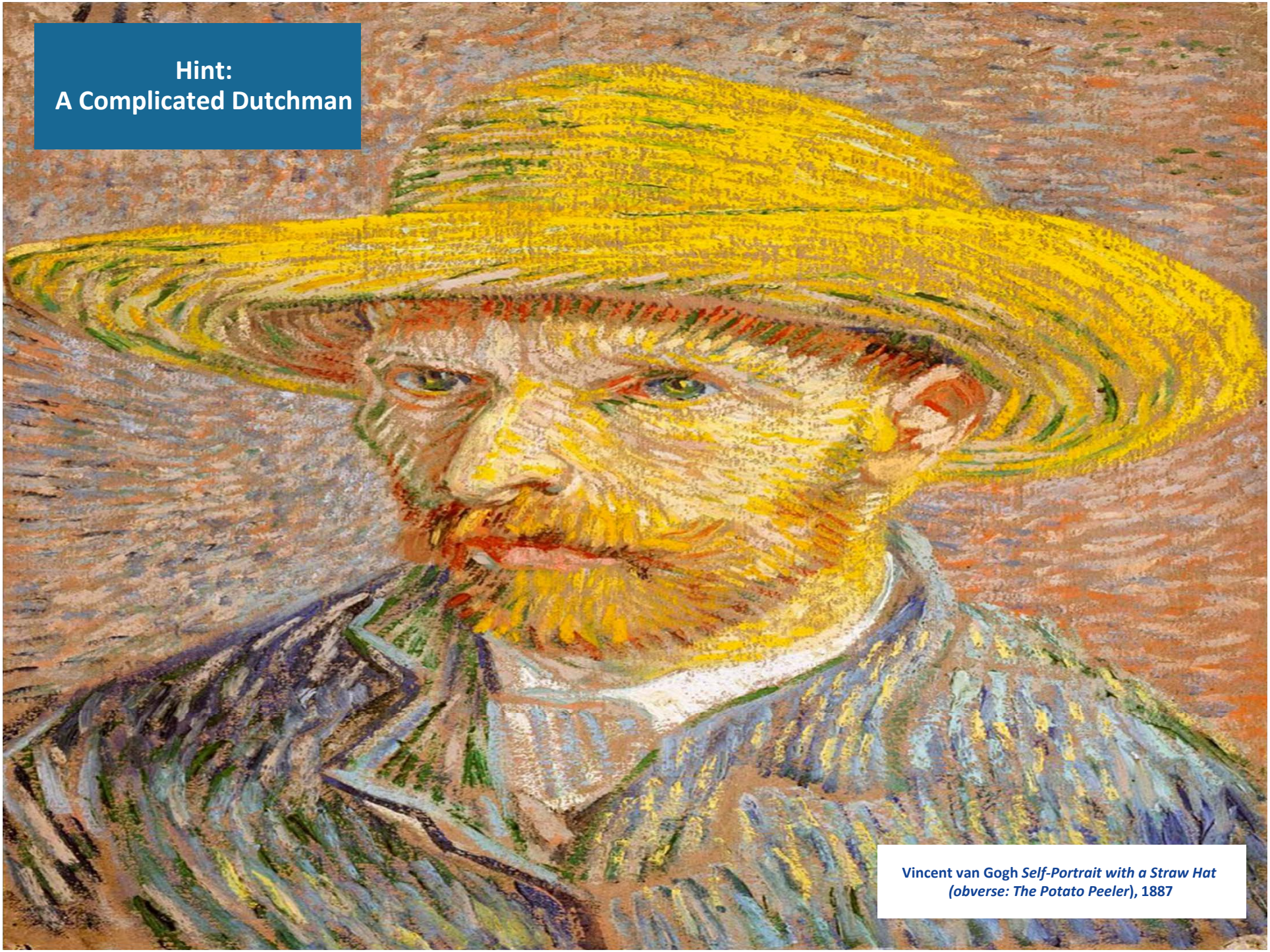
Future Point
Fenway Park
24 October 2018 Game 2
FOX WS
BOS LEADS 1-0
BALL STRIK
Ryu P: 54
LAD 2
BOS 1
5 2 Outs
You WILL NOT be "Surprised"
by Emerging Technologies

Future Point

Most trends are forecastable

Can Anyone Tell Me the Artist who painted this Painting?
x

Hint:
A Complicated Dutchman



Vincent van Gogh *Self-Portrait with a Straw Hat (obverse: The Potato Peeler)*, 1887

Vinny was not
the most stable fellow
Vincent van Gogh
Self-portrait with Bandaged Ear, 1889

What is the Dominant Visible Element in this painting?
x
Vincent Van Gogh, *The Outskirts of Paris* [1886].

While the “future” may not be “Knowable”

Hypothesis

with decimal-point-precision

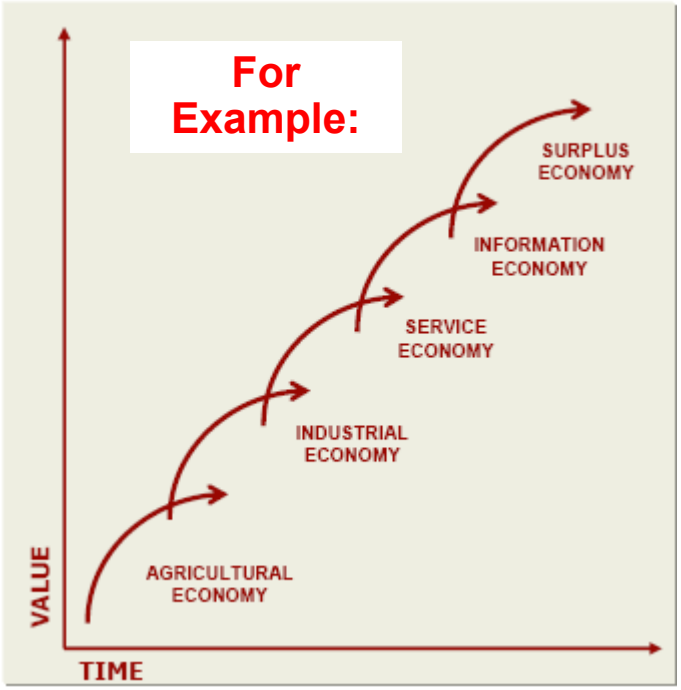
It is forecastable to the extent that Directionally-non-toxic preparations can be begun

Back-At-Work Labeling the Eras Exercise

What should we call

the Era/Economy/Society
'place in time'

[1] We have just left?
[2] We inhabit currently?
[3] We are about to enter?

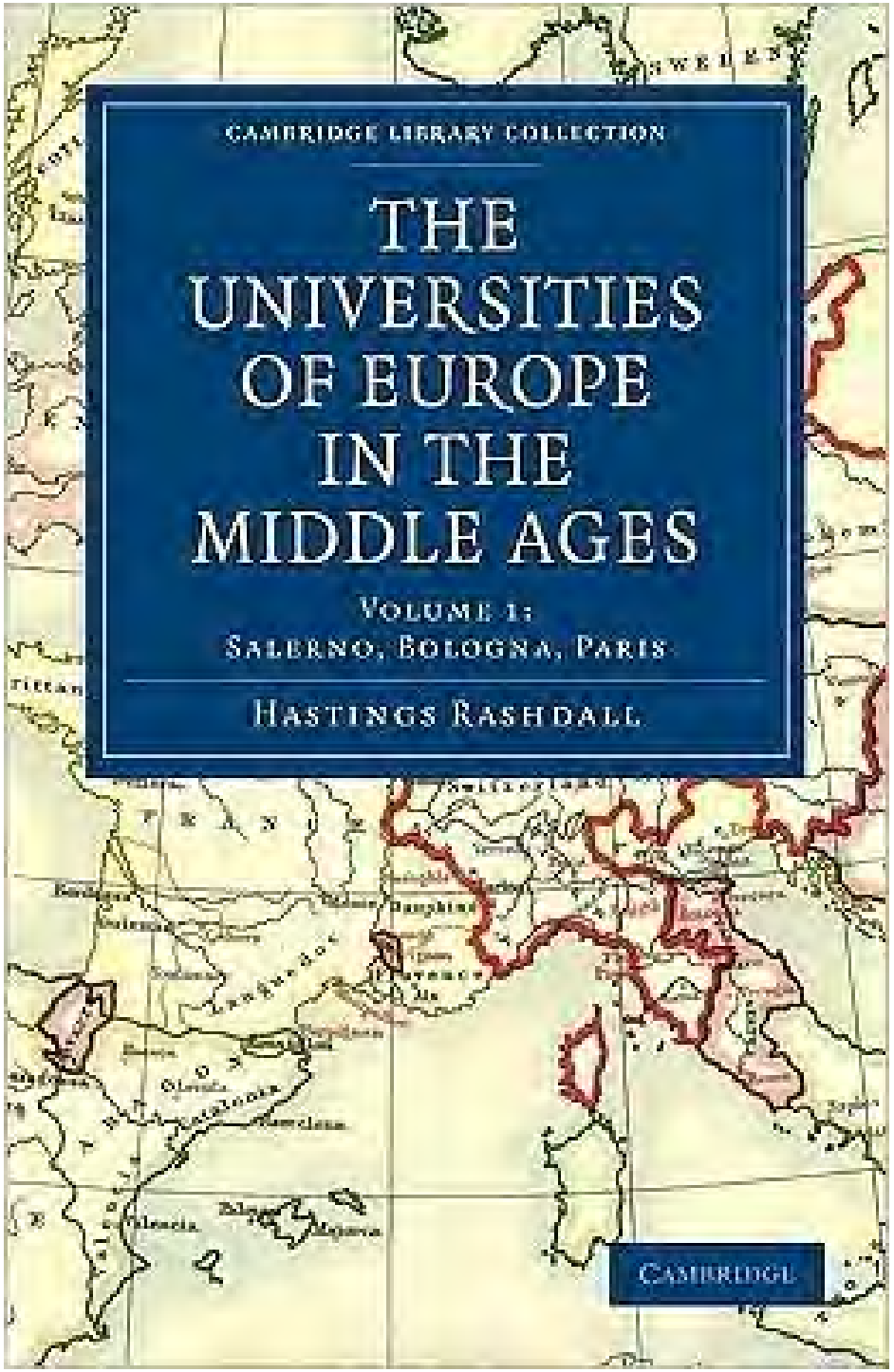


Future
Point
Every age, era and epoch
has a feel to it.

Framing Question

Did people living in "*The Middle Ages*" *KNOW* They Were Living in the Middle Ages?

In the Middle Ages…



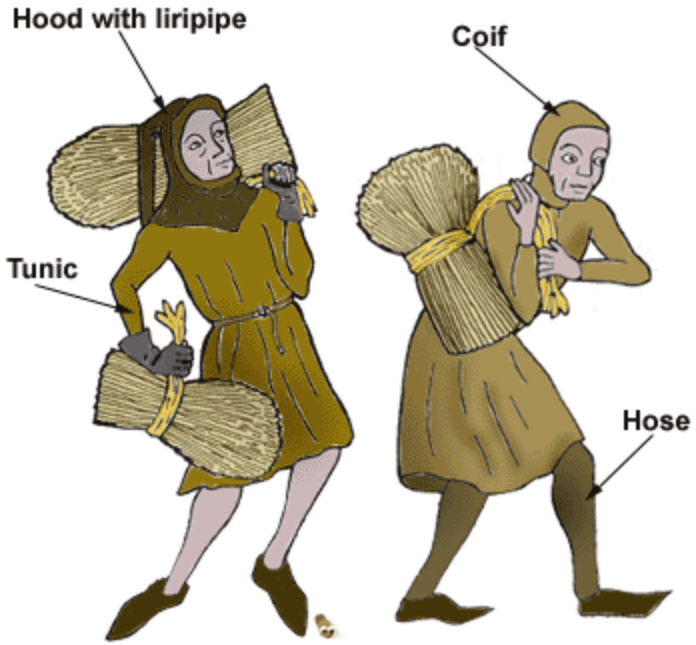
People had
no Concept of Progress

In the Middle Ages…

Life sucked…

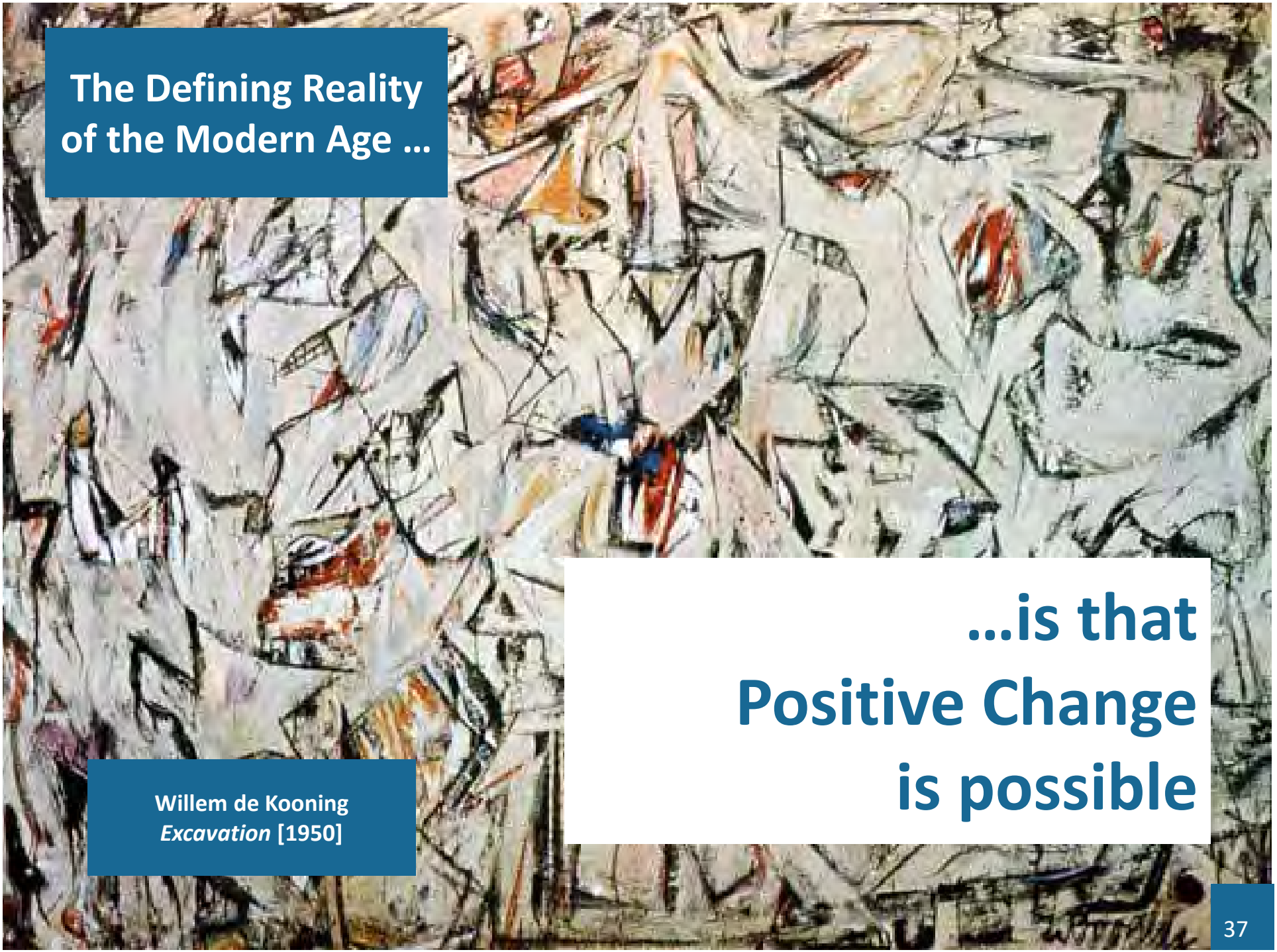
And then you died

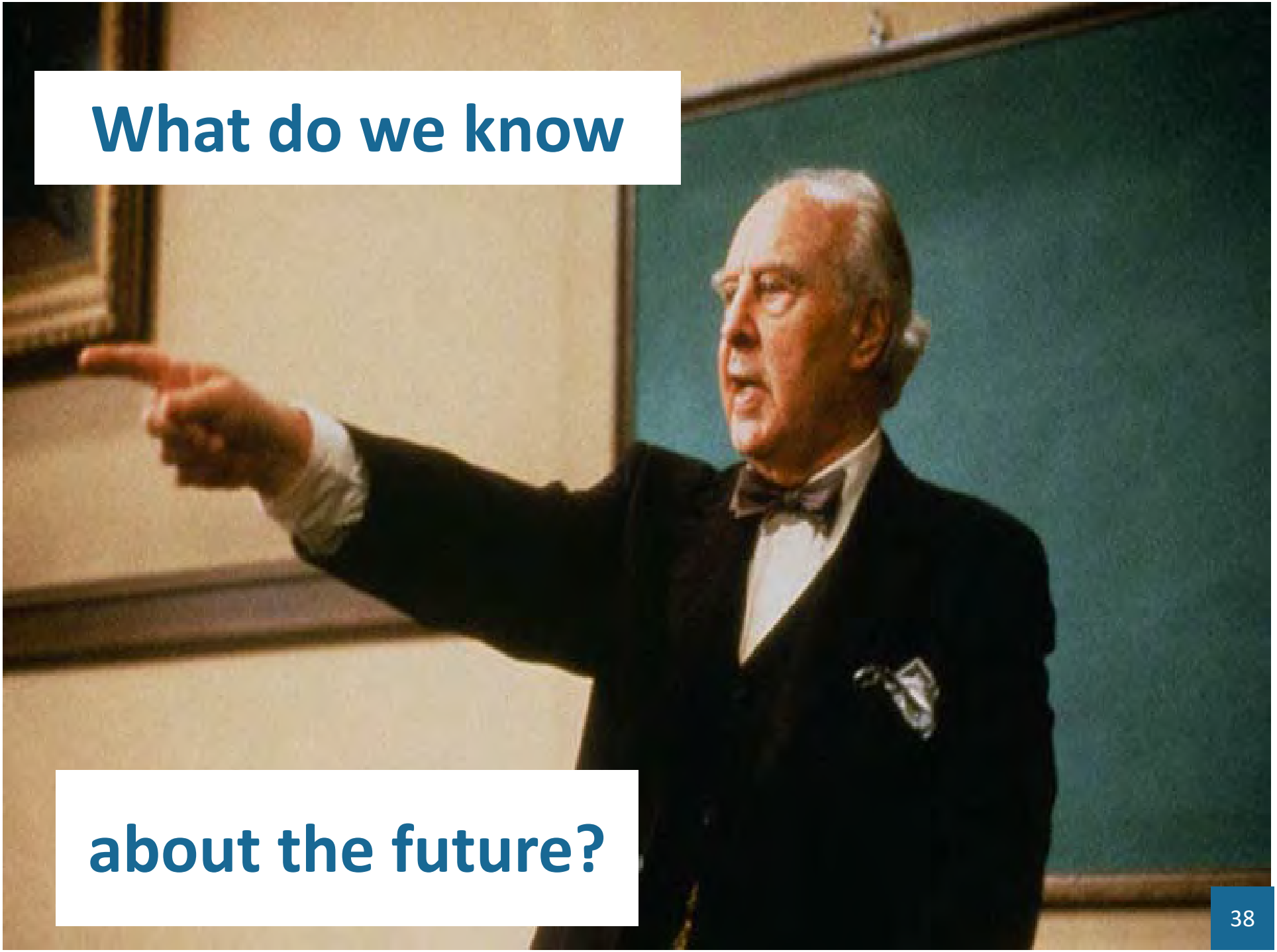
We are No Longer…



Living in the Middle Ages

And Yet,
Many Leaders…
George Tooker
Landscape with Figures
1965-66
…still seem
to behave
as if we do


The Defining Reality of the Modern Age …
…is that Positive Change is possible
Willem de Kooning
Excavation [1950]


What do we know
about the future?

Henri Julien Rousseau, *The Boat In The Storm* [after 1895].

Future Point

The world has gone DIGITAL

Behind the "Green Monster" Fenway Park

Observation

The World has Changed Its Mind

…about Knowing

Observation

During the 1st Decade of the 3rd Millennium…

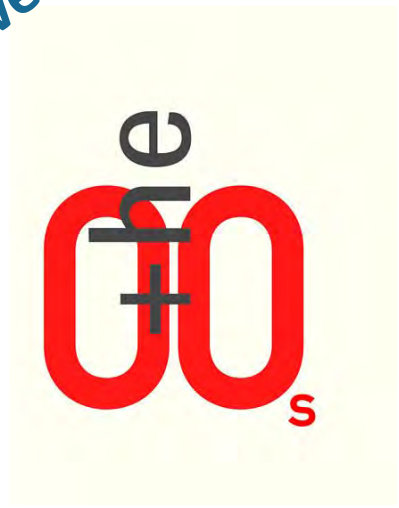
Somewhere

Sometime

Some Place

Some Why…

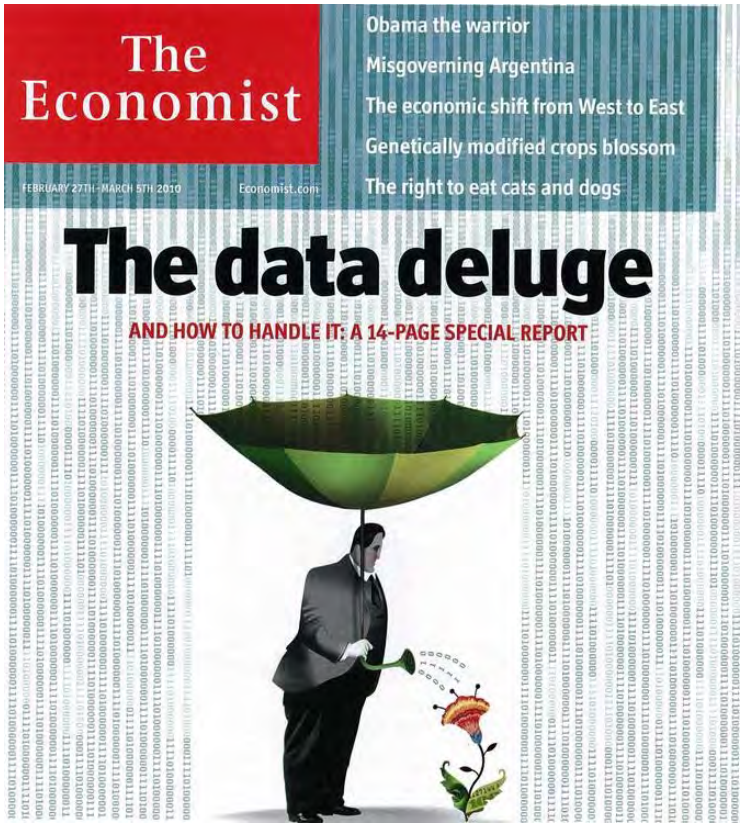
Our species [particularly *homo in chargus*] re-discovered DATA



Observation

There is a lot of data

2.5 quintillion new bytes generated each day



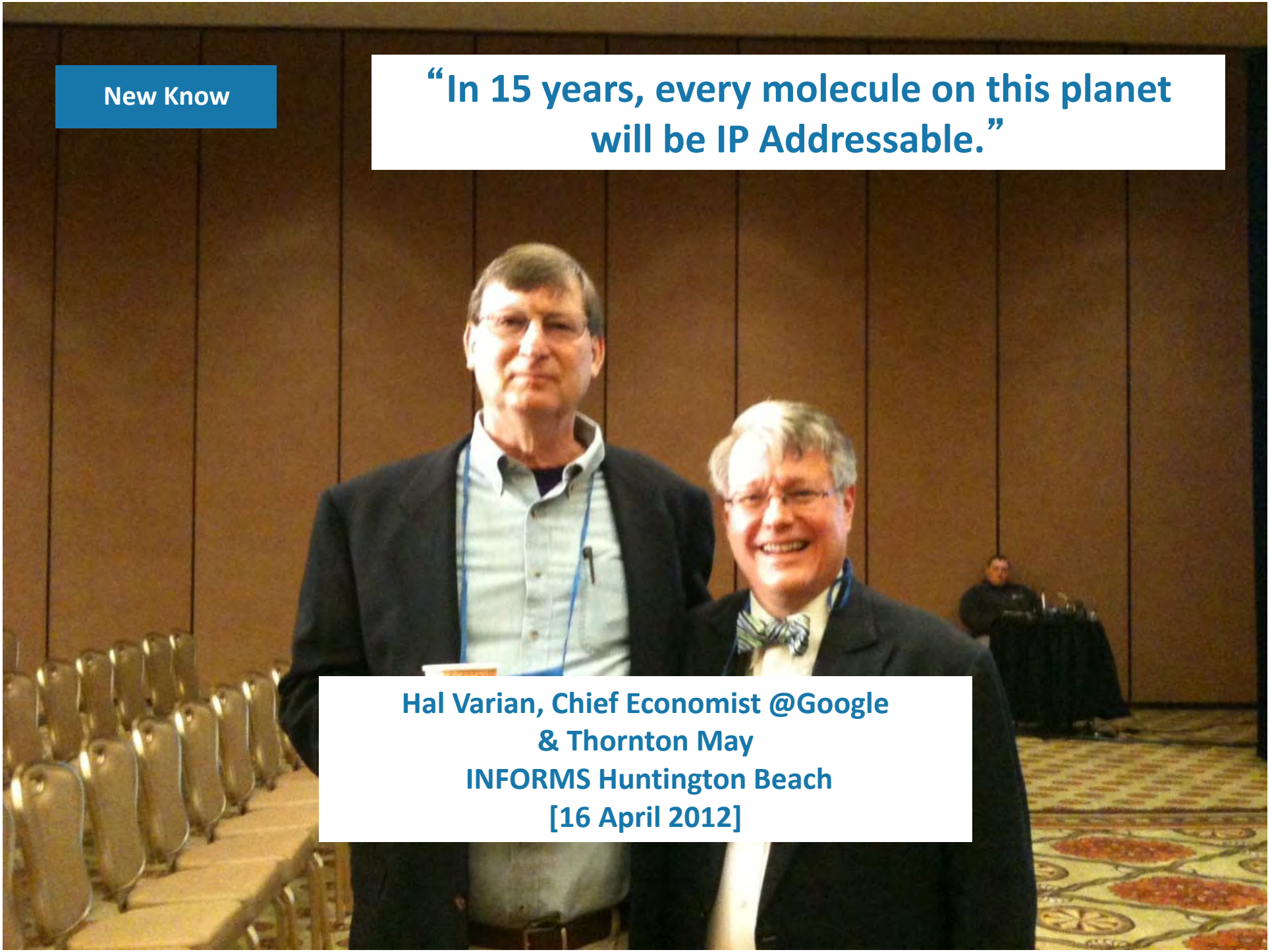
New Know

In 1980, the PGA collected
one data point per golfer, per hole.

In 2019, the PGA collects
40 data points per golfer, per second

Pebble Beach 2019

New Know



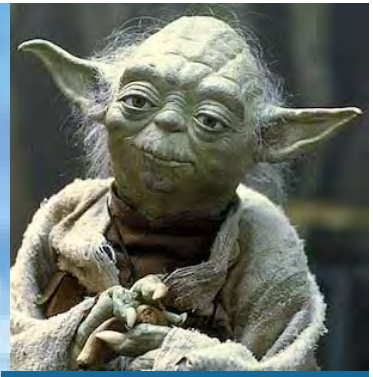
"In 15 years, every molecule on this planet will be IP Addressable."

Hal Varian, Chief Economist @Google
& Thornton May
INFORMS Huntington Beach
[16 April 2012]

The Fact That There is More Data is…

NOT News

What is News…



Hypothesis

There are growing expectations that organizations will do something efficacious with all that data

Observation
EVERY organization has
different expectations of “data”
Tatsuro Kiuchi

Observation
Not every expectation is rational

EVERY Organization
MUST HAVE:
Hypothesis
a mechanism to articulate
what expectations are
Rodin Museum, PHL [8 May 2017]

Hypothesis

We have entered
the Age of
the Know-It-All Organization

Executives and Organizations are now expected
to have a continuous & comprehensive awareness of
ALL that is occurring in their company's operations.

Observation

We have entered the:

KNOW-Tolerance

era

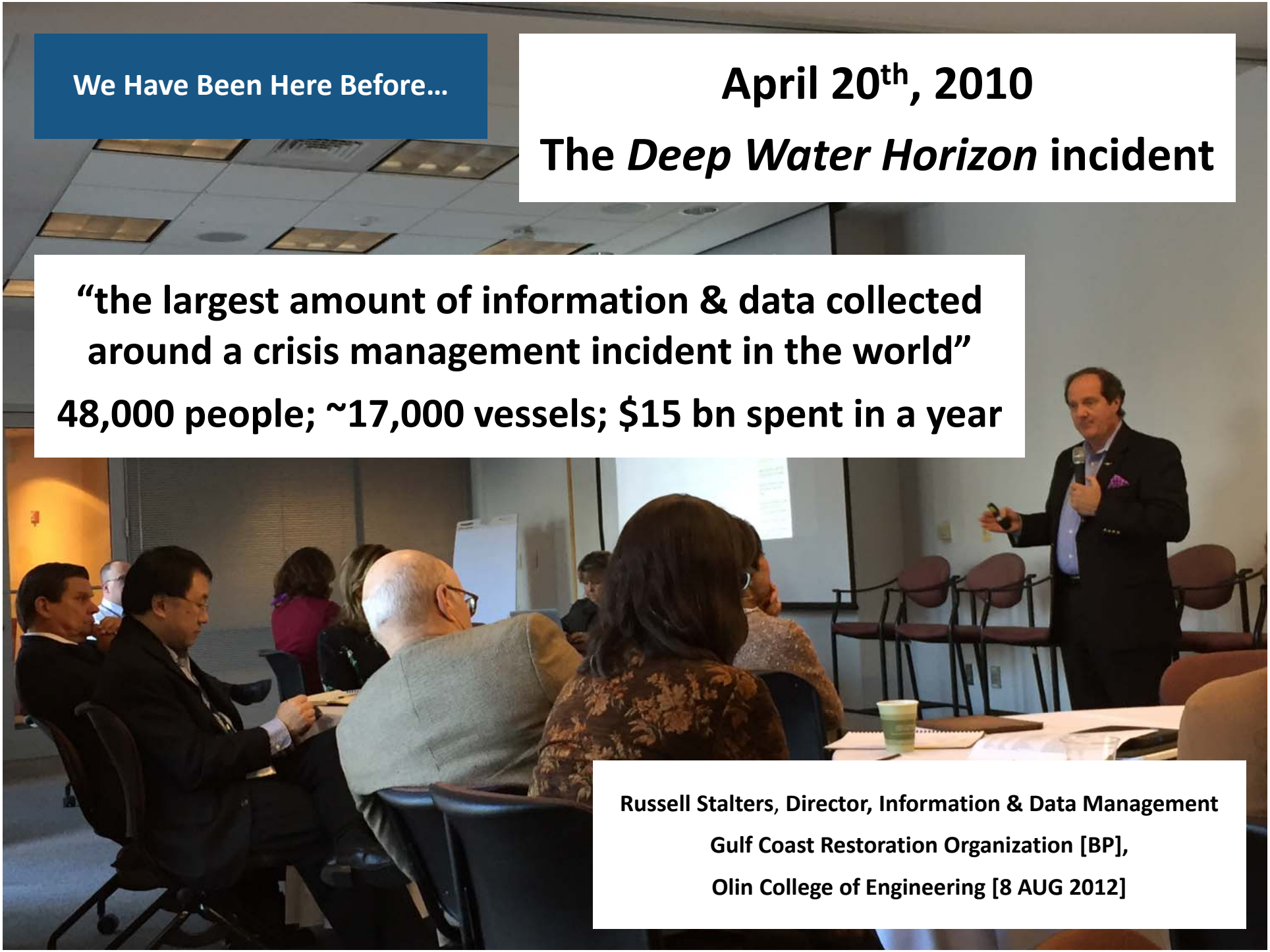
Introductions by **Jean E. Carter,** Chief Knowledge Officer, NASA;
John Chickering, CIO Fidelity Information Management and
Chairman of the Association of Information and Image Managers.

The New Know

Innovation Powered by Analytics

THORNTON MAY

Afterword by Alan Webber,
former editor of the Harvard Business Review
and founder of Fast Company magazine



We Have Been Here Before…

April 20th, 2010

The *Deep Water Horizon* incident

"the largest amount of information & data collected around a crisis management incident in the world"

48,000 people; ~17,000 vessels; $15 bn spent in a year

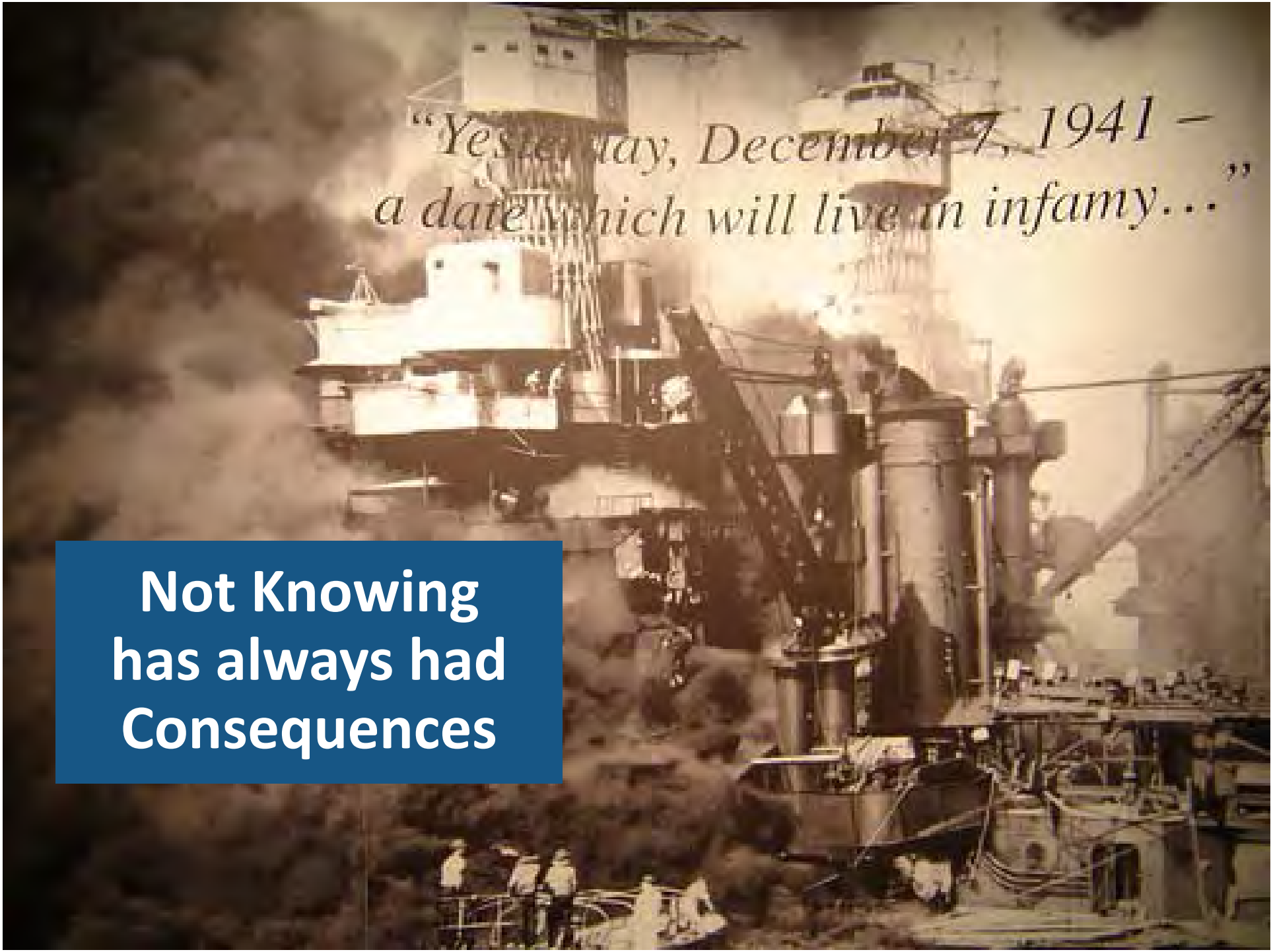
Russell Stalters, Director, Information & Data Management

Gulf Coast Restoration Organization [BP],

Olin College of Engineering [8 AUG 2012]

Randy Krotowski, CIO for Chevron Global Exploration & Production, he led IT strategy, delivery & operations for Chevron's $100 billion exploration and production business.

He delivered a $1 billion modernization program and spearheaded a new solution delivery model, accelerating Chevron's digital oilfield transformation



Not Knowing has always had Consequences

Delegate Information

March 15-17, 2009 | Sawgrass Golf Resort & Spa | Ponte Vedra, FL

About 10 Years Ago, Ignorance became a "prosecutable" offence

New Expectations

The manslaughter trial of six seismologists and a government official in the central Italian city of L'Aquila, stemming from what the authorities say was a failure to warn the population before a deadly 2009 earthquake, has outraged many scientists.

Thousands have signed petitions protesting the prosecution as anti-science.

Henry Fountain, "Trial Over Earthquake in Italy Puts Focus on Probability and Panic," *New York Times* [3 October 2011].

New Expectations

September 20, 2011 Italy: 7 Go on Trial Over Quake
By ELISABETTA POVOLEDO

Seven Italian seismologists and scientists went on trial on manslaughter charges on Tuesday, accused of not adequately warning residents of a central Italian region before an earthquake that killed 309 people in April 2009.

Prosecutors say that the seven defendants, members of a national panel that assesses major risks, played down the risk of a major earthquake's occurring even though there had been significant seismic activity near L'Aquila, the capital of the Abruzzo region, in the months before the quake. The case has drawn the attention of the international scientific community, which argues that it is impossible to predict an earthquake. Prosecutors, in actuality, charge that the panel did not fulfill its mandate and instead conveyed "incomplete, imprecise and contradictory information."

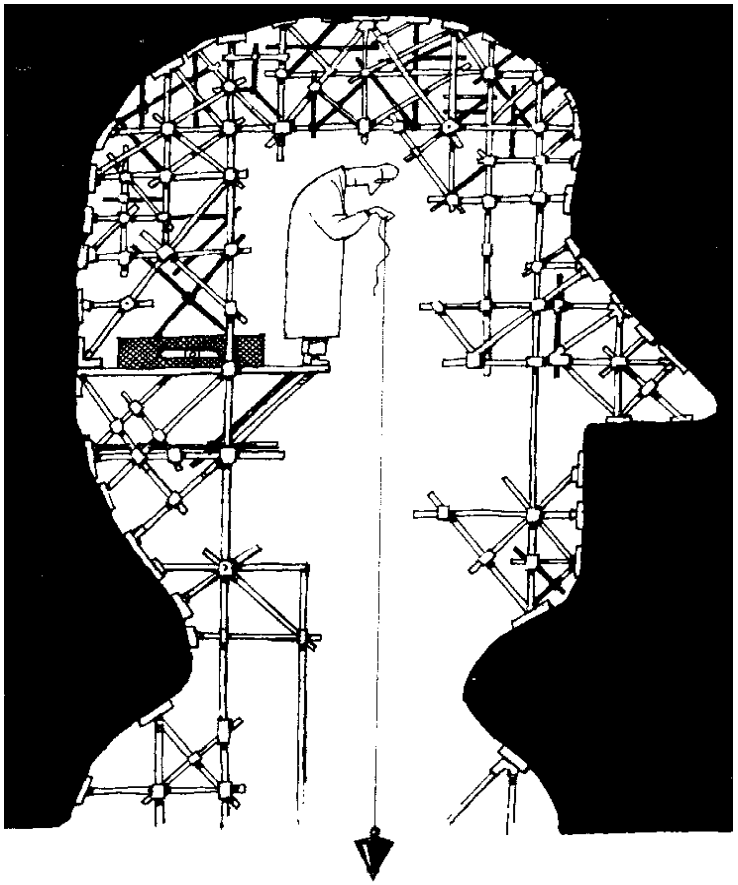
http://www.nytimes.com/2011/09/21/world/europe/italy-7-go-on-trial-over-quake.html?pagewanted=print

The New Know

Paul Otellini, CEO at Intel was asked by Charlie Rose:

The New Know

“What is going to be obsolete next?



Otellini responded:

“Ignorance.”

Future Point

Ignorance is no longer a state of nature.

It is a choice!

Hinge of History

Society Has Changed Its Mind about Knowing

Un-augmented human cognition [the *old know*] is no longer sufficient.

***The New Know,* 1.**

Medical Analog

What are you going to do?

Katie Olivas, *Hesitate*

My Research Surfaced:

Three [3] Foundational Elements of Successful Data Mastery Initiatives

Three [3]
Foundational Elements
of Successful Innovation

Attitude
Aptitude
Ambience

Let's Talk Skill Set

[Aptitude]

DIGITAL SKILLS GAP

The Digital Skill Set

European Commission

A Digital Europe needs Digital Skills

The Digital Skills Summit:

5 TOP DIGITAL SKILLS

Digital leadership principles self-assessment

How do you rate on the six digital leadership principles?

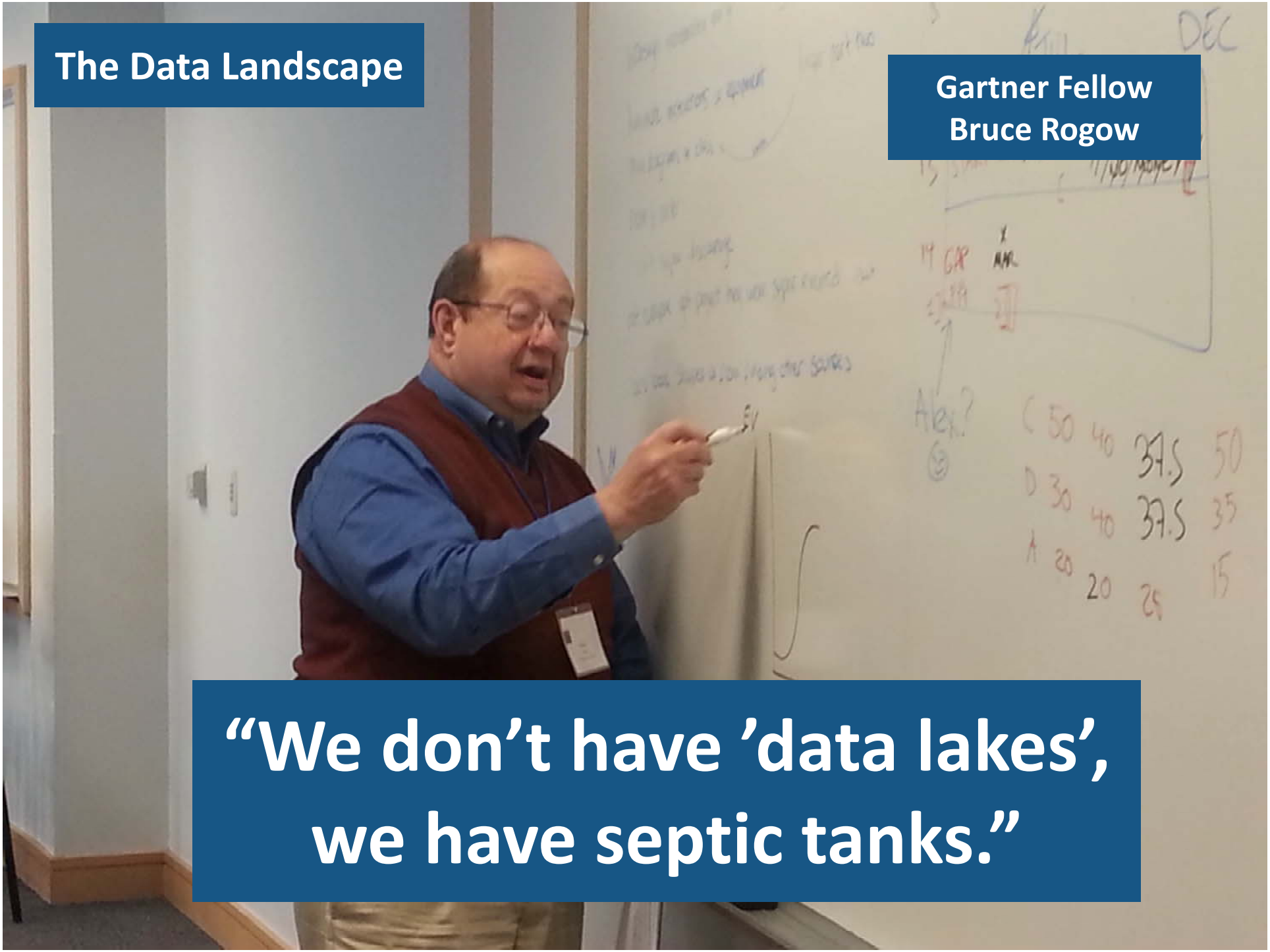
The Data Landscape

FLORIDA COMMUNITY COLLEGE at Jacksonville

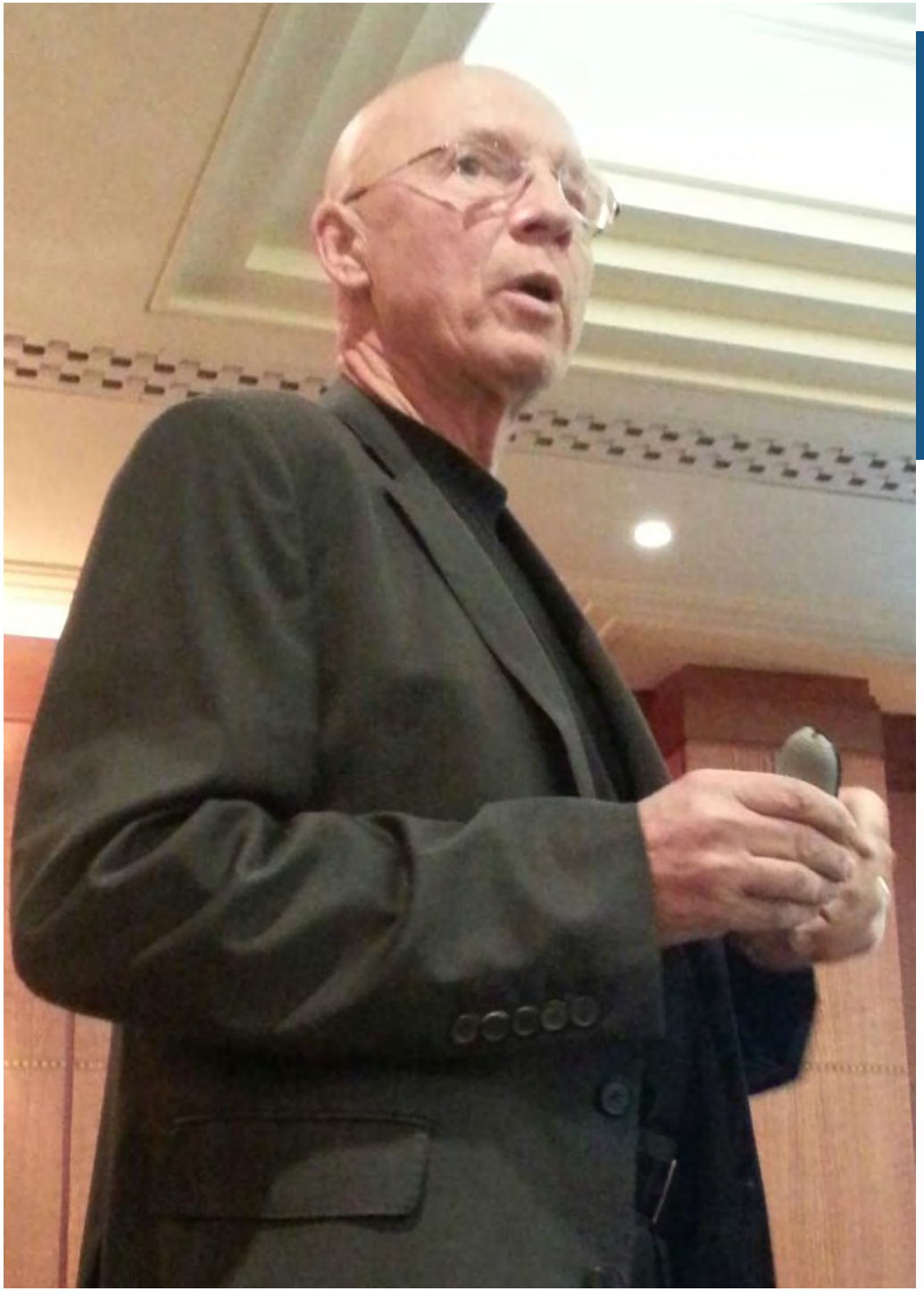
Most organizations just plain

SUCK

at “data”


The Data Landscape
Gartner Fellow
Bruce Rogow
“We don’t have ’data lakes’,
we have septic tanks.”

Generally Speaking,
the State of Data
in EVERY Vertical Market…
Francesco Giuseppe Casanova
[younger brother of Giacomo],
Rupture of the Bridge



“When riding a dead horse….Dismount!

Wisdom of the Dakota Indians

John Leggate,
Group Chief Information Officer
at BP from 1999 to 2007

John was responsible for a budget of $2.5 billion annually and 4000 staff.

Led $5 bn transformation initiative; made $250 mm VC investments

There is Hope

What was the driving force behind Great Britain's empire?

The Path to Mastery

Honest Appraisal of Competence

At the end of the reign of Henry VIII (1509-47 AD) only 20 of so English masters dared to sail beyond sight of land.

Walter A. McDougal, *Freedom Just Around the Corner: A New American History 1585-1828,* 30.

The Path to Mastery

Identify Knowledge Opportunity

The East India Company was launched in 1600.

The governors of these national start-up firms realized…

Walter A. McDougal, *Freedom Just Around the Corner: A New American History 1585-1828,* 30.

The Path to Mastery

Create a "Get Smart" Program

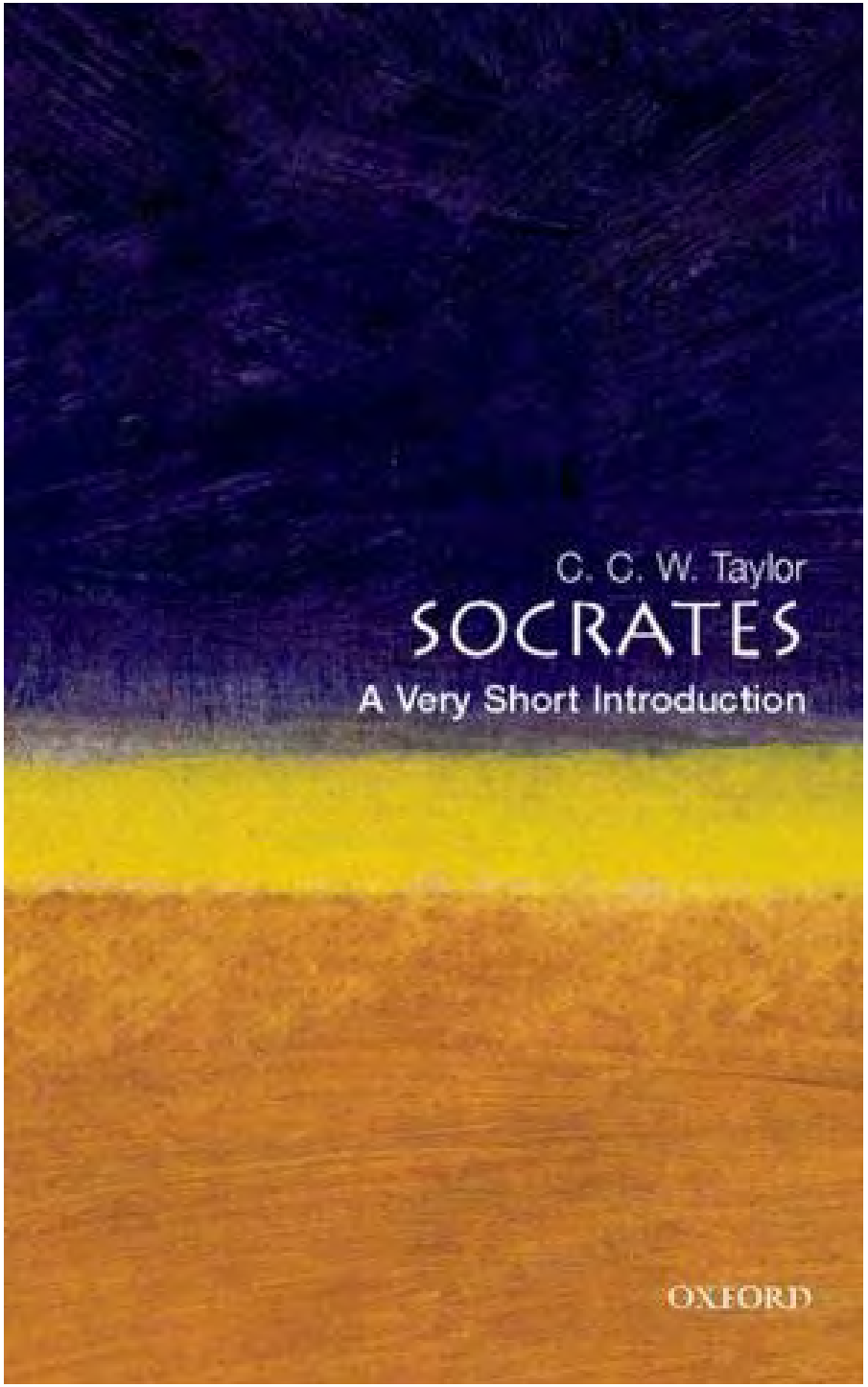
Walter A. McDougal, *Freedom Just Around the Corner: A New American History 1585-1828,* 30.

So they ordered their agents to purchase or steal maritime intelligence from the Iberians, French, and Dutch. A Muscovy pilot scored the biggest coup when he returned from Seville with a copy of Spain's textbook

for sailors.

Translated in 1561 under the title

***The Arte of Navigation,* it was probably 'one of the most decisive books ever printed in the English language. It held the key to the mastery of the sea."**



The Third Socratic Principle

[3] Excellence (ἀρετή) is teachable & learnable

Three [3]

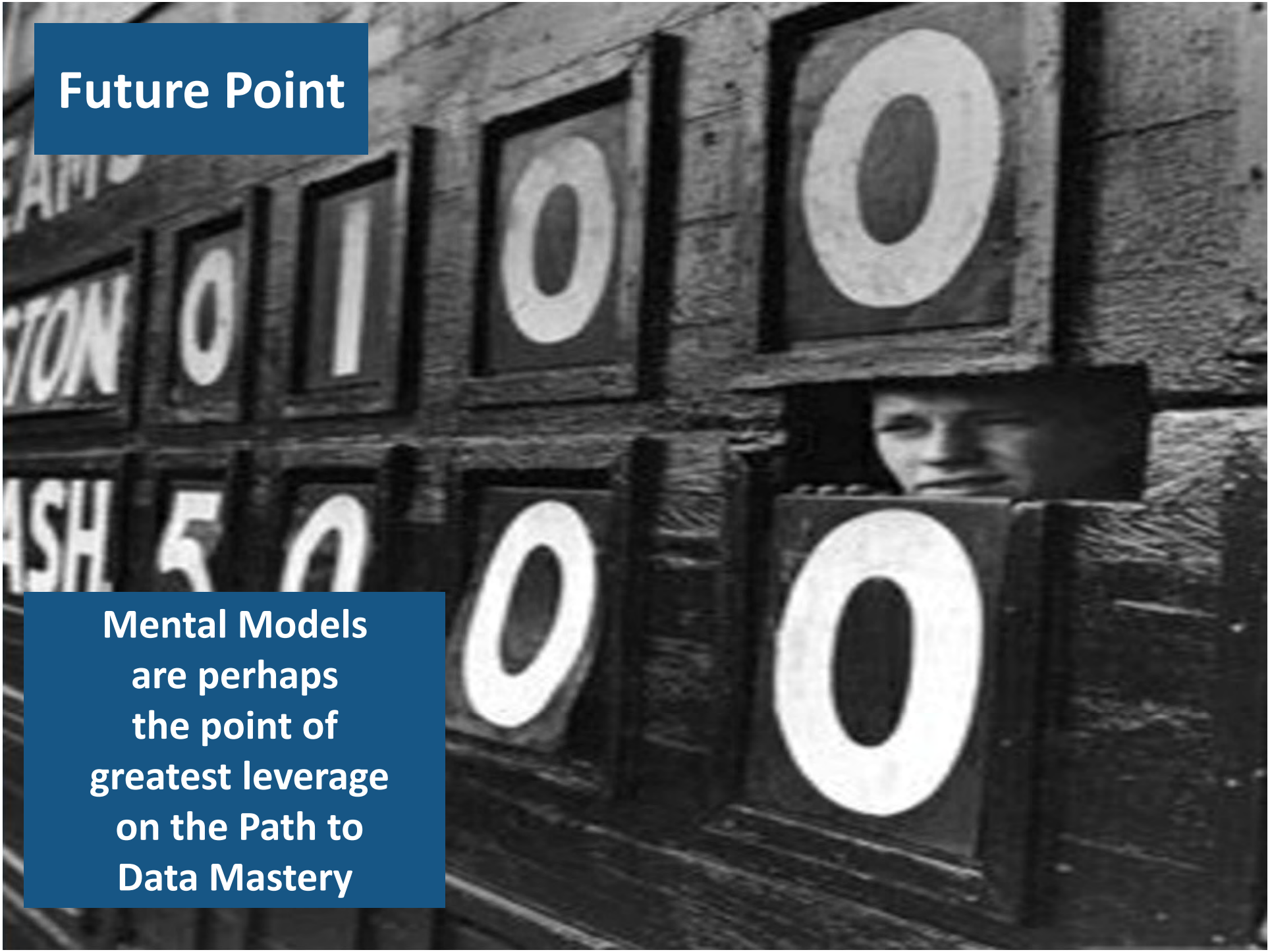
Foundational Elements

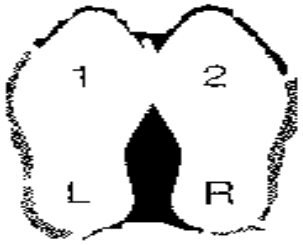
of Successful Data Journeys

Attitude = Mindset

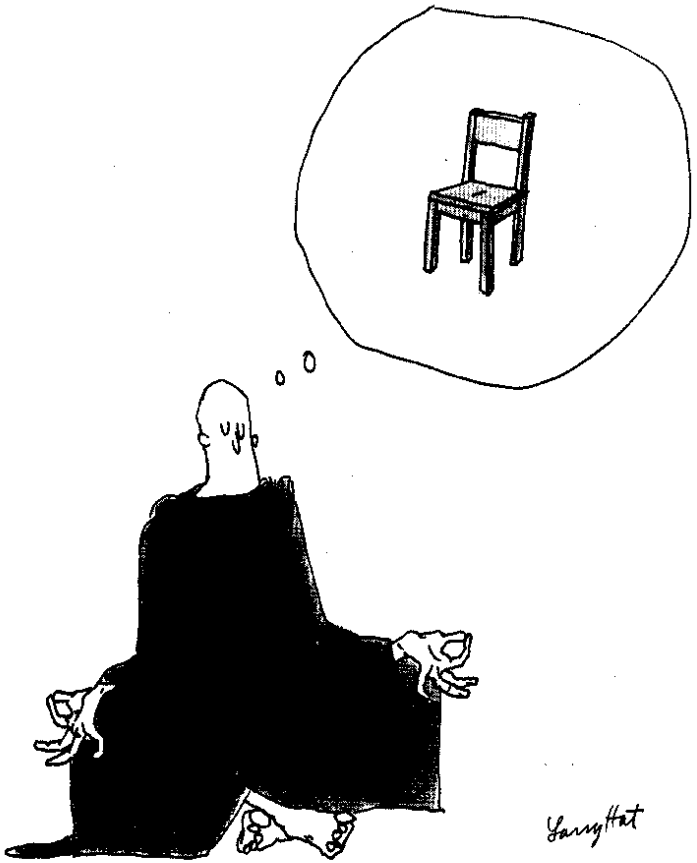
How Do People Think about “Data”?

I am a
‘mental models’
kind of guy


Future Point
Mental Models are perhaps the point of greatest leverage on the Path to Data Mastery



STEP #1: Managing Mindsets & Mental Models

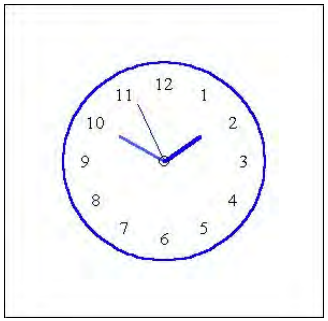


What are People Really Thinking?

Future Point
Behind the “Green Monster”
Fenway Park
What the boss wants matters!

SUB-POINT
What customers
& regulators want,
Matters too!

For Key Stakeholders
I Suggest Doing
a Quick Level Set



30 second exercise

Aural
Rorschach Test

www.wordle.net

When they hear the word

“data”

what is the First Thing That Leaps To Mind?

Heightened Sensitivity to Under-performing Assets

Boss Wants

WSJ [23 JAN 2019]

Asset operators are expected to save about

$1 trillion a year

as a result of data-driven predictive maintenance techniques

By 2022, 40% of organizations in the industrial sector
are expected to predict maintenance problems
using data-driven predictive maintenance techniques,
up from 10% in 2018.

Data Driven Predictive Maintenance

The world's largest beer maker is using low-cost sensors & machine learning to predict when motors at a Fort Collins, Colo. brewery might malfunction.

Wireless sensors monitor motor vibrations

Out-of-norm vibrations –
sounds undetectable by human hearing
signal possible problems
& predict when machines will fail –
sounds humans can't hear

10x ROI

George de La Tour, *The Fortune Teller* 1630

Boss Hate Spending Money They Don't Have To

JPMorgan Software Does in Seconds What Took Lawyers 360,000 Hours

The program, called COIN, for Contract Intelligence, does the mind-numbing job of interpreting commercial-loan agreements that, until the project went online in June, consumed 360,000 hours of work each year by lawyers.

The software reviews documents in seconds, is less error-prone and never asks for vacation.

Big Data is Like a Maestro Hopping in a Cab…

Cab driver asks,

"Where to Maestro?"

Link New Modes of Knowing to Strategic Objectives of the Enterprise

A K-Score is a prediction of success.
It's used to give students an understanding
of how well they are doing over time.

We use factors such as their academic work, how engaged they are in Blackboard and engagement in campus activities to generate a K-Score.

We also rely on traditional, non-evasive survey techniques to help round out the student performance statistic.

“We exist because clients trust us with data.”

Ginny Rometty, IBM CEO *Squawk Box* [22 JAN 2019]

The Top of the House
Is talking about “data”

“the world collects & uses less than 1% of all the data generated”

Ginny Rometty, IBM CEO *Squawk Box* [22 JAN 2019]

Some Quick Thoughts about Ambience

A New Word Not Much Used in the IT Arena

am·bi·ence

/ˈambēəns/

noun

the character and atmosphere of a place.
"the relaxed ambience of the cocktail lounge is popular with guests"
synonyms: atmosphere, air, aura, climate, mood, feel, feeling, character, quality, impression, complexion, flavor, look, tone, tenor; More

- background noise added to a musical recording to give the impression that it was recorded live.

Atmosphere, context, environment, moment, zeitgeist

NBC

FOX

abc

Big Media has misrepresented the "State of Play" in the Data World

George de La Tour, *The Fortune Teller* 1630

Big Tech has over-focused on the Consumer Sector in the Data World

(L-R) Vice President and General Counsel for Facebook Colin Stretch, General Counsel for Twitter Sean Edgett, and Senior Vice President and General Counsel for Google Kent Walker are sworn in during a hearing before the Senate (Select) Intelligence Committee November 1, 2017 on Capitol Hill in Washington, DC.

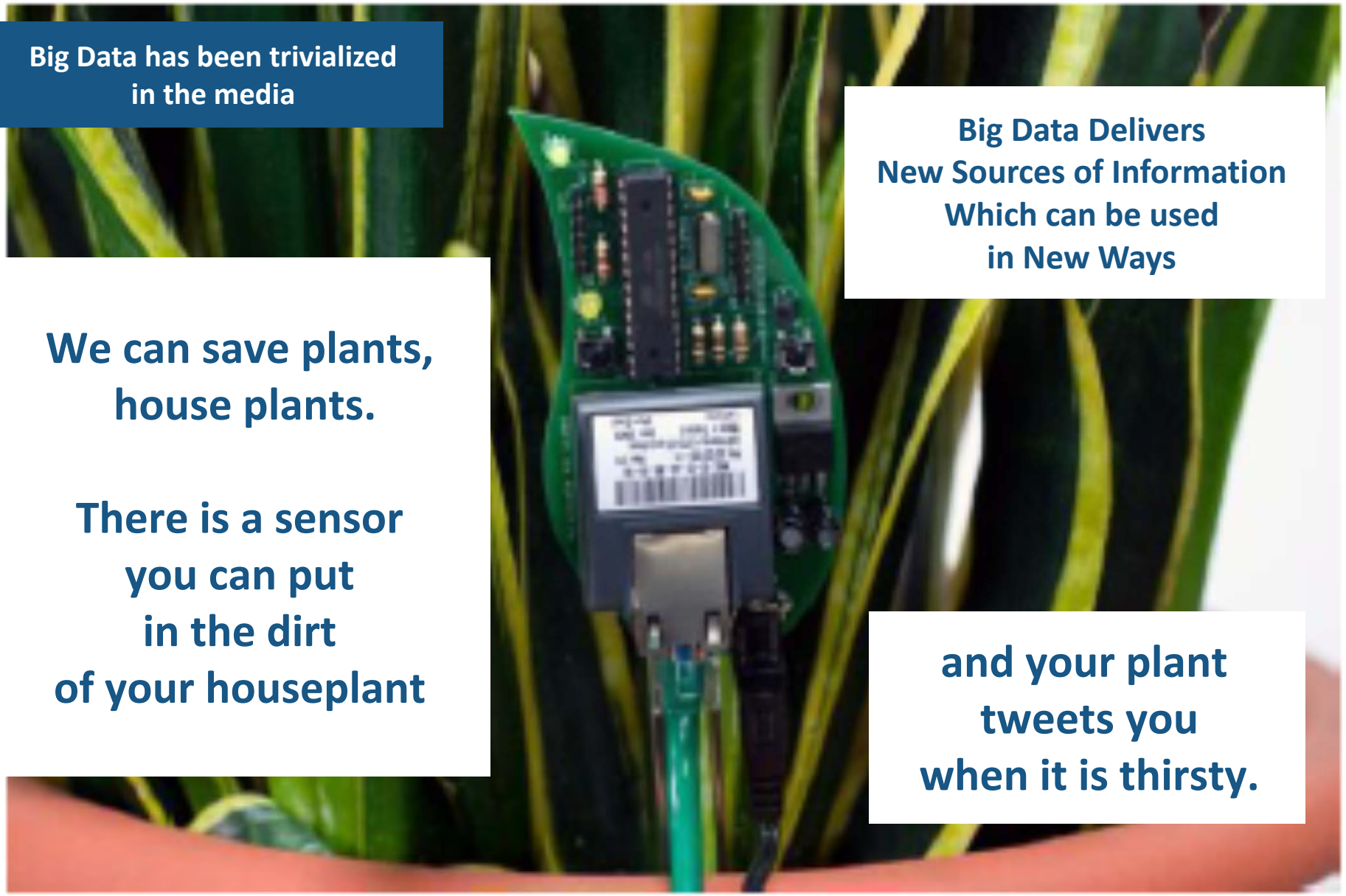
In the Early Days of BIG DATA…

“In Silicon Valley, there’s lots of big minds chasing small ideas.”

Kara Swisher, Technology Writer

Big Data has been trivialized in the media

Big Data Delivers New Sources of Information Which can be used in New Ways



We can save plants, house plants.

There is a sensor you can put in the dirt of your houseplant

and your plant tweets you when it is thirsty.

Source: www.botinacalls.com

You will be pleased to note…

We are now entering an era of BIG Minds focused on BIG ideas

The VC Community has labeled 2019 as: "a year of fulfilled promises"

We have entered an Age of …

Digital that Matters

On the Path
to Data Mastery…

There will be data management activities [policies, practices & procedures -P^3] you will perpetuate

There will be P^3 you will terminate

There will be P^3 you will initiate

On the Path
to Data Mastery…

Don't Do's

New Do's

Thru Do's

#1 New Do

Engage Actively With Industry-Wide Data Sharing Initiatives

Gustave Caillebotte, *The Floor-Scrapers* [1878]

Vatican Signals

Each day smoke rises from the chimney, once in the morning

and once in the afternoon.

Black smoke = no decision

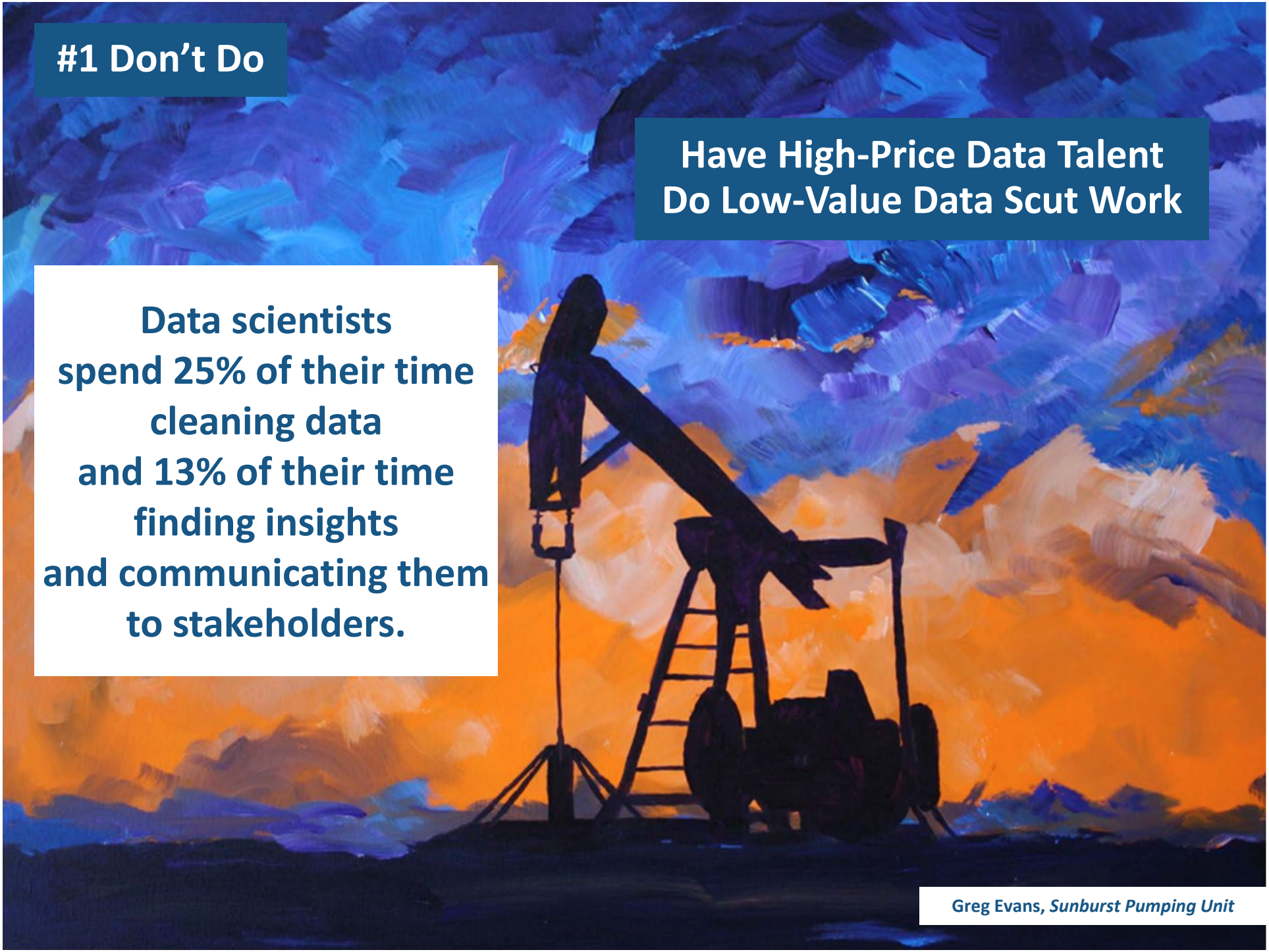
White smoke – new pontiff

that you are thinking about the issue &
exposing yourself to industry best data management practices

#1 Don't Do

Have High-Price Data Talent Do Low-Value Data Scut Work

Greg Evans, *Drill Pipe*


#1 Don't Do
Have High-Price Data Talent
Do Low-Value Data Scut Work
Data scientists
spend 25% of their time
cleaning data
and 13% of their time
finding insights
and communicating them
to stakeholders.
Greg Evans, *Sunburst Pumping Unit*

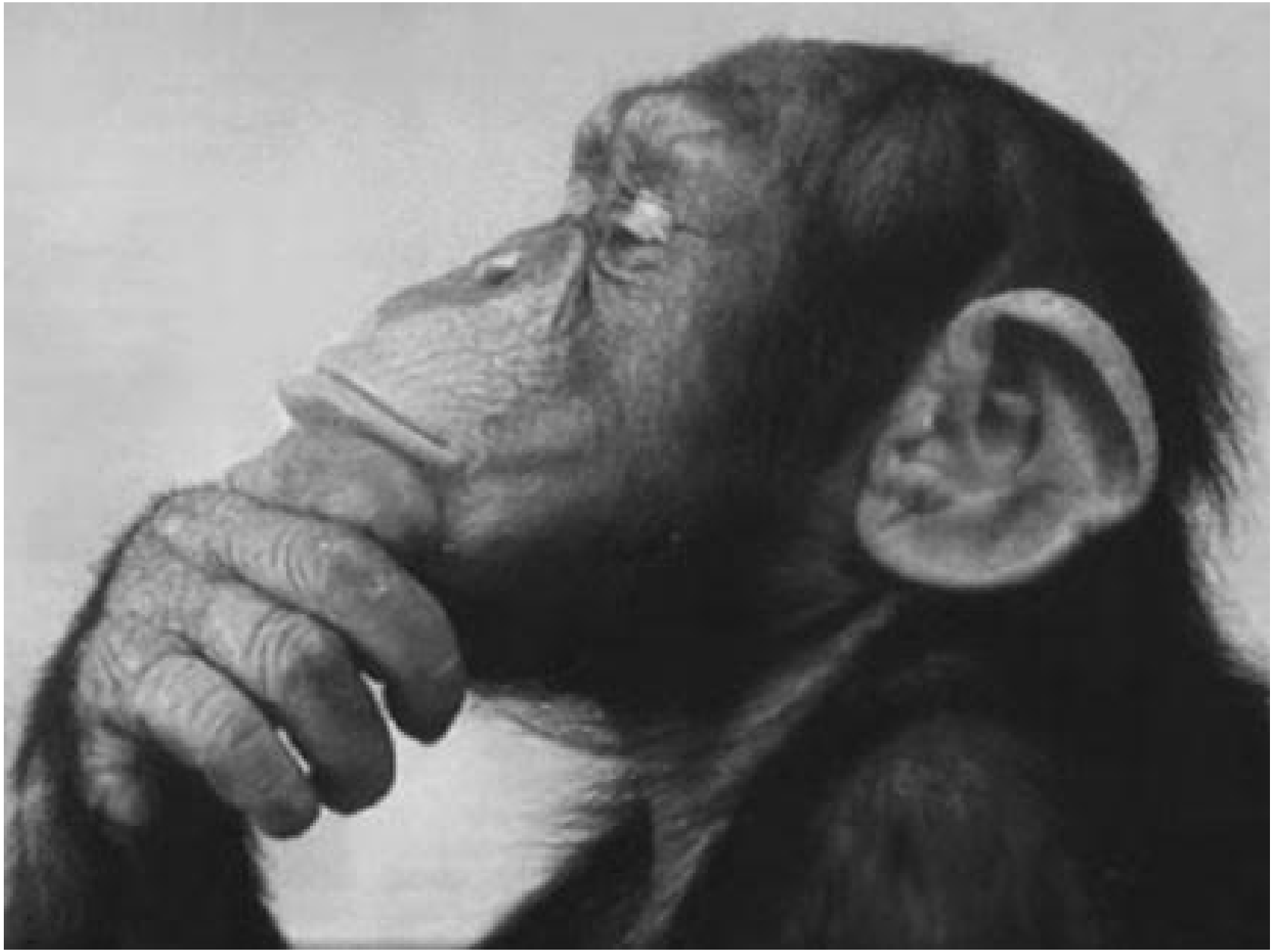
#2 To Do

Don’t forget to manage the Human Side of Your Path to Data Mastery

Daniel J. Barchi, Chief Information Officer at NewYork-Presbyterian {$8 bn health system]

80 – 15 - 5

Closing Thoughts

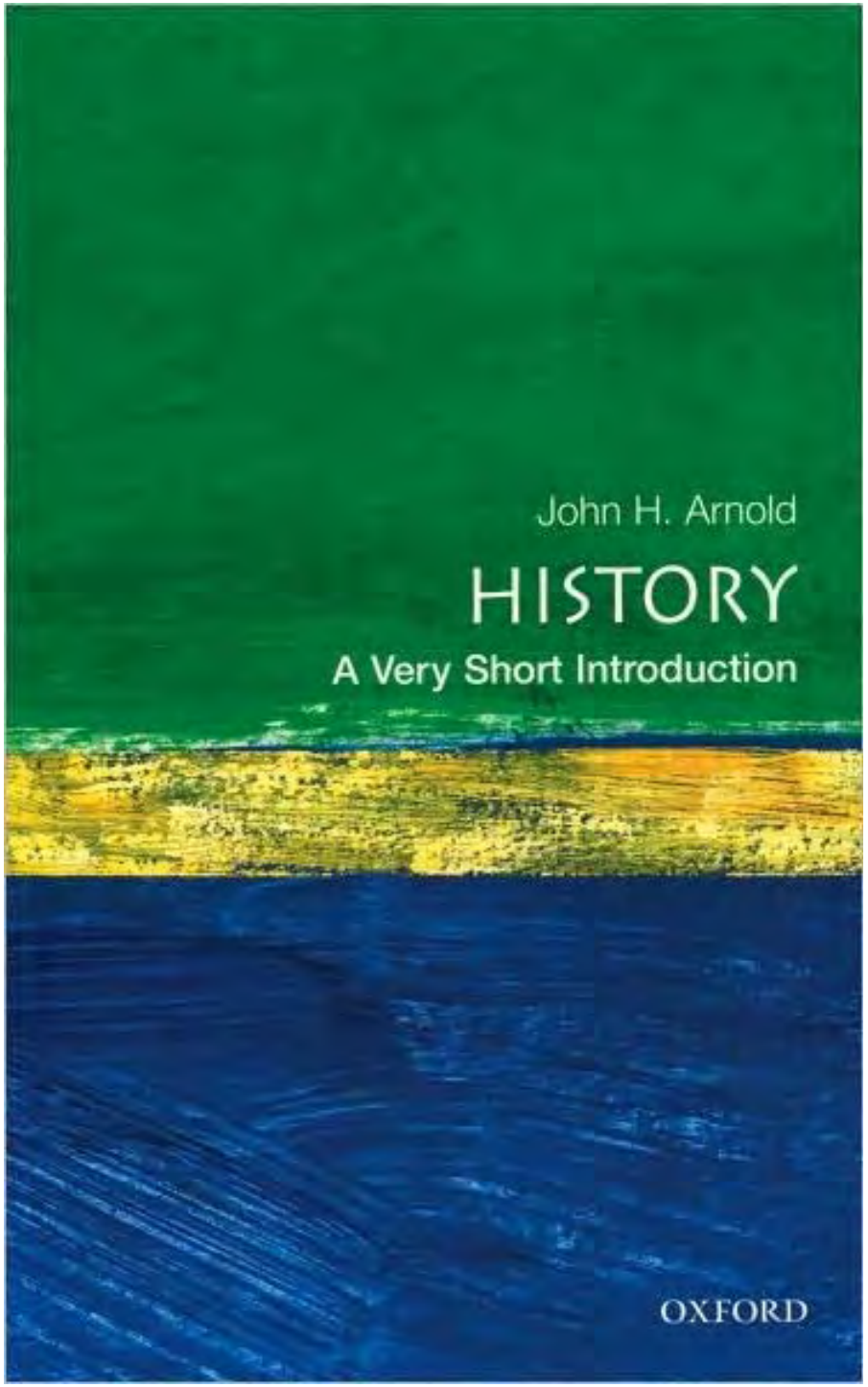


Historically ….

The essence of Leadership

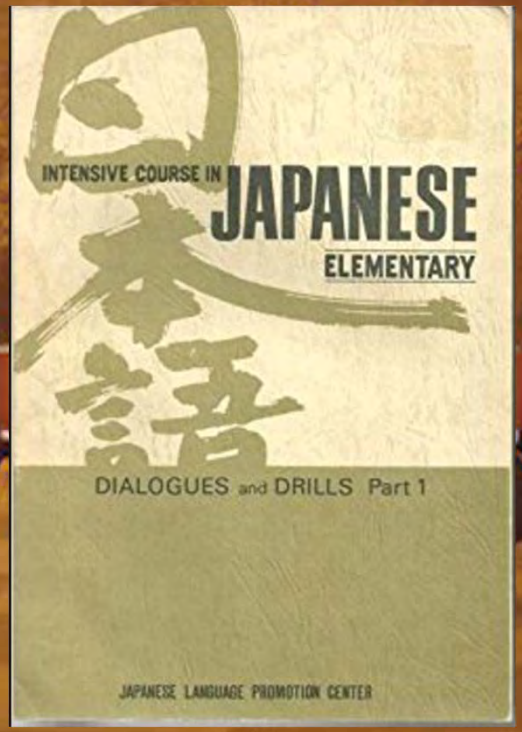
Has ALWAYS BEEN

Knowing

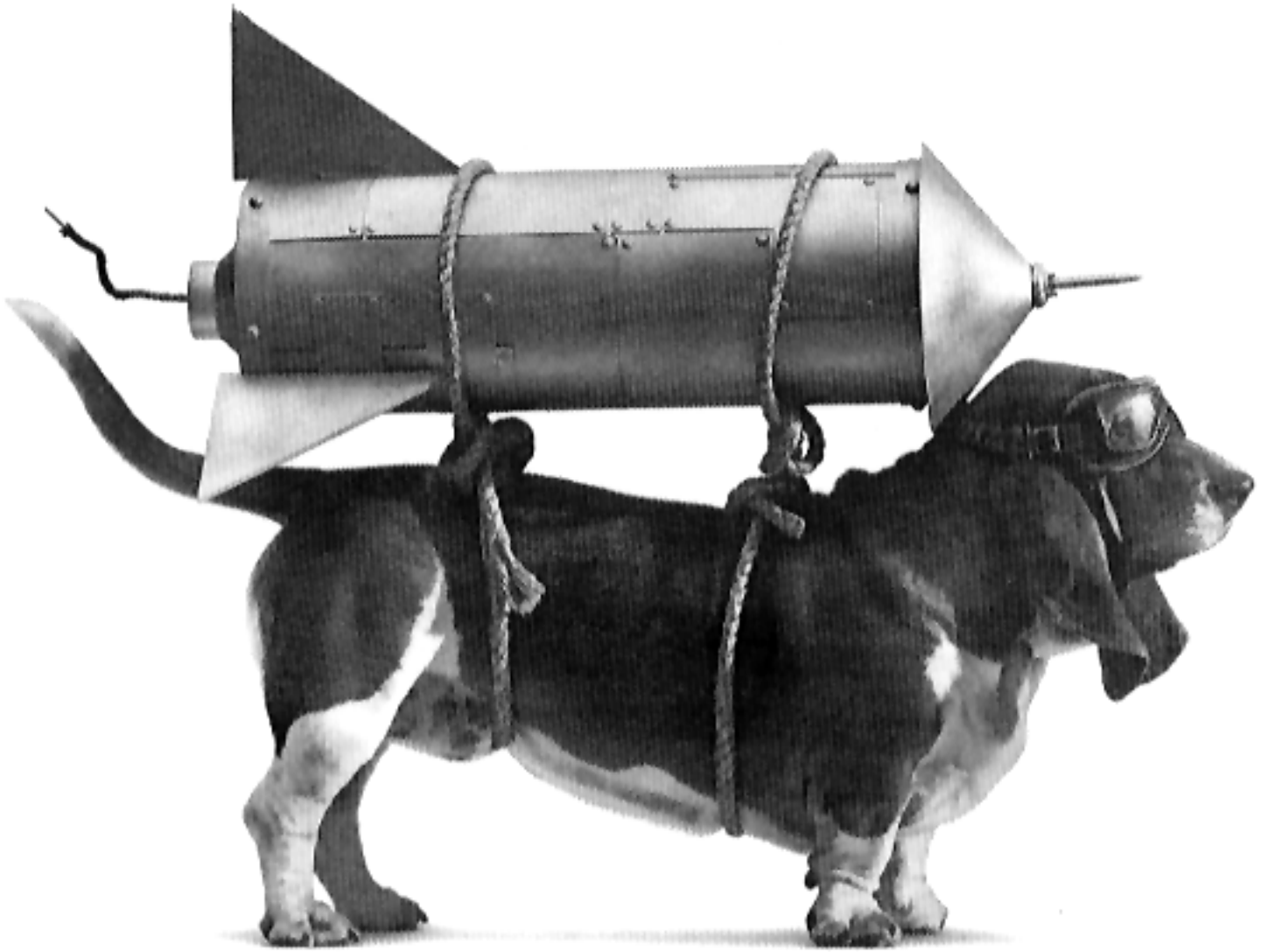


Action Item
Develop Mastery in
Creating Value with Data

The Okura Hotel



Visual Summation



Thank You
for your Service
I would love to continue our Conversation
thornton@digitalvalue.institute
@deanitla
Jacqueline Humphries, *Antic (detail)*, 1994

Data Hub Update

REX March 2019

- **Intent - modernize from our current data sharing capability**
- **Data Hub activities:**
  - NDE 4E Pilot (aka NDE 4-7) annual Crack ILI State-of-Art reports
  - Intent and Charter documents developed
  - Data Science internal resources underway
  - Historical Data Library drafted
  - Many stakeholder communications (membership, agencies, etc.)
  - Alignment with DOT VIS
  - On track for Sept 2019 rollout
- **Goal: more projects scoped around data sharing**

Dept of Transportation (DOT)
Voluntary Information Sharing (VIS)

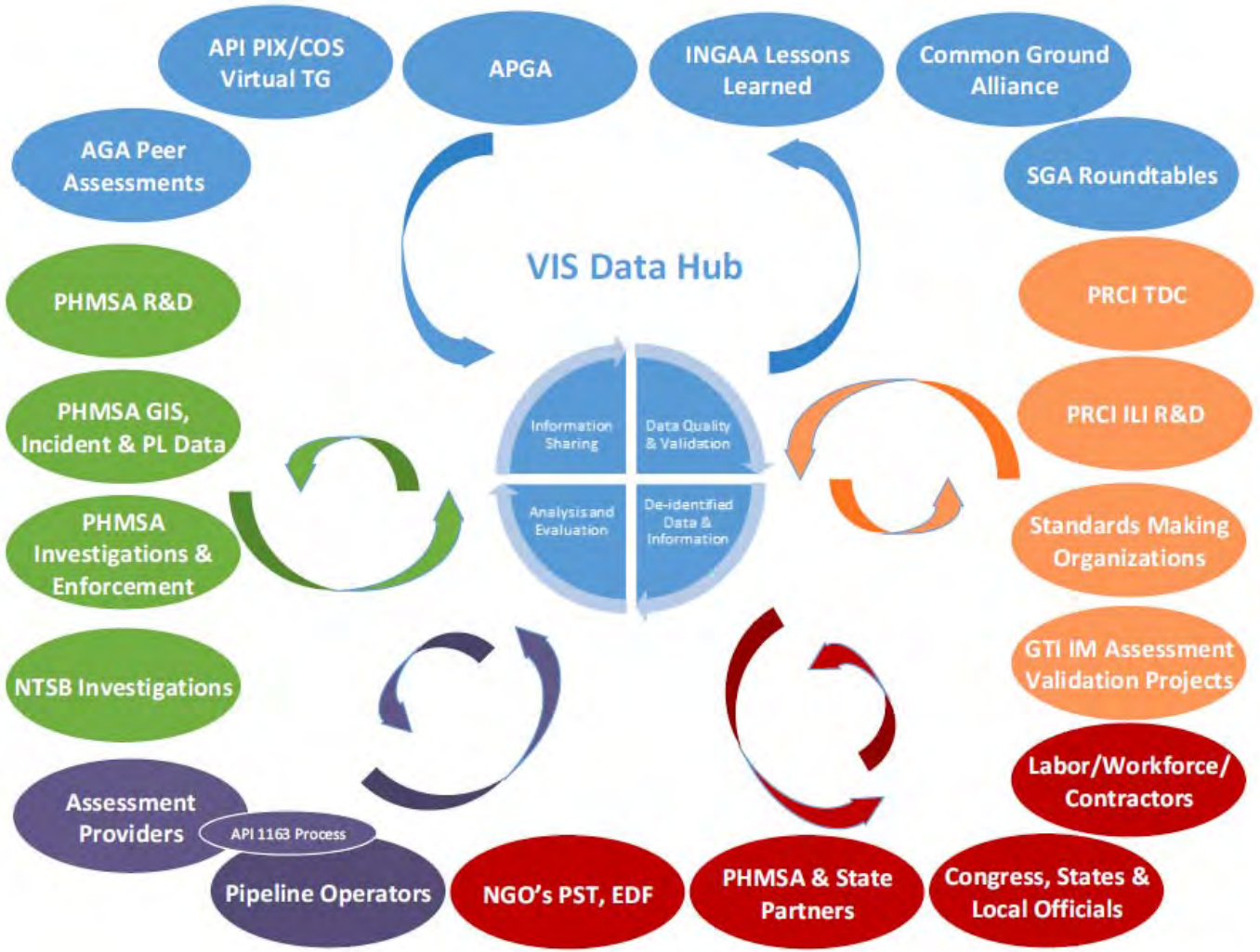


Figure 5

Pipeline Research Council International, Inc.

US Department of Transportation

Pipeline & Hazardous Materials Safety Administration

Volunteer Information Sharing (VIS) System

2019 Research Exchange Meeting

March 5, 2019

Houston, TX

LEADING PIPELINE RESEARCH

VIS Recommendation Report References

- **Voluntary Information-Sharing System Working Group**
  - https://www.phmsa.dot.gov/standards-rulemaking/pipeline/voluntary-information-sharing-system-working-group
- **Voluntary Information-sharing System Recommendation Report (162 pages)**
  - https://primis.phmsa.dot.gov/meetings/FilGet.mtg?fil=1026
- **VIS Summary of Proposed Recommendations (19 pages)**
  - https://primis.phmsa.dot.gov/meetings/FilGet.mtg?fil=1027

VIS Working Committee Recommendations

Three primary recommendations to the Secretary:

1. *Congress should authorize and stand up a VIS, to include participation by pipeline operators, PHMSA, and other pipeline safety stakeholders.*
2. *Congress should enact legislation to provide confidentiality, non-punitive and other legal protections to pipeline operators that participate in the VIS.*
3. *Distribution System information sharing must be included in the VIS program if meaningful industry incident reduction is to be achieved*

VIS Recommendation Report Considerations

"Sharing data and information within the industry is beneficial, would advance pipeline safety, and has demonstrated its substantial impact to safety in other modes of transportation."

"Enforcement alone is a limited tool. Many safety critical industries have shown that learning from all participants leads to greater improvements in safety performance."

Civil aviation industry example: "…an industry wide information sharing system was put in place over 20 years ago, leading to zero accidents for the past 9 years."

Recommendation Report – Barriers to Information Sharing

1. **Legal Barriers to Data and Information Sharing**
   - Identification of potential safety issues through information sharing
2. **Organizational and Governance Barriers**
   - Affordability and management if non-governmental
   - Potential complex data management and IT system
3. **Relationship/Trust Barriers**
   - Trust among industry participants and competition between industry service providers
   - Insufficient trust between industry and regulators – fear of enforcement action
   - Trust by public with regards to pipeline safety at an all-time low due to lack of historic lack of transparency and dishonesty
4. **Cost Barriers**
   - Who owns/maintains the system and how is it financially supported
   - Technology development costs and the need to acquire or adapt data sharing technology – specifically on up-front starting costs

Aviation Industry Information Sharing Example

Aviation Safety Information Analysis and Sharing (ASIAS)

1. A collaborative government-industry initiative on safety data analysis and sharing
2. A risk-based approach to aviation safety, identifying and understanding risks before accidents or incidents occur
3. Timely mitigation and prevention
4. Governing Principles
    1. *Voluntary Submission of safety sensitive data*
    2. *Transparency for how data are managed and utilized*
    3. *Analysis approved by an ASIAS Executive Board*
    4. *Procedures and policies based on collaborative governance*
    5. *Operator/Original Equipment Manufacturer (OEM)/Maintenance, repair and overhaul (MRO) date are de-identified*
    6. *Data used solely for advancement of safety*

VIS Industry Segment Considerations

Supplemental Recommendations

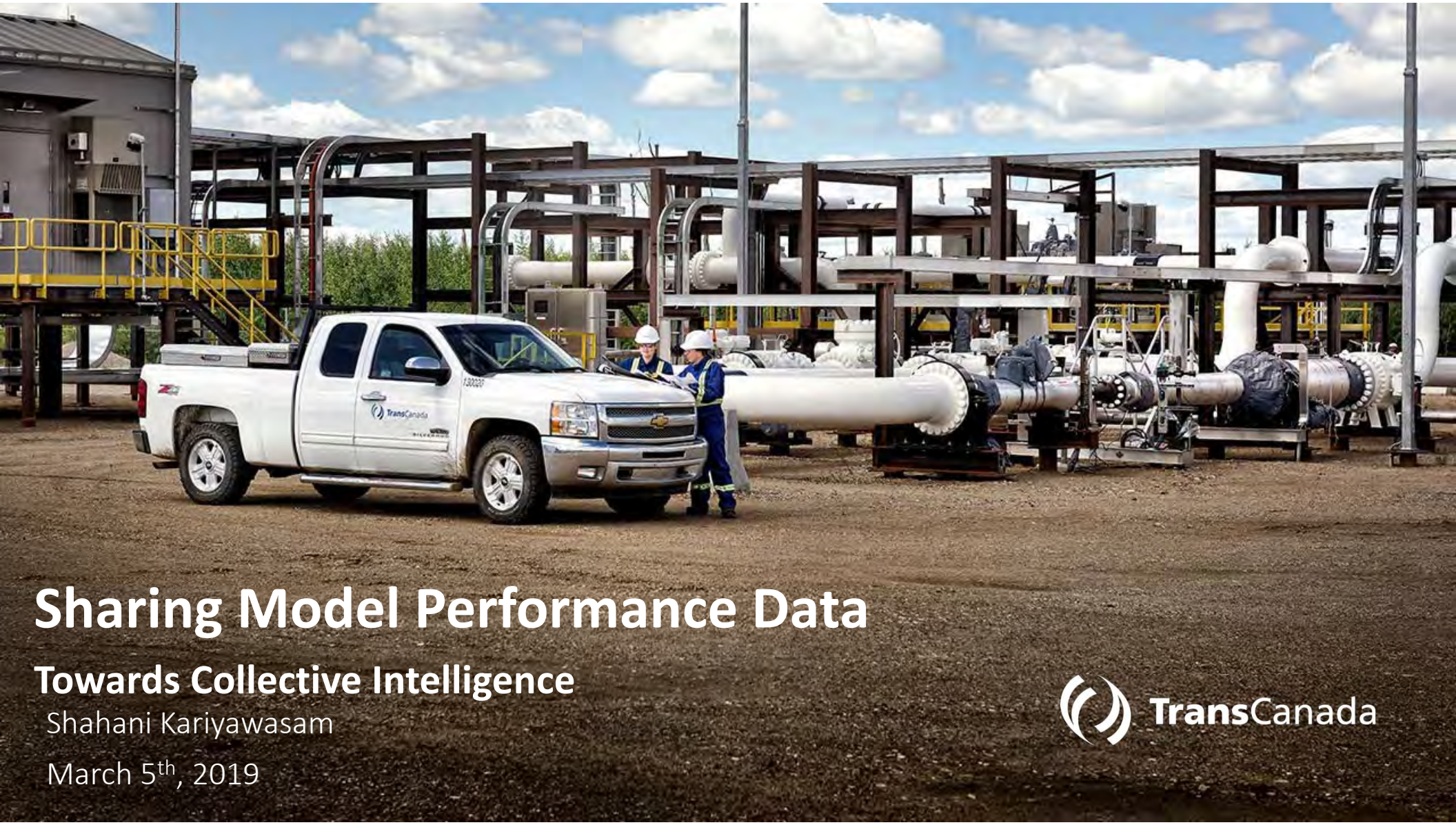
1. **Regulatory, Funding, and Legal Infrastructure**
2. **Governance Structure**
3. **Competence, Awareness, and Training**
4. **Process for Sharing Information**
5. **Technology and Research & Development**
    1. Supporting Recommendation (SR) T-1: Adopt a API RP 1163 Framework for Information Sharing
    2. SR T-2: Develop a Process for Pipeline Operators to Share Integrity Assessment Lessons Learned
    3. SR T-3: Define Processes to Share Discrete Integrity Assessment Data
    4. SR T-4: Evaluate Existing Information Sharing Systems in Use
        a. ***PRCI Pipeline Data Hub***
    5. SR T-5: Develop a Process for Integrity Assessment Service Providers to Share Lessons Learned
    6. SR T-6: Develop a Process for NDE Service Providers to Share Lessons Learned
    7. SR T-7: Define and Develop a Community of Practice
    8. SR T-8: Consider Conforming to Industry Recommended Practices and Standards to Standardize the Sharing of Qualitative and Quantitative Data
    9. SR T-9: Consider Design and Implementation Requirements for Input Validation for System Quality and Consistency
6. **Best Practices**

Pipeline Research Council International, Inc.

Wrap Up, Questions, Discussion

Gary W. Hines, PE, CAE
Vice President, Operations
Pipeline Research Council International
ghines@prci.org | +1 214.226.6110

LEADING PIPELINE RESEARCH



Sharing Model Performance Data

Towards Collective Intelligence

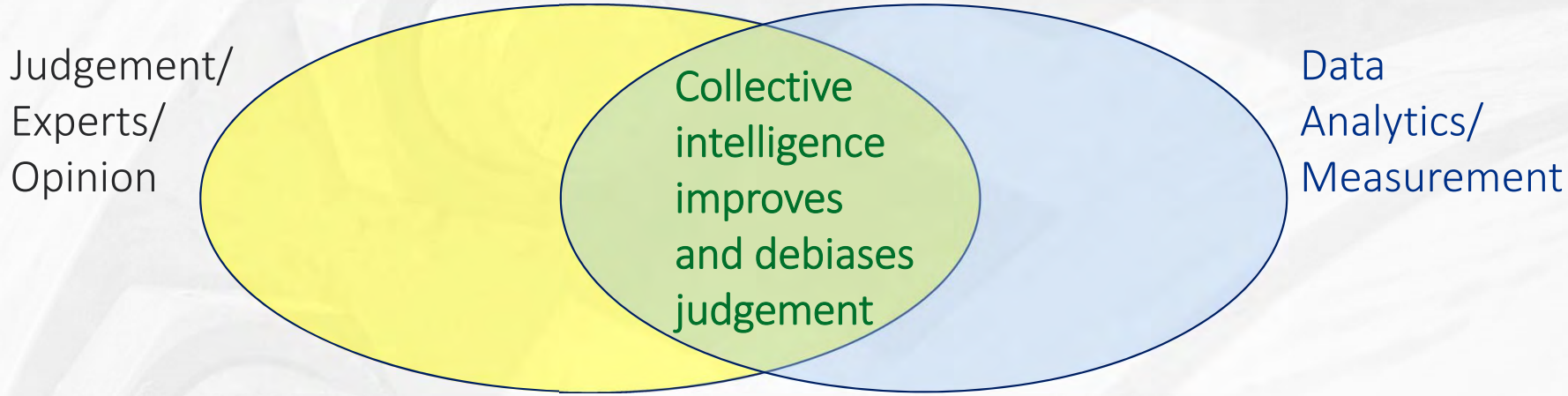
Shahani Kariyawasam

March 5th, 2019

TransCanada

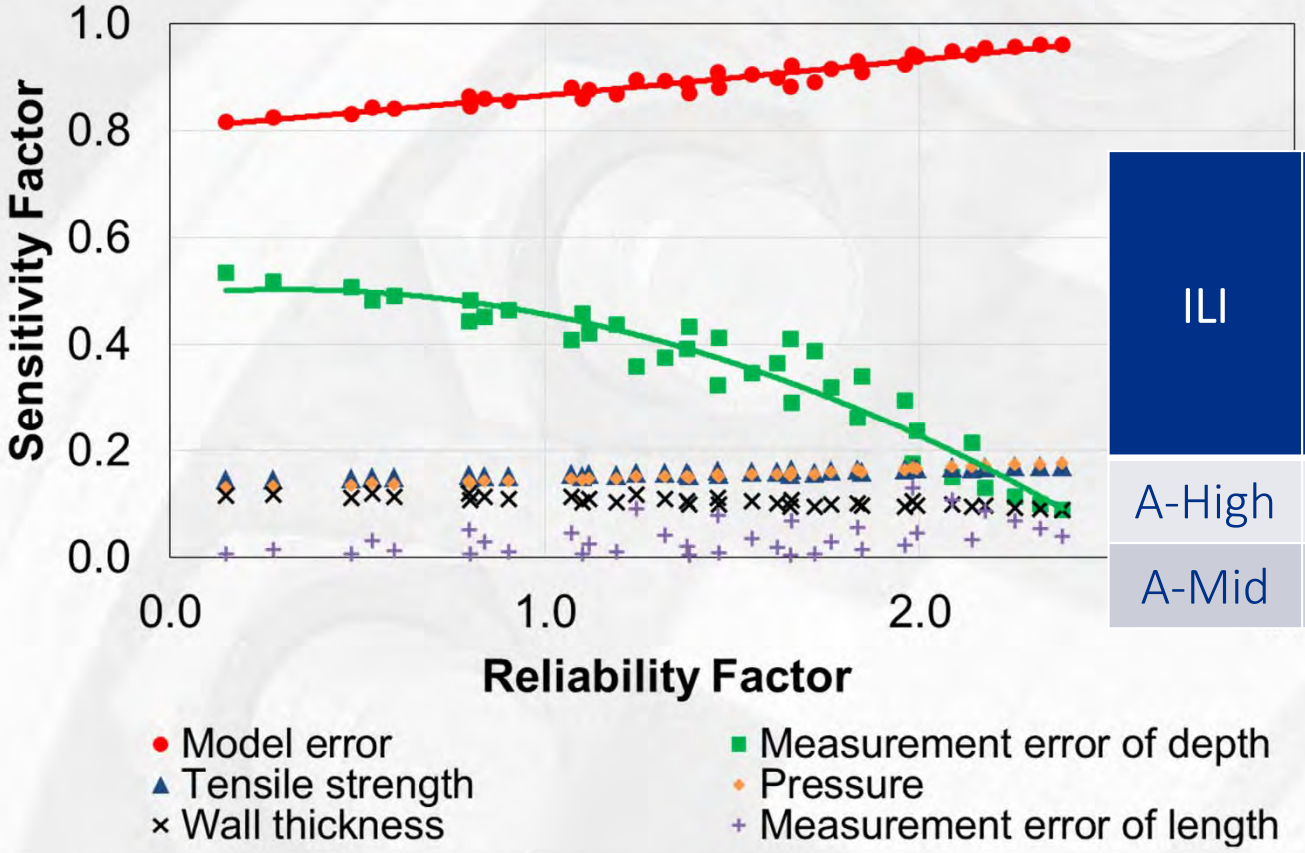
Collective Intelligence that enables a high reliability industry

Successful strategy places resources on the correct alternative based on prediction of truth.
Data refines judgement in establishing truth.



Ref:
The role of expertise and judgment in a data-driven world (Mckinsey & Co)
Mind and Machine – the art of forecasting in the age of AI (Deloitte Review)

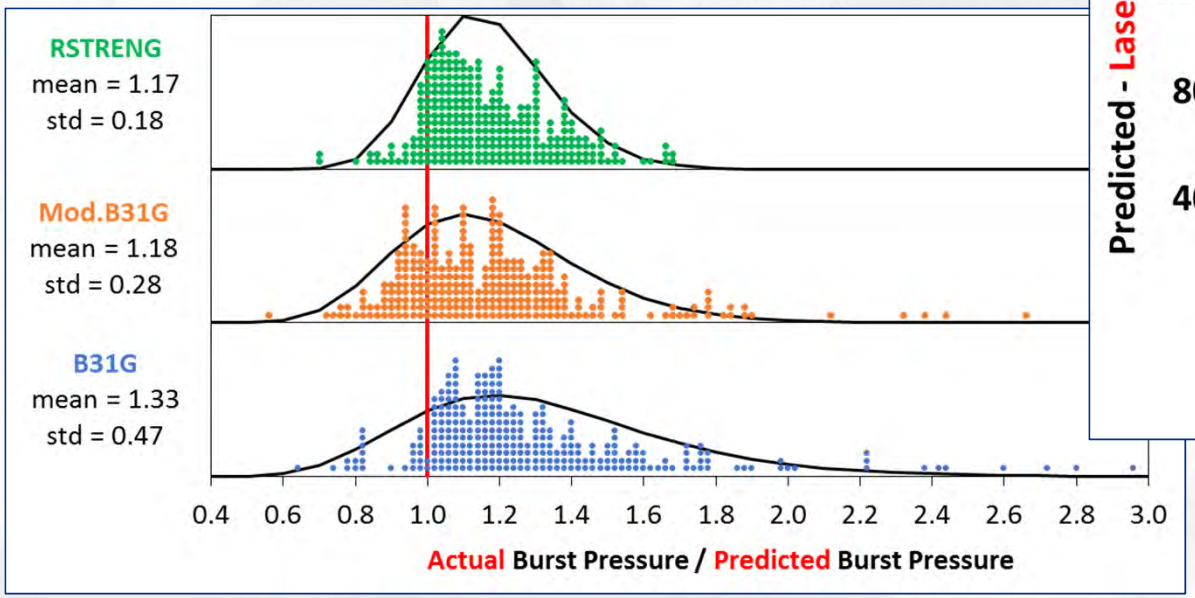
What impacts ILI based integrity decisions?

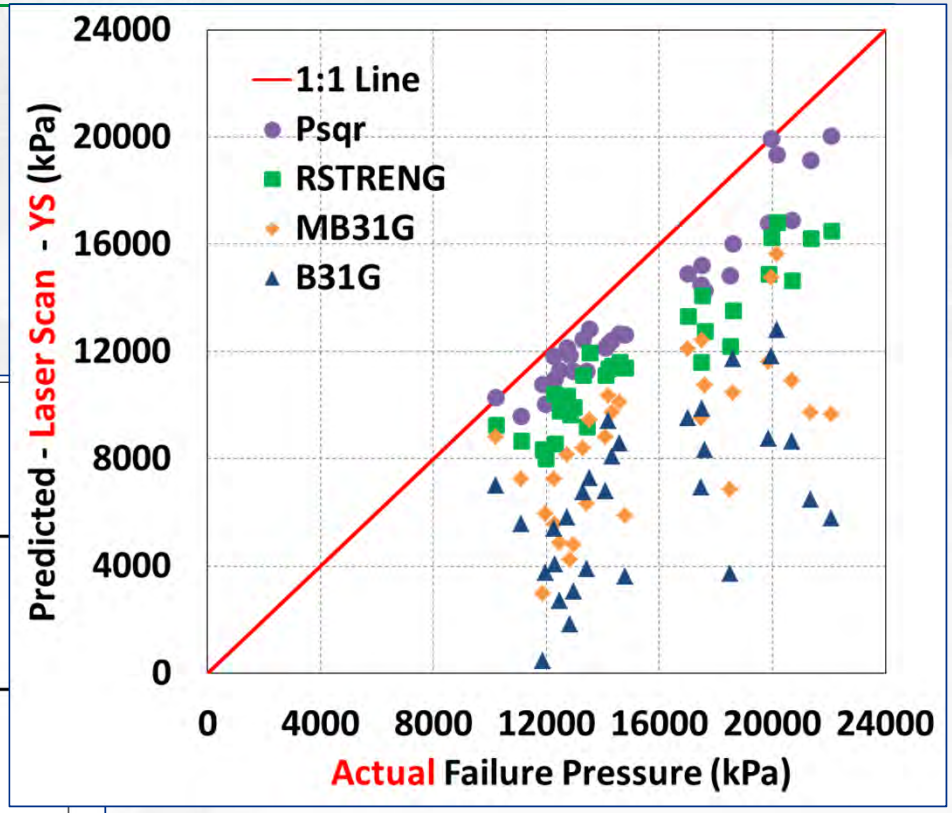


ILI	# of anomalies	# of anomalies with FPR ≤ 1.39		
		B31G	M. B31G	RSTRENG
A-High	3542	306	131	4
A-Mid	634	19	1	0

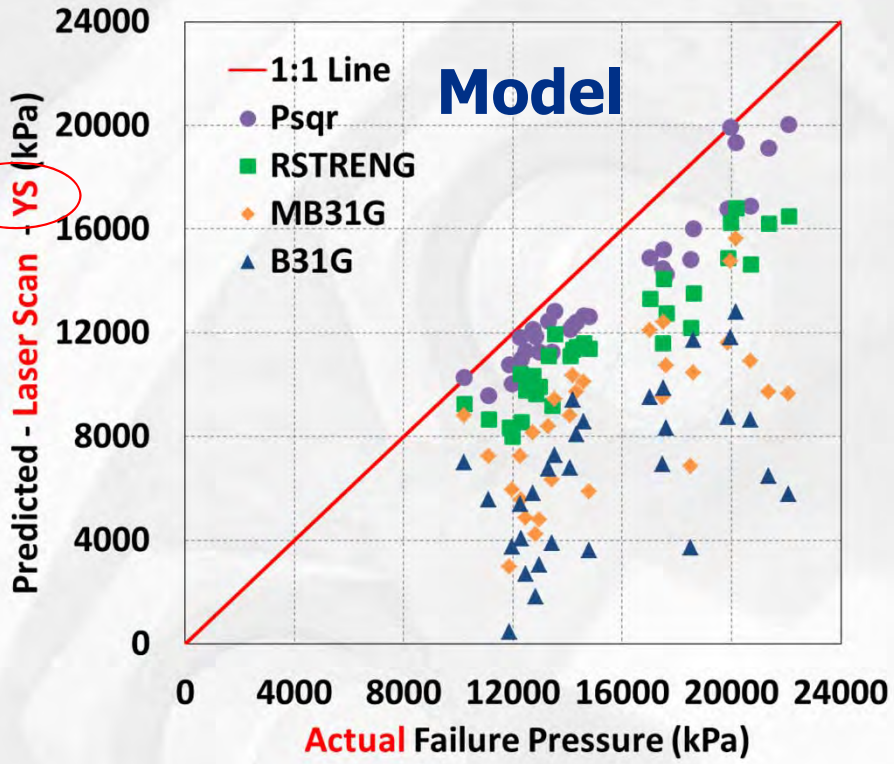
Why is model so significant?

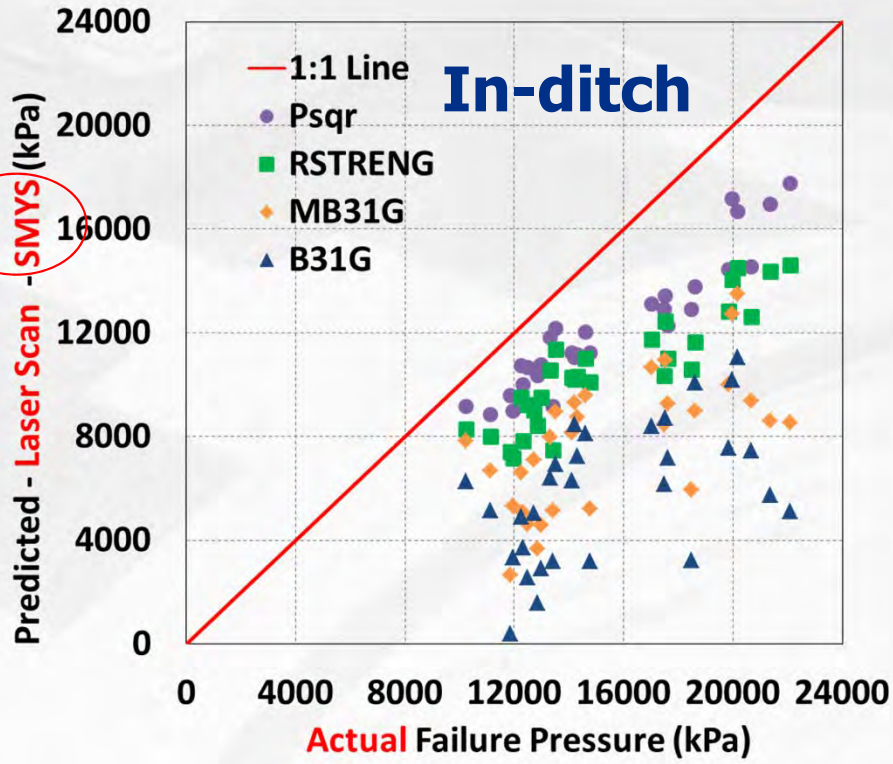
Model uncertainty (without other errors)





Effect of using SMYS instead of YS

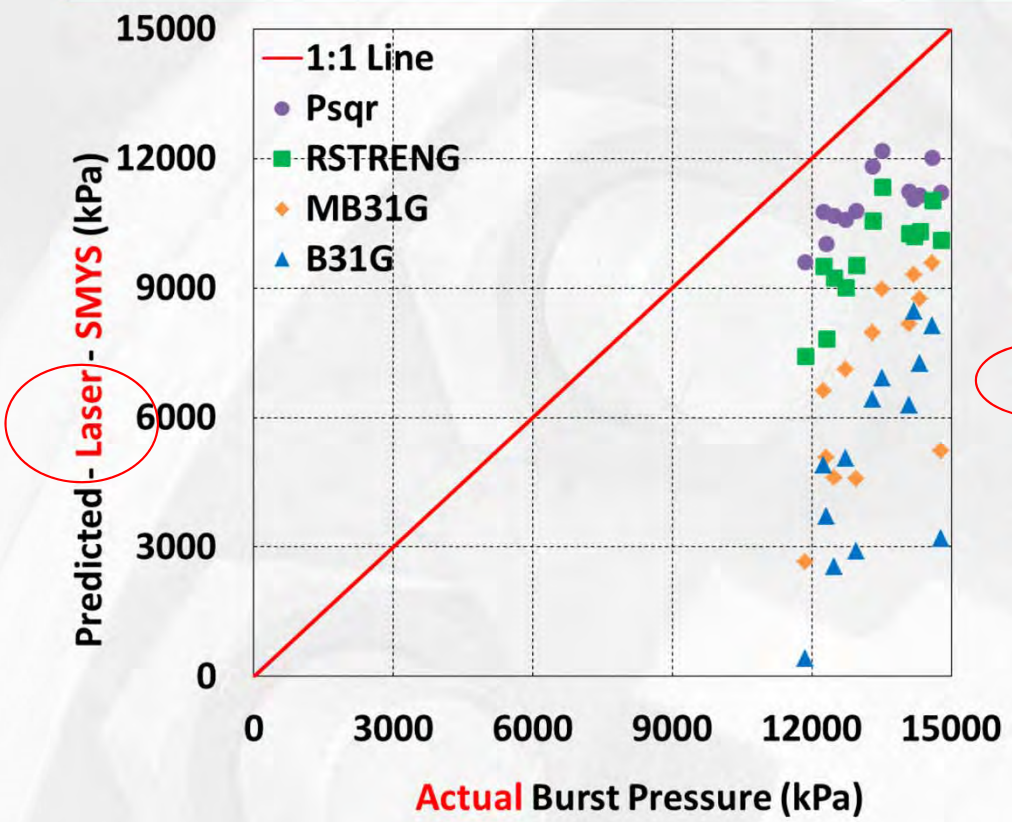


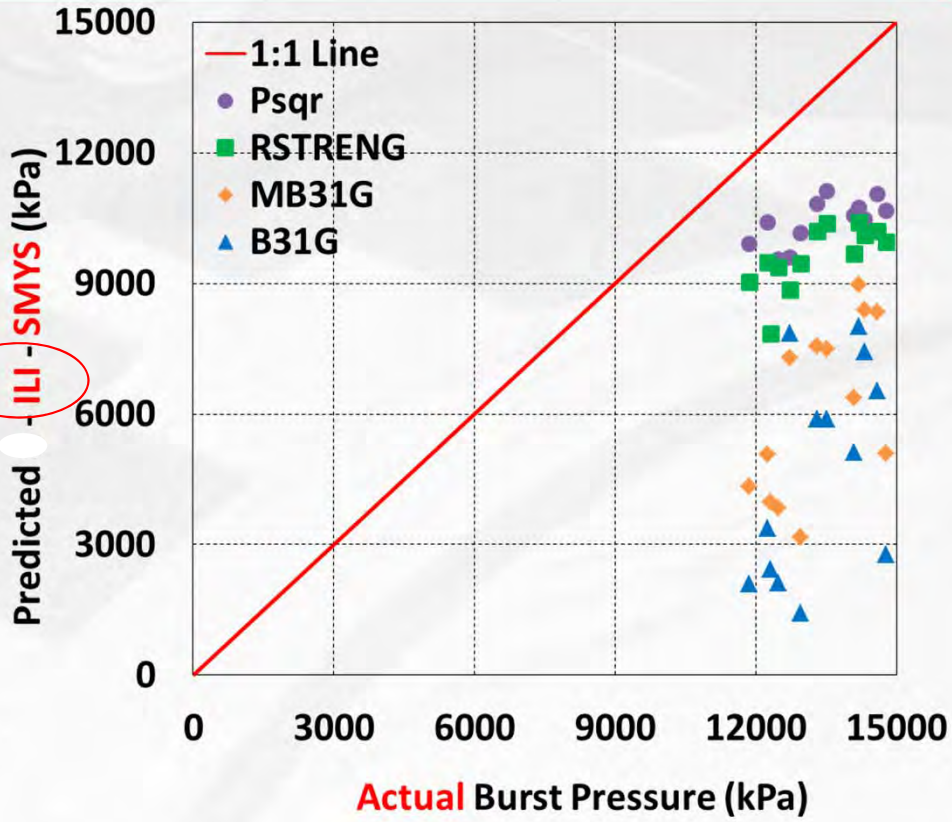


- Inditch predicted pressures are safe

Effect of using ILI measurements

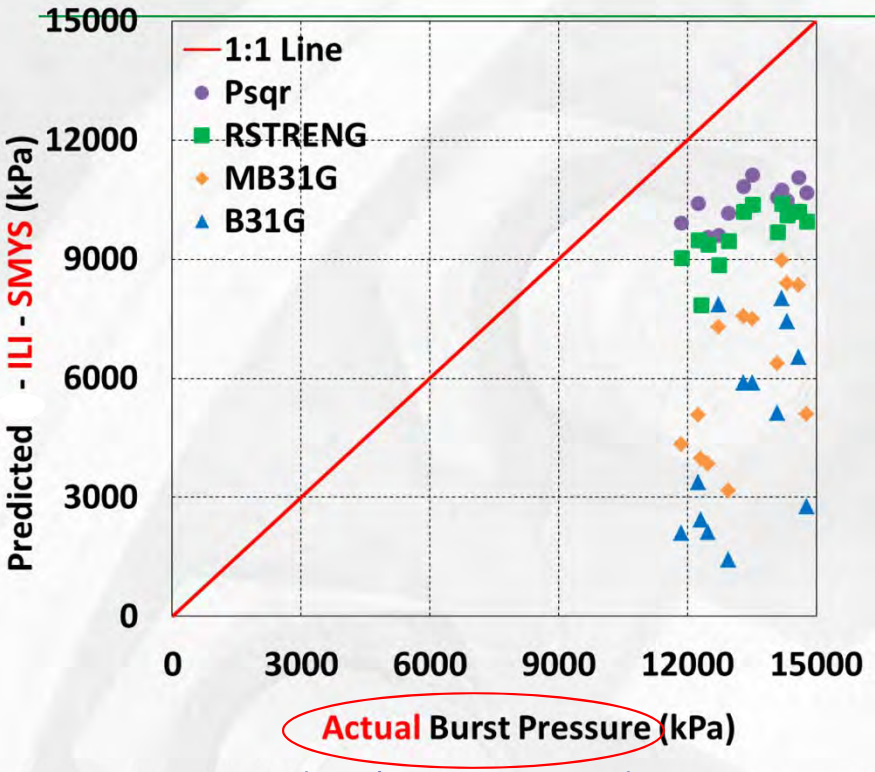
13 burst tests with ILI data

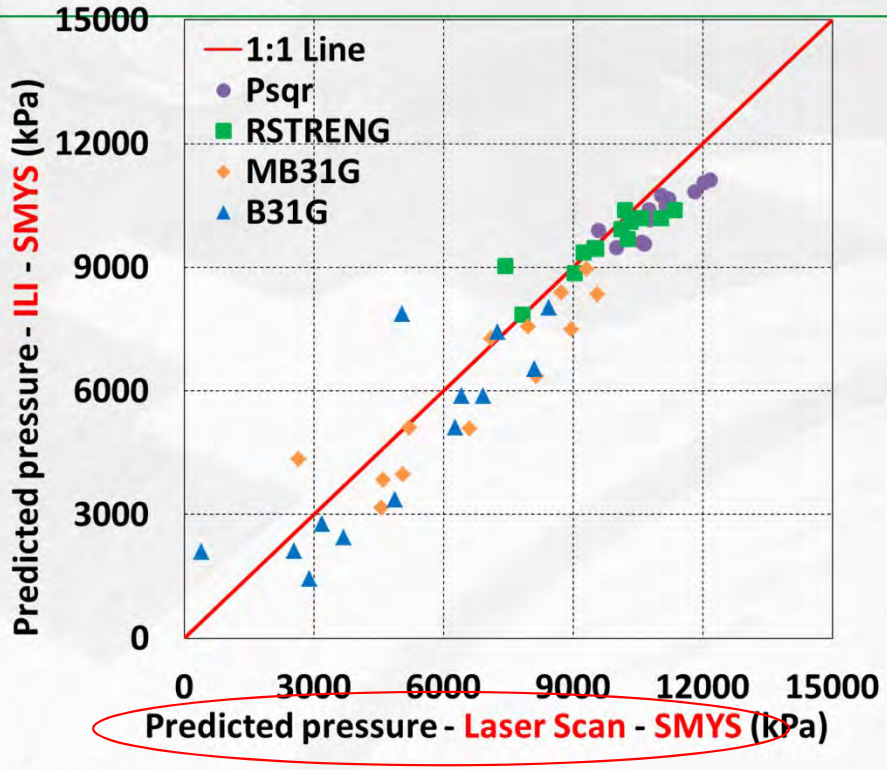




- All ILI based predicted pressures are safe
- Precise methods can be more accurate (less unnecessary conservative)

ILI vs actual burst and ILI vs in-ditch

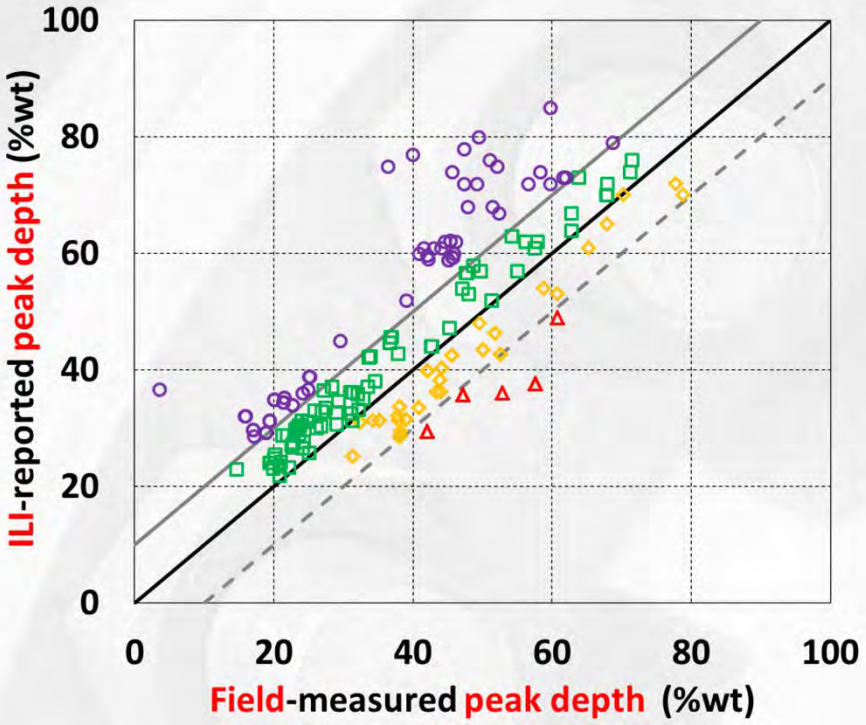


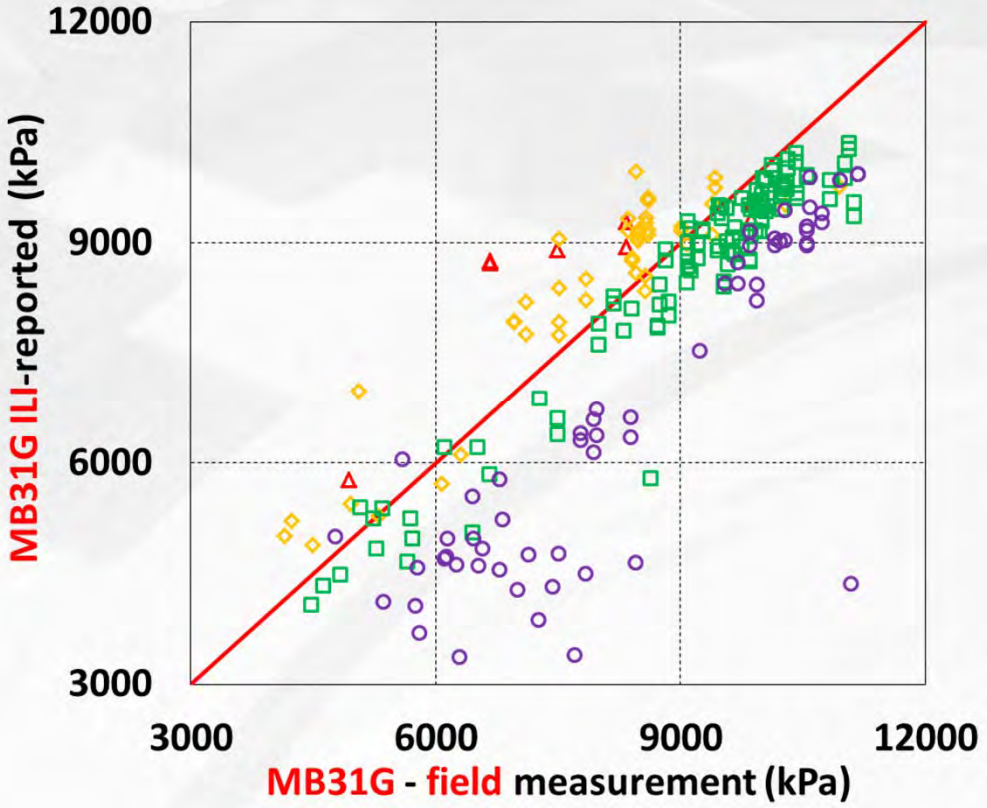


- ILI vs in-ditch cannot demonstrate safety
- Simple models do not compensate for ILI error
- Accurate and precise models provide safety and economy

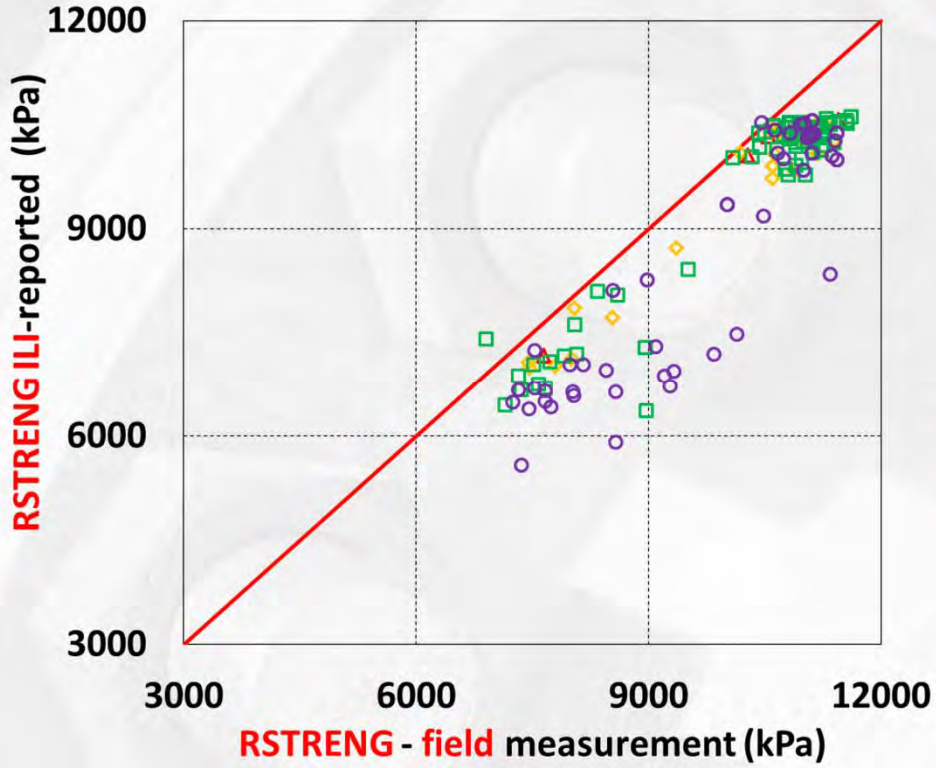
Questions?

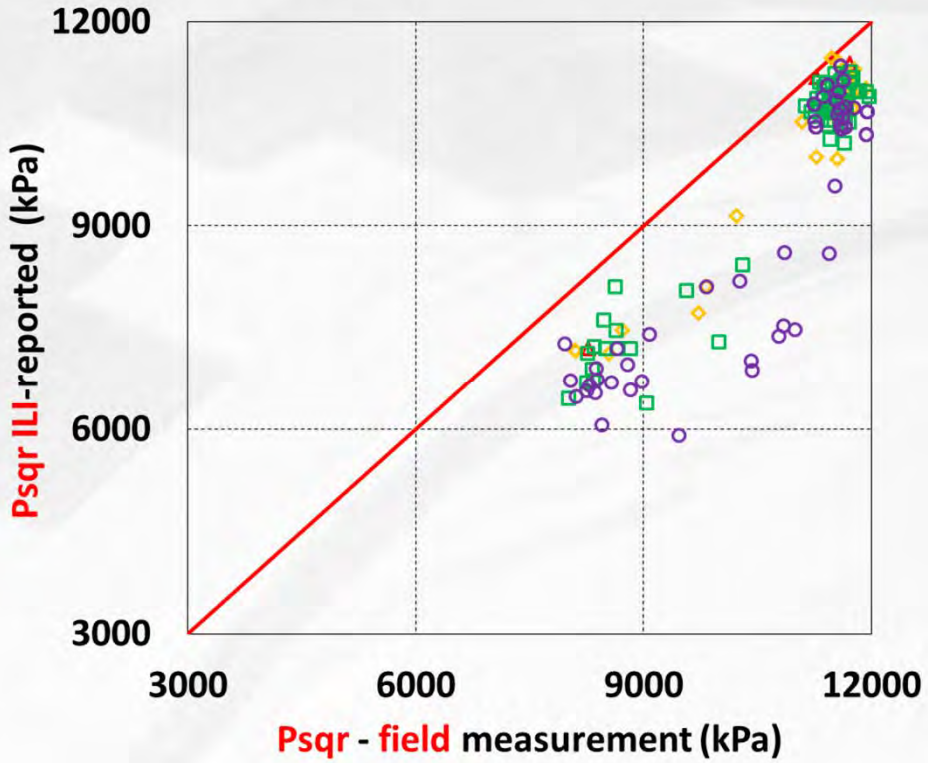
Depth unity plot and MB31G pressure unity plot



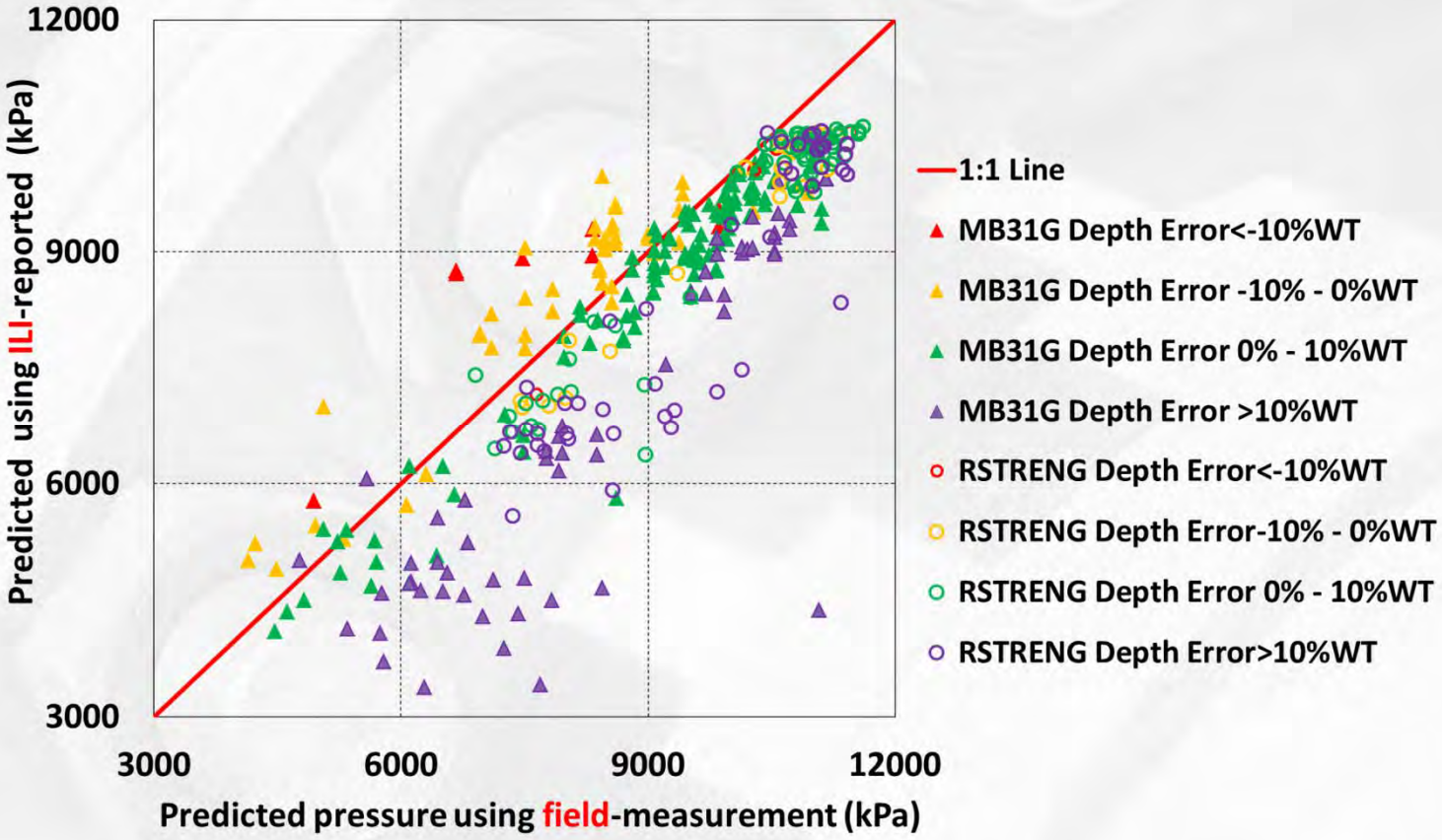


RSTRENG and PSQR Pressure unity plots



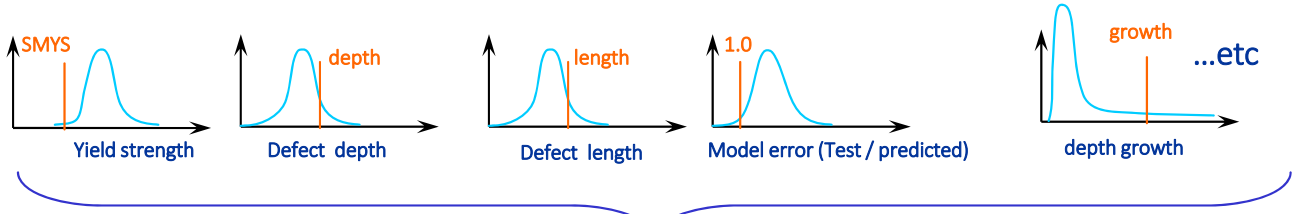


MB31G and RSTRENG Pressure unity plots

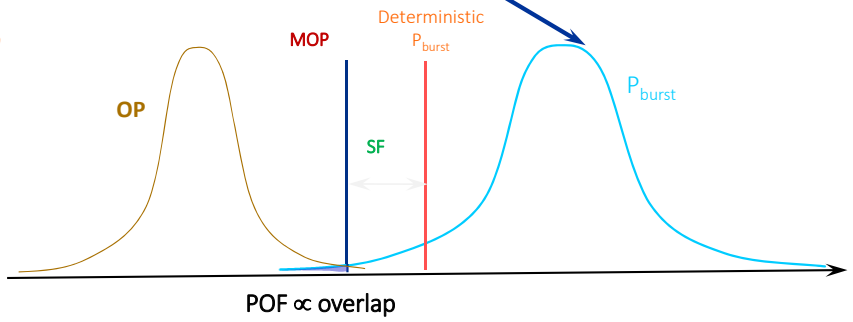


Providing Safety using Deterministic Methods – Role of Conservatism

- Uncertainties associated with input variables



- Conservatism in deterministic assessments
  - conservative constant inputs (e.g. SMYS) – *accounts for uncertainty in variables*
  - further conservatism with safety factors (SF) – *accounts for different consequences, human error etc.*



FPR = $P_{burst\ Det}$ / MOP > SF => acceptable POF

Pipeline Research Council International, Inc.

FHR Crack Evaluation Effort From One - Many

Jim Andrew

March 5, 2019
Research Exchange Meeting
Houston, Texas

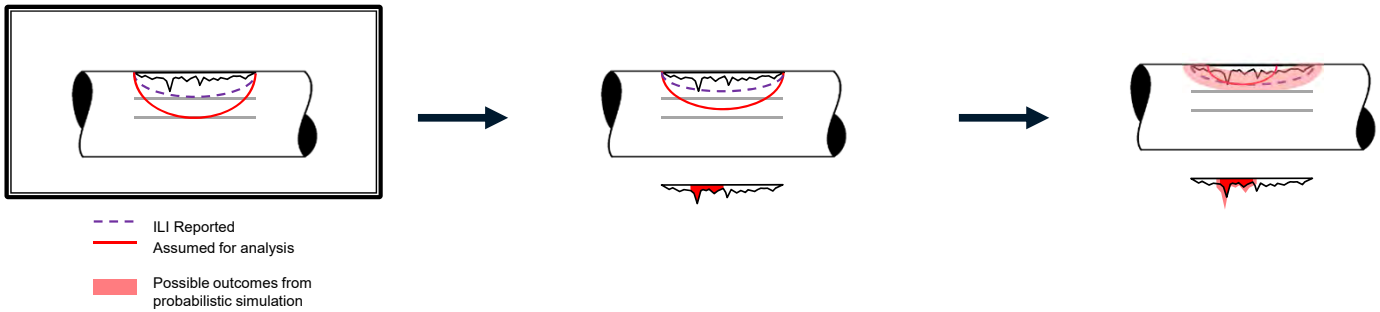
Pipeline Data Hub Example 3 – FHR Crack Evolution Example

- **The objective of this presentation is show FHR's development of our crack program over a period of the last eleven years with the emphasis on what the combination of one versus two versus many companies can accomplish.**
- **There are hurdles to overcome in the process and one of the biggest is deciding to share information with others.**
  - **The advantages for FHR far outweighed the disadvantages such as:**
    - *Better economics of development*
    - *Much better schedule to develop the technology*
    - *Significantly better results from the development – significantly better discrimination of injurious versus non-injurious features, less field investigation, and better understanding of the threat*

FHR Evolution of Crack Analysis

2008-2013

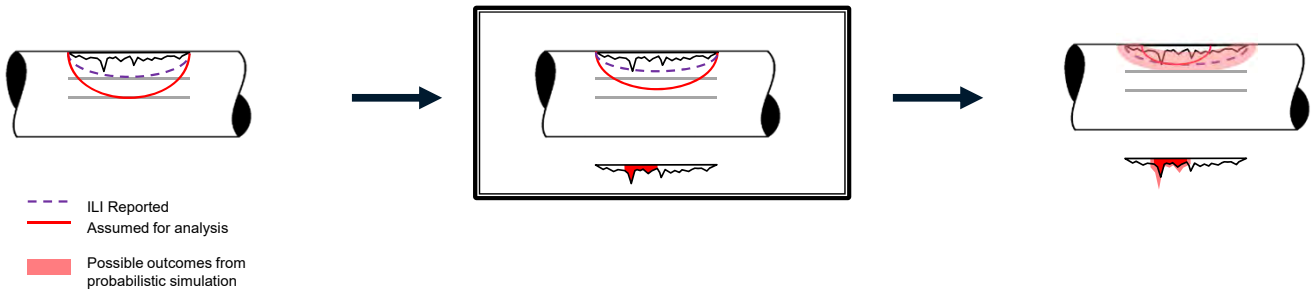
- Depths reported in buckets. Tools under-calling and missing features within vendor's POD
- Added tool tolerance to upper bucket limit and used lower-bound pipe properties for burst pressure calculation
- No crack profiles
- Half-life used for fatigue analysis, all cracks placed at pump discharge



FHR Evolution of Crack Analysis – The Power of One

2013-2015

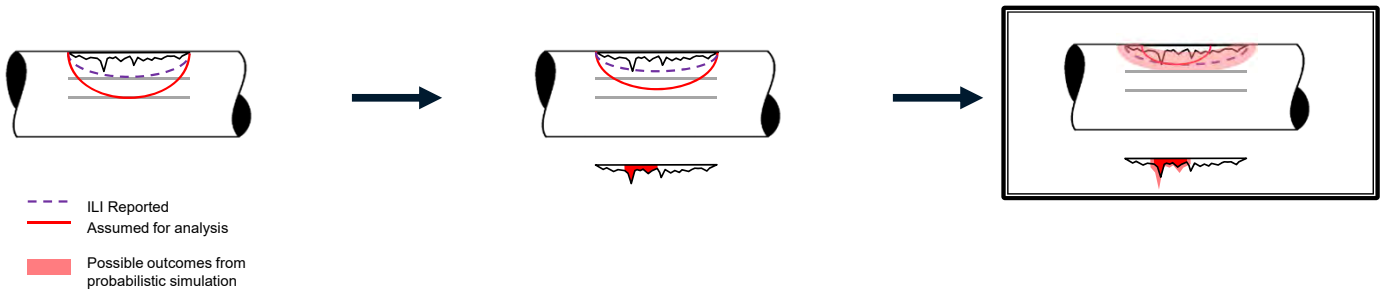
- Depths reported in absolute values. Tools beginning to meet published performance specifications
- Added tool tolerance to absolute depth and used lower-bound pipe properties for burst pressure calculation
- Utilized KAPA to calculate deterministic burst pressure from crack profile
- Accounted for hydraulic gradient in fatigue half-lives



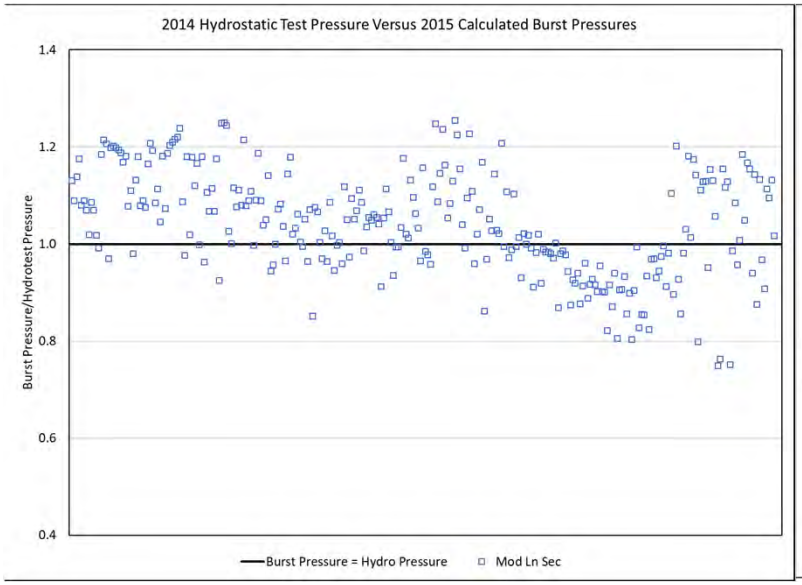
FHR Evolution of Crack Analysis – The Power of One

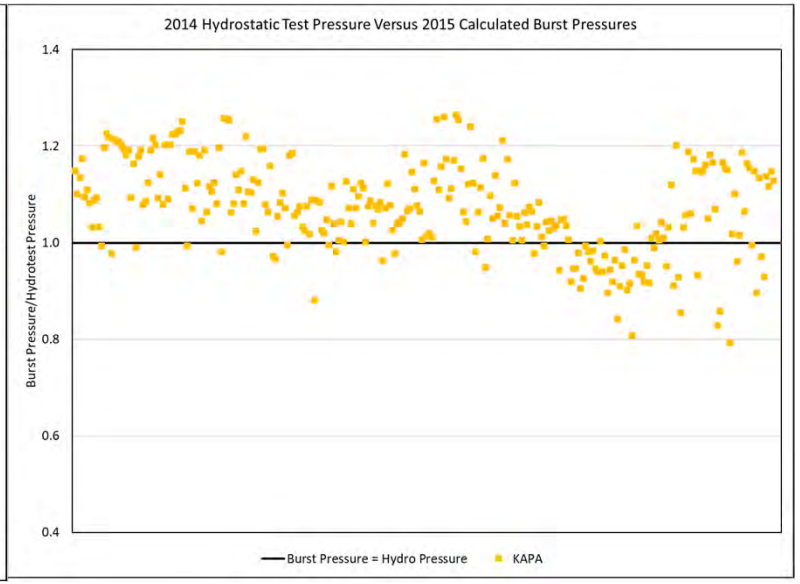
2015-2018

- Tools run-over-run repeatability for characterizing crack population improving
- Statistical distributions based on real pipe data used in burst pressure calculations
- Fatigue life and crack growth assessment used in dig selection
- Time-Dependent Probabilistic based analysis leveraging previous hydrostatic test results
- ILI vendor able to deliver crack profiles on a timely basis
- Incorporate crack profiles with MAT-8 fracture model



Sharing of Cost and Information Between Two Companies

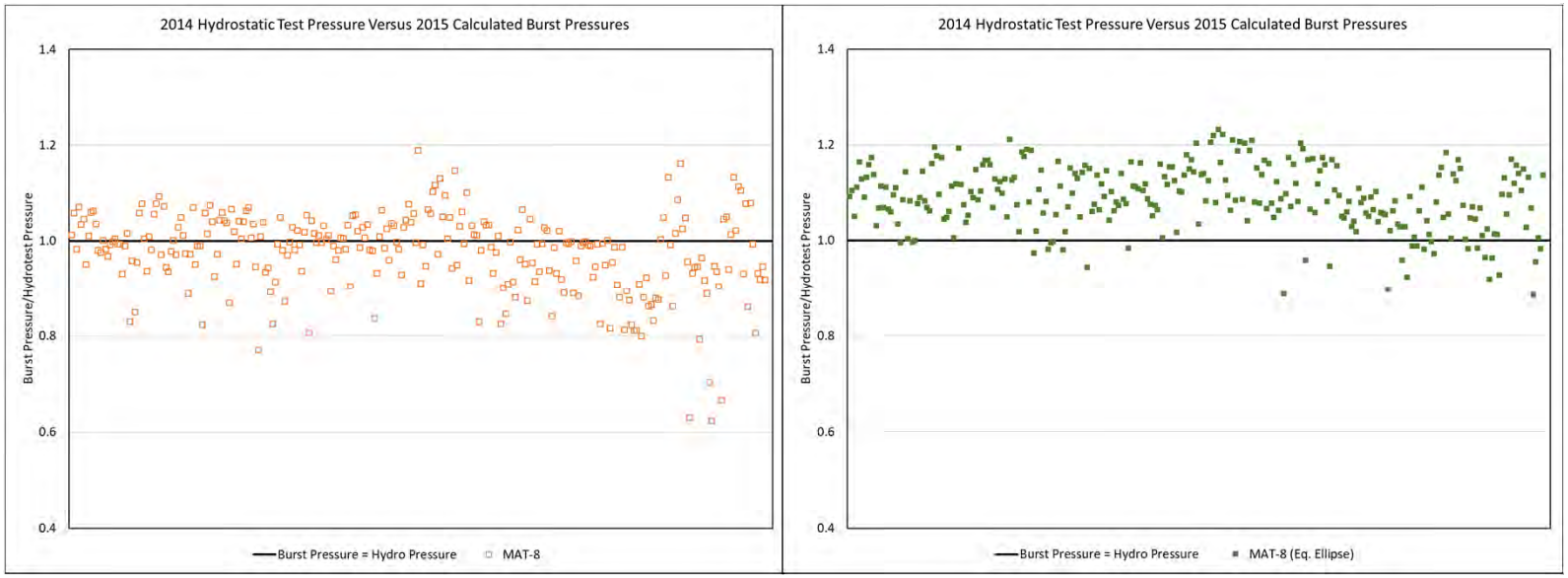




<u>Mod. Log-Secant</u>
Predicted P_{burst} falls below hydro pressure in 110 cases (38%)

<u>KAPA</u>
Predicted P_{burst} falls below hydro pressure in 63 cases (22%)

Sharing of Cost and Information Between Two Companies



Orig. MAT-8

Predicted P_{burst} falls below hydro pressure in 168 cases (58%)

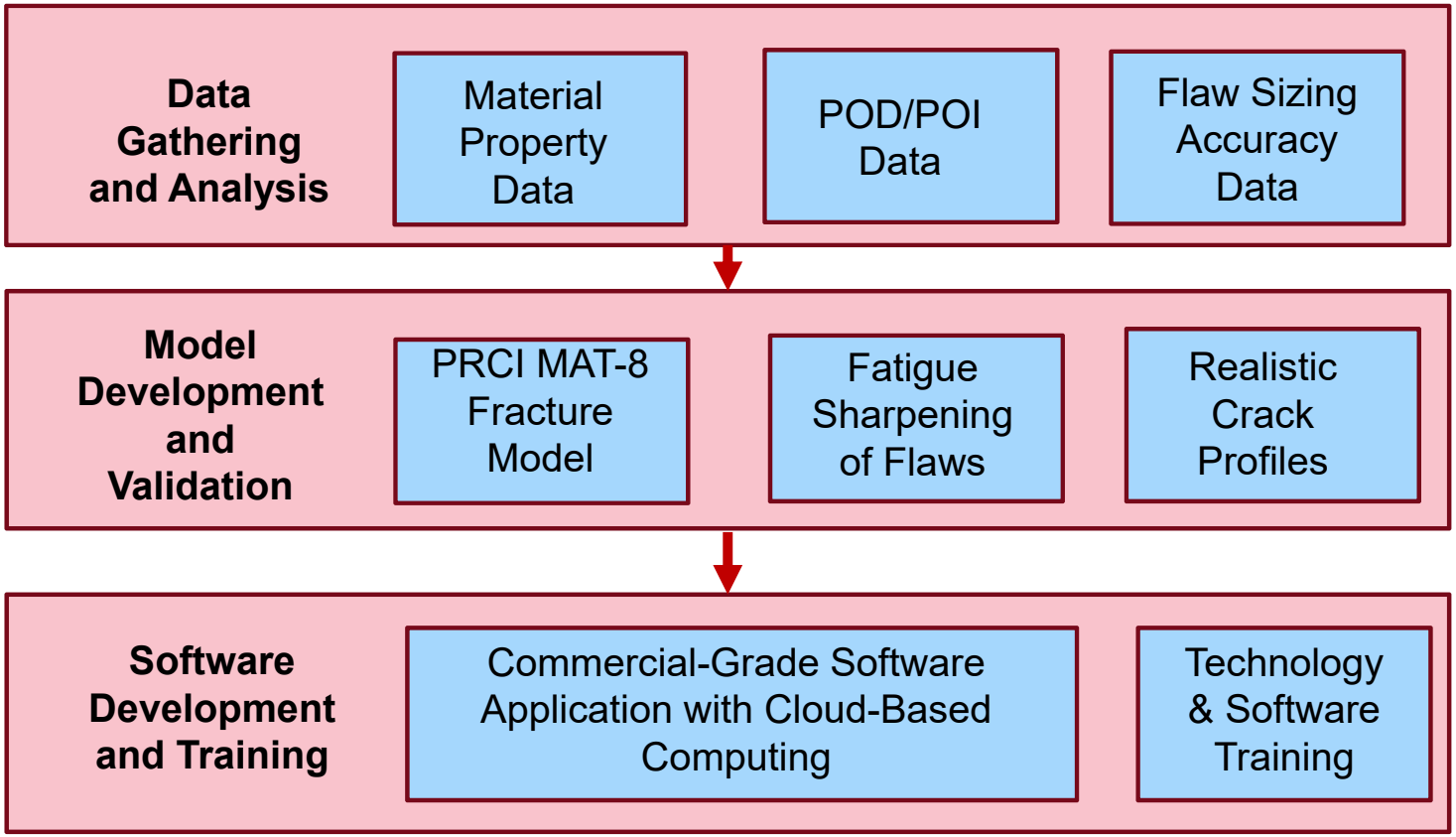
Mod. MAT-8

Predicted P_{burst} falls below hydro pressure in 29 cases (10%)

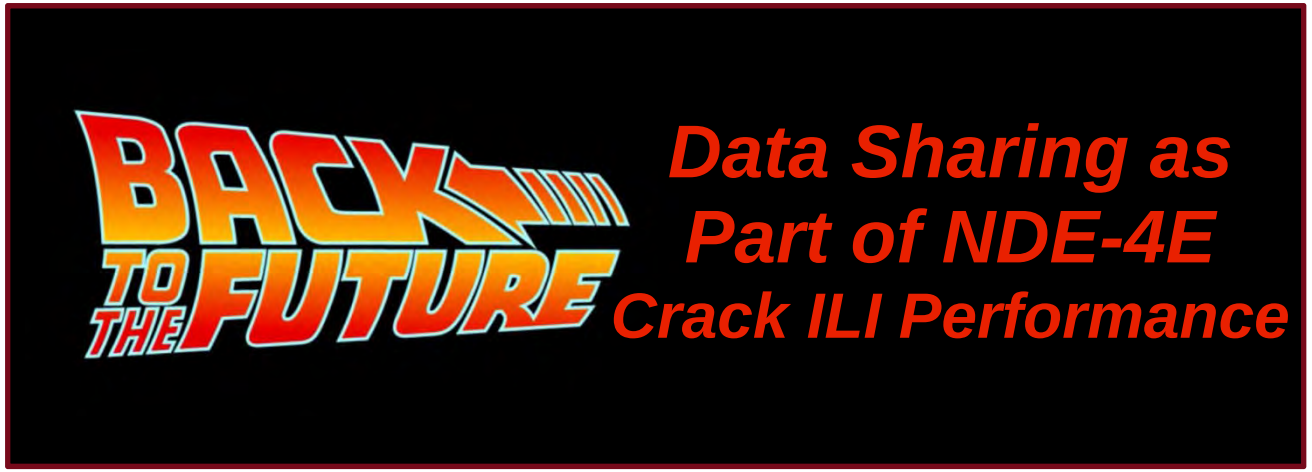
PRCI Crack Consortium – The Power of Many

- An improved version of the PRCI MAT-8 model for seam weld anomalies:
  - Realistic crack front profiles – better accuracy
  - Predict the sharpening of blunt seam weld flaws (ex. lack-of-fusion or hook crack features) – reduced conservatism
- The JIP members will contribute data to the program:
  - Statistical distributions for fracture toughness and other material properties for vintage pipe
  - ILI tool Probability of Detection (POD) / Probability of Identification (POI) performance
  - ILI Flaw sizing distributions (actual versus as-called)
- A cloud-based software application that
  - Implements a structural reliability probabilistic version of MAT-8 model with functionality to predict future crack growth
  - Evaluates mitigation: hydrostatic tests, pressure reductions, future in-line inspections

PRCI Crack Consortium – The Power of Many
The Three Main Activities will Proceed in Parallel



Pipeline Research Council International, Inc.



2019 Research Exchange Meeting

March 5, 2019

Sean Keane, Enbridge

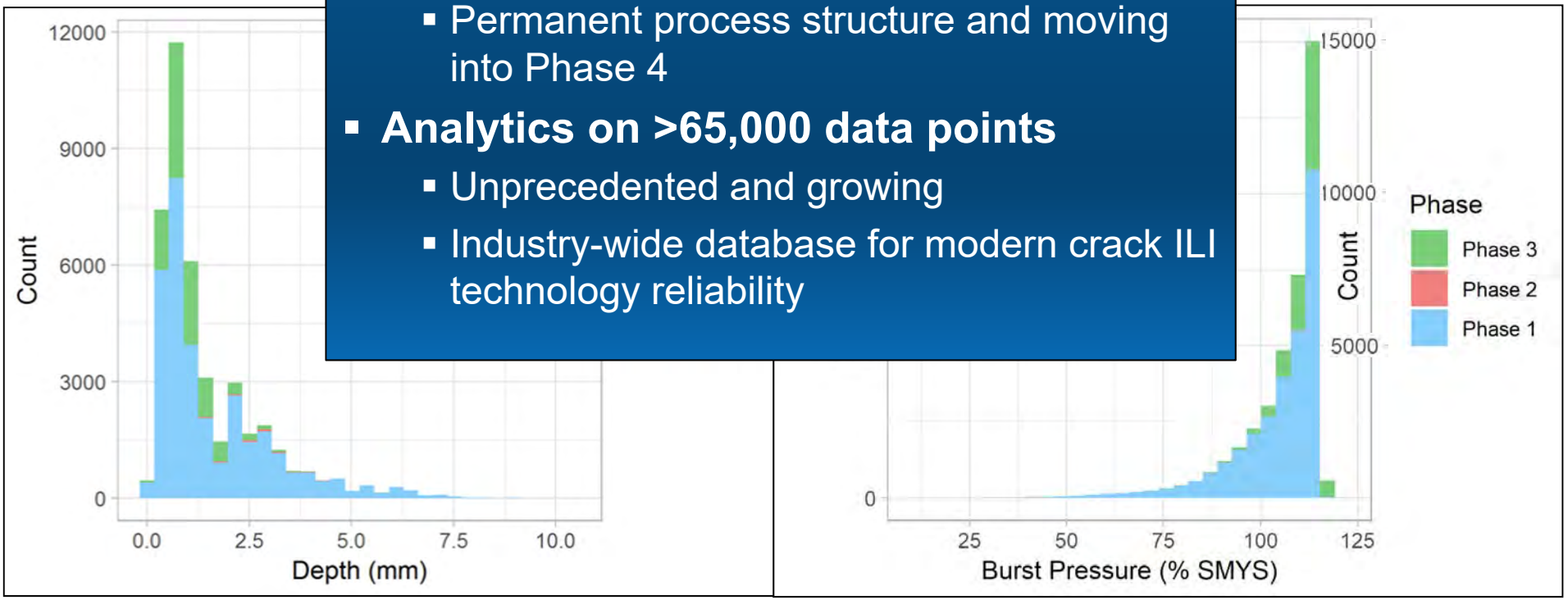
The NDE 4E Suite of Projects

- **Motivation**
  - Establish comprehensive reliability assessment of crack ILI
  - Improve program effectiveness by knowing the strengths and weaknesses of measurement technologies

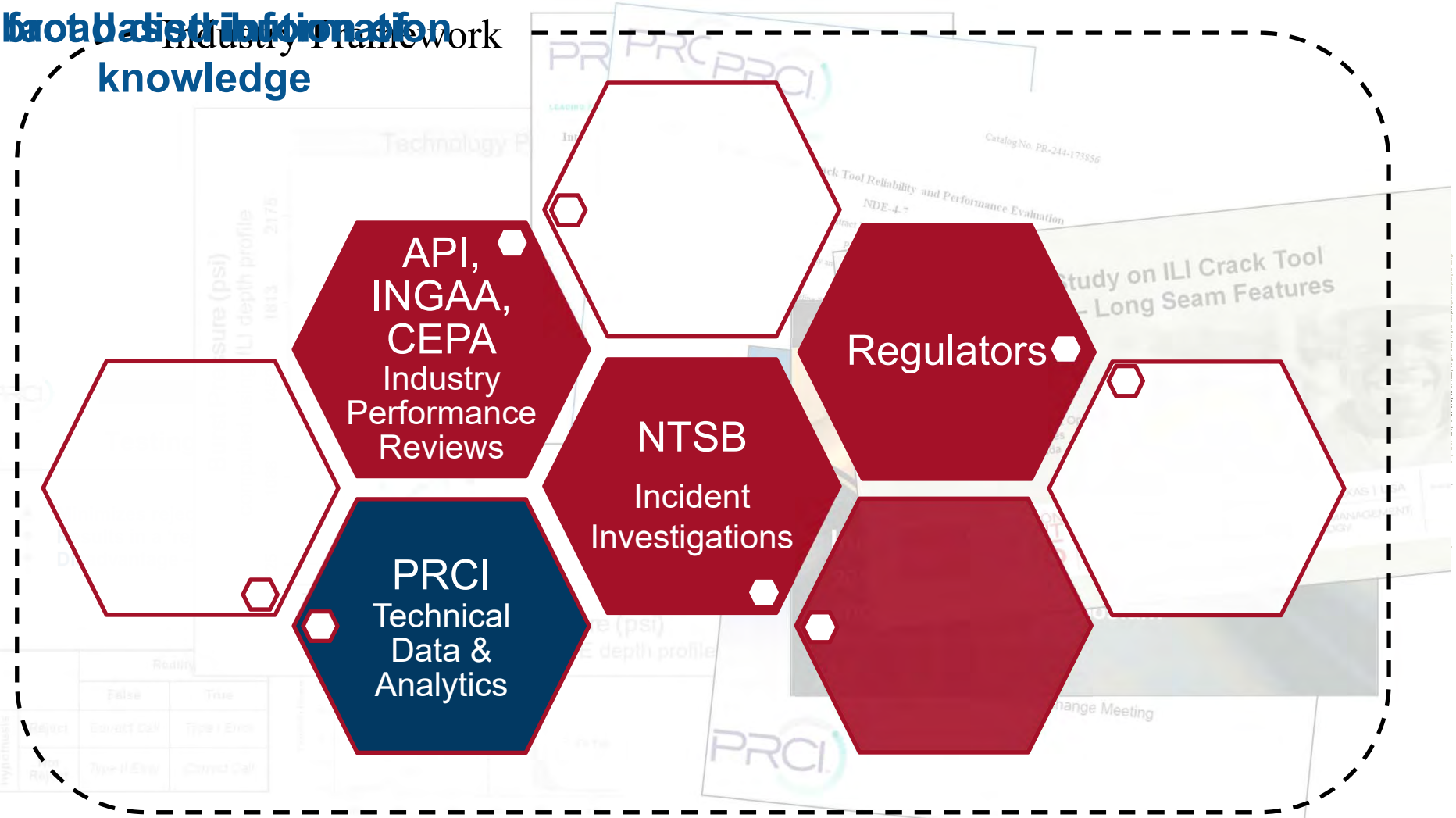
- **Objectives**
  - To collect, validate and store existing industry data on the measurement, characterization, assessment and repair of crack and crack-like features measured by ILI and field excavation techniques
  - To evaluate the performance, capability of different ILI technologies in detecting, identifying and sizing cracks and crack-like features

Database for Crack ILI Reliability

- **Broad operator collaboration**
  - Resolved complexities around data collection, confidentiality, data integrity
  - Permanent process structure and moving into Phase 4
- **Analytics on >65,000 data points**
  - Unprecedented and growing
  - Industry-wide database for modern crack ILI technology reliability



Putting R&D to Work



Observations from NDE-4E

- **Data sharing in NDE-4E facilitated accelerated scientific progress**
  - Improved outcomes for integrity management
  - Reduced research and development cost
  - Decreased time to move discovery from report into practice

- **Continue journey into future of data sharing**
  - Bring the DeLorean and industry into the future
  - Framework to leverage todays data sharing technologies and governance concerns

Clearing of Shorted Casings vs ILI Based Management – A Data Driven Approach to Prevent Failures

Shahani Kariyawasam, Terry Huang, Daniel Herpin, & Jennifer Klementis

PRCI REX, Houston, 2019

TransCanada

History

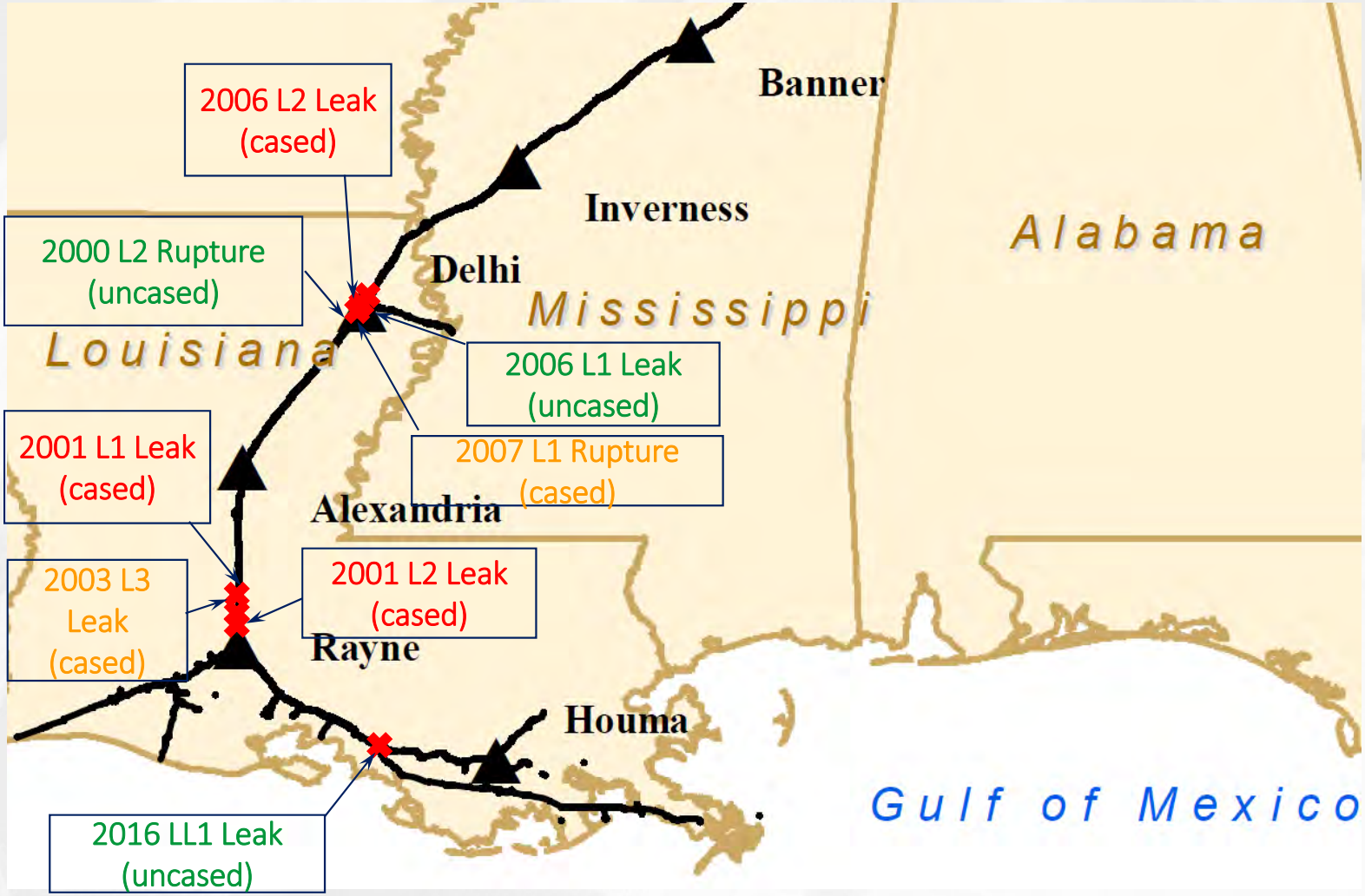
Issue:

- Older pipeline systems have cased crossings - some shorted
- Shorted casings can cause higher growth rates
- Failures under shorted & non-shorted casings and on uncased pipe

Regulators concerns:

- If heightened integrity is required- clear all shorted casings - high cost
- Can ILI effectively:
  - Identify and size anomalies?
  - Manage corrosion rates in shorted casings?

Background


2006 L2 Leak
(cased)
Banner
Inverness
Alabama
2000 L2 Rupture
(uncased)
Delhi
Mississippi
Louisiana
2006 L1 Leak
(uncased)
2001 L1 Leak
(cased)
2007 L1 Rupture
(cased)
Alexandria
2003 L3
Leak
(cased)
2001 L2 Leak
(cased)
Rayne
Houma
Gulf of Mexico
2016 LL1 Leak
(uncased)

Incidents – uncased vs non-shorted cased vs shorted

In System XX

- 3 failures uncased – 2 leaks and 1 rupture
- 5 failures cased – 3 shorted(leaks), 2 non-shorted (1 leak and 1 rupture)

Cased?	EC Incidents			
	# of Leaks	# of Ruptures	Total # of Incidents	Incident Rate (/km/yr)
No	2	1	3	1.05E-05
Yes	3+1	1	5	1.81E-03

To prevent failures both shorted & non-shorted casings need to be managed – as well as uncased

Casings had worse failure rate than uncased (up to 2007 see next slide)

Summary of ILI Data

Line Name	Historical ILI Runs (Year, Vendor, Resolution of MFL Tool)					Notes on Failures
L1	1999, BB*, Low Res	2005, CC, High Res	2012, BB, High Res			2001 L1 Leak (cased)
	1999, BB*, Low Res	2008, CC, High Res	2015, AA, High Res			2006 L1 Leak (uncased); 2007 L1 Rupture (cased)
	2004, CC, High Res	2009, CC, High Res	2010, BB, High Res	2015, AA, High Res		SPIA
	2008, CC, High Res	2015, AA, High Res				SPIA
L2	2005, CC, High Res	2012, BB, High Res				2001 L2 Leak (cased)
	2001, BB, Low Res	2008, CC, High Res	2015, AA, High Res			2000 L2 Rupture (uncased); 2006 L2 Leak (cased)
	2005, CC, High Res	2010, BB, High Res	2015, AA, High Res	2018, AA, High Res		SPIA
L3	2005, CC, High Res	2012, BB, High Res				2003 L3 Leak (cased)
	2004, CC, High Res	2010, BB, High Res	2015, BB, High Res	2016, BB, High Res	2017, BB, High Res	SPIA
LL1	Unpigged					2016 LL1 Leak at water crossing

No failures after High Resolution ILI program

High Resolution ILI data – non-cased vs cased

ILI Section	ILI Year/Vendor	In Casing?	Length (ft)	Deepest Depth (%WT)	Lowest FPR effective area	Total # of ML Features >= 10%WT	# of ML Features >=30%WT Depth	Feature Density - all features >=10%WT (# per ft)	Feature Density - features >= 30%WT depth (# per ft)
L1 – H to CR	2015	Yes	1763	64	1.61	60	3	0.0340	0.0017
	AA	No	372610	44	1.45	518	16	0.0014	0.0000
L1 – CR to HCS	2015	Yes	339	18	1.65	8	0	0.0236	0.0000
	AA	No	76277	17	1.56	24	0	0.0003	0.0000
L2 – H to HV	2015	Yes	5174.	33	1.63	53	3	0.0102	0.0006
	AA	No	447687	43	1.37	551	21	0.0012	0.0000
L3 – H to HV	2017	Yes	6832	28	1.69	179	0	0.0262	0.0000
	BB	No	447252	59	1.31	3730	57	0.0083	0.0001

Features most likely to leak (Deepest) in cased and non-cased pipe

Features most likely to rupture in non-cased pipe

Feature density generally higher in cased pipe

Test Lead Data Available on System XX

# of Casings	Line Name	Non-Interrupted Survey Data (2005-2017)	Interrupted Survey Data (2013-2017)
System XX SPIA	L1	13	13
	L2	44	44
	L3	63	63

(C/S on P/S on) <100mv shorted

(C/S on – C/S off) / (P/S on – P/S off)x100≥75% shorted – more reliable

Corrosion on shorted casing

- Based on 2005-2017 Non-Interrupted On Potential Survey (120 casings)

Criteria - On difference < 100mV	No - Corrosion Reported	Yes - Corrosion Reported
for 5 years or longer	63%	37%
for 80% of time or above	55%	45%
continuously for the most recent 3 years	52%	48%

Majority of the pipes that were shorted for many years have no corrosion

Corrosion on shorted and non-shorted casing

- Based on 2005-2017 Non-Interrupted On Potential Survey (120 casings)

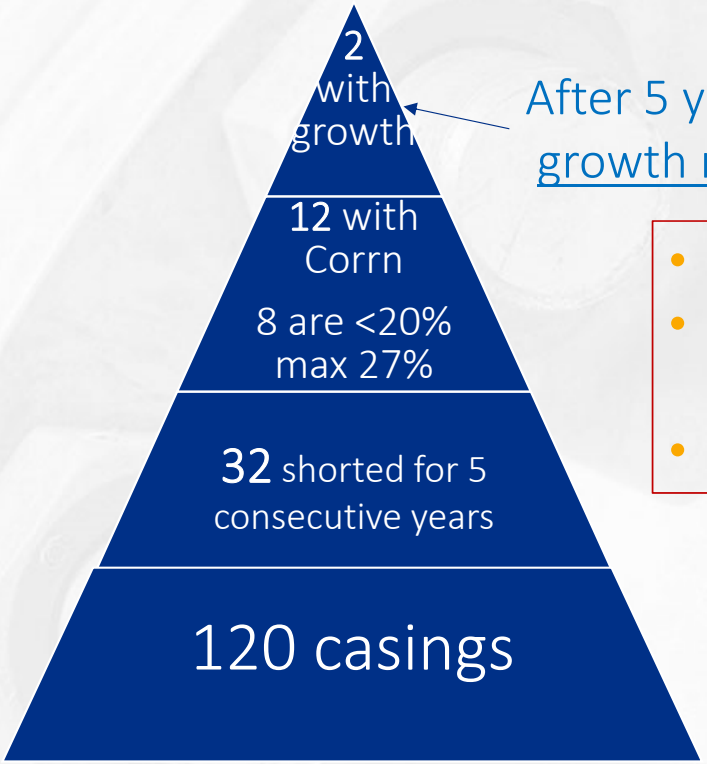
Criteria - On difference < 100mV	Meet Criteria?	No Corrosion Reported	Yes Corrosion Reported
for 5 years or longer	No	79%	21%
	Yes	63%	37%

- Both shorted casings and non-shorted casings have corrosion:
  - shorted casings have higher cases of corrosion than non-shorted
  - Majority (63%) of shorted casings (for 5 yrs) have no corrosion

To prevent failures both shorted and non-shorted casings need to be managed

Background – corrosion growth on shorted pipe

- Based on 2013-2017 Interrupted Survey (120 casings)



After 5 years of being metallically shorted growth rates can be detected by ILI

- some casings removed after 2015
- most extreme - 64% (2015) which was 31% (2010)
- managed by High Resolution ILI

Shorted has few high growth– all managed well by ILI

History of Managing Casings

Background from Other Studies (see ref.)

- US survey results on 51,500 casings [2]
  - 17% shorted (metallically or electrolytically)
  - 4% corroded - 2% shorted, 2% non-shorted
- Barlo - Low incidence of corrosion at cased crossings – but higher consequence[5]
- Gibson – 50+ years of good service with shorted & isolated casings [3]
- Perry - appears to be very little evidence of issues with casings [4]
- OPS concurs based on survey of 1043 casings – "it appears that corrosion of the carrier pipe inside a casing is not dependent on the casing being shorted"[1]

Verification of ILI Capability

Systematic Evaluation of MFL Performance

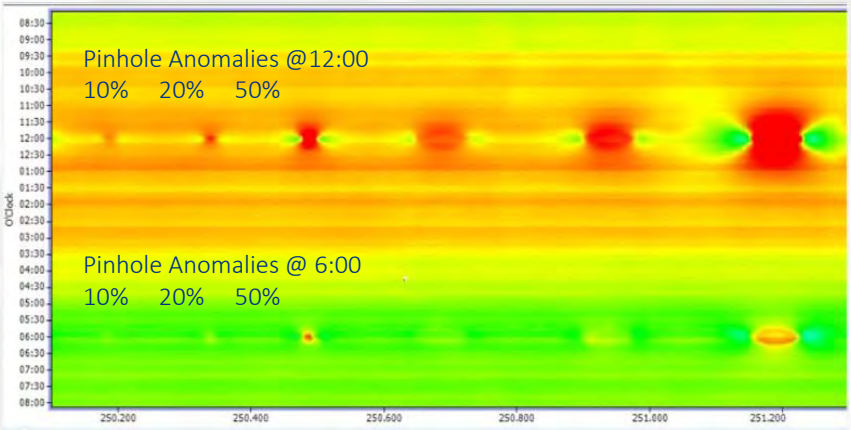
Pull-through testing for cased pipes

Phase 1 (Nov 2018 – April 2019)

- Validate detection and sizing specifications

Phase 2 (April 2019 – TBD)

- Identify significant variables affecting performance and extend specs
- Improve performance with blind tests



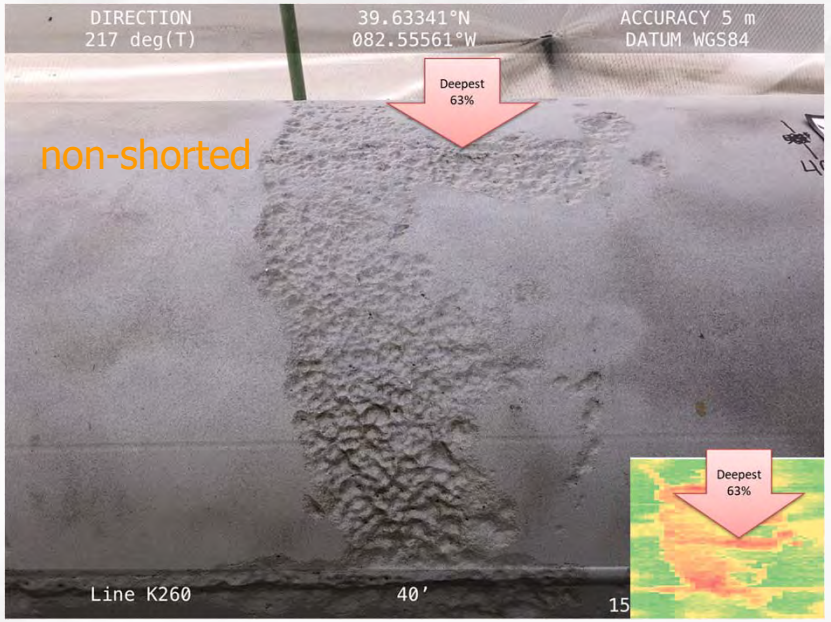
Summary and Path Forward

Summary

- Failures have occurred at casings
  - Ruptures occurred in non-shorted & non-cased pipe
  - Leaks occurred in shorted, non-shorted & non-cased pipe

To prevent failures need to manage all

- Majority of shorted casings have low/no corrosion - a few locations grow significantly
- Hi-res ILI based program is (able to size and quantify growth) more effective than clearing
- Reduce unnecessary costs and prevent failures more effectively



Questions?

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2. Camitz, G., "*Cathodic Protection of Natural Gas Pipelines with Casings at Road and Railway Crossings – International Practice and Experience*", NACE International Corrosion 1984 Conference, Paper No. 45
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4. Perry, F.A. and Burns, J., "*Measuring and Locating Contacts on Casings*", 38th Appalachian Underground Corrosion Short Course, College of Mineral and Energy Resources, West Virginia University, 1993, P. 170-190
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6. "*Guidelines for Integrity Assessment of Cased Pipe for Gas Transmission Pipelines in HCAs*", PHMSA, Revision 1, November 1, 2010
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14. Kariyawasam, S. N., Yeung, P., Clouston, S. and Hurd, G., "*Overcoming Technical Limitations in Identifying and Characterizing Critical Complex Corrosion*", IPC2012-90529
15. Kariyawasam, S. N. and Huang, T., "*How Safe Failure Pressure Ratios are Related to %SMYS*", IPC2014-33647

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18. Huang, T. and Kariyawasam, S. N., "*Effective Improvements to Overcome 'Blind Spots' in A Corrosion Management Program and Practical Measures to Verify Effectiveness*", IPC2014-33674
19. Huang, T. and Kariyawasam, S. N., "*An ILI Based Program That Prevents Reoccurrence of Post ILI Failures Seen in Industry*", Draft IPC2018-78604

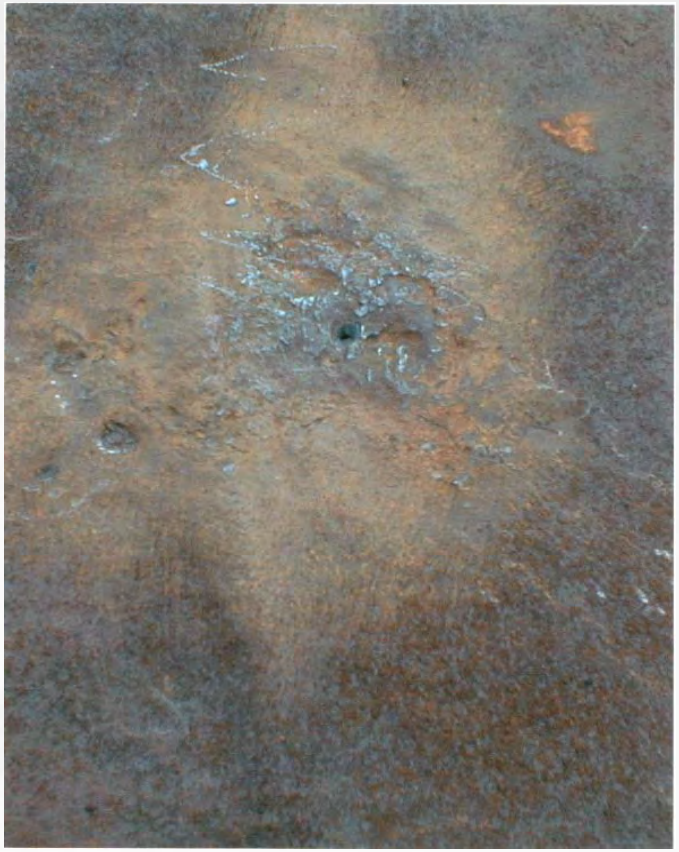
Backup

System XX Incidents at Casings

- Shorted based on On-Potential - all leaks
  - 2001 System XX L1 Leak
  - 2001 System XX L2 Leak
  - 2006 System XX L2 Leak
- Non-shorted based on On-Potential
  - 2003 System XX L3 Leak
  - 2007 System XX L1 Rupture

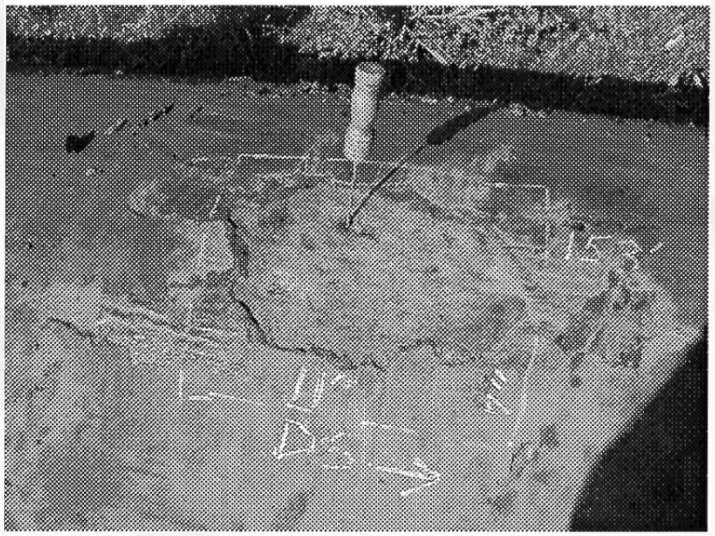
System XX Incidents at Casings

- 2001 System XX L2 Leak (Feb 2001)
  - Rayne LA section, not HCA
  - CoalTar Enamel coating, constructed in 1958
  - Was not previously ILI'd
  - Considered shorted, <100 mV "On" difference based on previous TL survey data
  - Localized pinhole
  - Casing displaced adding stress on the topside of pipe, damaged coating indicating direct contact
  - Positive SRB was also found in the corrosion area



System XX Incidents at Casings

- 2001 System XX L1 Leak (August 2001)
  - Rayne LA section, not HCA
  - CoalTar Enamel coating, constructed in 1953
  - Was previously ILI'd in 1996 with low-res MFL
  - Considered shorted, <100 mV "On" difference based on previous TL survey data
  - Localized pinhole
  - Coating underneath topside spacer was damaged due to significant stress



System XX Incidents at Casings

- 2003 System XX L3 Leak (August 2003)
  - Rayne LA section, not HCA
  - CoalTar Enamel coating, constructed in 1966
  - Was not previously ILI'd
  - Not considered shorted, >=100 mV "On" difference based on previous TL survey data
  - Localized pitting and pinhole
  - Coating underneath topside spacers was largely damaged due to significant stress

System XX Incidents at Casings

- 2006 System XX L2 Leak (Sep 2006)
  - Delhi LA section, not HCA
  - CoalTar Enamel coating, constructed in 1954
  - Was previously ILI'd in 2001 with low-res MFL
  - Considered shorted, <100 mV "On" difference based on previous TL survey data
  - Localized pinhole

System XX Incidents at Casings

- 2007 System XX L1 Rupture (Dec 2007)
  - Delhi LA section, in a HCA;
  - Not ignited, but earthen debris caused fatal injuries of a truck driver and also injured a passenger
  - CoalTar Enamel coating, constructed in 1954
  - Was previously ILI'd in 1991 with low-res MFL (indication of non-critical corrosion)
  - Not considered shorted, >=100 mV "On" difference based on previous TL survey data
  - Large area of pitting corrosion on the bottom side near end of the casing (at the fourth spacer)
  - Coating damaged underneath the bottom side of the spacer

Casing management history

- TC 3 systems have casings:
  1. System XX has 5 failures – 2000-2007 4 leaks and 1 ruptures all unpigged or with low-res ILI – since 2007 on High Resolution ILI program and no failures since then
  2. Canadian Mainline has many Casings – Since 1990 managed solely by High Resolution ILI – no post ILI failures due to EC
  3. US ANR has many casings – managed via High Resolution ILI – no post ILI failures due to EC

Pipeline Research Council International, Inc.

New HIC test solution with excellent pH stability for Fitness-for-Purpose evaluation

Nobuyuki Ishikawa, Daisuke Mizuno and Kyono Yasuda
JFE Steel Corporation

Taishi Fujishiro and Takuya Hara
Nippon Steel & Sumitomo Metal Corporation

PRCI 2019 Research Exchange Meeting
Houston, Texas
Date [March 5 OR 6, 2019]

Overview

- **Research activities of HLP committee**
  - Corrosion Working Group: HIC, SSCC, SCC
  - Fracture Working Group: Running shear fracture, Brittle fracture
- **Background**
  - Fitness-for-service evaluation for sour service application
  - pH stability under long test duration for milder sour conditions
- **HIC test solution**
  - NACE TM0284 sol. C: 5.0%NaCl + 0.4%CH_3COONa + HCl / NaOH
  - HLP solution: 5.0%NaCl + 0.93N (CH_3COOH+CH_3COONa)
- **Feature of the HLP solution**
  - Excellent pH stability for long duration without solution adjustment
  - Same corrosion rate and HIC test results as conventional NACE solution
- **Future work**
  - Standardization as Solution D in NACE TM0284
    (Currently, noted in TM0284 as alternative solution to Sol. B)

HLP Committee

Iron & Steel Institute of Japan (ISIJ)

HLP (High-strength Line Pipe) Committee

Member: Nippon Steel & Sumitomo Metals, JFE Steel
Univ. of Tokyo, Tokyo Inst. Technology, Osaka Univ.

Fracture Working Group

- Running share fracture
- Brittle fracture / DWTT

Corrosion Working Group

- Hydrogen induced cracking (HIC)
- Sulfide stress corrosion cracking (SSCC)
- External stress corrosion cracking (SCC)

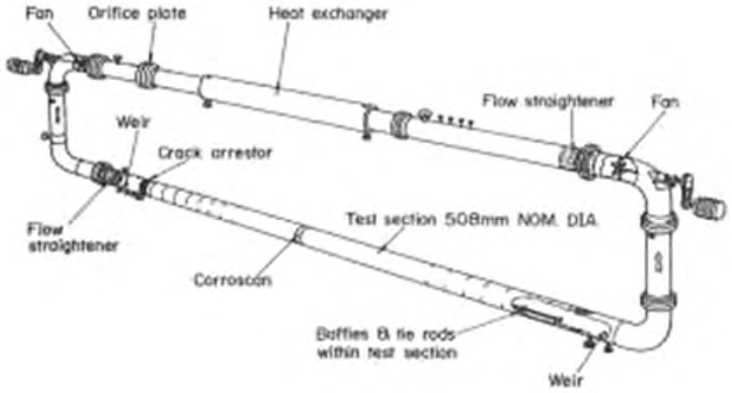
Research activities of Corrosion WG - Full scale HIC evaluation -

Purpose

- To investigate the validity of HIC test evaluation by comparing with full scale HIC behavior

Test conditions

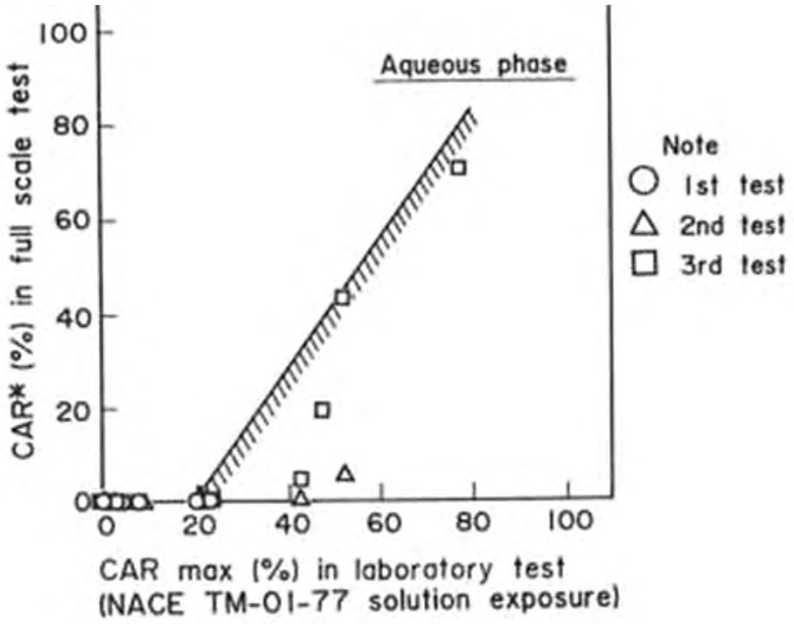
- Test site: BGC Spadeadam
- Pipe grade: X42-X65
  w/ different HIC susceptibility
- Size: 508mmOD x 7.0~10.9mmWT
- H_2S pressure: 0.2~1.5 MPa
- Solution: Sea water, pH3.6-3.7
- Test duration: 16~90 days



Test results

Hyodo, et al. Corrosion Science, vol.27(1987)

Burst pipe



Comparison of full-scale and laboratory test

Research activities of Corrosion WG - Near neutral SSC evaluation

Purpose

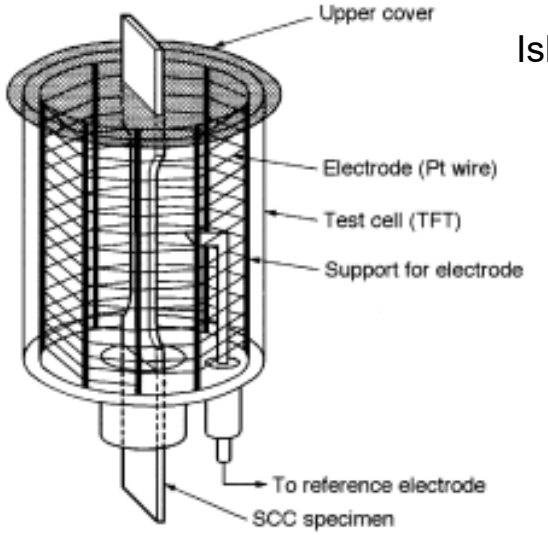
- To evaluate susceptibility to near neutral pH SSC of recent high strength linepipes

Test conditions

- Materials: TMCP X65, X80
- Solution: NS4 by Parkins
- Gas: 10%CO2+90%N2
- Cathodic potential: -1000mV
- Max. stress: 100%Actual TS
- Stress ratio: 0.5
- Test duration: 4 weeks

Test results

- No significant difference between X65 and X80
- Both corrosion and hydrogen embrittlement may affect SSC



Test cell

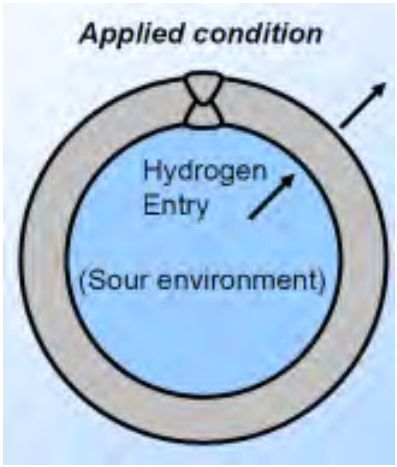
Ishikawa, et al. IPC2008-64281

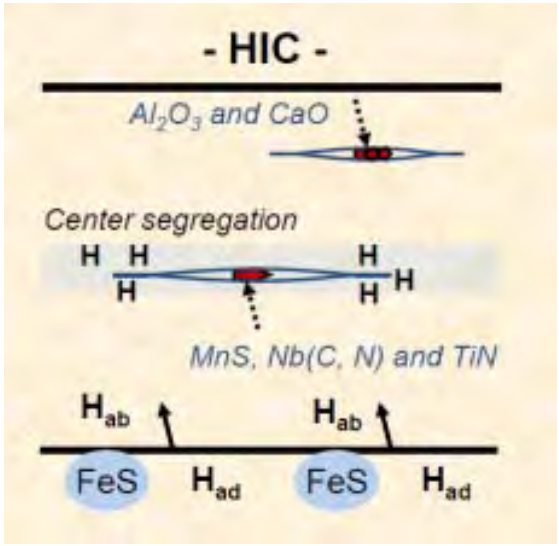
Transgranular cracking

Grade				X80	
Process		TMCP		TMCP	
Microstructures		Bainitic ferrite		Bainite	
YS(MPa)		524		565	
σmax.	Potential	P	M	P	M
85%YS	-930mV	NC	NC	NC	NC
100% YS	-830mV	NC	NC	C	NC
	-930mV	C	C	C	NC
	-1000mV	C	C	C	C

Background for HIC solution

Hydrogen Induced Cracking (HIC)

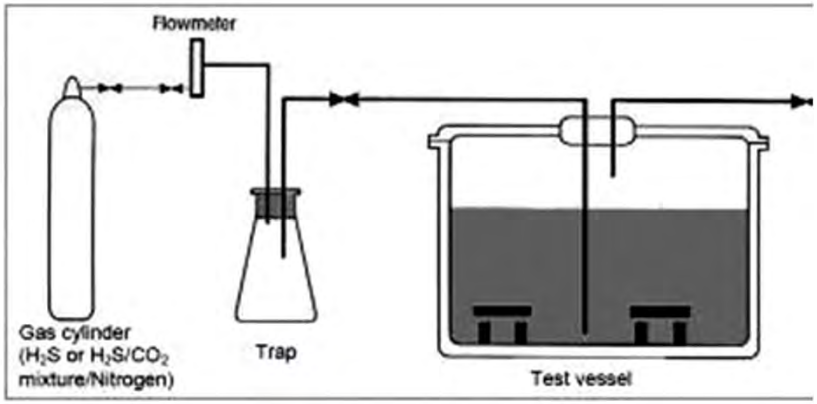




Mechanism of HIC

NACE TM0284 HIC test

- Solution A
  - 5%NaCl + 0.5%CH_3COOH
  - Initial pH 2.7-3.3
  - 100%H_2S
- Test duration: 96hr
- Evaluation: CLR, CTR, CSR



Fitness-for-Purpose/Service Evaluation

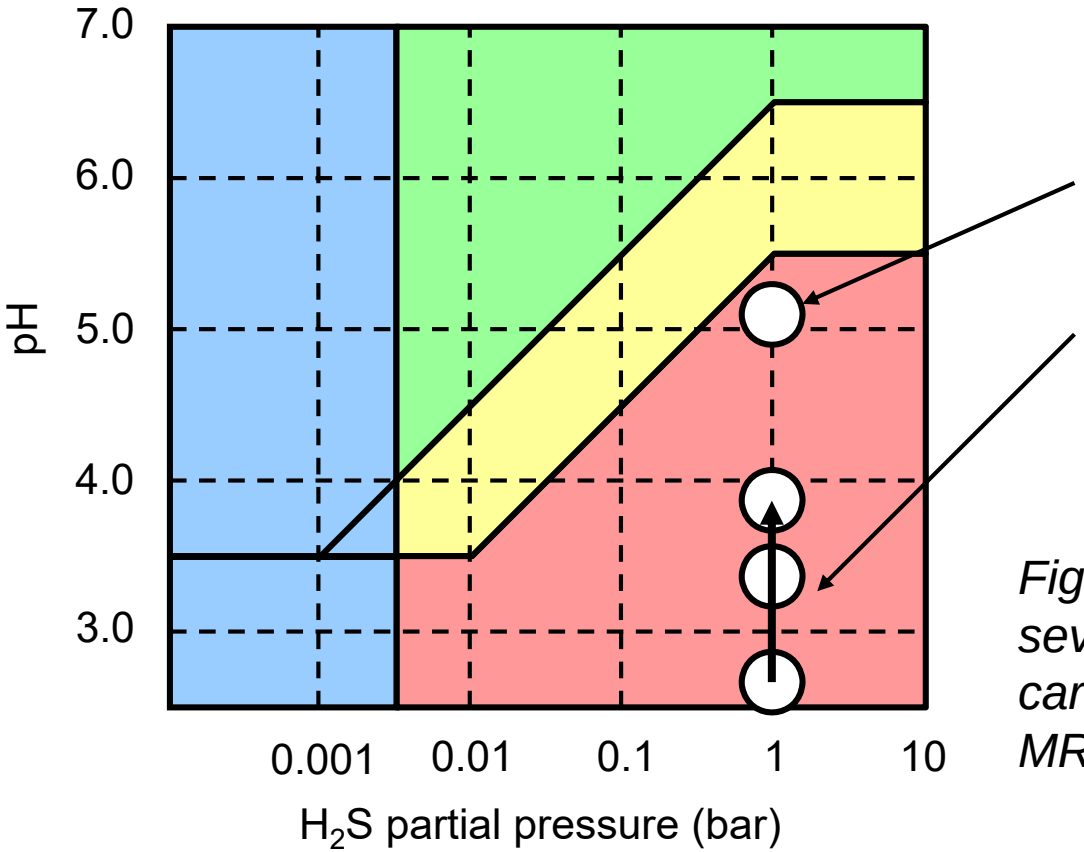


Figure - Regions of environmental severity with respect to SSC of carbon and low alloy steels (NACE MR0175 / ISO15156-2)

- Higher grade materials can be used in milder sour conditions
- Reliable FFP HIC evaluation method is considered to be required along with developing high strength steels

Present FFP evaluation methods

NACE Std.		Test solution	pH (initial/upper limit)	Gas
NACE TM0284 (2016)	A	5%NaCl+0.5%CH_3COOH	2.7~3.3 / 4.0	1 bar H_2S
	B	Synthetic seawater	4.8~5.4 / 4.0	1 bar H_2S
	C	5%NaCl+0.4%CH_3COONa +(HCl/NaOH)	Target pH ±0.2	H_2S or H_2S/CO_2
NACE TM0284	B	5%NaCl+0.47N (CH_3COOH/CH_3COONa)	3.4~3.6 / 4.0	H_2S, CO_2, N_2

Test duration for Solution C

pH_2S bar	xH_2S mole-%	Test Duration hours/days
$0.001 \le pH_2S \le 0.003$	$0.1 \le xH_2S \le 0.3$	2160/90
$0.003 < pH_2S \le 0.01$	$0.3 < xH_2S \le 1$	720/30
$0.01 < pH_2S \le 0.1$	$1 < xH_2S \le 10$	336/14
$0.1 < pH_2S$	$10 < xH_2S$	96/4

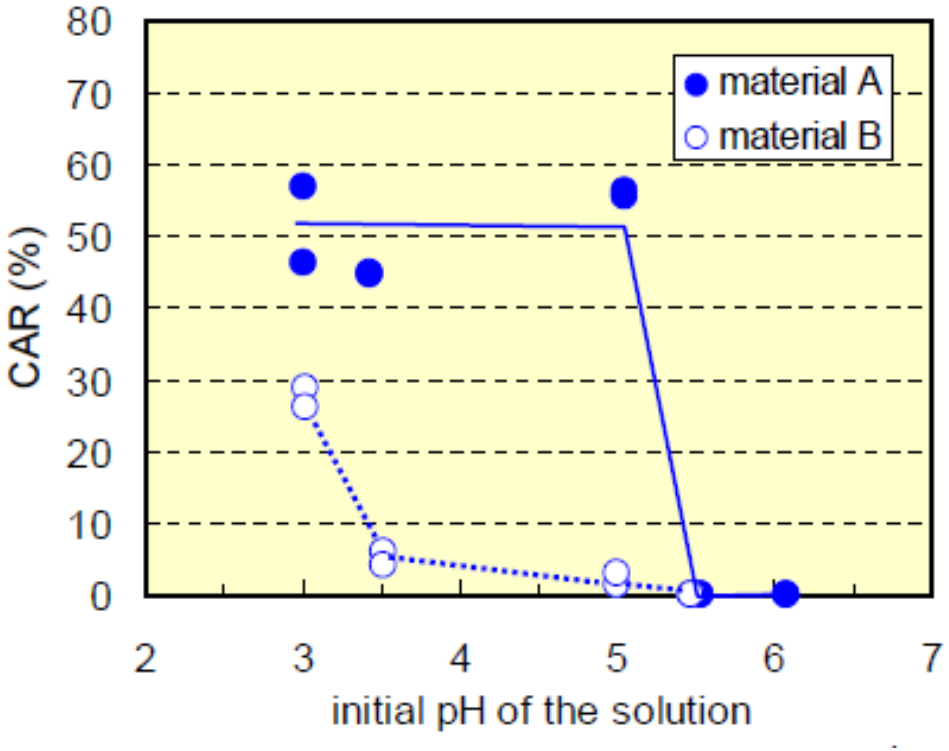
Longer test duration is required for lower H_2S condition

Note: For tests requiring greater pH stability

- NACE TM0177 Solution B (0.47 N total acetate) + HCl/NaOH
- HLP solution including CH_3COOH / CH_3COONa (0.93 N total acetate)

Motivation for Strong pH Stability

Effect of pH on HIC



Small pH change can give different test results
pH:3.0⇒3.5 CAR:30%⇒5%
pH:5.0⇒5.5 CAR:55%⇒0%

Inappropriate material selection for FFP/FFS

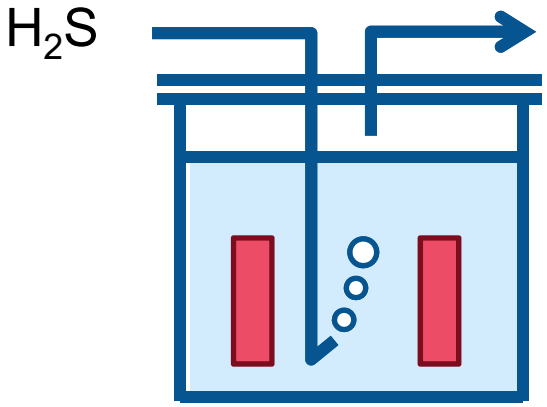
ISIJ International, Vol. 56 (2016), p.498

Objective

- To develop HIC test solution with strong pH stability
- To demonstrate availability of HLP solution

Effect of Acetate Concentration on Buffering Capacity

HIC test procedure



HIC specimen: 12 x 50 x 100 mm
Solution volume: 3.0 ml/cm^2
Initial pH: 3.5
H_2S partial pressure: 1 bar
Temperature: 25^{o}C

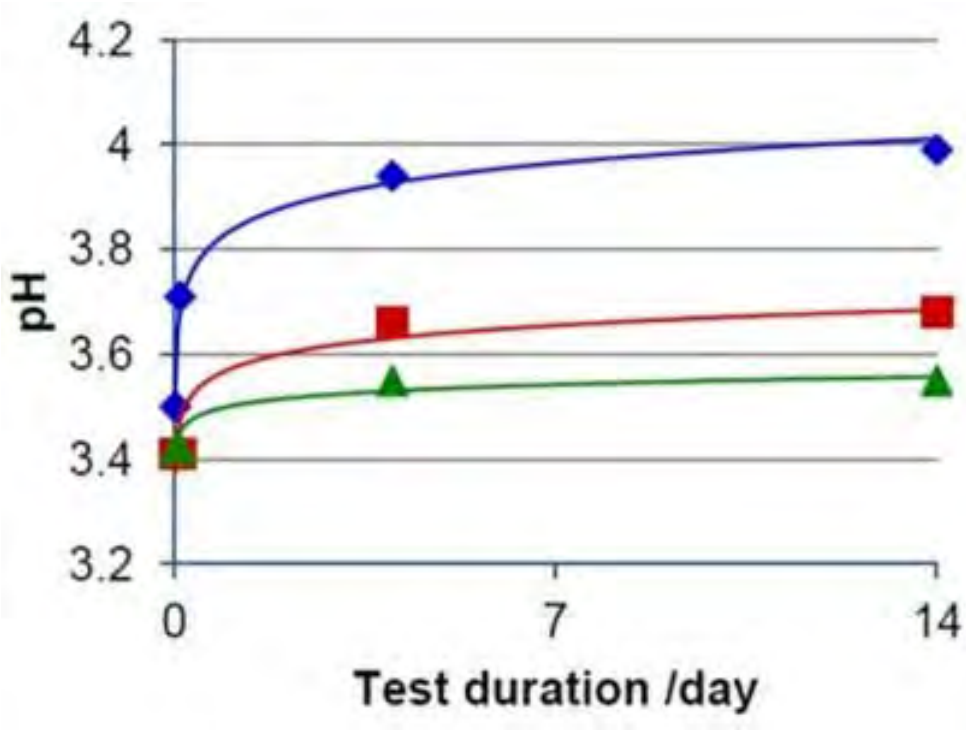
Test solution

No	Acetate concentration	Solution
A	0.05N	5%NaCl+0.4%CH_3COONa+HCl
B	0.47N	5%NaCl+0.4%CH_3COONa+2.5%CH_3COOH
C	0.92N	5%NaCl+0.8%CH_3COONa+5.0%CH_3COOH

Corrosion 2013 Paper no.2289

Effect of Acetate Concentration on pH Stability

pH change during HIC test



Initial pH	Final pH	pH change
3.5	4.0	0.5
3.4	3.7	0.3
3.4	3.5	0.1

✓ pH buffering capacity increases with increasing acetate concentration

Corrosion 2013 Paper no.2289

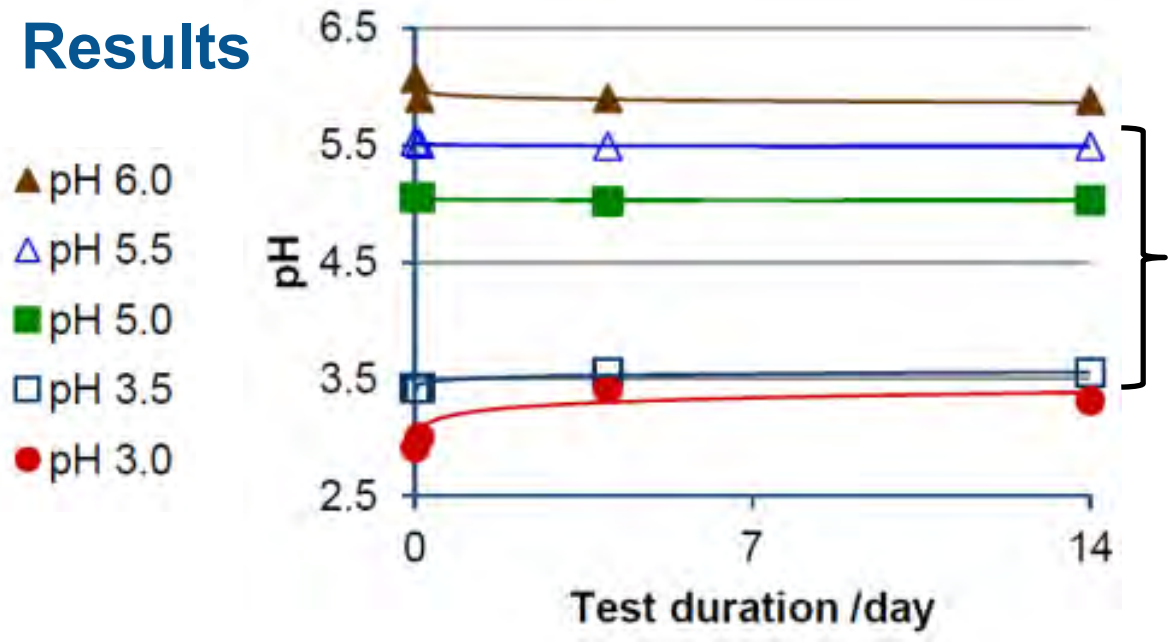
Effect of Initial pH on pH Stability

Test solution

, *K. Kobayashi et al., Corrosion 2013 Paper no.2289*

No	Initial pH	Solution
D	3.0	5%NaCl+0.28%CH_3COONa+5.39%CH_3COOH
(C)	3.5	5%NaCl+0.80%CH_3COONa+5.00%CH_3COOH
E	5.0	5%NaCl+6.05%CH_3COONa+1.17%CH_3COOH
F	5.5	5%NaCl+7.06%CH_3COONa+0.43%CH_3COOH
G	6.0	5%NaCl+7.45%CH_3COONa+0.14%CH_3COOH

Results

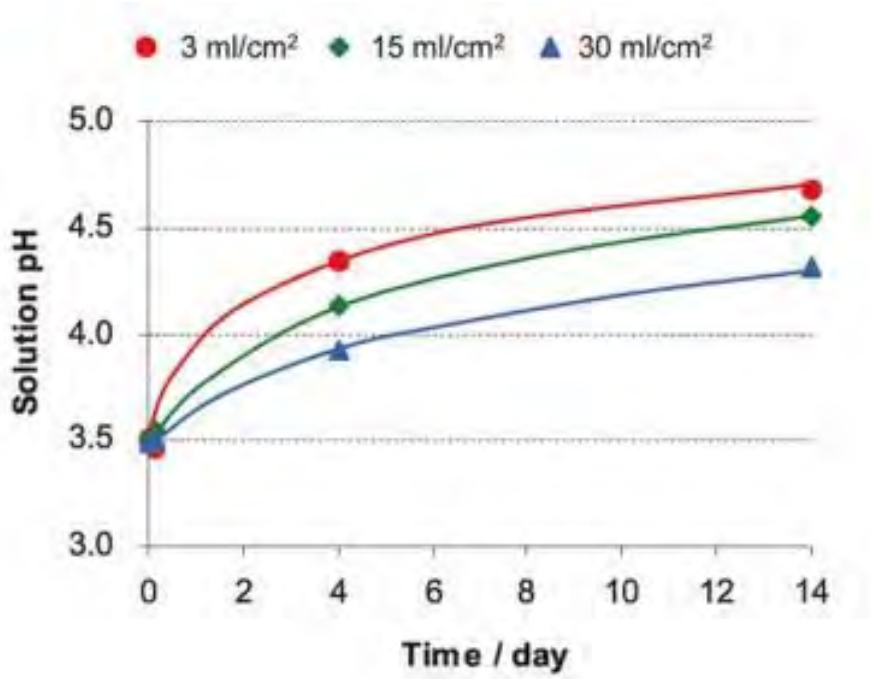


✓ Constant pH in the case of initial pH 3.5 to 5.5

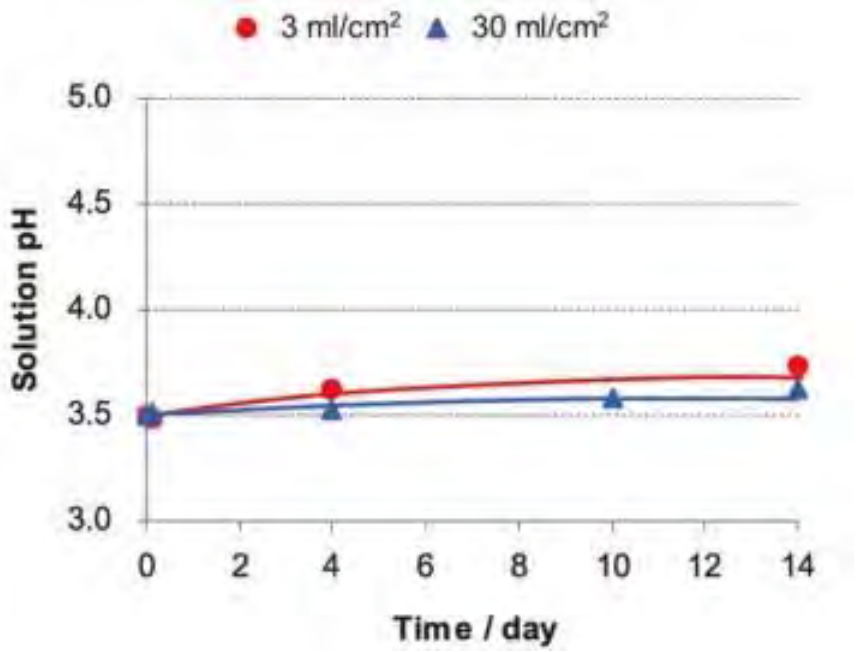
Corrosion 2013 Paper no.2289

Comparison of Buffering Capacity

Solution C
5%NaCl+0.4%CH_3COONa



HLP Solution
5%NaCl+0.93N（CH_3COOH+CH_3COONa）

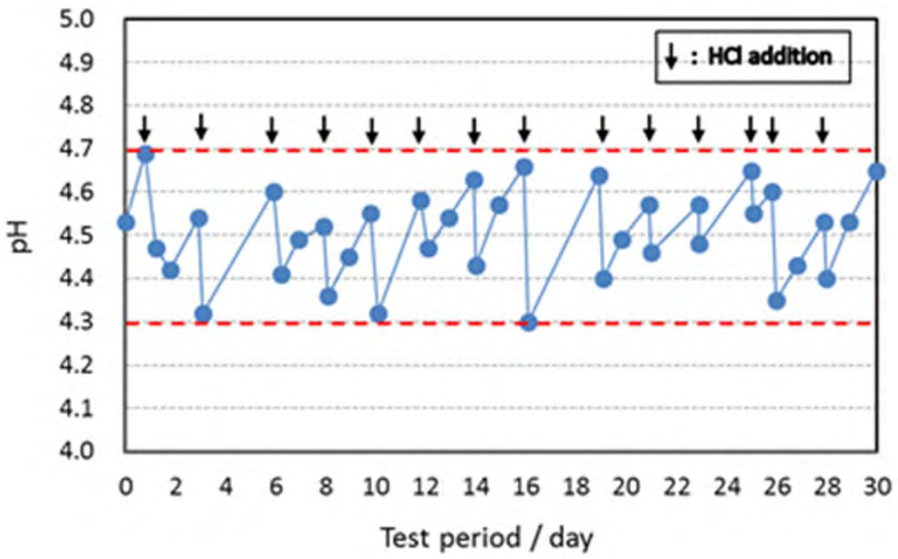


- ✓ HLP solution shows strong pH buffering capacity with increased acetate concentration

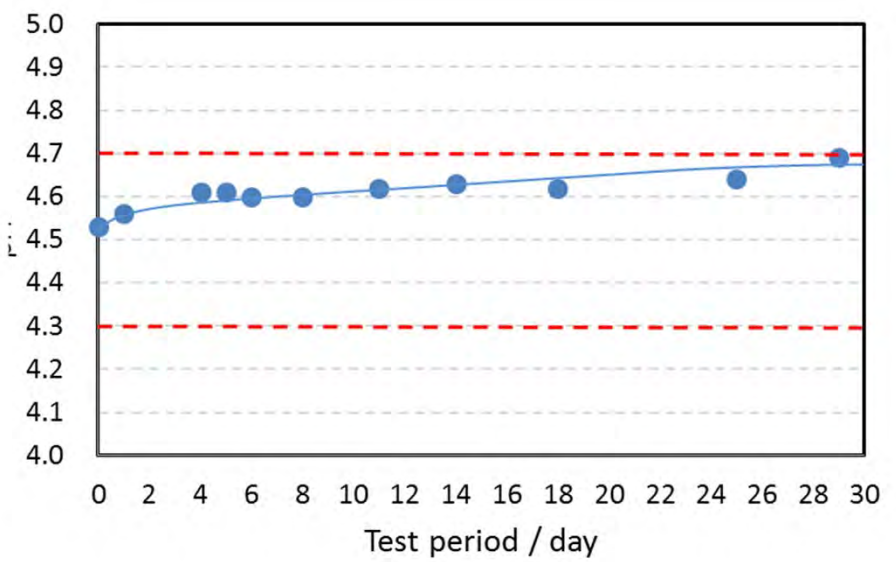
ISIJ International, Vol. 56 (2016), p.498

Comparison of Buffering Capacity

Solution C
5%NaCl+0.4%CH_3COONa



HLP Solution
5%NaCl+0.93N（CH_3COOH+CH_3COONa）



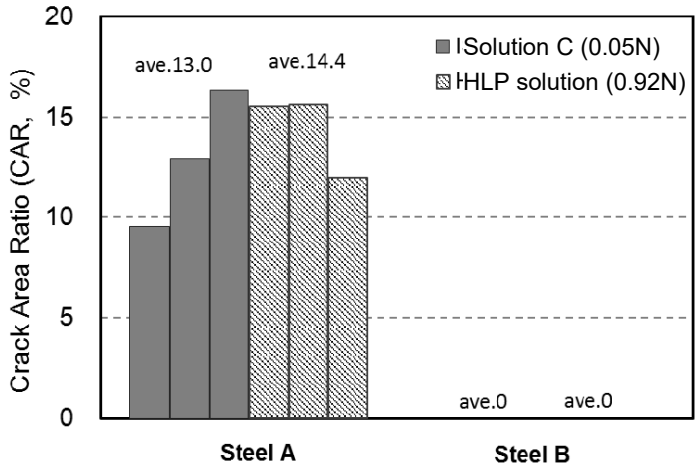
- ✓ Frequent pH adjustment is needed for the solution C, while HLP solution showed stable pH without solution adjustment

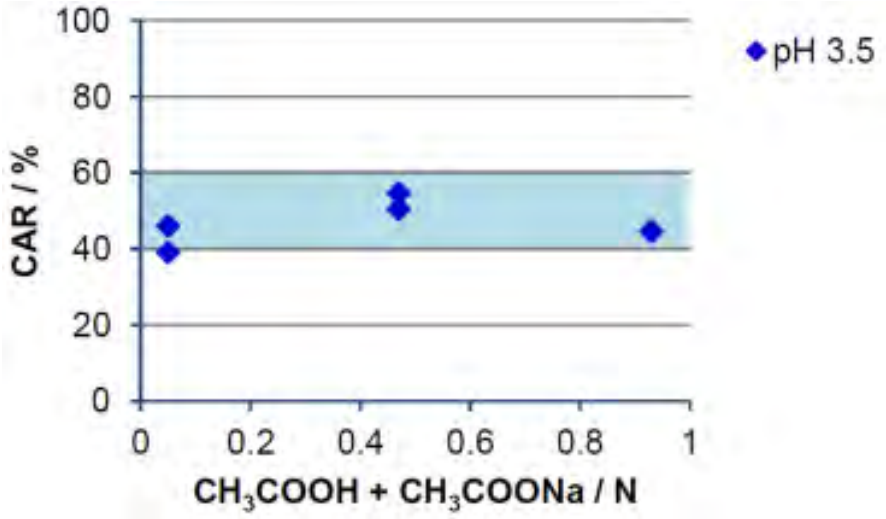
Corrosion 2017, Paper no.9129

Comparison of HIC Test Results

Solution C
5%NaCl+0.4%CH_3COONa

HLP Solution
5%NaCl+0.93N（CH_3COOH+CH_3COONa）

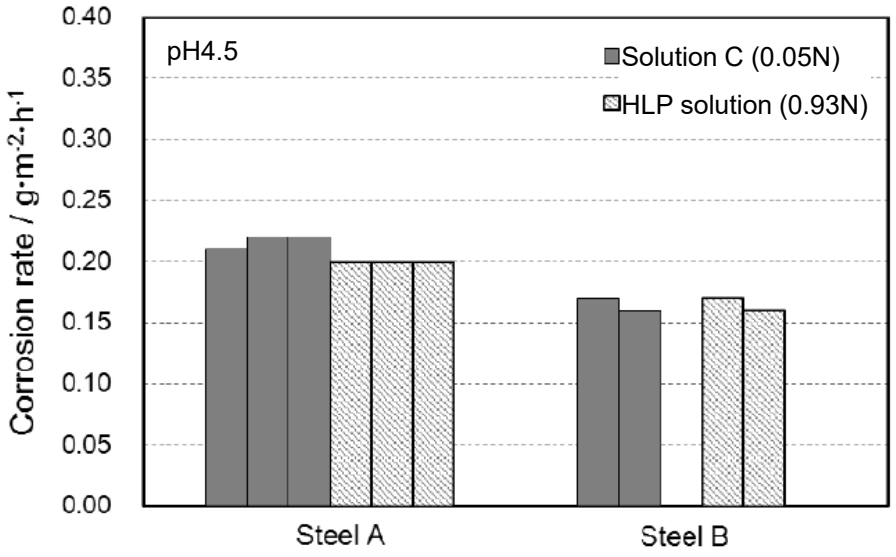


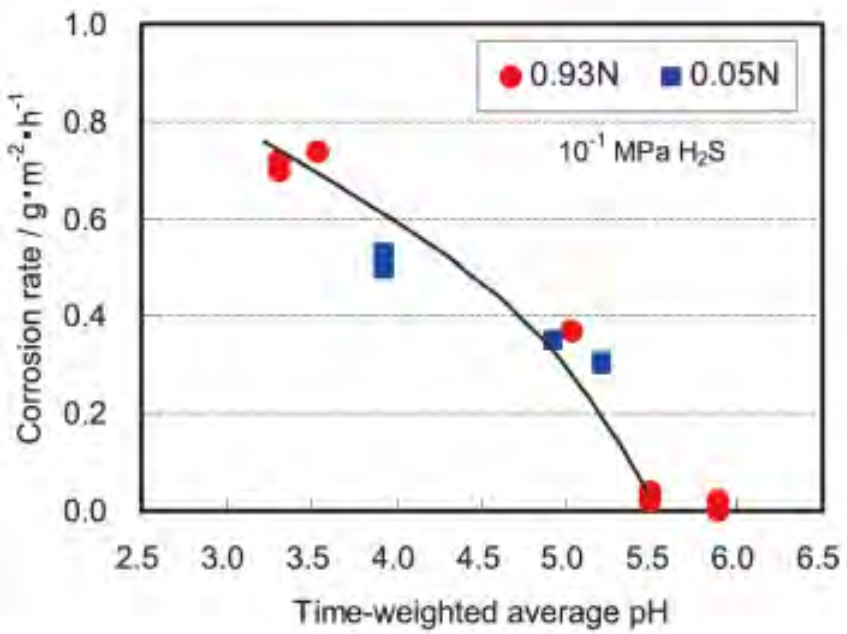


✓ Same HIC test results were obtained for both Sol. C and HLP solution

ISIJ International, Vol. 56 (2016), p.498

Comparison of Corrosion Behavior



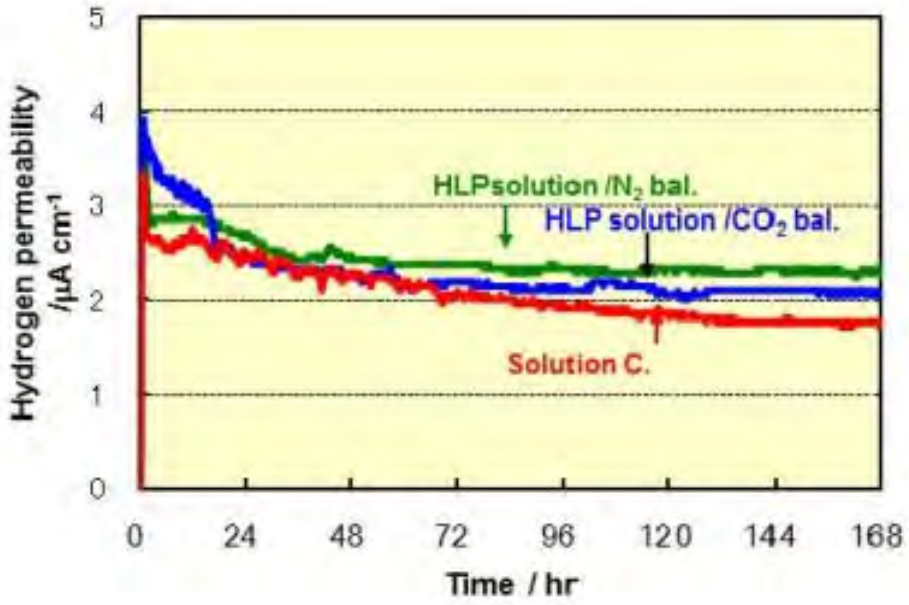


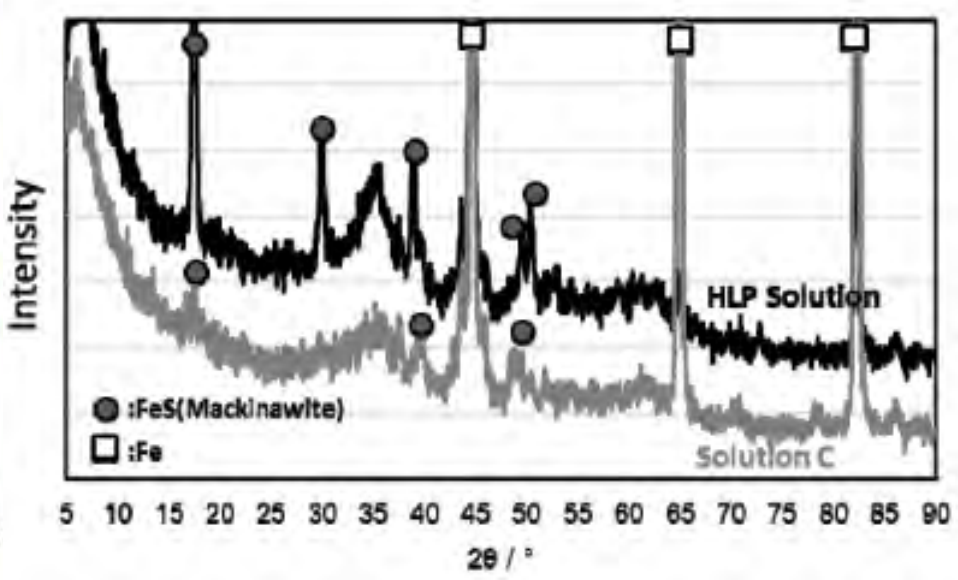
✓ There is no effect of acetate concentration on corrosion rate

Corrosion 2017, Paper no.9129

ISIJ International, Vol. 56 (2016), p.498

Hydrogen Permeation and Corrosion Products





- ✓ High acetate concentration of HLP solution does not have significant influence on corrosion and hydrogen entry behavior

ISIJ International, Vol. 56 (2016), No. 3, pp. 498–503

Conclusions

- ✓ HLP solution has been designated as alternative test solution to solution C in NACE TM 0284 2016
- ✓ Since HLP solution has a greater pH stability, targeted pH value can be stably maintained during HIC test.
- ✓ High acetate concentration of HLP solution does not have significant influence on corrosion and hydrogen entry behavior

Pipeline Research Council International, Inc.

EC-2-9

Peer Review of the Plausible Profile (Psqr) Corrosion Assessment Model

Shahani Kariyawasam, Shenwei Zhang,

Jason Yan, Terry Huang, Mohammad Al-Amin, Erwin Gamboa

TransCanada (TC Energy)

PRCI 2019 Research Exchange Meeting
Houston, Texas
March 5 , 2019

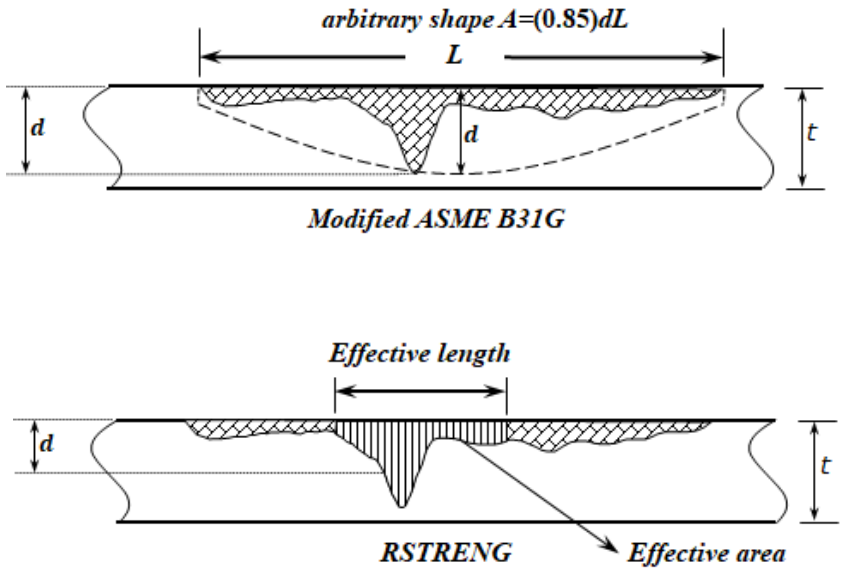
TransCanada
In business to deliver

PRCI 2019 project: EC-2-9 – Peer Review of the Plausible Profiles (Psqr) Corrosion Assessment Model

- **Objectives**
  - Peer review and vet the Psqr model
  - Share benefits – (safety & optimization)
  - Provide method and software for industry
- **Execution plan**
  - Conduct PRCI workshops with related SMEs, and :
    - *Workshop #1- Jun 20th 2018 in Houston*
    - *Workshop #2- Sept 26th 2018 in Calgary*
  - Obtain peer reviewed report with feedback from official reviewers
    - ***John Kiefner, Michael Rosenfeld/Bruce Nestleroth, Ming Gao/Ravi Krishnamurthy, Phil Hopkins, Andrew Cosham and Maher Nessim***
  - John Kiefner collates all comments and discusses with TCPL and reviewers
  - John Kiefner provides final report to PRCI

Conservatism in Corrosion Idealization

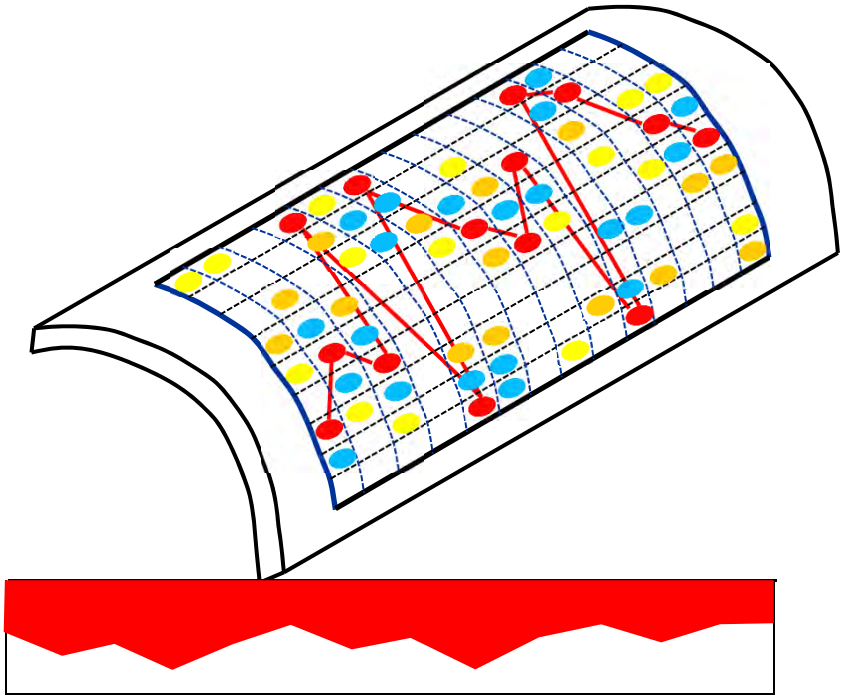
Mod. B31G (0.85dl) and RSTRENG (effective area)



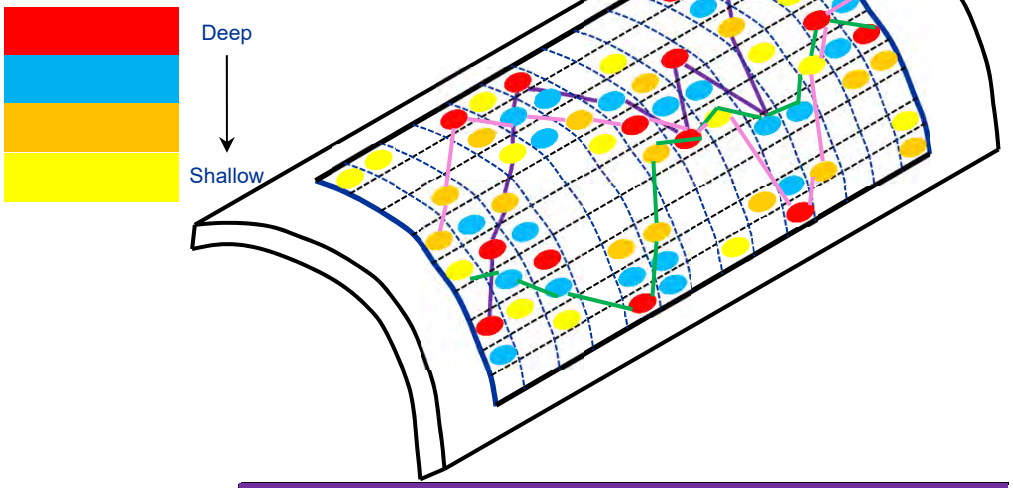
Difference between Mod. B31G and RSTRENG is that the corrosion shape is characterized more accurately by RSTRENG

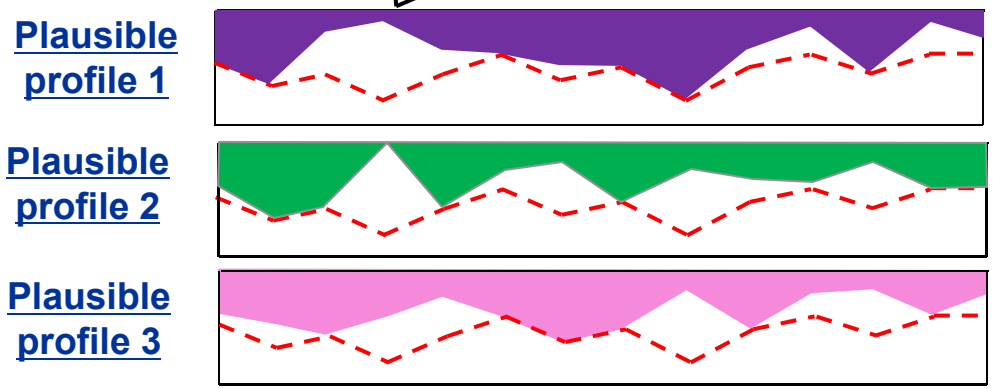
Conservatism in Corrosion Idealization

- **RSTRENG and Psqr**



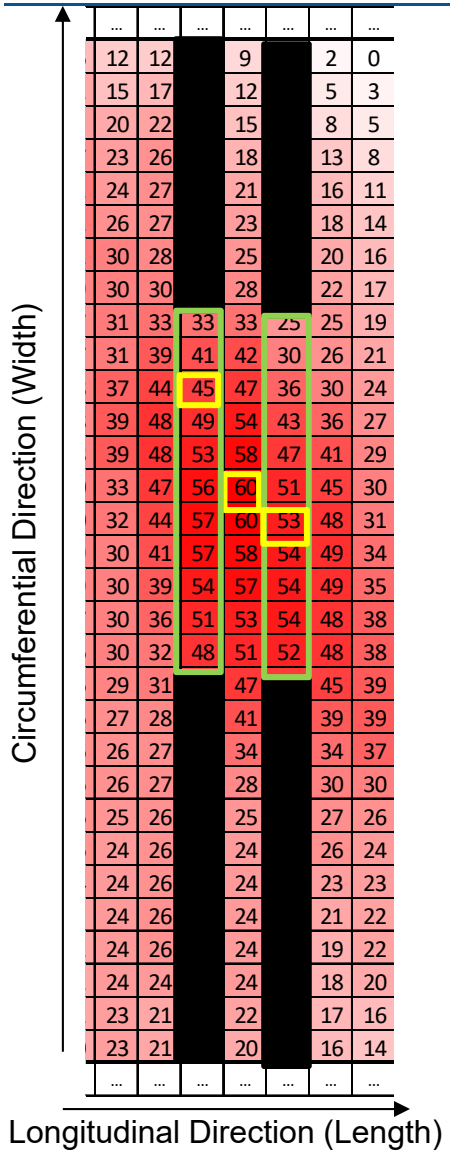
River bottom profile
(most aggressive but not plausible for wide corrosion morphologies)





Difference between Psqr and RSTRENG is that interacting corrosion shape is more accurately characterized.

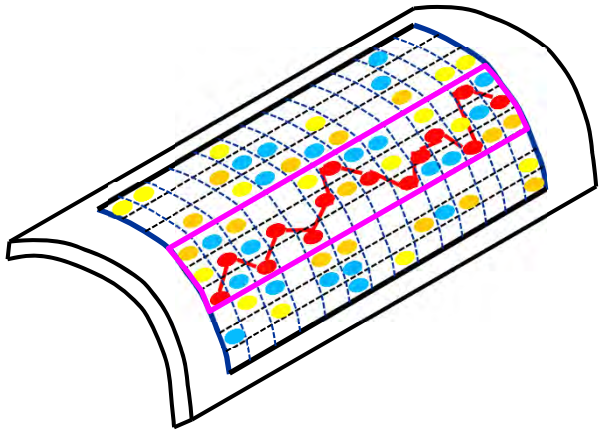
Plausible Profile Generation

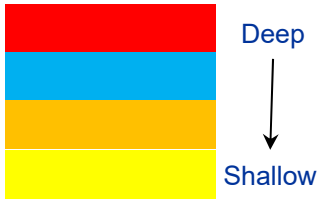


- **Start point:**
  - Depth-weighted start point
- **Subsequent points**
  - Interaction window: **6t**
  - Likelihood of selection: **proximity- and depth-weighted**

Axially Aligned Corrosion (AAC)

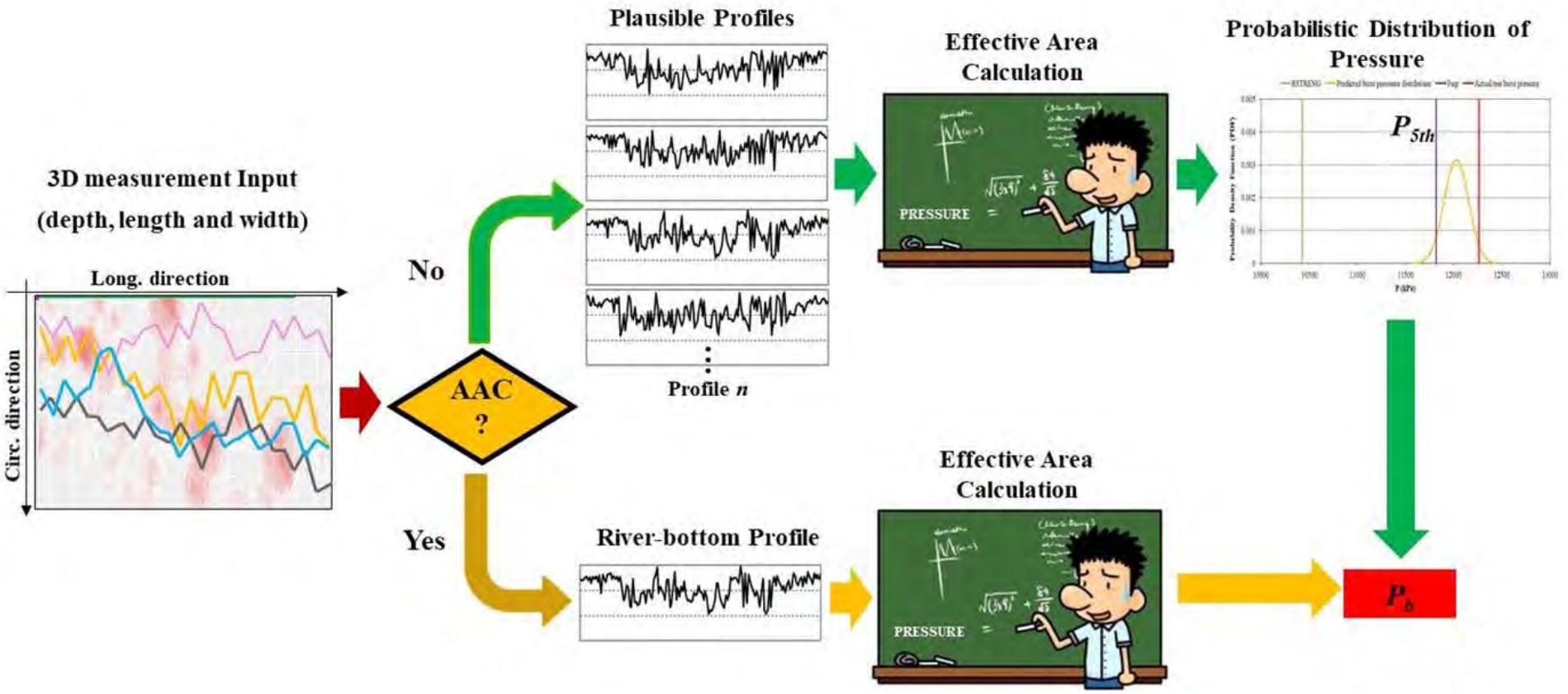
- Axially aligned corrosion morphology- river bottom profile is within a narrow band of 6wt



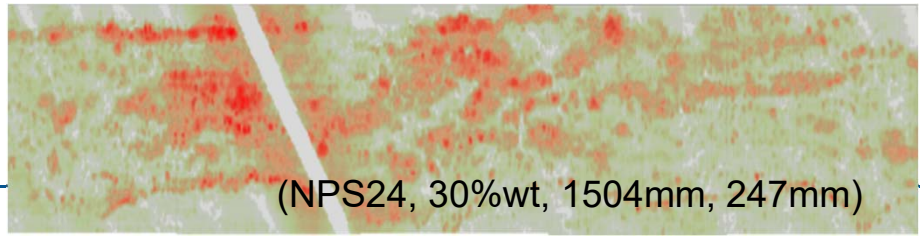


- For axially aligned corrosion River bottom is plausible $P=P_{RSTRENG}$
- Psqr provides higher burst pressure only when river bottom profile is not plausible

Pressure Calculation Using Psqr Model



Burst Tests


(NPS24, 30%wt, 1504mm, 247mm)

- **Fourteen (14) tests in 2015**
  - Naturally-occurring corrosion

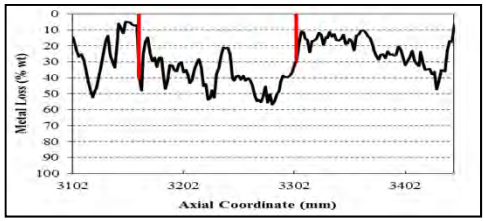
OD (NPS)	Number of Samples	NWT (mm)	SMYS (MPa)
30	6	8.34	483
24	2	6.8	483
16	6	6	359

- **Sixteen (16) tests in 2018**
  - Two (2) pipes with naturally-occurring corrosion
  - Fourteen (14) pipes with “3D-printed” morphology
  - Designed morphology to test assumptions

OD (NPS)	Number of Samples	NWT (mm)	SMYS (MPa)
8	2	4.6	359
12	2	6.4	359
20	3	9.5 6.3	483 359
24	2	9	483
30	1	9.53	359
34	1	11.9	483
36	1	11.8	483
42	2	14.3	483
48	2	11.6	483

Parameters for Sensitivity Analysis

Plausible Profile generation

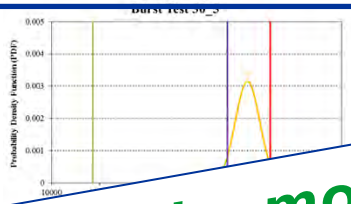


- start point
- interaction window width
- likelihood of selection

Simulation Runs

- number of plausible profiles

Pressure Calculation



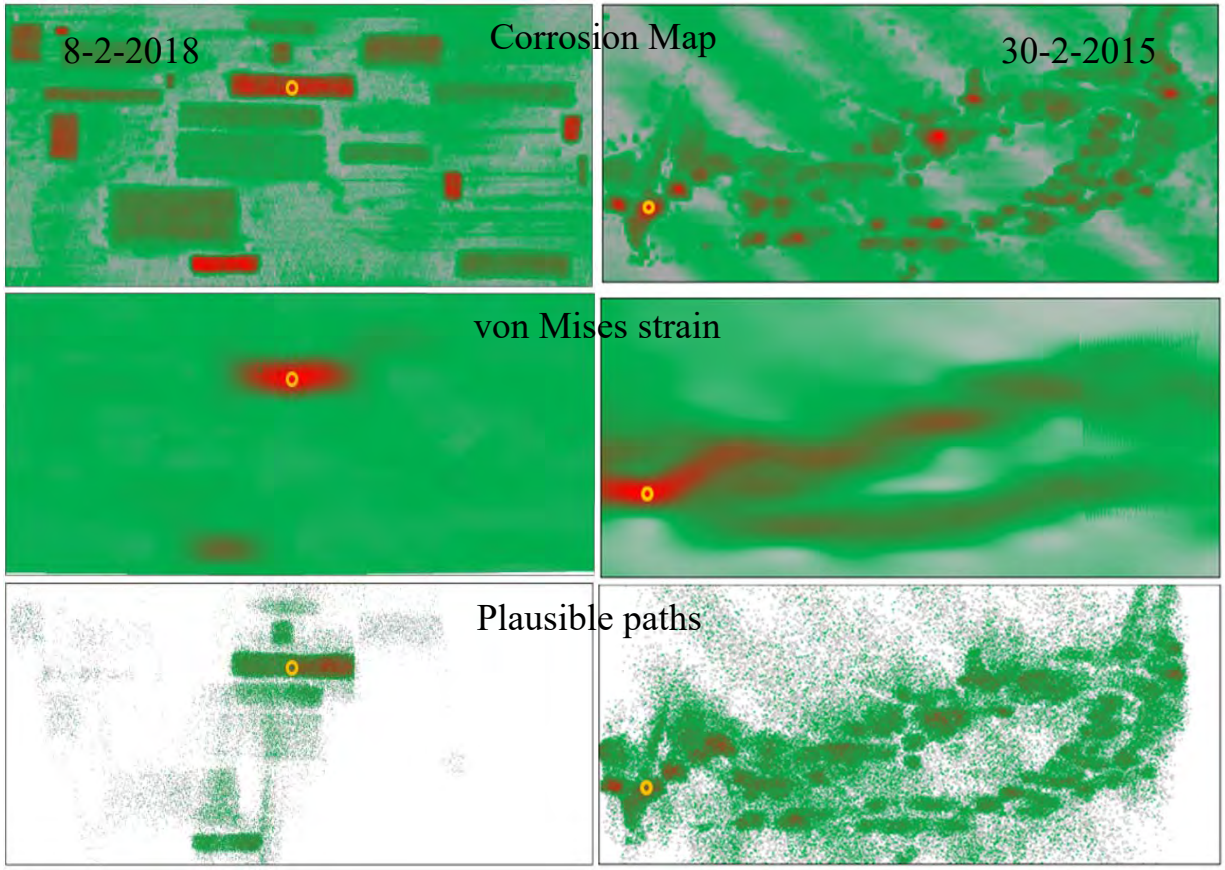
How sensitive is the model to these 5 parameters?

ILI Input

- grid size of the ILI output

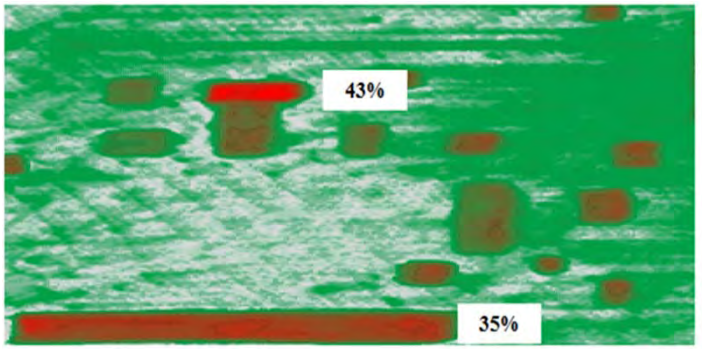
Initiation Point-Verification

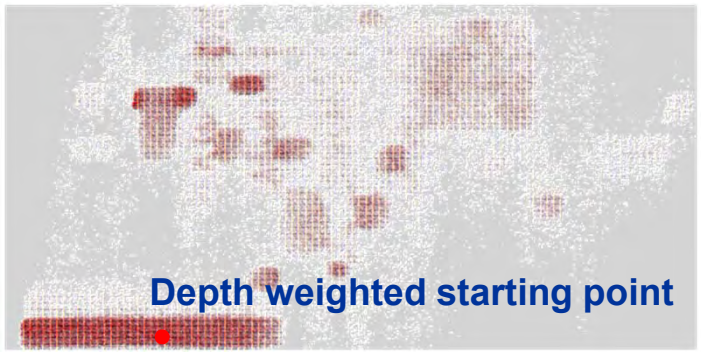
- Von Mises strains capture the initiation location of burst (i.e. the local area with the highest strain)
- Plausible profiles capture initiation of burst
- River bottom profile does not always capture the initiation point



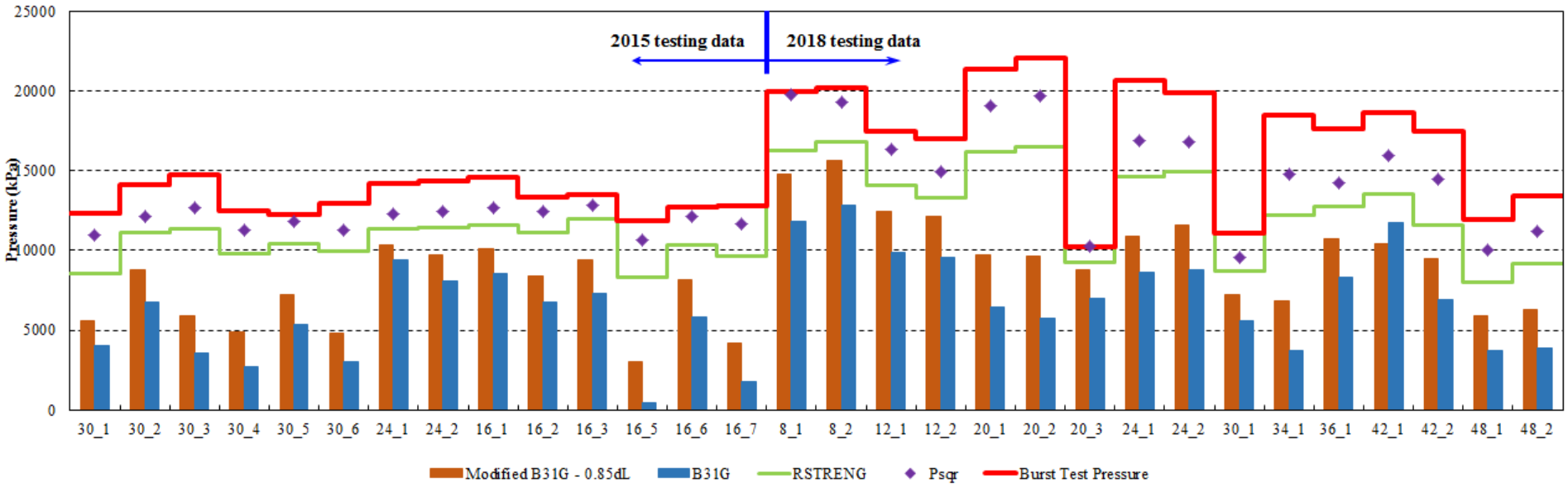
Starting Point-Burst Test Verification

- Single starting point could miss critical corrosion areas in extreme morphologies
- Depth-weighted starting point captured all critical areas of corrosion
- Both are lower than actual pressure
- Depth-weighted method adopted





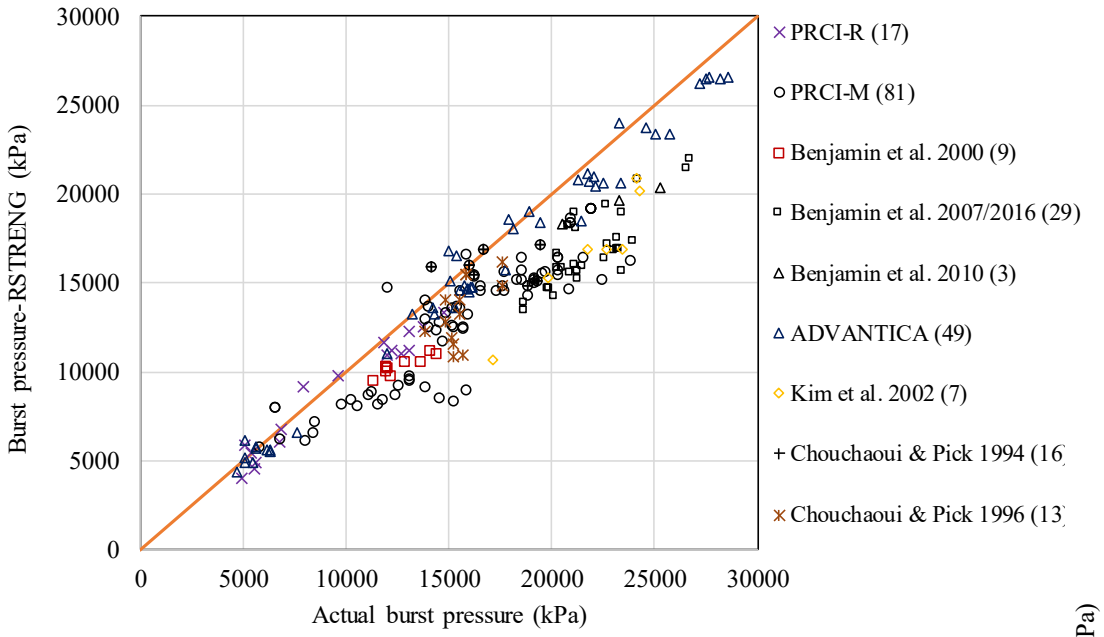
Model Validation Results-TCPL Tests



Parameter	Test-to-prediction ratio	
	Psqr	RSTRENG
Mean	1.13	1.31
Std	0.07	0.10
COV (%)	5.9	8.0

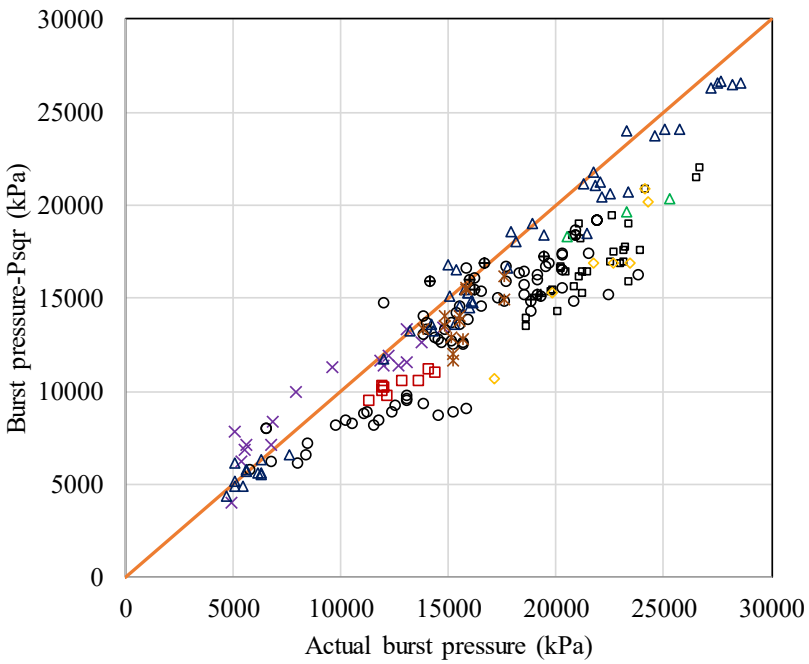
Compared to RSTRENG, Psqr is **more accurate** and **more precise**

Model Validation-Public Test Data

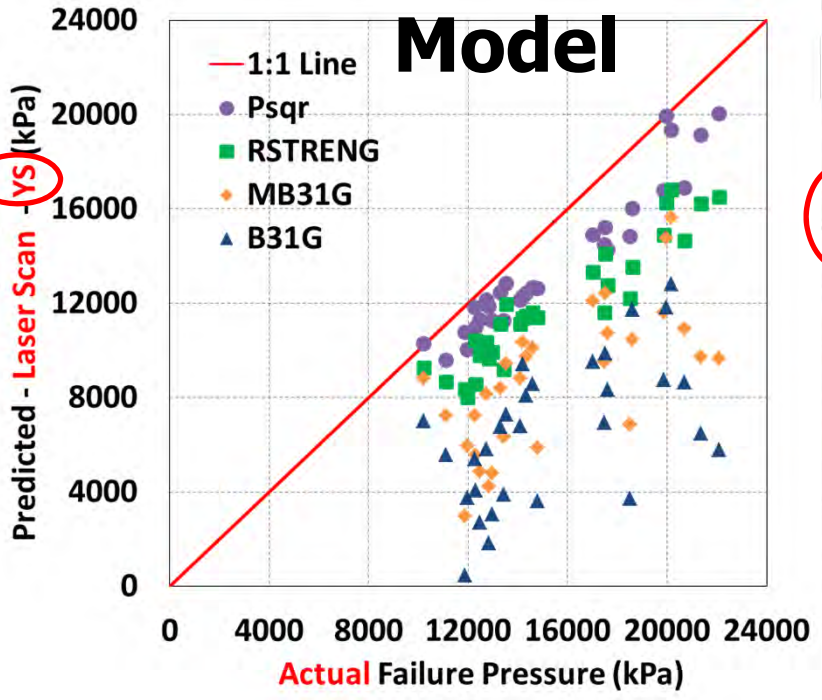


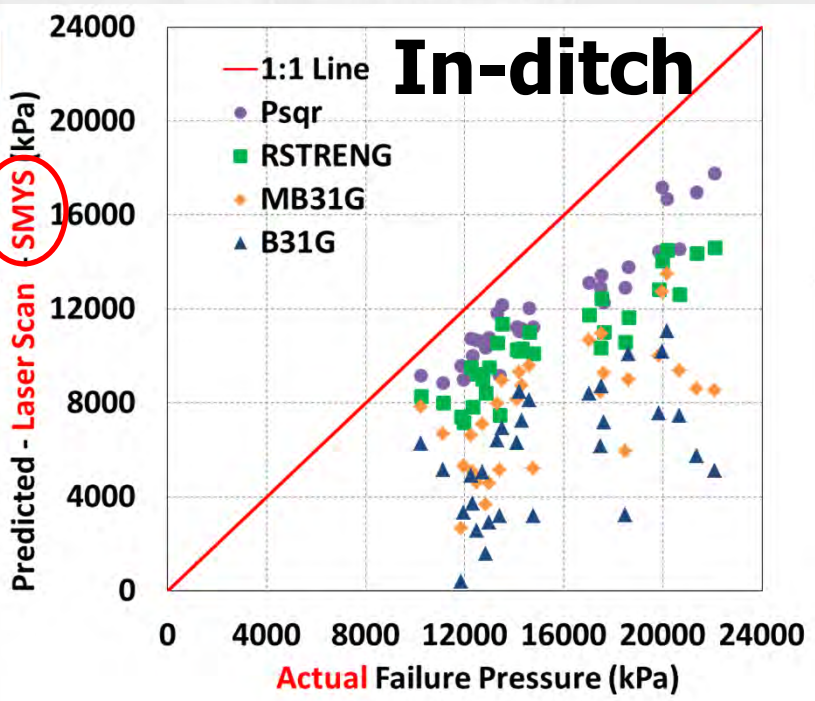
- **Applicability limits: same as RSTRENG**

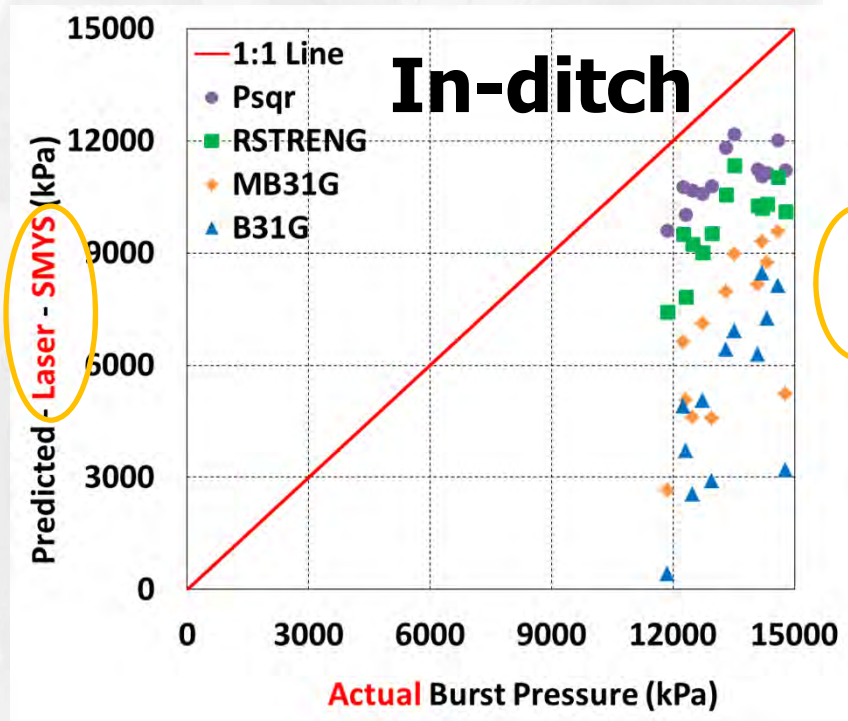
- **224 tests with sufficient information**
- **Mostly machined flat bottom and simple corrosion**
- **Uncertainties in digitization**

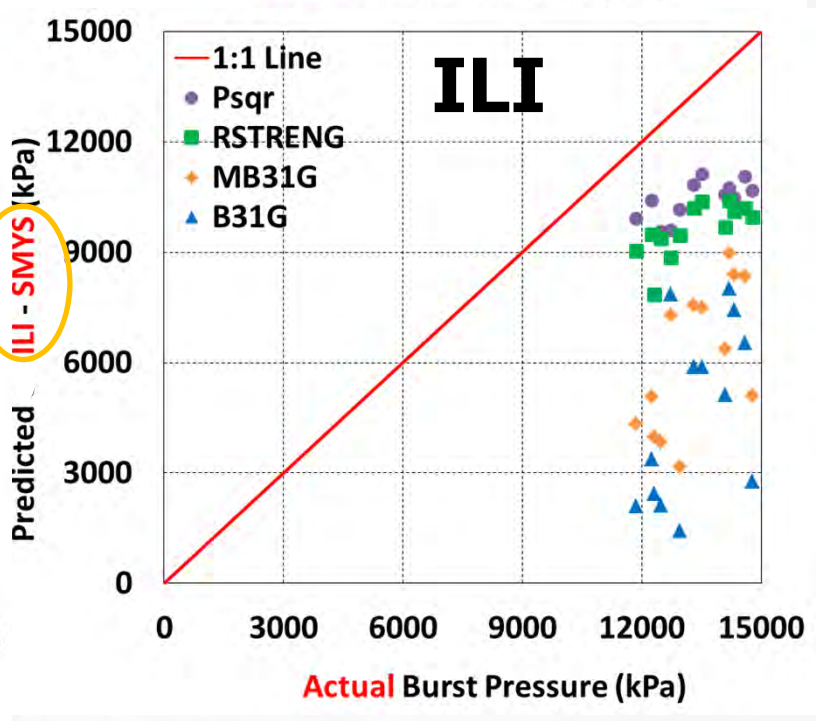


Safety checks









Benefit: Expanded Case Studies

- **ILI by different ILI vendors – low performance coated lines**

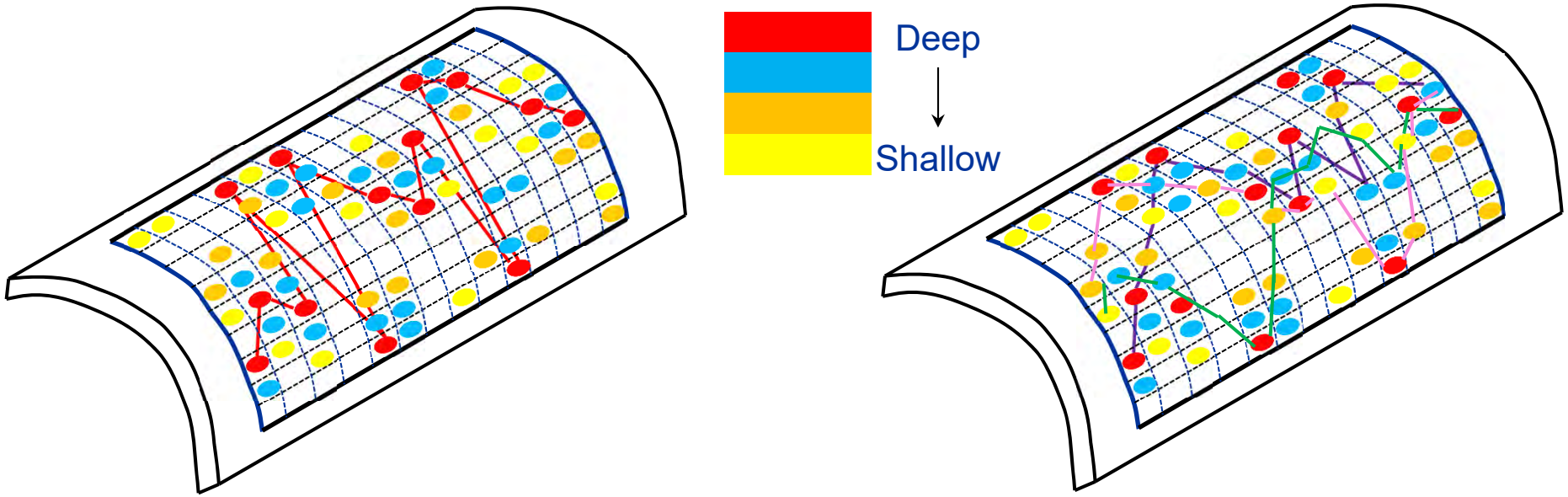
Cluster Dataset	Total Number of Features	Excavation decision – Number of Features with FPR ≤ 1.25			
		B31G	MB31G	RSTRENG	Psqr
ILI Data	23502	868	600	154	31
	650	130	96	20	6
	169	16	12	6	4

- **Field-measurements on different pipe sections**

Cluster Dataset	Total Number of Features	Repair decision - Number of Features with FPR ≤ 1.25			
		B31G	MB31G	RSTRENG	Psqr
Laser Scan data	84	81	77	15	0
	6	6	6	2	0

Summary - RSTRENG vs Psqr

- Many users avoided implausible river bottom profiles on an adhoc basis
- Psqr does this with a well validated rigorous process - Checked safety, sensitivity and extremes, implementation guidelines
- Removing digs due to implausible profiles reduces unnecessary digs
- Right digs (not more) bring safety!
- Accuracy and precision brings safety and economy



Thank you – Questions?

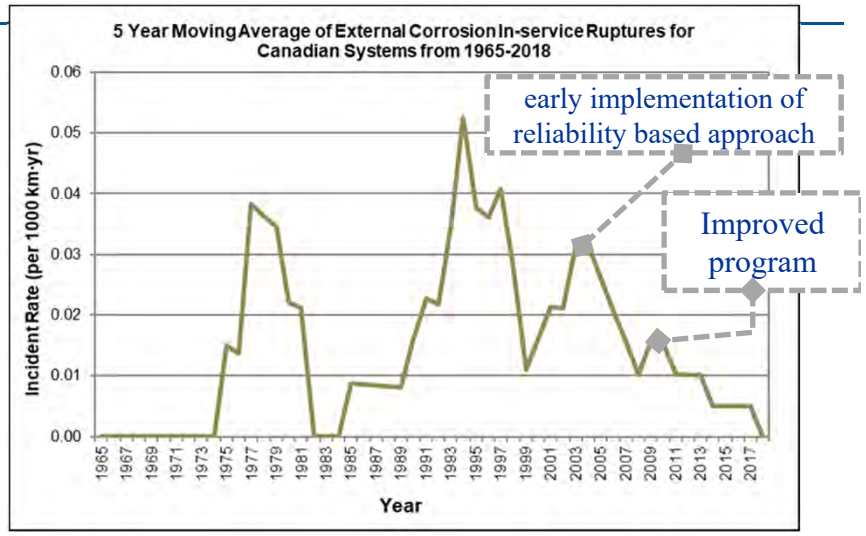
Acknowledgements:

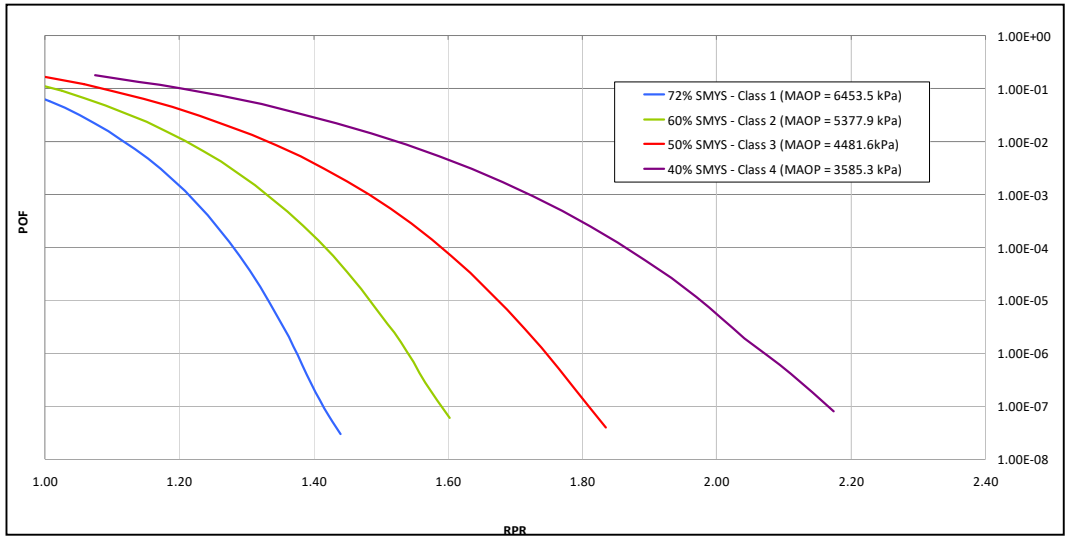
- **TransCanada development team:** Shahani Kariyawasam, Shenwei Zhang, Jason Yan, Terry Huang, Mohammad Al-Amin, Erwin Gamboa
- **TransCanada review team:** Corrosion Threat Management Teams, Technical Support Teams, Canadian/US/Liquid BU and Technical Centre Leadership
- **Initial burst testing protocol:** Dynamic Risk - Patrick Vieth and team
- **Burst testing:** C-FER -Tyler Johnson, Mark Stephens and Qishi Chen
- **External reviewer (2017):** Brian Leis
- **PRCI staff:** Cliff Johnson and Laurie Perry
- **PRCI reviewers (2018/19):** John Kiefner, Michael Rosenfeld/Bruce Nestleroth, Ming Gao/Ravi Krishnamurthy, Phil Hopkins, Andrew Cosham and Maher Nessim

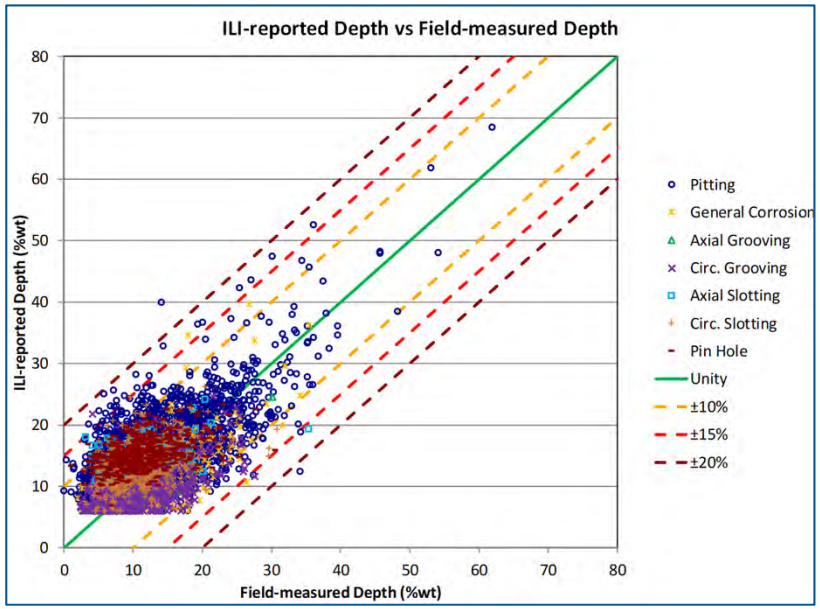
BACK UP SLIDES

Model Implementation – guidelines

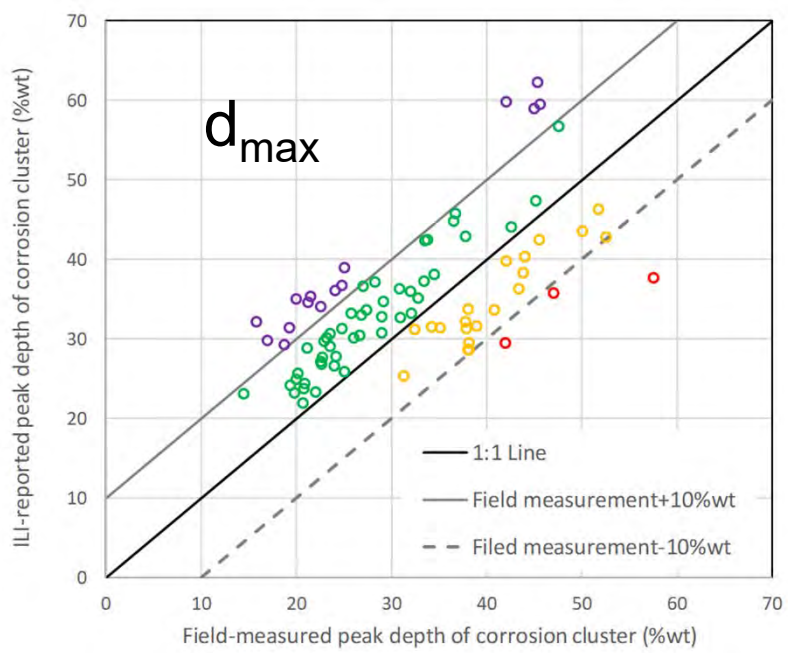
- Deterministic or probabilistic approach
- Model error- more accurate and precise model
- Measurement error- f (morphology); complex corrosion, defect-specific
- Growth rate: defect-specific
- Safety factor - consider %SMYS

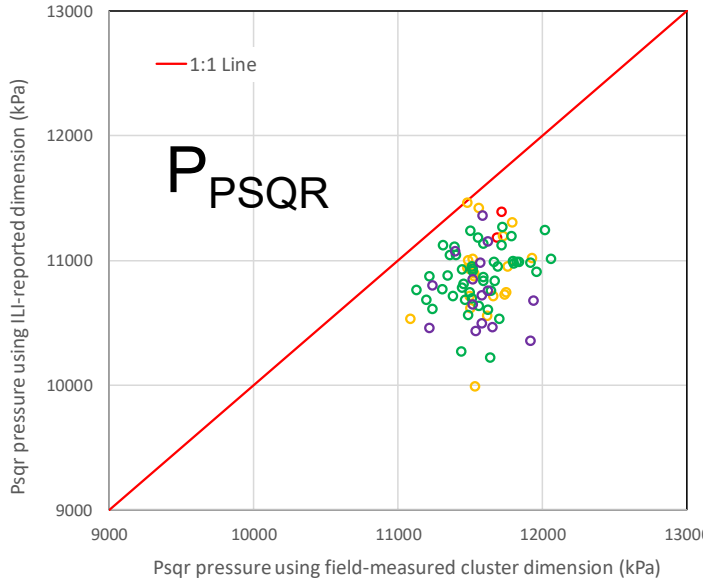


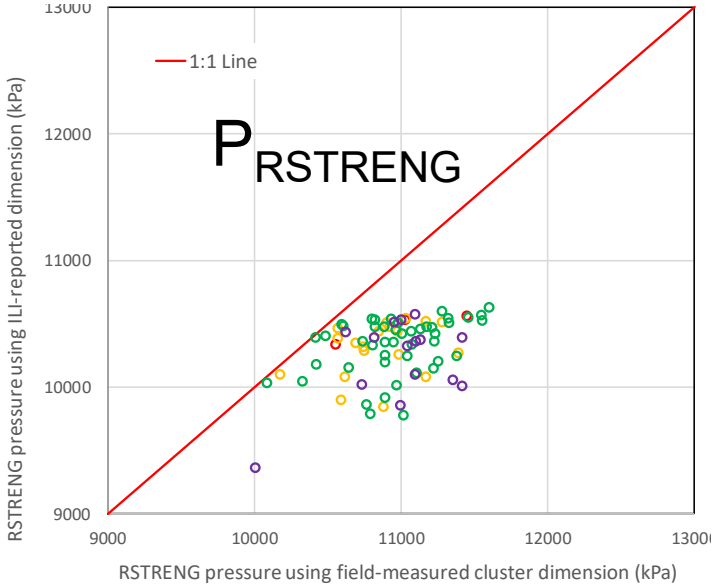




Unity plots for d_{max} and Calculated P_{burst}

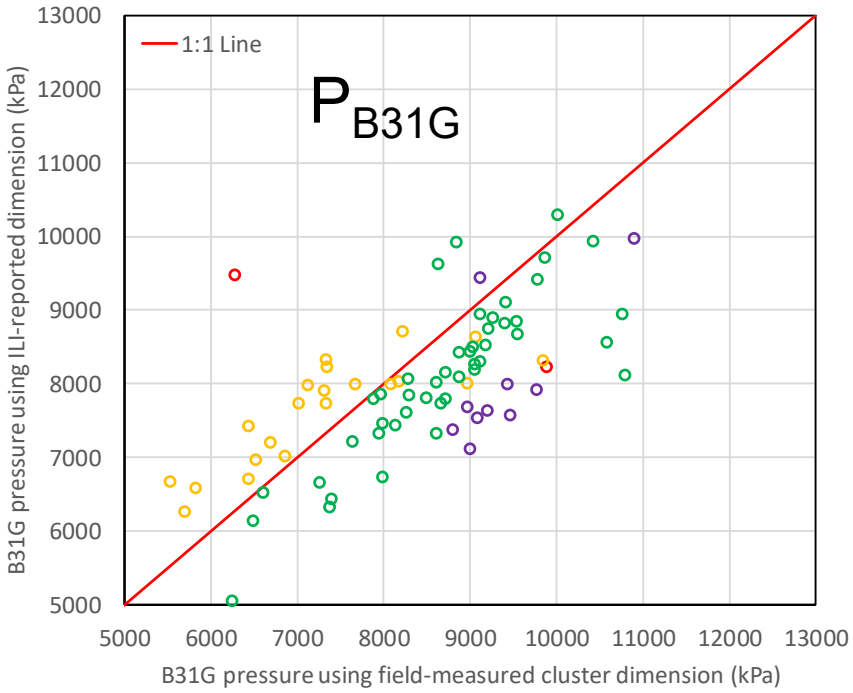


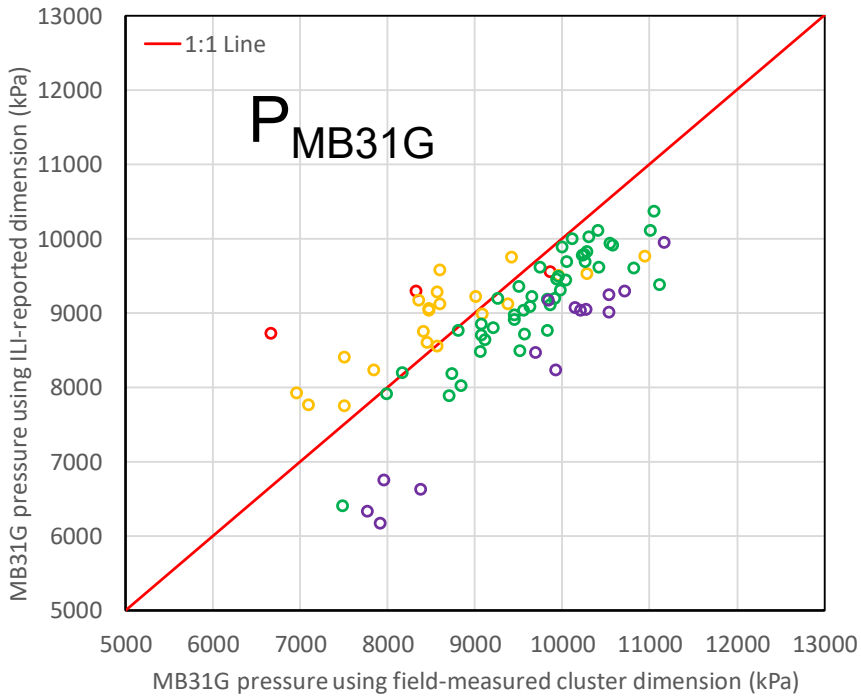




- ILI reports flat-bottomed pits vs laser reports granular profile
- Calculated P_{burst} using laser is more reliable (not actual)
- Pressure plots consider depth, length & other var.
- RSTRENG and Psqr are on conservative side (produce lower pressure using ILI than laser)

Unity plots for Calculated P_{burst} – B31G & MB31G





- B31G and MB31G produce lower pressure using ILI-reported dimension for only some of the features – not always on conservative side
- Less accurate methods - more digs but does not compensate for ILI error

Summary

- **Model development**
  - Psqr is more accurate and more precise than RSTRENG, and safe
  - Initiation point of burst is well represented by Psqr profiles
  - Rare extremes verified:
    - Depth weighted starting point captures the critical areas of a cluster
    - Axially aligned corrosion is well represented by RSTRENG and effectively addressed
  - Algorithm complication is not a barrier in todays world of high computational power
- **Model Implementation**
  - ILI measurement error, extremes, SF, and run specific aspects can be accounted for in many ways
  - Appropriate representation of each variable, and appropriate SF should be used in model implementation to provide safety – TC approach

External Communications

- **PRCI**
  - Research exchange meeting: 2018.3 Miami; 2019. 3 Houston
  - TC meetings: 2017.10 Atlanta; 2018.5 Calgary; 2018.10 San Diego
  - Workshops: 2018.6 Houston; 2018.9 Calgary
  - Workshops with reviewers: 2018.12; 2019.1 D.C.
- **ASME:** B31.8 and B31.8S O&M work group meeting, 2019.1
- **CEPA**
  - CEPA PIWG meeting: 2018.4
  - CEPA Foundation: 2018. 9
- **IPC:** 2018.9 Calgary
- **NACE:** 2019.3 Nashville
- **JTM: 2019.5 Brisbane**

The Journey

Burst tests on 14 corrosion clusters (2015)

Identified areas of conservatism in RSTRENG

Developed Psqr model and software

Sensitivity studies and validation

Performed Pilot studies to see impact

Internal and external Technical review

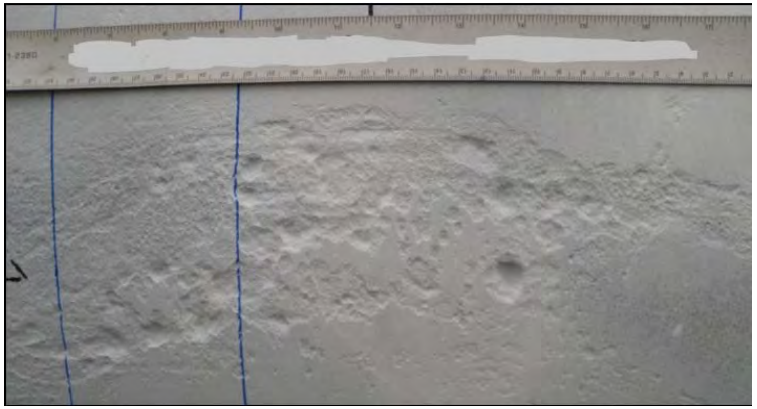
Performed 16 more tests and refined (2018)

Communicate – PRCI, ASME, CEPA, IPC etc (Patent pending)

Rigorous Industry review (PRCI project)

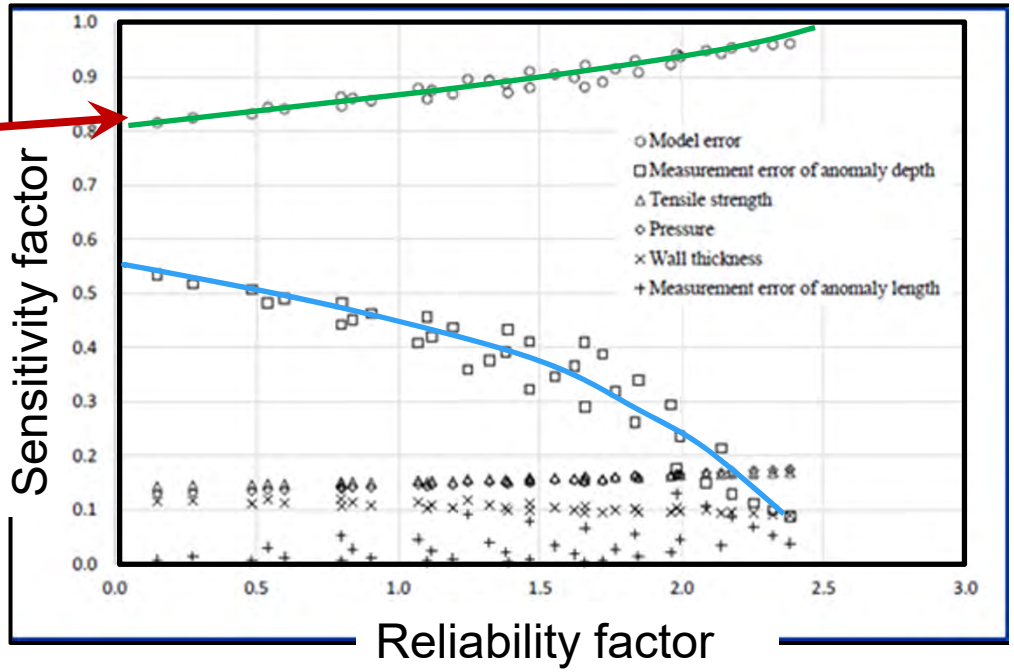
Learning

- **Learning from operations**
  - Large morphologies-caused failures but models developed on simple clusters
  - Many excavations/derates with wide corrosion
- **Learning from RSTRENG Development Project (PRCI PR3-805)**
  - river bottom profile - the worst case but not plausible for wide corrosion
  - circumferential separation and strengthening due to higher WT
  - Can consider multiple profiles(based on SMEs' knowledge)

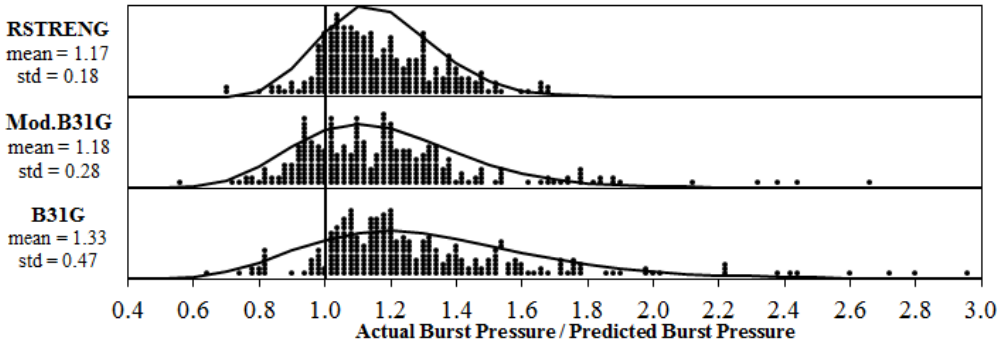


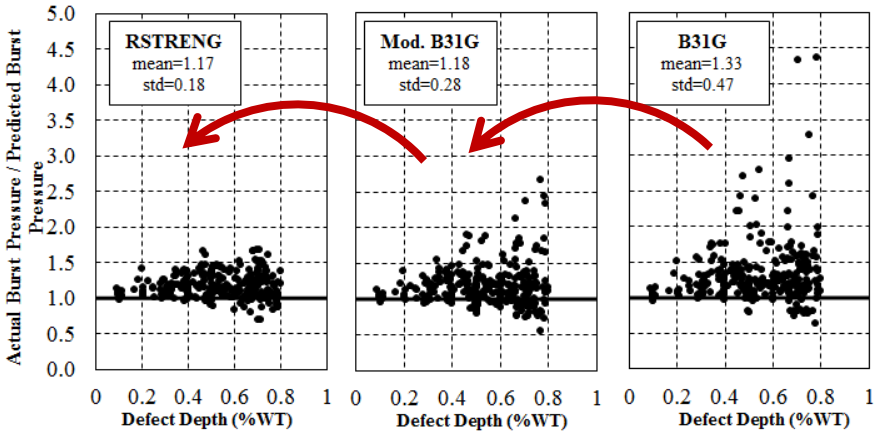
Observations

- **Corrosion - major integrity threat - ~70% of digs, ~80% of ILIs**
- **Key integrity decisions that use Assessment models**
  - ILI anomalies to excavate?
  - Excavated anomalies to repair?
  - Derate required?
- **Decisions are most sensitive to**
  - Model error
  - ILI measurement error
  - Growth rates



Effect of Model



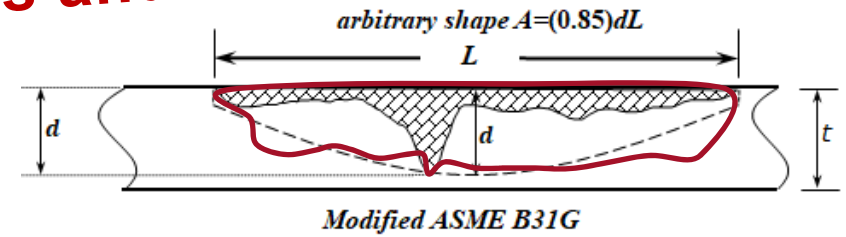


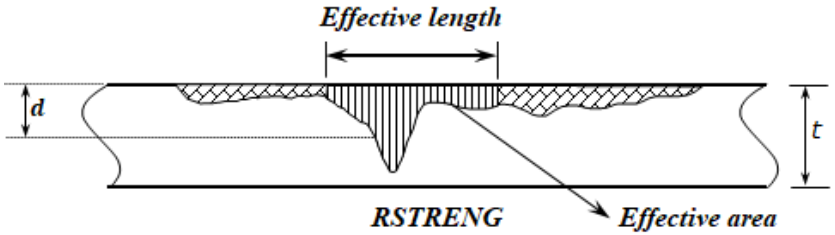
Pipeline section	Total number of Clusters	Excavation decision – number of features with FPR ≤ 1.25		
		B31G	MB31G	RSTRENG
1	23502	868	600	154
2	650	130	96	20
3	169	16	12	6

Conservatism in Corrosion Idealization

- Mod. B31G and RSTRENG

More precise & accurate models reduce unnecessary digs and increase necessary digs





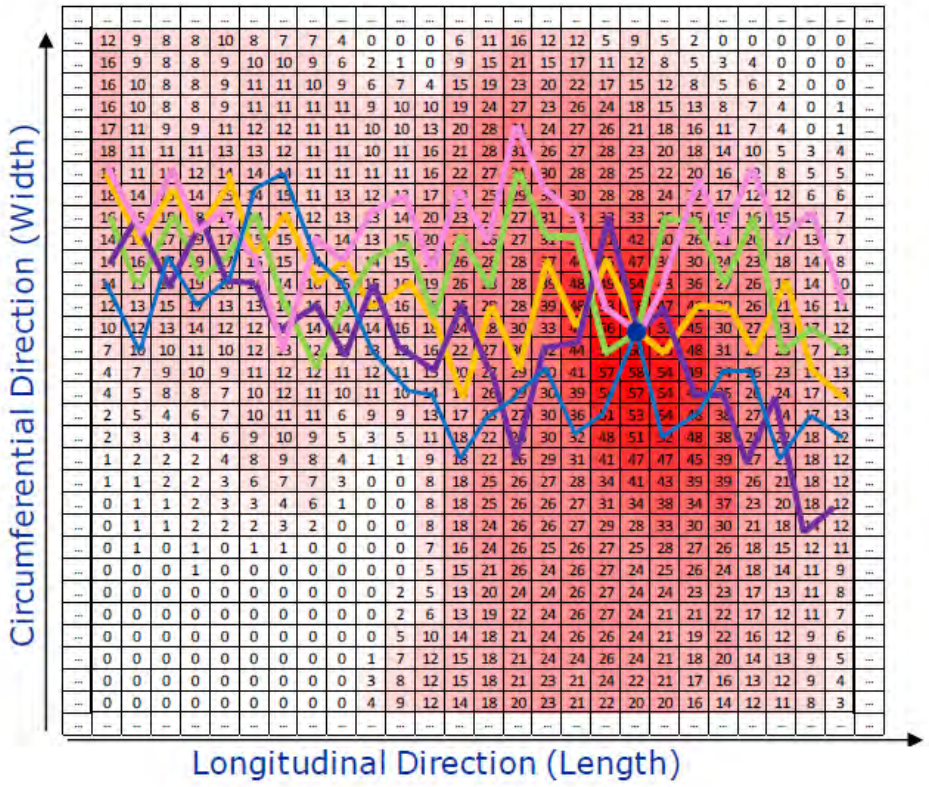
- The difference between Mod. B31G and RSTRENG is that the corrosion shape is characterized more accurately by RSTRENG

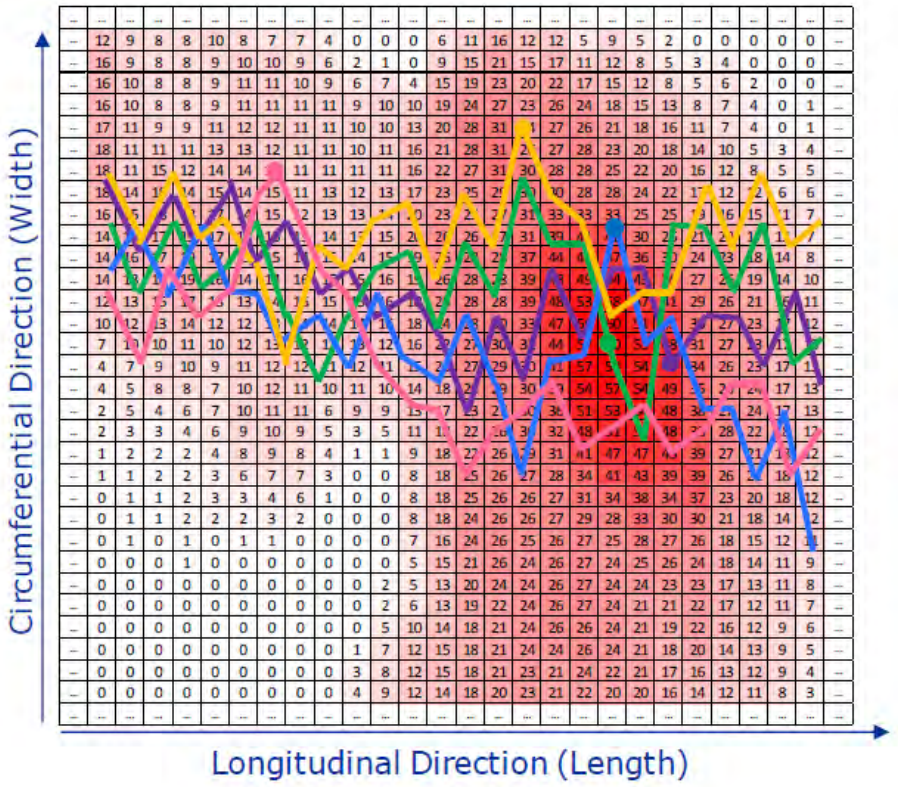
Defining Terms

- **An assessment model is used for PI decisions:**
  - Excavate ILI measured anomaly?
  - Repair inditch measured anomaly?
  - Derate ILI measured anomaly?
- **Objective of PI decisions is to avoid failures (in this case burst) by excavating and repairing (or derating) anomalies with unacceptable (high) probabilities of failure**
- **Safety is the absence of unacceptable risk (Broadly acceptable level of risk)**

Starting Point of Profile Generation

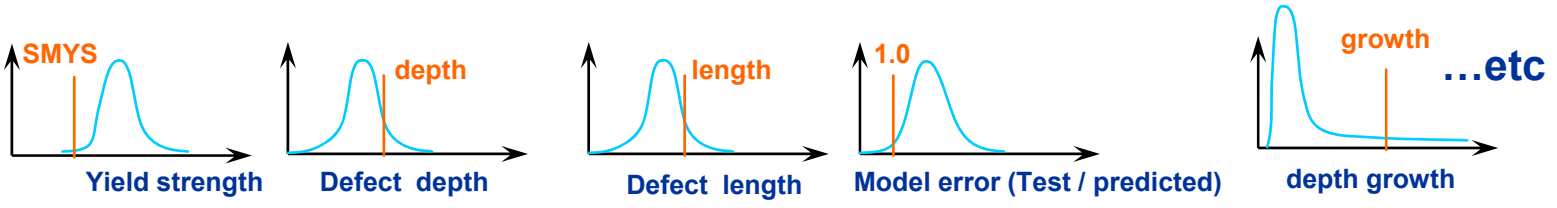
- Single starting point
- Depth weighted starting point
- Pushing the boundaries of assumptions



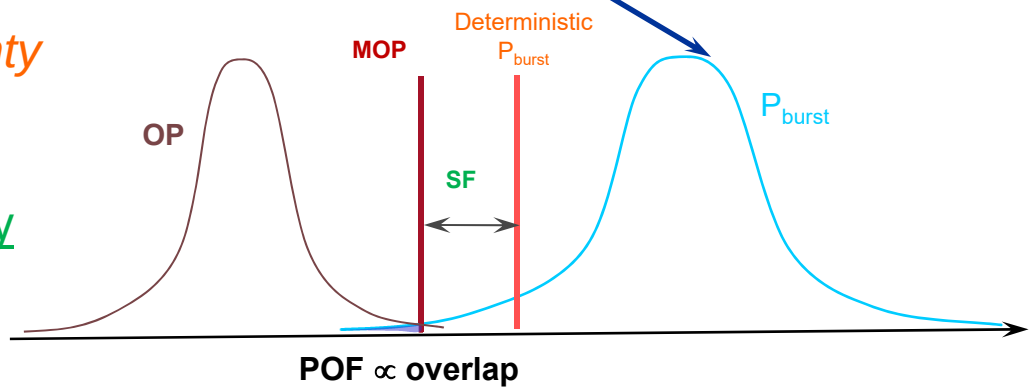


Providing Safety using Deterministic Methods – Role of Conservatism

- **Uncertainties associated with input variables**

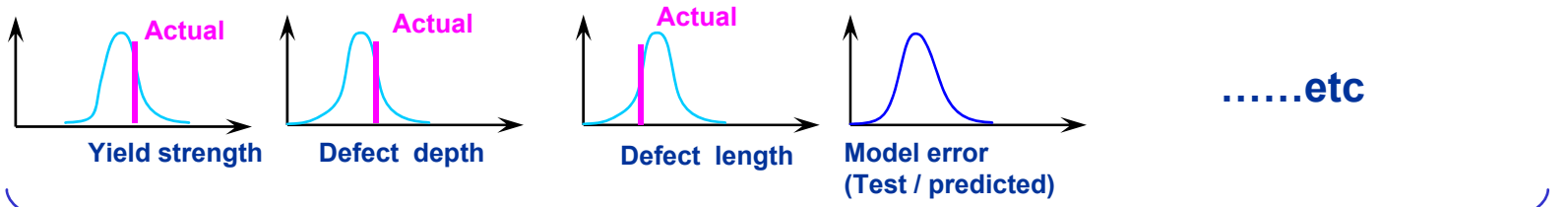


- **Conservatism in deterministic assessments**
  - o conservative constant inputs (e.g. SMYS) – *accounts for uncertainty in variables*
  - o further conservatism with safety factors (SF) – *accounts for different consequences, human error etc.*



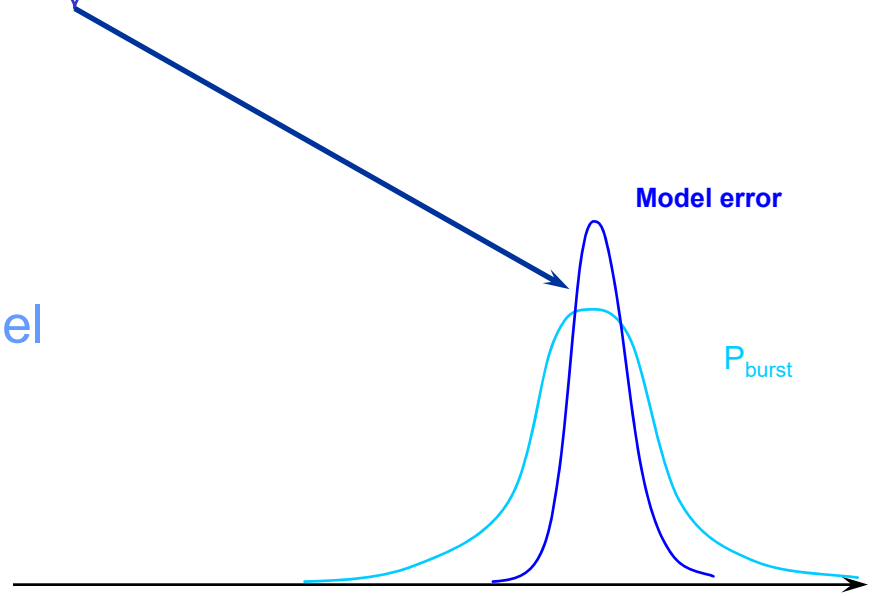
FPR = $P_{burst\ Det}$ / MOP > SF => acceptable POF

Isolating the Model Error in Tests



Two general types of uncertainty

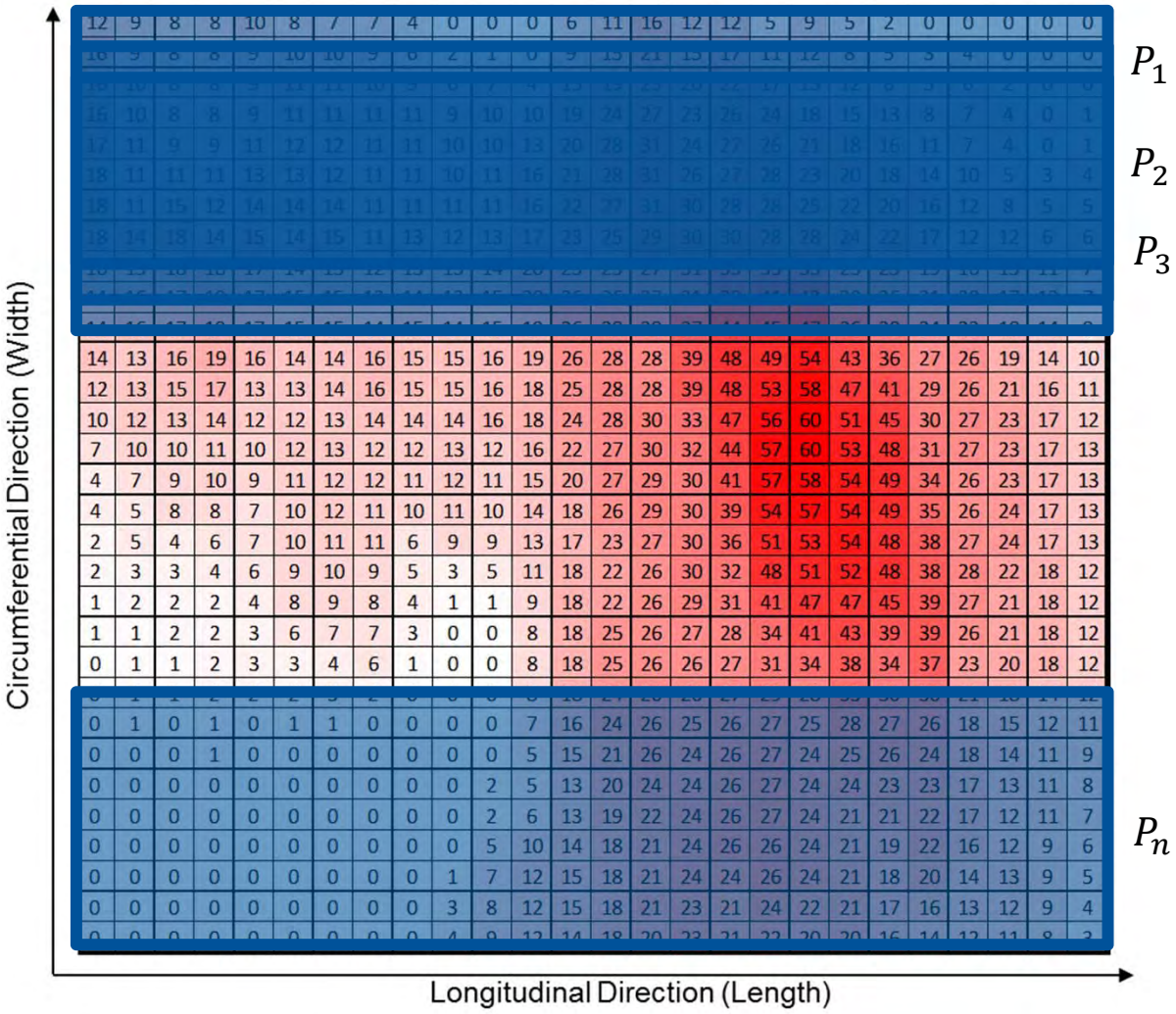
- intrinsic, physical or mechanical uncertainties (**aleatory uncertainties)**
- knowledge uncertainties, including model and statistical uncertainties caused by imperfect models and assumptions, (**epistemic uncertainties**)



Verify Initiation Point of Burst

- **Interaction path vs Fracture path**
  - Interaction path: the path that triggers the initiation of failure (i.e. burst)
  - Fracture path: the propagation path of fracture after burst initiation
- **TransCanada considers three distinct failure modes: small leak, large leak and rupture (CSA Z662-2015 Annex O)**
- **Large leak and rupture are initiated from burst (plastic collapse)**
- **The model predicts the pressure at time of initiation of burst**
- **Model should predict the potential interaction paths that are likely to trigger the initiation of burst and not to predict the fracture path**

Axial Aligning Factor (AAF) Calculation



- Consider *n* 6wt sub-windows
- Calculate the RSTRENG pressure for each window and denoted by P_1, P_2,…, P_n

$$AAF = \frac{min(P_1, P_2, P_3, \ldots, P_n)}{P_{RSTRENG}}$$

- If AAF =1.0 River bottom is plausible

Pipeline Research Council International, Inc.

Investigation of biomethane trace elements composition: a tool to better know the composition of the gas injected

Amélie LOUVAT & Dairo BALLESTAS
GRTgaz - RICE

PRCI 2019 Research Exchange Meeting
Houston, Texas
March 5 2019

RICE : GRTgaz' Research & Innovation Center for Energy

~100 mbs of staff

Doctors, engineers, project managers and research technicians

3 locations

Saint Denis, Alfortville and Bois-Colombes

54 patent families

330 patents

Pipelines Lab

Gases Analysis Lab

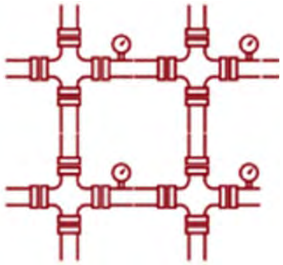
Metering & Test Center

Our 4 units are specialized in..

Gas Quality

Pipelines and their integrity

Networks' performance and safety



Innovation and protection / valorization

Gases Analysis & Metering Unit

- Quality of gases
- Odorization
- Gas leak detection
- Metering

Pipelines Unit (integrity of metallic and non-metallic pipelines)

- Inspection, Defect analysis, Repairs
- Anti-corrosion protection
- PE and polymer pipelines
- Pipe detection

Industrial Performance & Safety Unit

- Risk & Safety Reliability Maintenance
- Smart Gas Grid
- Optimization of Network performance
- Network equipment

Innovation & Valorization Unit

- Innovation
- Intellectual Property
- Knowledge Management
- Technological Watch

Overview

- Biomethane in Europe and in France
- The CARABIO project
- Conclusions and next steps

Definitions

- Biomethane = upgraded raw biogas
- Biomethane must be compliant with gas operators specifications
- Biomethane also called Renewable Natural Gas (RNG)

Biomethane in Europe

- **European objectives = 10% of renewable gases in 2030**
- **Biomethane injection well established in some countries**
  - 450 units in Europe (2017)
  - Annual production = 18 TWh (2017)
    - *Germany: 208 units, 9.8 TWh/year*
    - *Netherlands: 36 units, 900 GWh/year*
    - *UK: 81 units, 3.6 TWh/year*
    - *France: 44 units, 406 GWh/year*

Biomethane in France

- **Situation at the end of October 2018**
  - 59 biomethane injection sites on the distribution network put in service at the end of October 2018 (57 for GRDF, 2 for RGDS);
  - 7 biomethane injection installations on the transmission grid (5 for GRTgaz, 2 for Teréga)
- **Expectations for 2019**
  - ≈ +25 biomethane on the distribution network
  - ≈ + 5 biomethane on the transmission network
- **Expectations of ADEME (French Environmental Agency)**
  - to set between 500 and 1400 biomethane installation by 2030
  - Goals of the gas operators = 10-30% of renewable gas by 2030

Compatibility of the gas network with biomethane

- **Gas network infrastructures need to estimate the compatibility of biomethane and trace compounds with its infrastructures**

- **For TSO and DSO:**
  - Impact on the network (corrosion)
  - Impact on gas odorization
  - Impact on end-users (gas combustion)

- **For the Undergrounds Storage:**
  - Impact on the wet gas network (corrosion)
  - Impact on the elastomers seals
  - Sanitary impact on aquifer storage

The CARABIO project

- **CARABIO for ChARActerisation of BIOmethanes injected on the French transmission and distribution network**
- **Observations: few data available on the literature for biomethane**
- **Consequences: few knowledges on the trace compounds of the biomethane (vs. natural gas)**
- **Biomethane quality based on European standard EN 16723-1**
  - For some parameters = no threshold value
  - Threshold values maybe not be in adequation with reality?
- **What about the compounds outside the specifications and standards?**
- **Need to increase the knowledge**

The CARABIO project

- **Several companies involved**

storengy

GRDF
GAZ RÉSEAU DISTRIBUTION FRANCE

RICE GRTgaz
Research & Innovation Center for Energy

GRTgaz

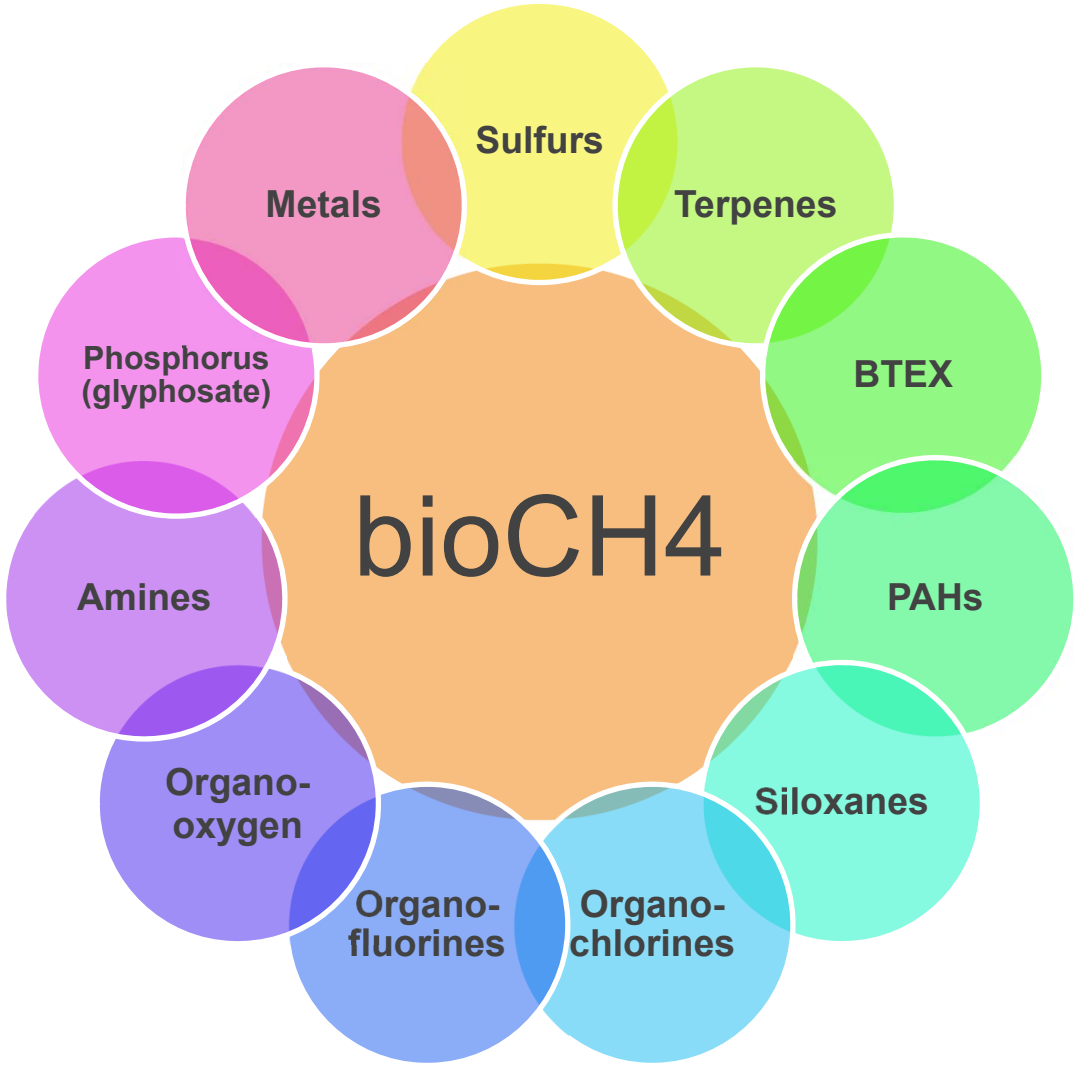
TERĒGA

Bibliographic data on biomethane

Type of compounds	Data
Sulfurs	AFSSET, ANSES, GTI
PAHs (Polyaromatic hydrocarbons)	ENGIE LAB CRIGEN
Cyclical Hydrocarbons	ENGIE LAB CRIGEN
Organochlorines	AFFSET, ANSES, GTI
Metals	ENGIE LAB CRIGEN
Terpenes	ENGIE LAB CRIGEN, ANSES, AFSSET
Furannes	AFSSET
Ketones	AFSSET
Siloxanes	GTI

- **AFSSET = French Agency for Health Security became ANSES in 2010**
- **ANSES = National Agency for Health Security of foods, environment and work**

The CARABIO project



- 11 chemical classes
- More than 300 compounds identifiable
- Three-years projects
- 59 campaigns
- 5 different types of inputs:
  - Agricultural
  - WWPT
  - Domestic waste
  - Industrial waste
  - Landfill

The CARABIO project

1. Sampling

- Location: biomethane injection plant
- Biomethane compliant with networks operators specifications
- 100% biomethane

2. Analysis on the lab

- Shipping to the lab
- Analysis by @RICE (except metals)

Sampling methods

- **3 types regarding the analytical methods chosen**

Sorbent tubes sampling

Bubbling traps sampling

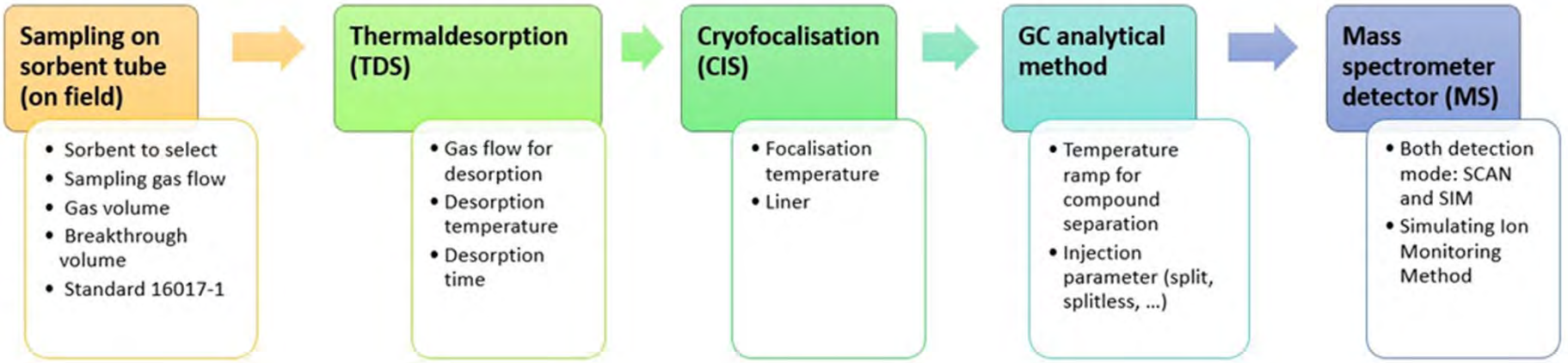
Treated pressurized canisters

Analytical methods

- **4 different analytical methods used**
  - Sulfur compounds → GC-PFPD: following ISO19739
  - Heavy Metals → ICP-MS (subcontracted)
  - BTEX and Terpenes → µGC-TCD: internal method
  - Trace components → TD-GC-MS: internal method

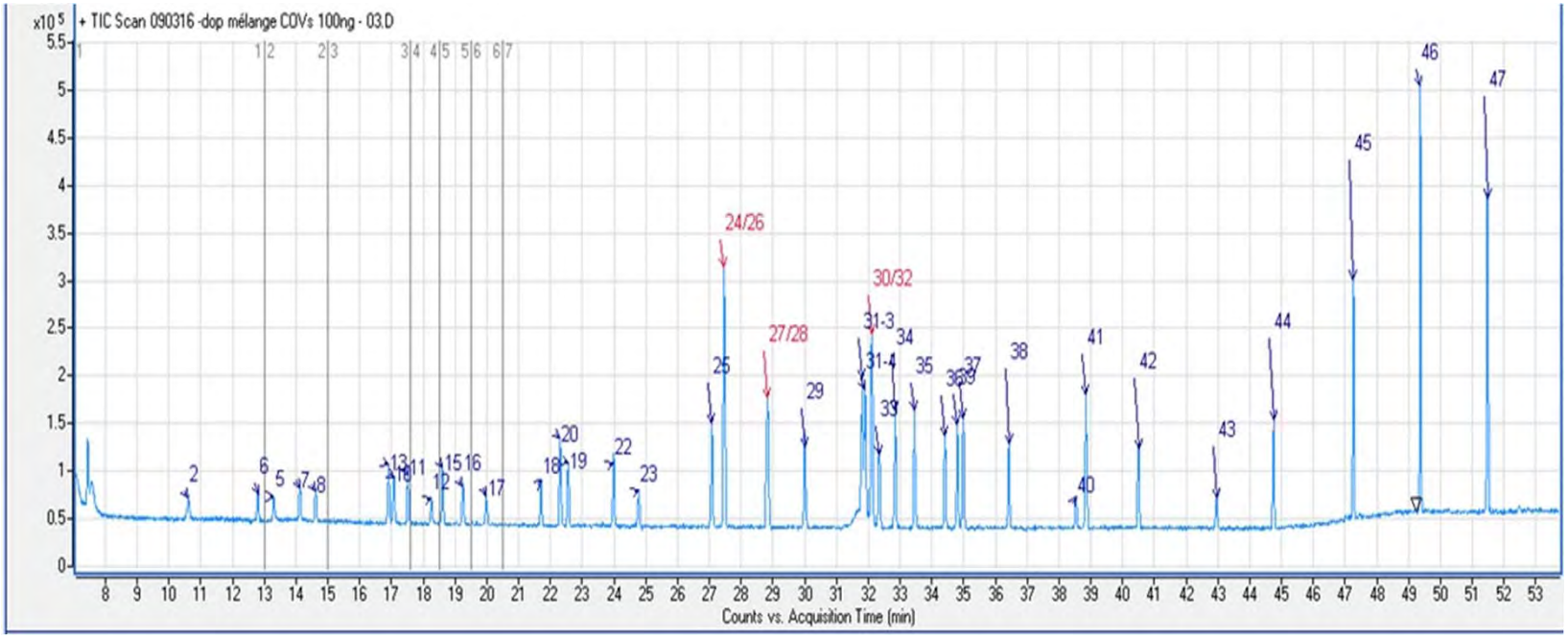
Focus on TD-GC-MS

- **Method optimized in 5 steps**



Focus on TD-GC-MS

- Example of chromatograms obtained



- Detection limits were between 1 µg/scm and 10 µg/scm

Analytical methods - Conclusions

- TD-GC-MS = dedicated method & meet R&D expectations
- Combination of 4 analytical tools enable to have a global view of the content of the biomethane sample → analytical screening
- All data collected on a database

Use of the results obtained

- **Underground storage facilities**
  - Study from Storengy & Teréga on the impact of the aquifer UGS and especially the water quality of
  - Used CARABIO data and others data
  - Modeling on the impact of biomethane trace compounds on the aquifer (interface between gas and water) [hypothesis of 100% biomethane]
  - Conclusion: based on the available data, no impact detected regarding the water quality

Use of the results obtained

- **Transmission & distribution**
  - Gas odorant (THT, 6ppm) masking effect: compounds and concentration identified, low risk
    - *GERG 1,75 project (2014): masking effect of terpenes with THT (4.6 ppm). 4 ppm of terpenes can have this impact*
    - *Data recorded: terpenes are found but less than 4 ppm*
    - *Conclusion: low risk of masking effect due to terpenes when gas is odorized with at least 6 ppm of THT*
  - Corrosion:
    - *Sulfur compounds detected same level as for natural gas*
    - *Conclusion: risk of corrosion same as for natural gas (need to be confirmed by GERG project)*
  - Use of gas (combustion): siloxanes identified and compliant with existing data. A GERG project study the impact of siloxanes on boiler and engine and help to confirm the 1st conclusions

GERG : European Gas Research Group

Next steps

- Continue the CARABIO project → to have more data
- Follow-up some biomethane plants every year → to determine the effect of the aging on the quality of the results
- Try to establish a correlation between the type of inputs, the upgrading system and the trace components identified

Conclusion

- **CARABIO project gives important inputs on biomethane trace compounds injected in France**

- **French network is now fully open to the injection of first generation of biomethane (produced by methanization) → decision made on June 2017**

- **But still, open questions:**
  - Impact of siloxanes and which maximum allowed in biomethane ?
  - Impact of others trace compounds
  - What about trace compounds on biomethanes injected in the USA ?
- **A great step towards energy transition !!!**

- **BUT R&D studies are still needed to improve our knowledges**

Acknowledgements

- **GRDF:**

Maïlys Pale (mailys.pale@grdf.fr)

- **Storengy :**

David Dequidt (david.dequidt@storengy.com)

- **GRTgaz :**

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- **Teréga :**

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THANK YOU FOR YOU ATTENTION

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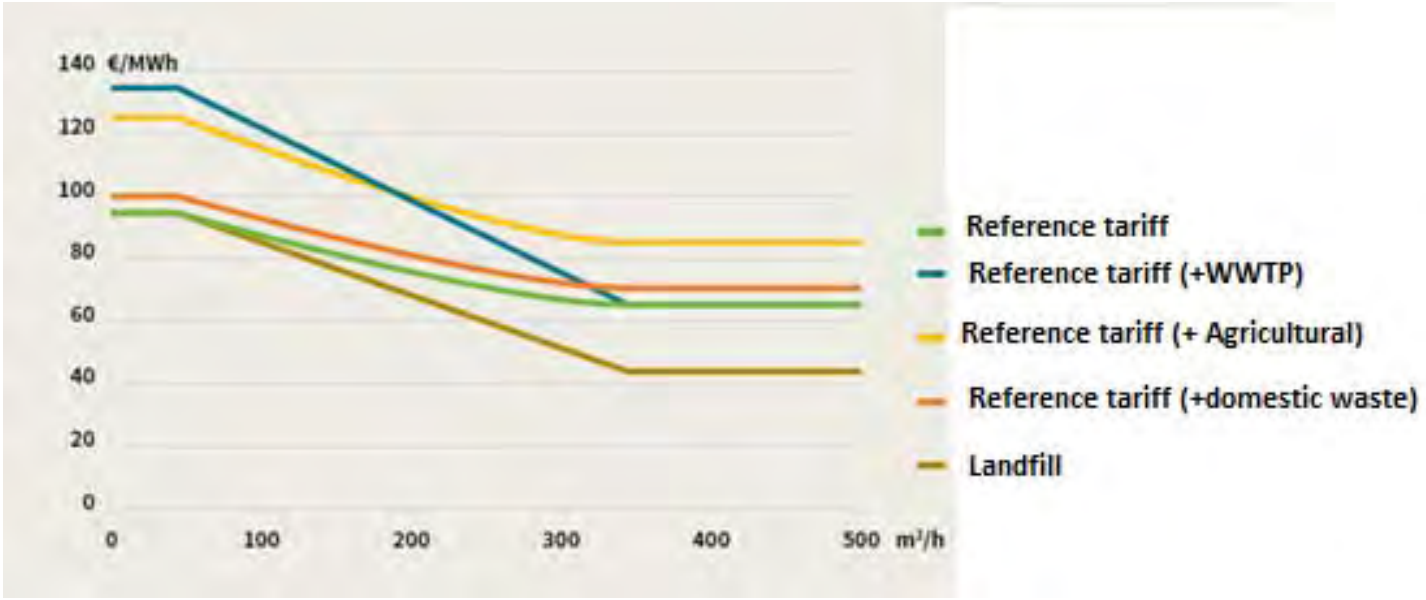
Biomethane Tariffs Limits in France

- Tariffs limits fixed for 15 years
- Depending on type of inputs, flow rate
- Tariffs limits: 45 to 130€/MWh



The French specification

Billing	GCV, Z, Gas metering ISO 6974 – ISO 6976
Domestic use	Wobbe Index ISO 6976
Network Integrity	Moisture : water dew point ISO 18453 H_2S & sulfur compounds ISO 19739 CO_2, O_2, NH_3, Cl, F
Safety	Odorization & sulfur compounds
Security & environment	Mercury ISO 6978 CO, Cl, F

The technical specification in France

- **The same criteria as for Natural gas**

Parameters	Limitations
High Calorific Value (reference conditions 0 °C et 1.01325 bar)	H Gas: 10.7 à 12.8 kWh/Sm^3
	L Gas : 9.5 à 10.5 kWh/Sm^3
Wobbe Index (reference conditions 0 °C et 1.01325 bar)	H Gas: 13.64 à 15.70 kWh/Sm^3
	L Gas: 12.01 à 13.06 kWh/Sm^3
Density	Between 0.555 and 0.70
Water Dew Point	Less -5°C at the maximum pressure of the network downstream
Hydrocarbon Dew Point	Less -2°C from 1 to 70 bar
Total sulfur	Less 30 mg(S)/Sm^3
Total mercaptan	Less 6 mg(S)/Sm^3
Total concentration of H2S and COS	Less 5 mg(S)/Sm^3
Carbon dioxide - CO_2	Less than 2.5 %
Thiophane –THT	Between 15 to 40 mg/Sm^3
Oxygen - O_2	Less than 100 ppm

Some exceptions for biomethane

- **Some limitations are too restrictive. 2 deviations for the DSO/TSO.**
- **Oxygen (value for GRDF - DSO)**
  - Less than 0.75% (H gas)
  - Less than 3% (L gas)
- **Carbon dioxide**
  - Less than 3.5 % (H gas)
  - Less than 11.7% (L gas)
- **With ∑O2+CO2**
  - Less than 3.5% (H gas)
  - Less than 11.7% (L gas)

Technical specifications only for biomethane

Compounds	Limitations
Mercury Hg	Less than 1 mg/Sm³
Cl	Less than 1 mg/Sm³
F	Less than 10 mg/Sm³
H_2	Less than 6 %
NH_3	Less than 3 mg/Sm³
CO	Less than 2 %

Pipeline Research Council International, Inc.

An Alternative Approach to the Assessment of Corrosion Anomalies within Pipelines

Ryan O'Kelley
Atteris LLC

PRCI 2019 Research Exchange Meeting
Houston, Texas
Date [March 5 OR 6, 2019]

Overview

- Motivation
- Case Study Outline
- Assessment Methodology
- Outcomes and Conclusions

Motivation

- Assessment of corrosion anomalies relies on inspection data
- Traditionally for pipelines we utilize inspection pigs

Retrieved from https://www.nord-stream.com/press-info/images/intelligent-pig-3488/

Pros

- Data along entire pipeline
- Can run multiple tools at once

Cons

- Expensive campaigns
- Not always practical

Alternative Inspection Strategies

- **Externally mounted inspection tools**

Pros

- Deployed from small vessel
- Rapid deployment

Cons

- Spot inspection only
- Surface preparation is important

Case Study Background

Background

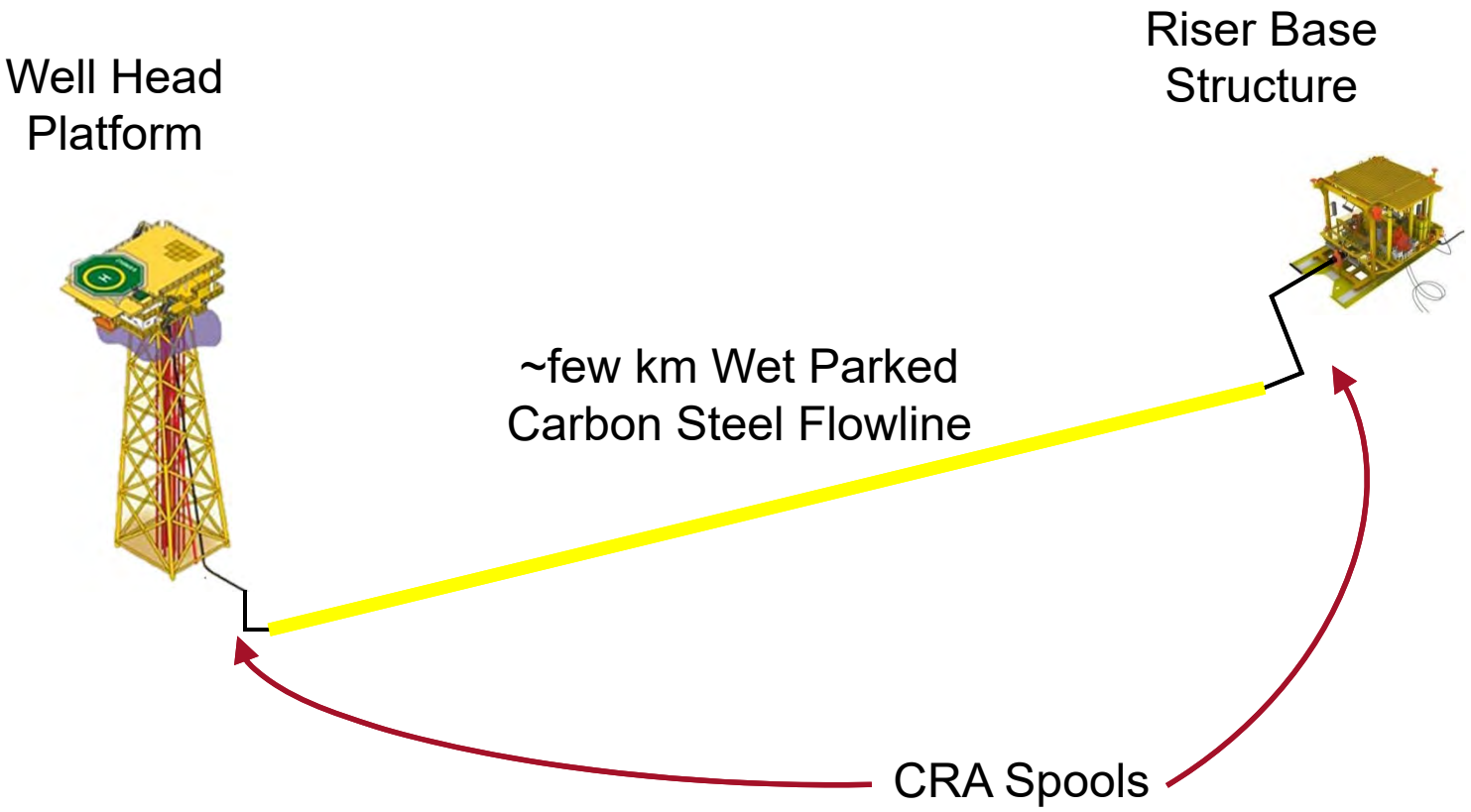
- **Wet parked flowline**
  - Treated seawater
  - Long term effectiveness of treatment?
- **Inline inspection not economical (expected to be US$7-14MM)**
- **Vessel of opportunity with external inspection tool**
  - Spot-checking a limited number of ~0.5m long sections
  - Complete external inspection was not economical.

Case Study Objectives

Objectives

- **Direct the external inspections**
  - Ensure cost efficient data collection
  - Demonstrate pipeline reliability targets are achieved
  - Avoid a full pipeline ILI or complete external inspection

Case Study Indicative System



Flowline History

- **Installed a few years ago**
  - Pipelay
  - Flooded treated seawater (CI and Biocide)
  - Spool installation (chemical sticks in spool and flowline ends?)
  - Hydrotested.
- **Wet parking**
  - Planned: 2 years
  - Actual: 2 + few years
  - No corrosion inspections undertaken.
- **Requalification required**
  - Significant change in the pre-start-up configuration.

Requalification Philosophy

Need to confirm the current status of the flowline.

- **No baseline data**
  - Cannot calculate corrosion growth rates
- **Assume no corrosion at installation**
  - Conservative basis for inferring corrosion rates
  - Growth rates would not be applicable as different fluid and operating conditions…

- **Re-qualification in accordance with DNV-OS-F101.**

Pipeline Design is Risk Based

- **Pipelines in Australia are designed to AS 2885.4 which refers to DNV-OS-F101**
- **This is a risk based code.**

Serviceability Limit State (SLS): A condition which, if exceeded, renders the pipeline unsuitable for normal operations

We need probability of risk of 85% wt loss < 10^{-3}

Table 2-5 Nominal annual target failure probabilities per pipeline vs. safety classes[5)]

Limit State Category	*Limit State*	*Safety Classes*			
		Low	*Medium*	*High*	*Very High[4)]*
SLS	All	10^{-2}	10^{-3}	10^{-3}	10^{-4}
ULS ALS	Pressure Containment[1)]	10^{-4} to 10^{-5}	10^{-5} to 10^{-6}	10^{-6} to 10^{-7}	10^{-7} to 10^{-8}
ULS FLS[2)] ALS[3)]	All other	10^{-3}	10^{-4}	10^{-5}	10^{-6}

1) The failure probability for the pressure containment (wall thickness design) is one to two order of magnitudes lower than the general ULS criterion given in the Table, in accordance with industry practice and reflected by the ISO requirements.

2) The failure probability will effectively be governed by the last year in operation or prior to inspection depending on the adopted inspection philosophy.

3) Nominal target failure probabilities can alternatively be one order of magnitude less (e.g. 10^{-4} per pipeline to 10^{-5} per km) for any running km if the consequences are local and caused by local factors.

4) See Appendix F Table F-2.

5) The target shall be interpret as "probability that a failure occurs in the period of one year".

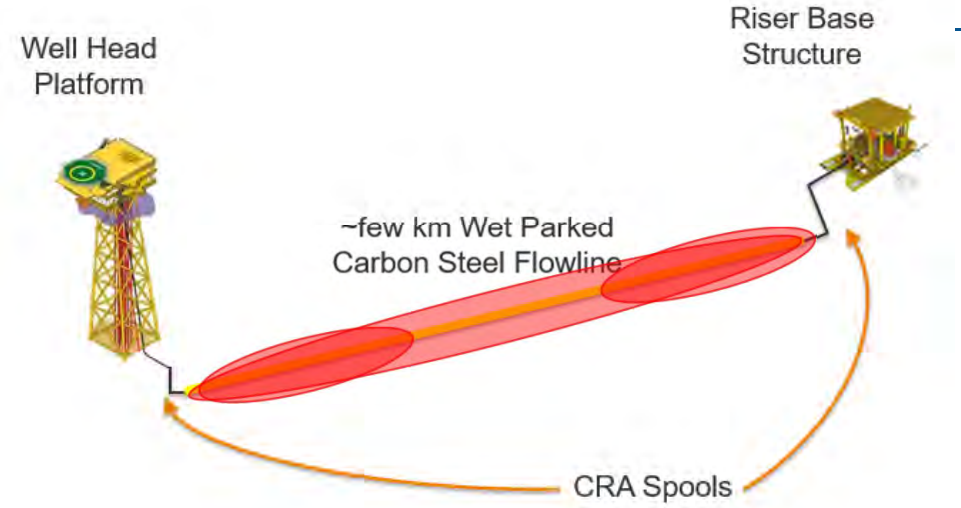
Assessment Methodology Summary

1. **Consider the potential corrosion mechanisms**
2. **Define inspection locations**
3. **Undertake inspection**
   - Provide processed inspection data in near real time
4. **Split dataset into sub-populations**
5. **Fit appropriate distribution to the sub-populations**
6. **Bootstrap the distribution to provide confidence bounds**
7. **Determine probability of a defect greater than 85% wt**

1. Corrosion Mechanisms

- **Use an expert!**

- **Wet parked flowline:**
  - Oxidation
  - MIC.

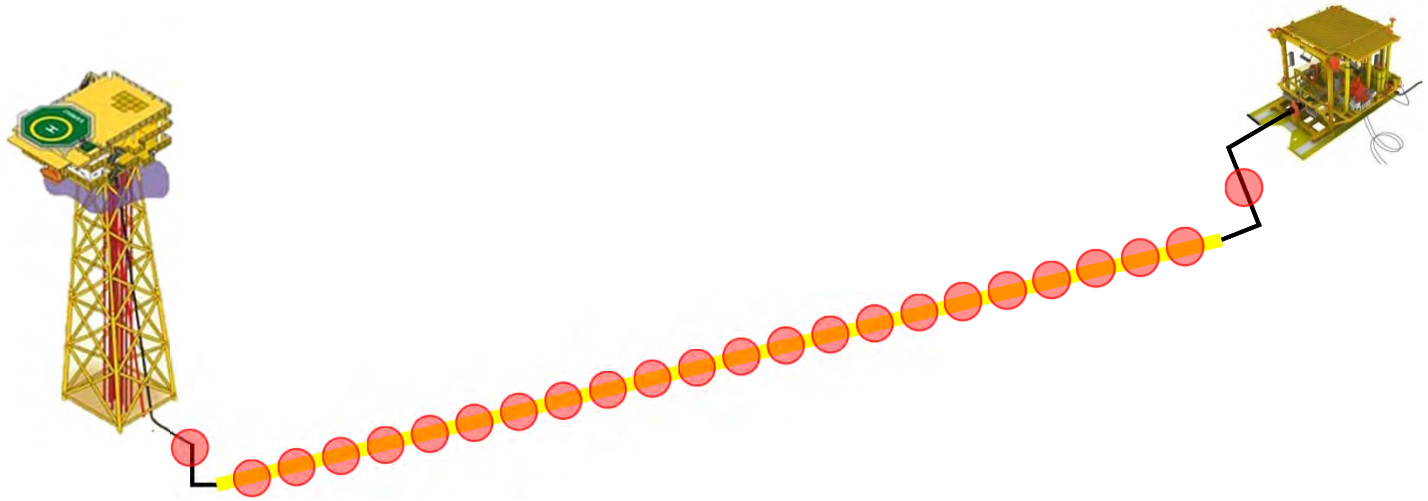


- **Oxidation**
  - Corrosion is expected throughout the flowline

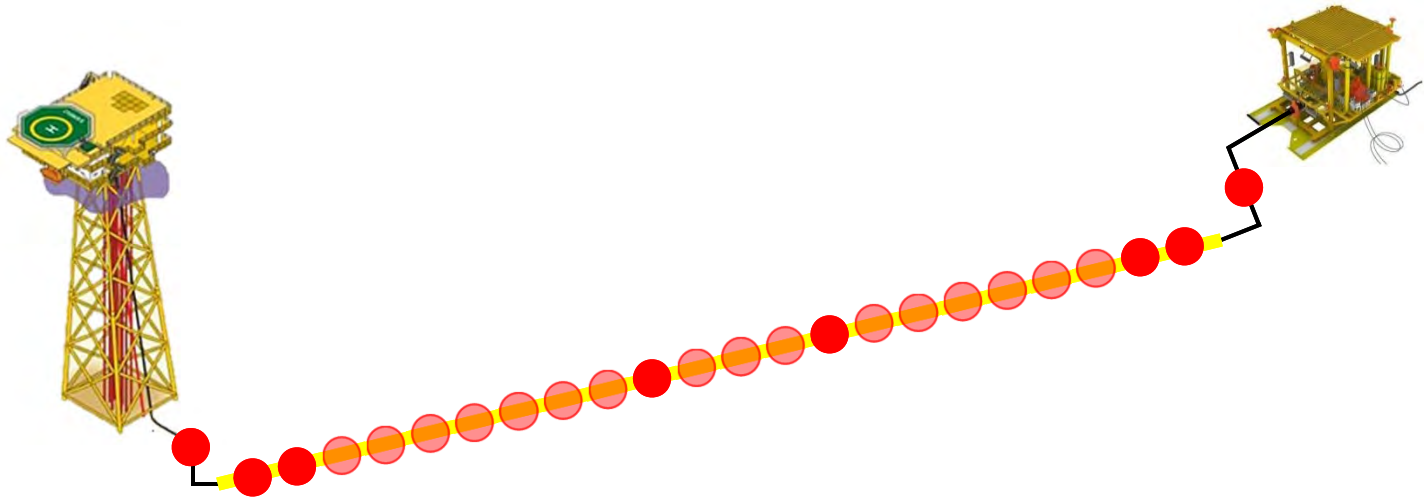
- **MIC based corrosion has four broad breeding scenarios:**

1. **Perfectly sterilised – No MIC corrosion**
2. **Biocide but bacteria ingress at North end – MIC at North**
3. **Biocide but bacteria ingress at South end – MIC at South**
4. **No biocide (or ineffective) – MIC throughout.**

2. Define Inspection Locations

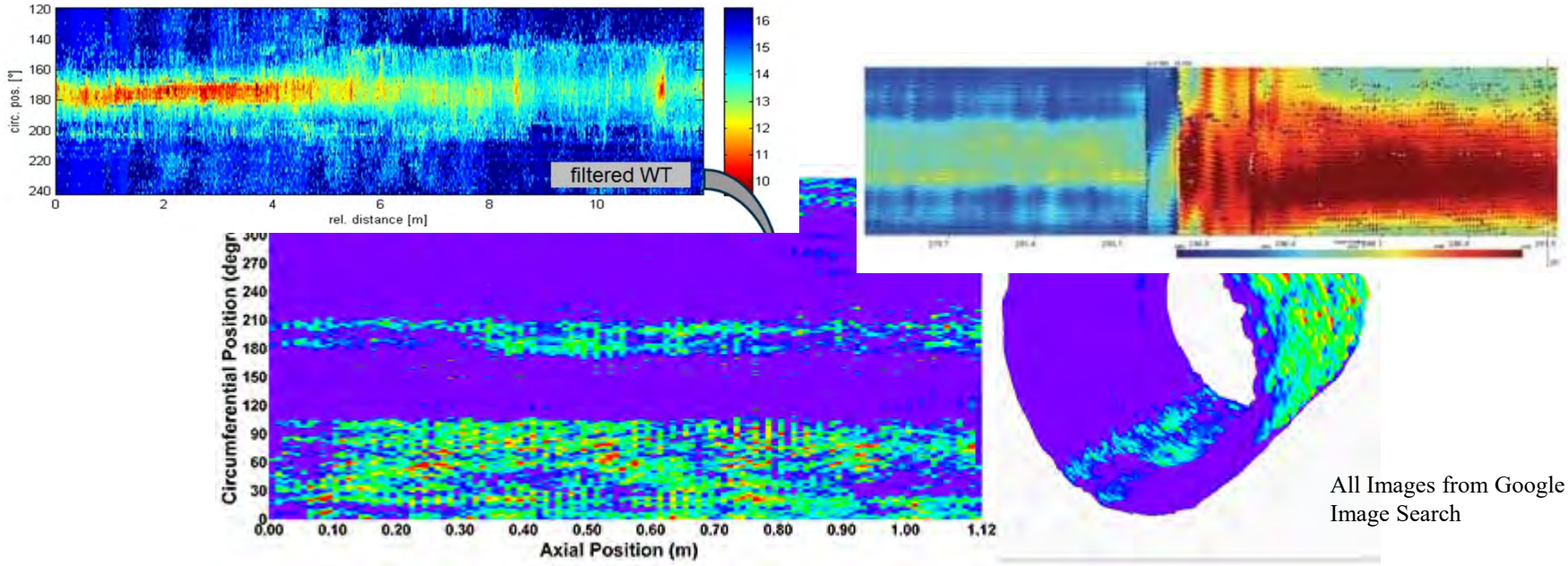


2. Define Inspection Locations



3. Inspection

- **Undertaking spot inspections and provided wt datasets**



All Images from Google Image Search

- **Datasets were full circumference**
  - Approximately 750 mm flowline length
  - WT provided in 1 mm x 1 mm units
  - 750,000 data points per inspection site)

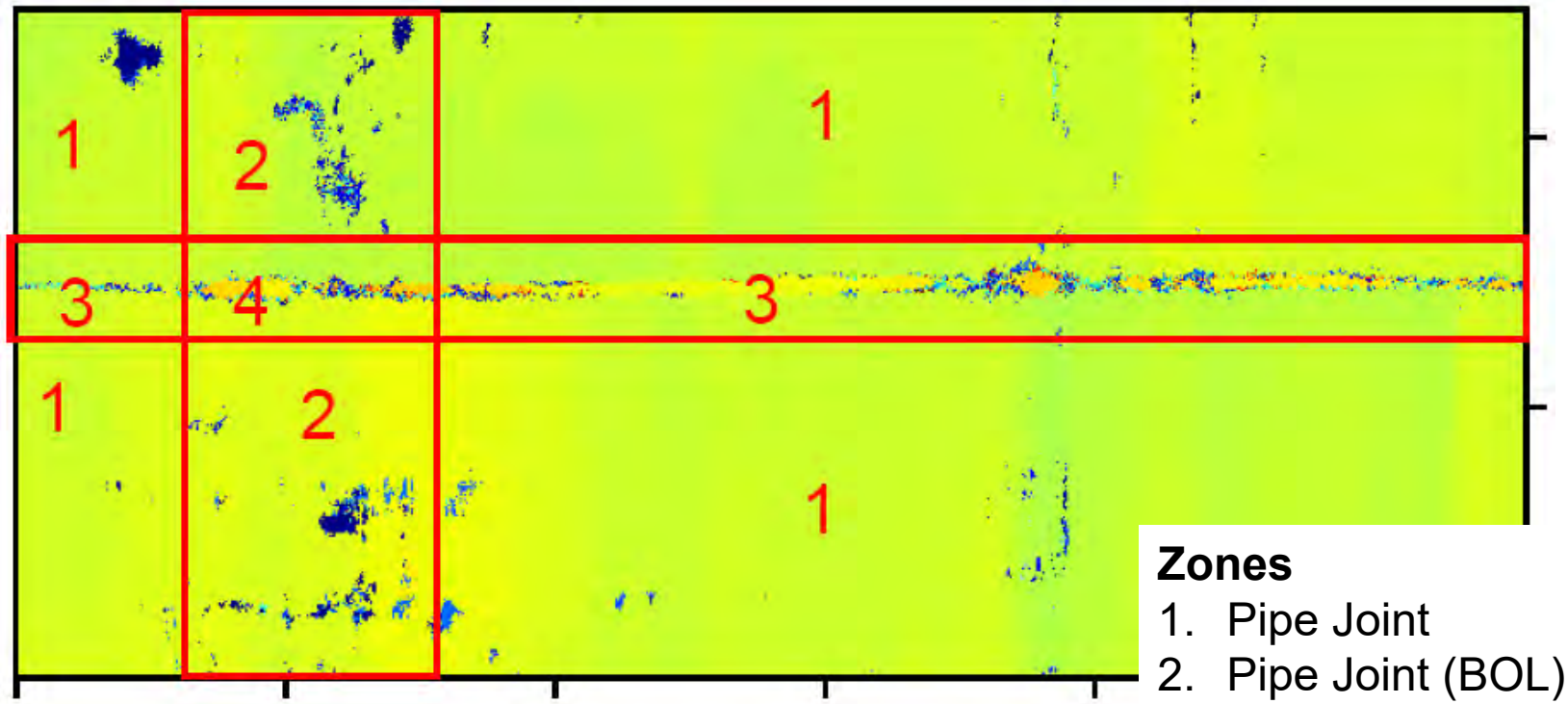
4. Sub-Populations

- **Considered full population but also the following sub-populations**

Population ID	Flowline End	Girth Weld or Pipe Joint	Top or Bottom of Line
1	North	~0.02m long Girth Weld	TOL
2			BOL
3		~12m long Pipe Joint	TOL
4			BOL
5	South	~0.02m long Girth Weld	TOL
6			BOL
7		~12m long Pipe Joint	TOL
8			BOL

4. Sub-Populations

- **Considered full population but also the following sub-populations**

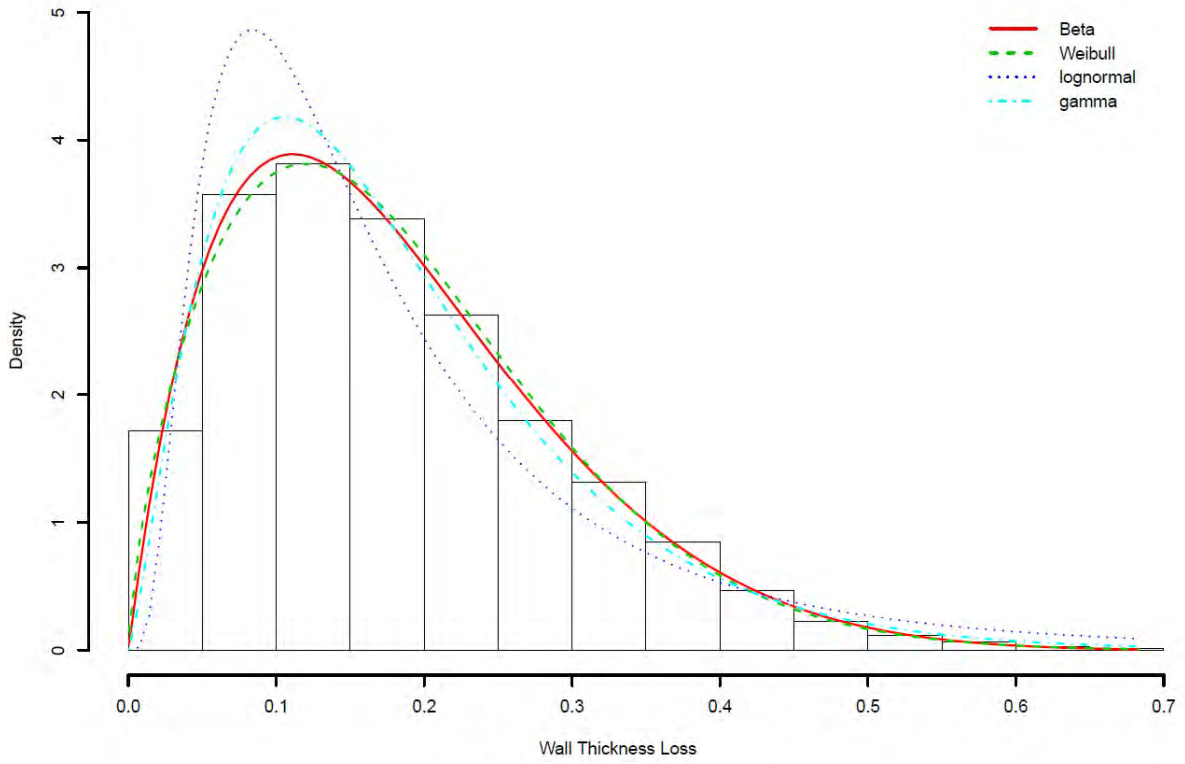


Zones

1. Pipe Joint
2. Pipe Joint (BOL)
3. Girth Weld
4. Girth Weld (BOL)

5. Determine Distribution

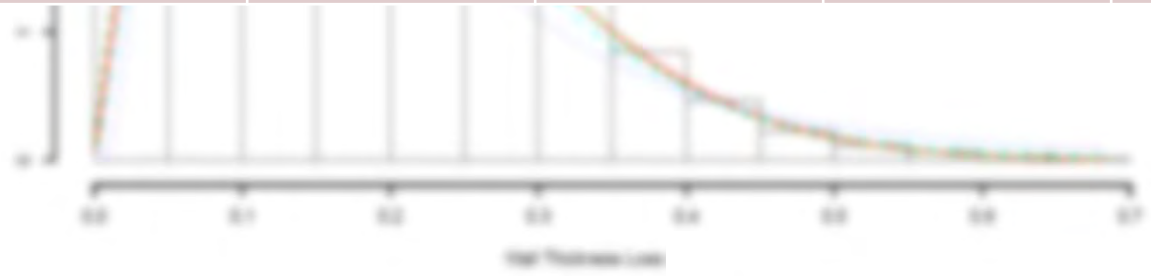
- Wall thickness data converted to a percentage wall loss
- Number of distributions are fitted to represent data



5. Determine Distribution

- Wall thickness data converted to a percentage wall loss
- Number of distributions are fitted to represent data

Goodness of Fit Test	Beta	Weibull	Lognormal	Gamma
Kolmogorov-Smirnov	0.00680	0.01371	0.06159	0.02071
Cramer-von Mises	0.05572	0.35049	14.29473	1.26400
Anderson-Darling	0.37108	2.10447	91.37840	8.28134



6. Bootstrapping

Statistical process of resampling the original dataset:

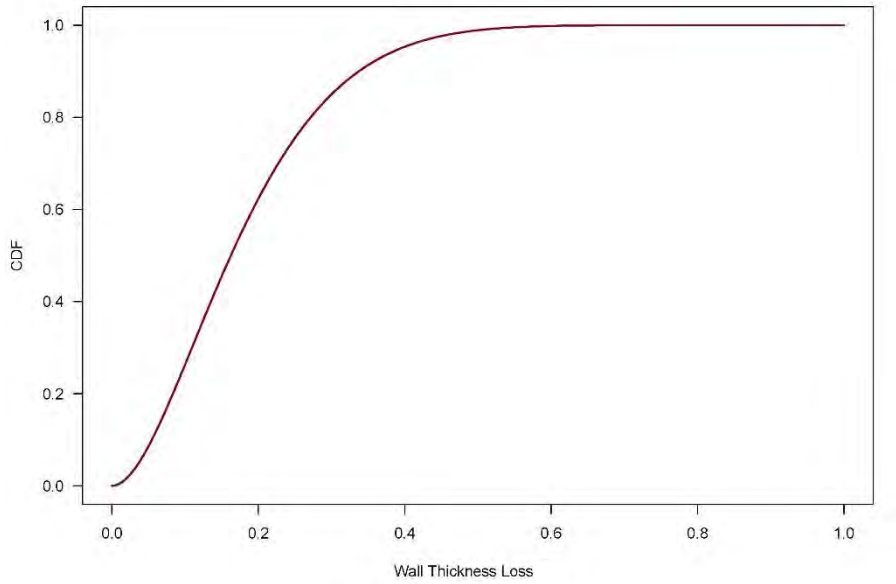
- **Infer further information on the overall sample**
- **Provide confidence limits for the overall population**

<u>Underlying Concepts</u>

1. **Dataset is representative of the population**
2. **Dataset is the best information to describe the population**
3. **Any further samples taken will look similar to the current dataset**

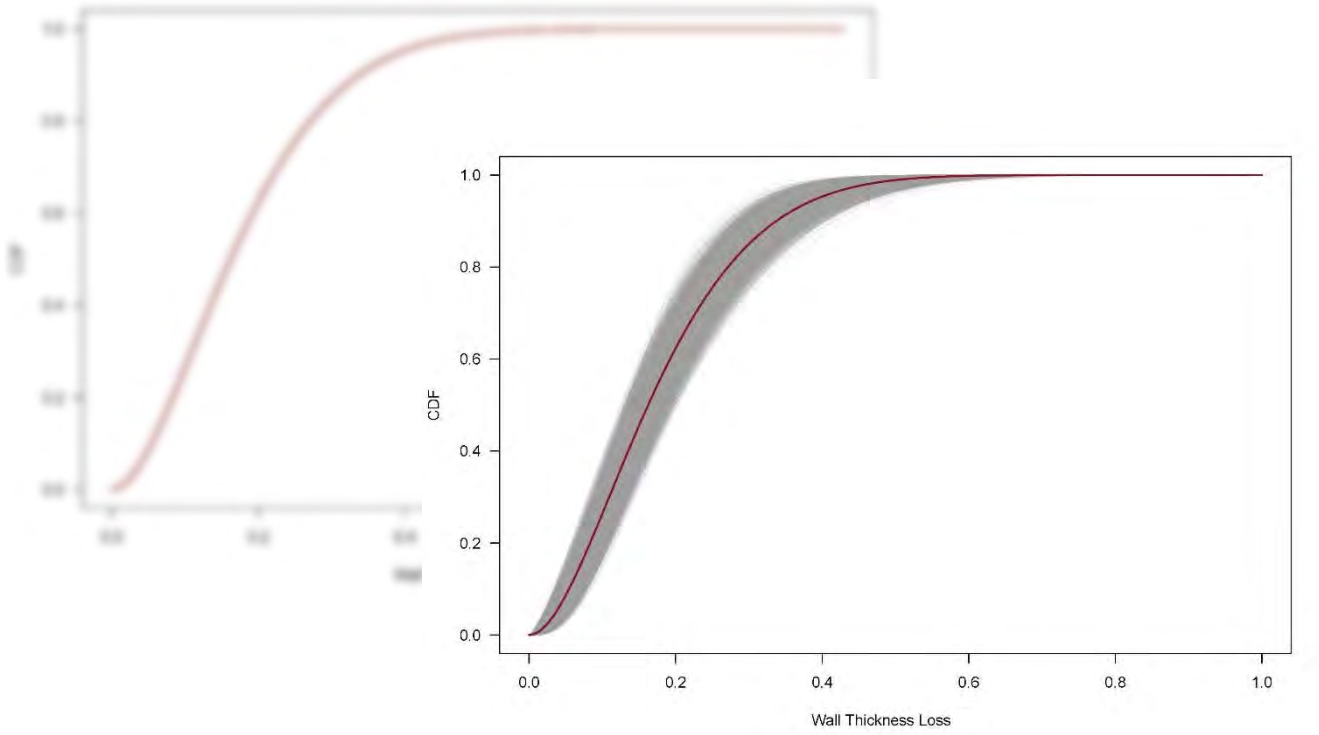
Resample from the current dataset with replacement and use these as separate *Bootstrap* datasets

6. Bootstrapping



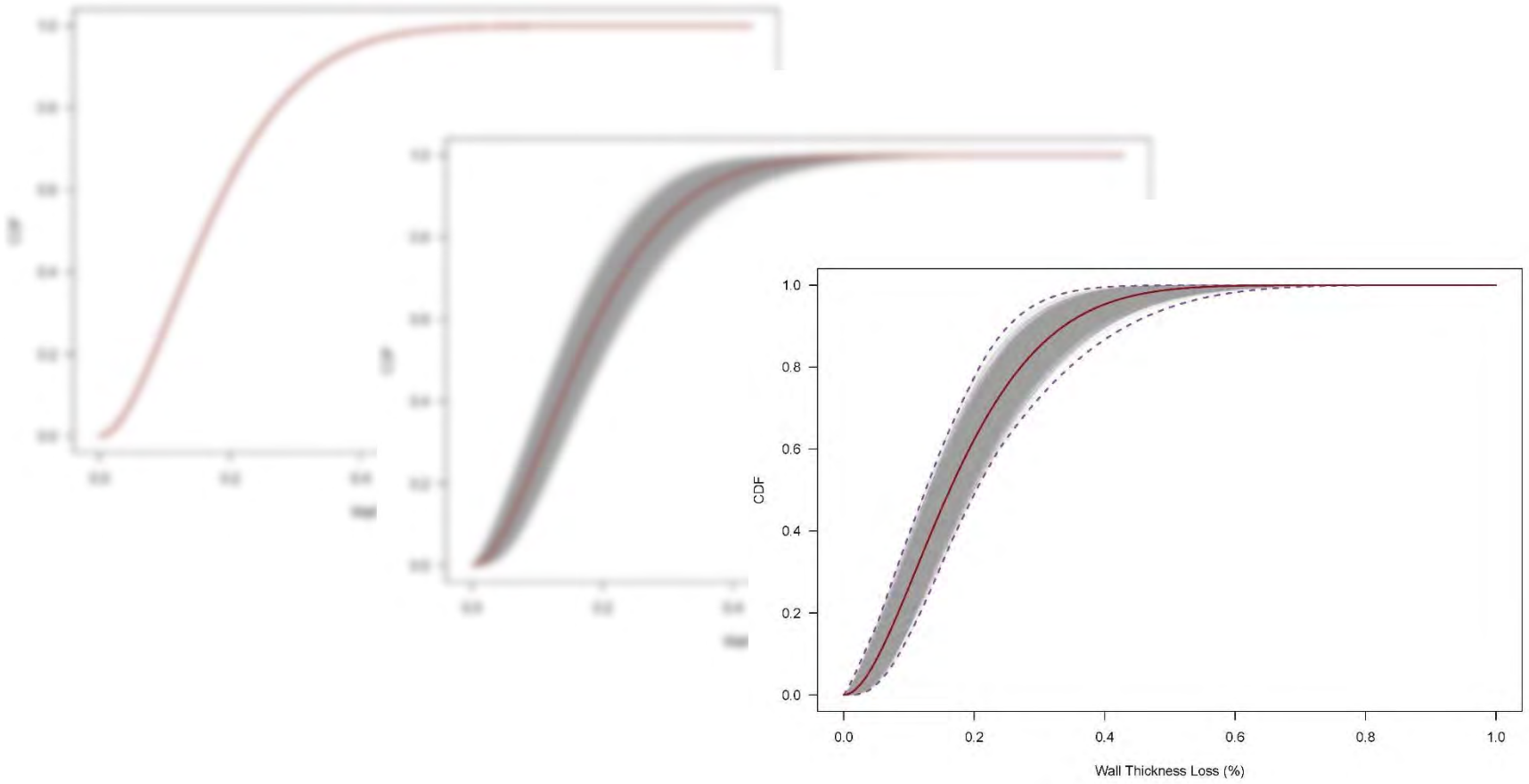
CDF for the fitted distribution

6. Bootstrapping



Overlay 100,000 bootstrapped samples

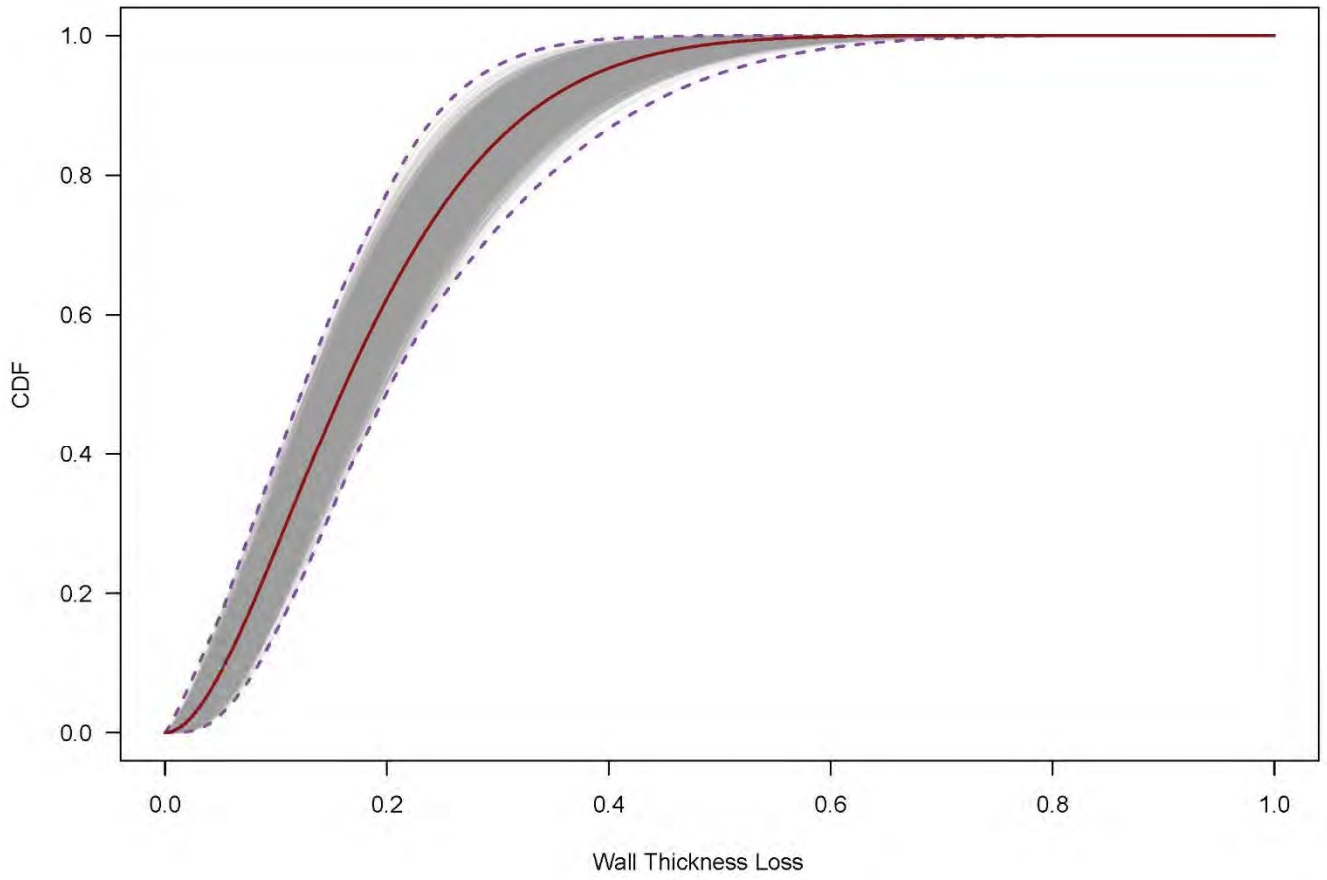
6. Bootstrapping



Limit of the bootstrapped CDFs

7. Assess

- **Consider the outer limit on the bootstrapped data at 85% wt loss**



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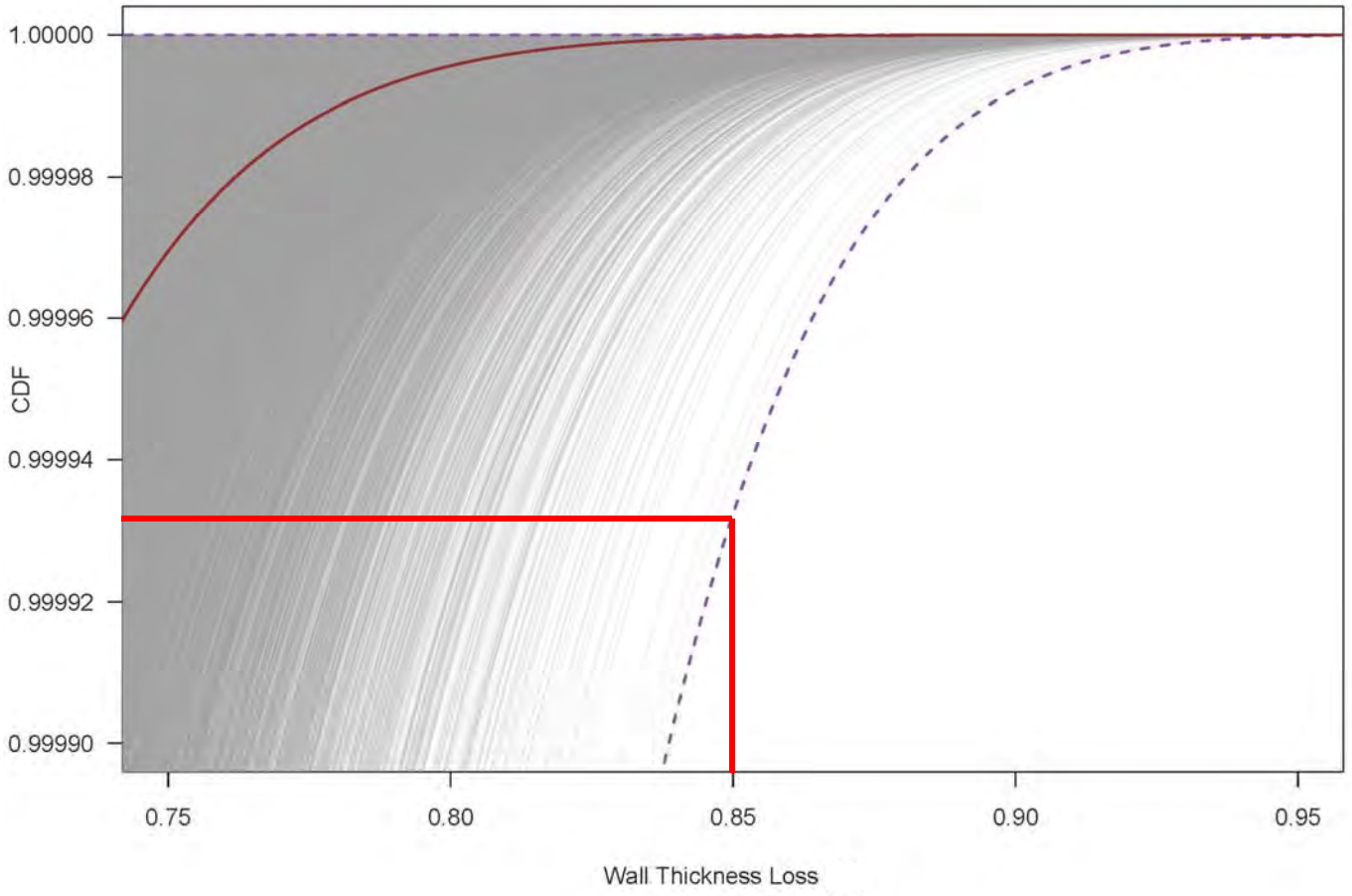

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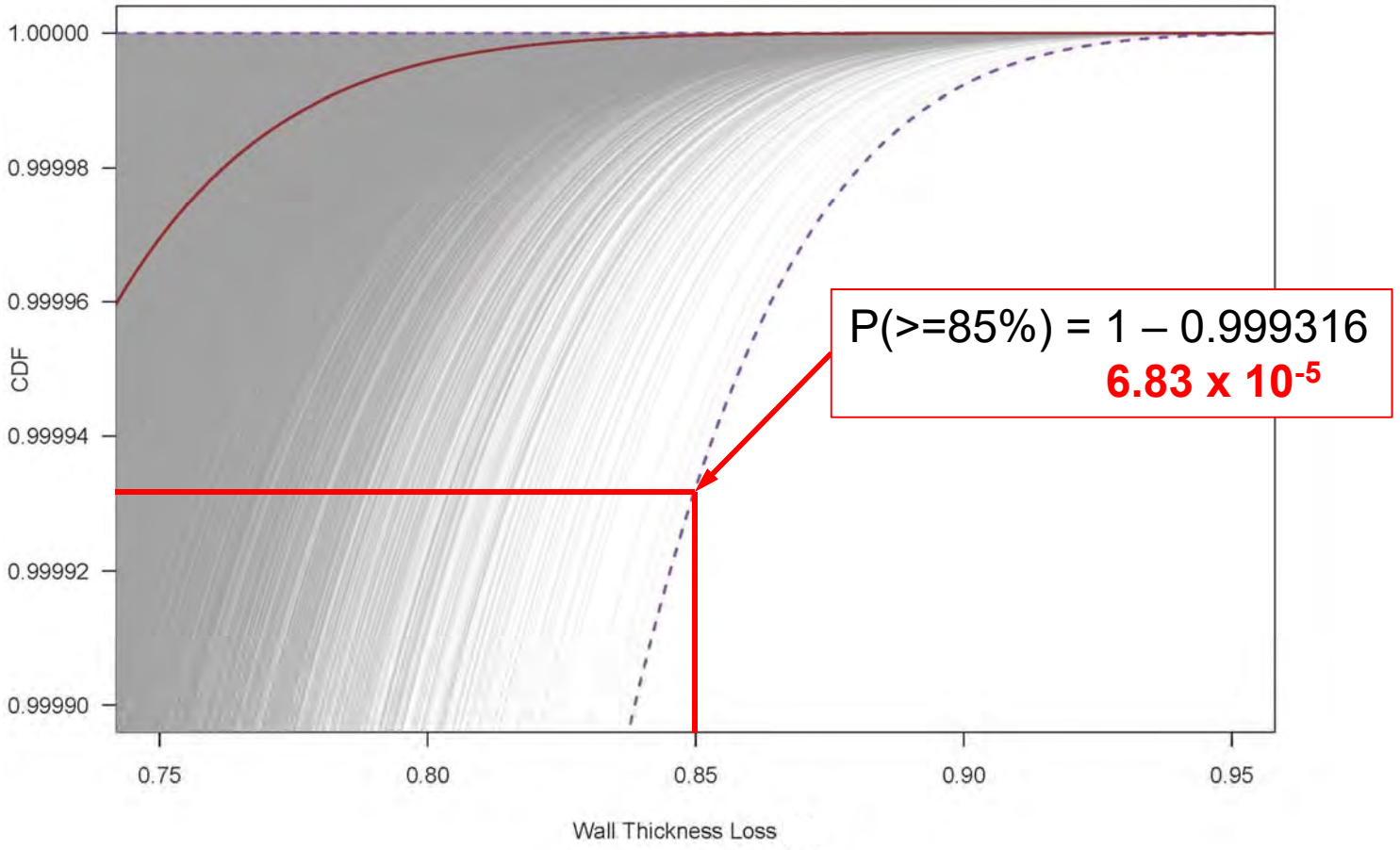
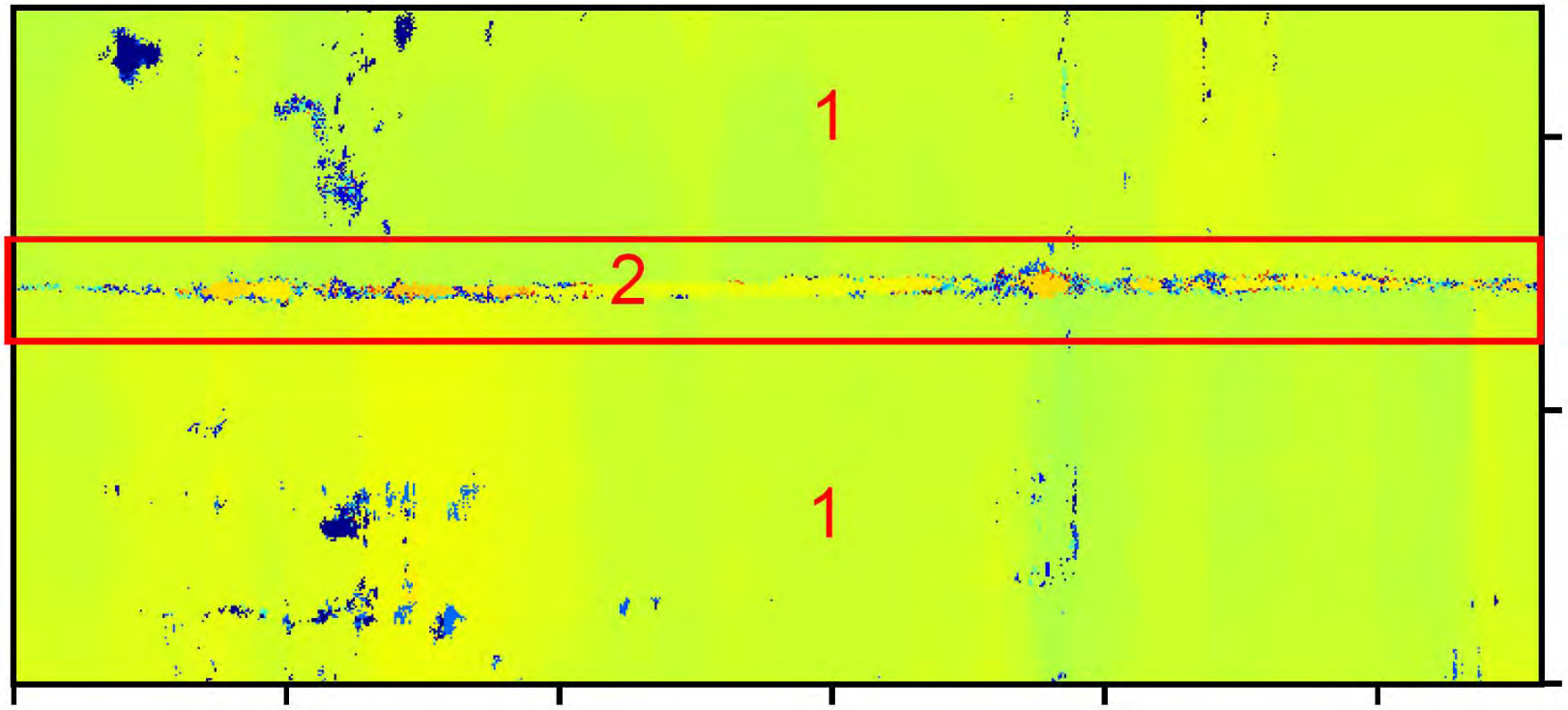


Case Study Data

Considered 2 sub-populations

1. Bulk Flowlines
2. Girth Welds.



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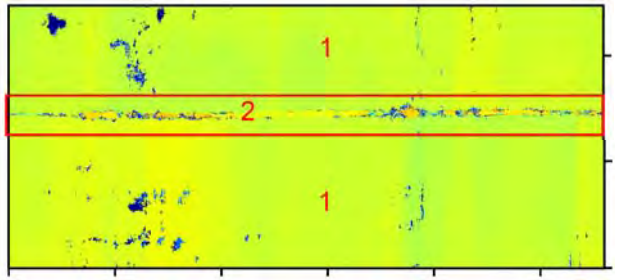
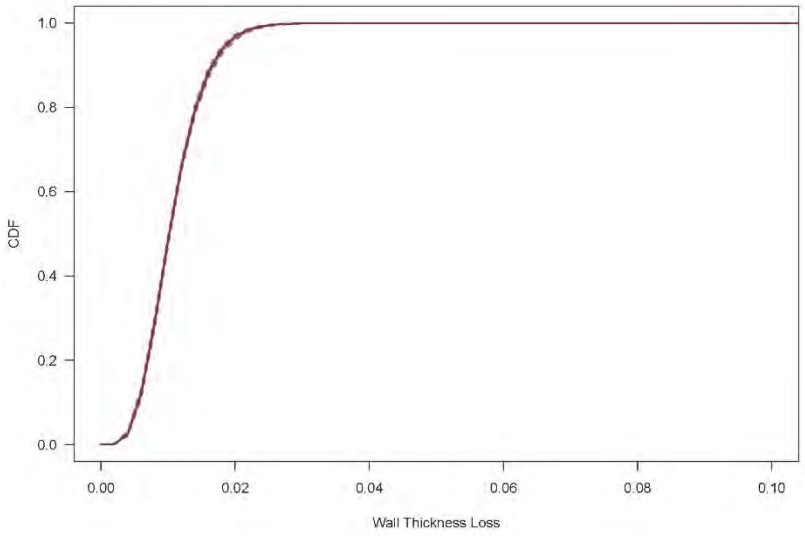
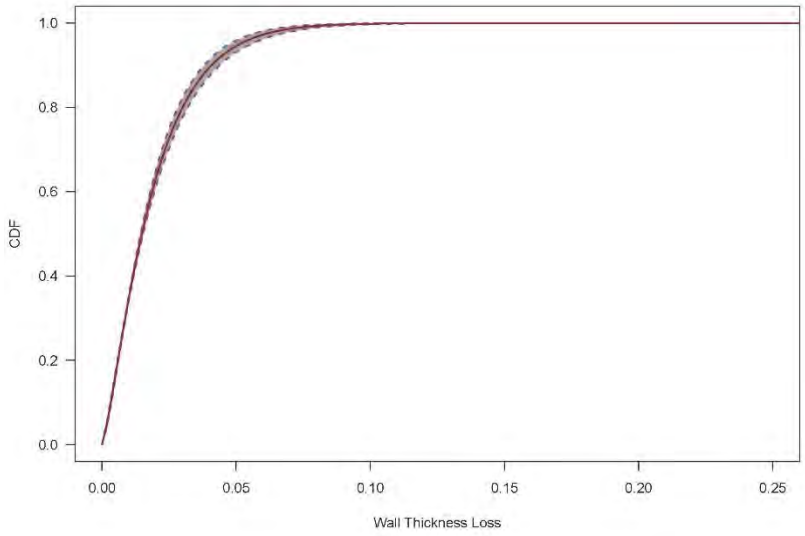




Bulk Flowline

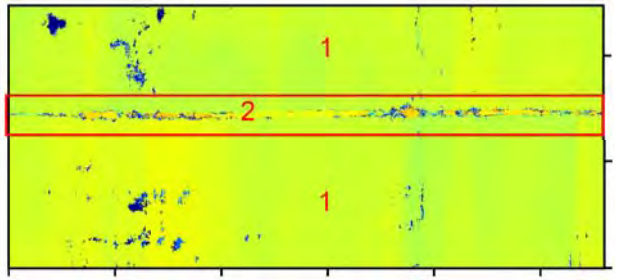


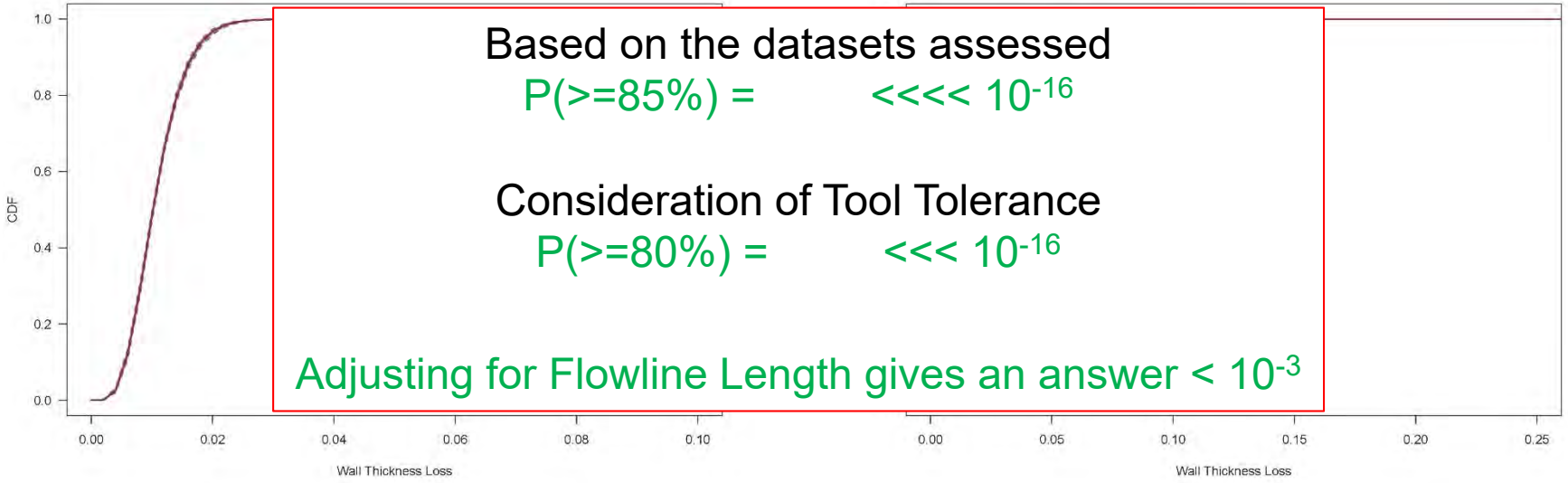
Girth Welds

Case Study Data

Considered 2 sub-populations

1. **Bulk Flowlines**
2. **Girth Welds.**





Based on the datasets assessed

P(>=85%) = <<<< 10^{-16}

Consideration of Tool Tolerance

P(>=80%) = <<< 10^{-16}

Adjusting for Flowline Length gives an answer < 10^{-3}

Bulk Flowline

Girth Welds

Conclusions

- **Risk based assessment of internal corrosion features**
- **Reduces overall inspection requirements and costs**
  - Required handful spot inspections along flowline (~4 days vessel time)
  - Saved Client US$6-14MM
    - *Engineering is cheap compared to vessel dayrates and impact on production.*
- **Requires expert knowledge of the corrosion mechanisms**
  - Where to inspect
  - Sub-populations.

Questions?

Pipeline Research Council International, Inc.

Microbiological, chemical, and corrosion analyses of solids samples collected from a leak site at a crude oil facility

Trevor Place, Enbridge Inc.
Mohita Sharma, University of Calgary

Co-authors: Amanda Kapronczai, Enbridge Inc.
Joshua Handy, Lisa Gieg, University of Calgary

PRCI 2019 Research Exchange Meeting
Houston, Texas
March 5, 2019

Objectives

- **Present an interesting case study (corrosion failure)**
- **Showcase the power of genetic sequencing in MIC study**

- **Key information to be gained:**
  - Discuss the practicalities of effective sample handling and storage

- **Encourage participation (IC failures w/ MIC suspect)**
  - Field samples hard to get
  - Much larger dataset is required

- **(Future)** → **Better predictive tools**
  → **Better diagnostics (based on field sampling)**
  → **Improved (targeted) prevention**

Overview

- **Preamble – how the case study presented itself**
- **How we approached an emerging opportunity**
- **How we executed the sampling, handling, and shipping**

- **Description of sample processing**
- **Results and Analysis**
  - Genetic analysis for microbe identification
  - Chemical analysis
  - Culturing and surface microscopy
- **Conclusions (Case Study)**

- **Discussion (future applications / question period)**

The Leak

- **October 17, 2017**
  - Routine inspection
  - All necessary notifications
  - Containment applied
  - Isolated and drained
  - Plans established to cutout the failed pipe within days!

Emerging development

- **Oct 18, 2017**
  - Contacted genoMIC team for guidance on sampling/preservation
  - (this became beta test a standard we were recently developing)
- **Oct 18 - Oct 19, 2017 (exchanged dozens of email/phone calls)**
- **Time constraints predicated substantial deviation for ideal**

Field Sampling Protocol (ideal)	What had to happen
Sterile packaged sampling tool kits sourced by laboratory supplier	Walmart stock (mason jars, plastic knives/spoons)
Reagent grade preservatives (such as EtOH, “DNAzol”, “RNAlater”)	190 proof “Everclear” or drug store IPA
Detailed instructions per industry consensus and testing	What could readily be explained in email / phone
Refrigeration 1-4°C and immediate shipping	Ice packs and best-available shipping

Samples obtained

Storage and shipping

- **Samples were collected October 20-21, 2017**
  - Maintained in refrigerator (cold-ish)
- **MEARS Group Inc. coordinated international shipping**
  - Obtained samples from site on October 25, shipped next day via Detroit broker
  - Expected in Calgary on Friday October 27
- **Package received at University of Calgary on October 30, 2017**
  - Still cold!
  - Weather likely had something to do with this success
- **Key learnings:**
  - Easiest instructions are likely the best
  - Best plan allows for contingencies (like using Everclear for preserving)
  - International shipping can be expected to take several days

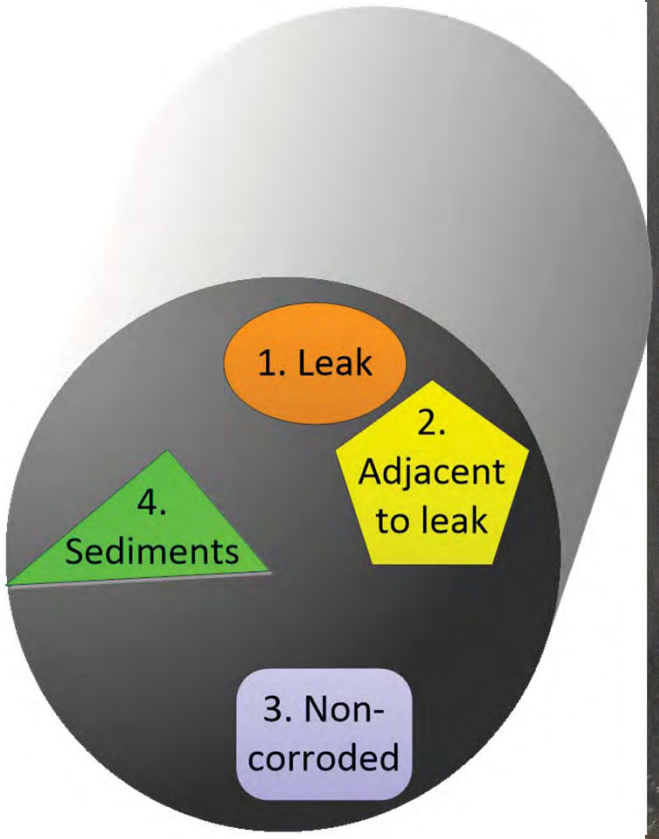
Case study

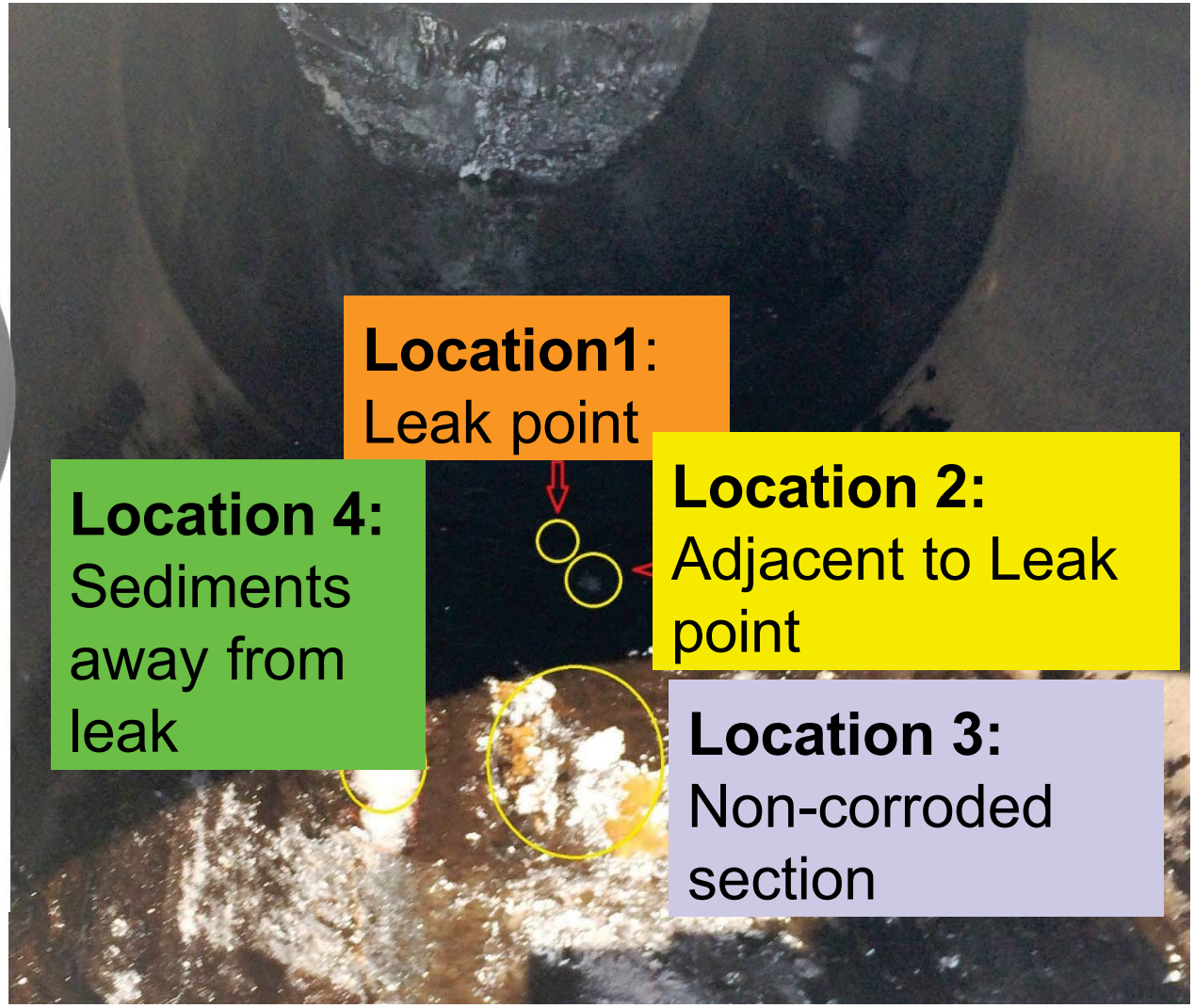
DID MIC OCCUR?

Holistic Approach:

1. Genetic tests to identify microbes
2. Water chemistry analysis
3. Corrosion & surface analysis

Sample collection locations





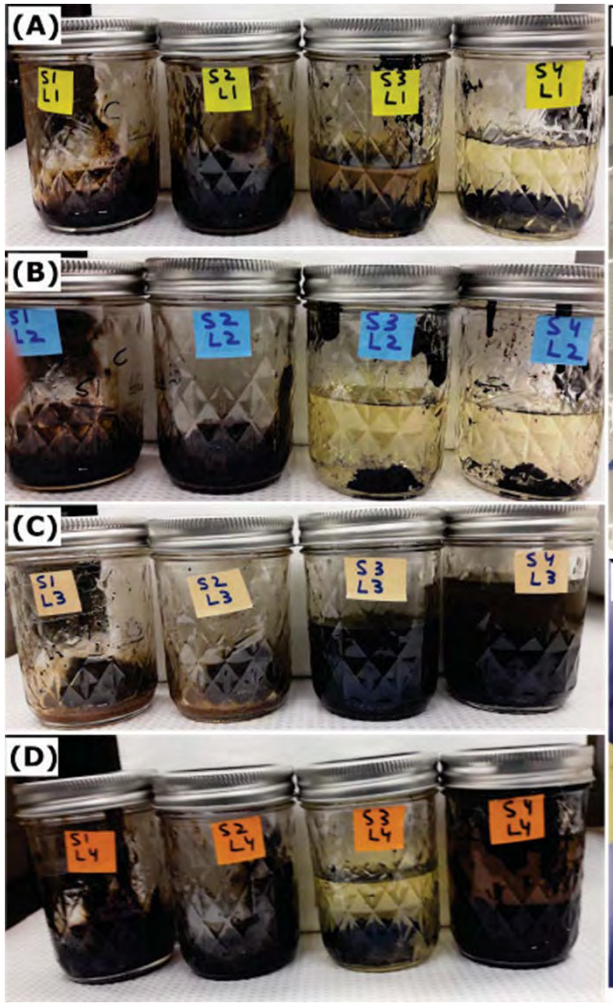
Non-Preserved | **Preserved (with isopropanol)** | **Pseudo-Preserved**

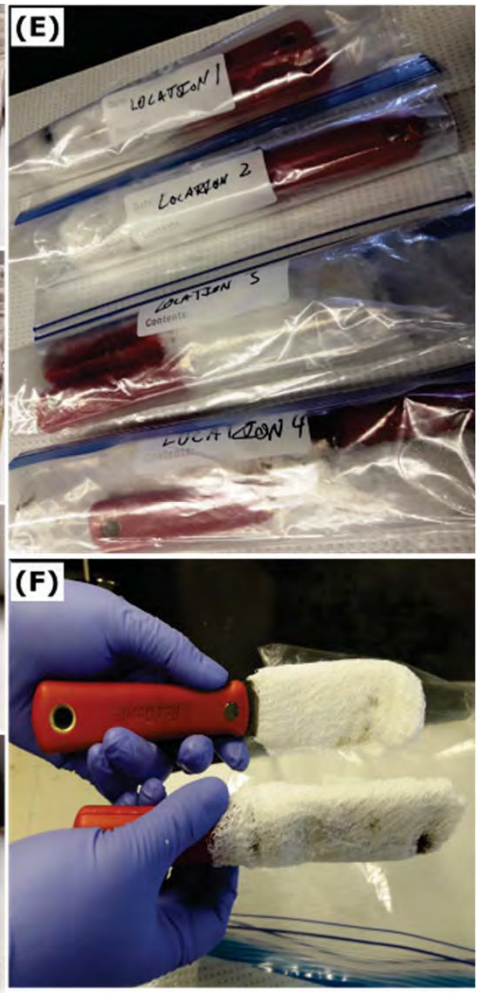
Location1: Leak point

Location 2: Adjacent to Leak point

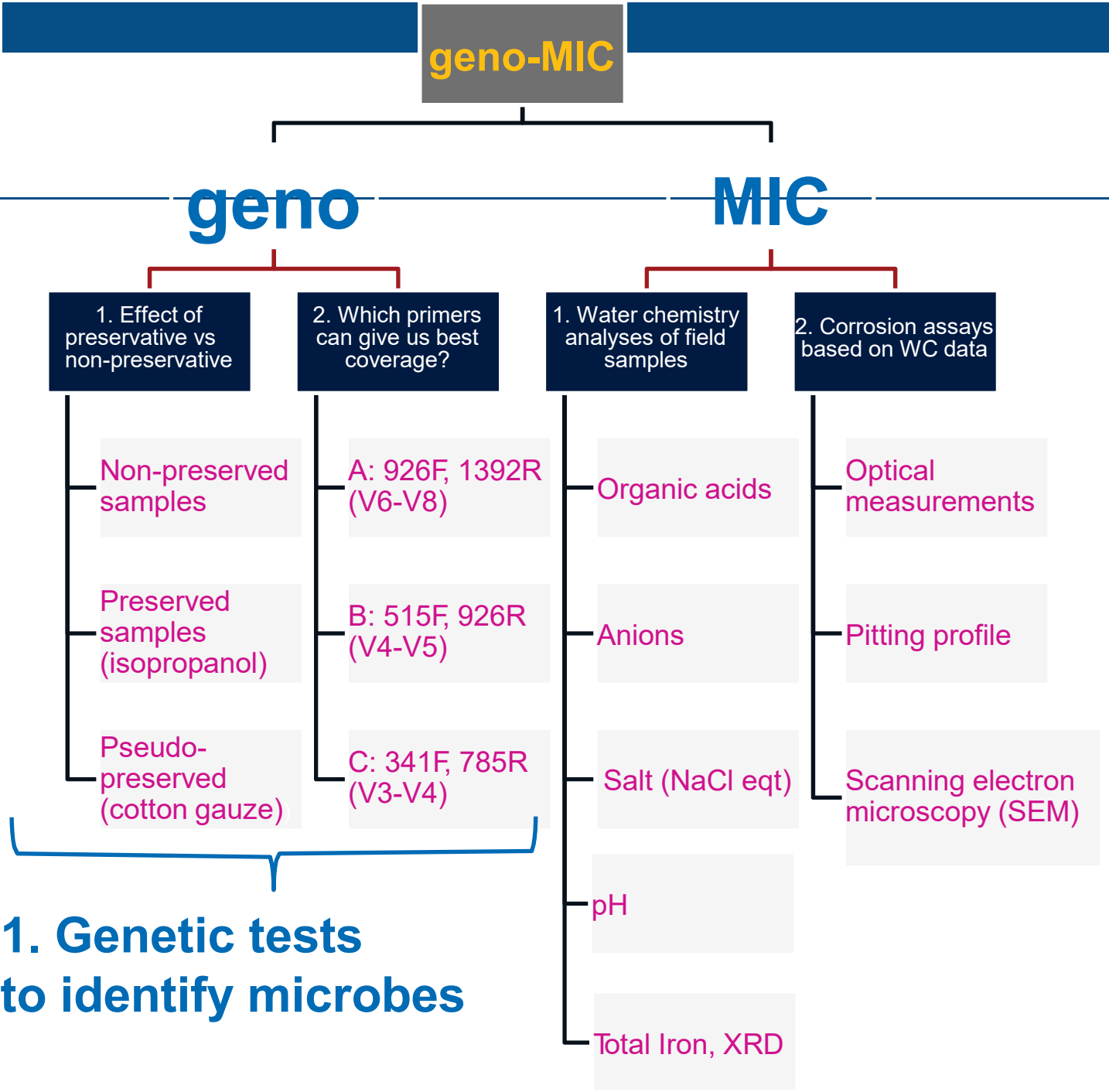
Location 3: Non-corroded

Location 4: Sediments away from leak



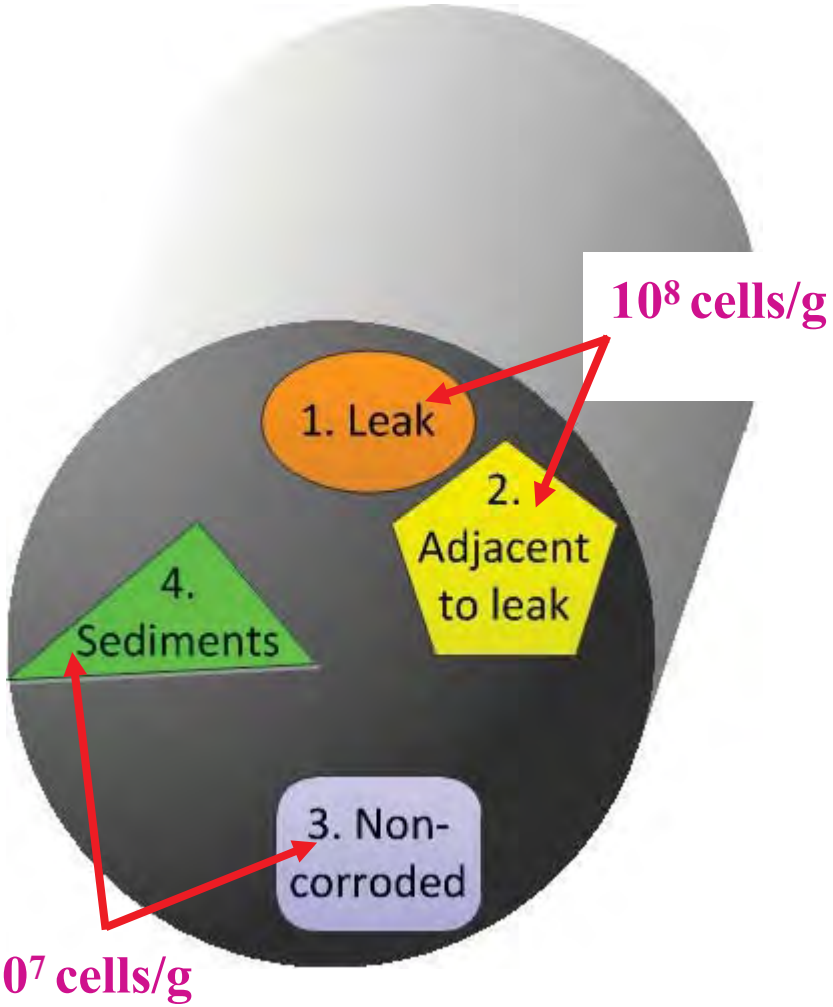


Holistic approach



1. Genetic tests to identify microbes

Extract DNA



No.	Sample Name	Type of sample	Biomass conc. DNA (ng/ul)	Gram of sludge used for DNA extraction	Total elution volume (ul)
1	Sample 1 Location 1	non-preserved solid collected in sterile mason jars	10.5	0.5	75
2	Sample 2 Location 1		4.18	0.5	75
3	Sample 3 Location 1	preserved solid collected in mason jars with isopropanol	2.28	0.5	75
4	Sample 4 Location 1		6.07	0.5	75
5	K1 a	non-preserved solid collected on knife and wrapped in sterile gauze	6.95	0.5	75
6	K1 b		0.102	0.5	75
7	Sample 1 Location 2	non-preserved solid collected in sterile mason jars	2.7	0.5	75
8	Sample 2 Location 2		11.9	0.5	75
9	Sample 3 Location 2	preserved solid collected in mason jars with isopropanol	4.64	0.5	75
10	Sample 4 Location2		1.22	0.5	75
11	K2_a	non-preserved solid collected on knife and wrapped in sterile gauze	0.07	0.5	75
12	K2_b		1.03	0.5	75
13	Sample 1 Location 3	non-preserved solid collected in sterile mason jars	4.92	0.5	75
14	Sample 2 Location 3		6.91	0.5	75
15	Sample 3 Location 3	preserved solid collected in mason jars with isopropanol	0.974	0.5	75
16	Sample 4 Location3		2.45	0.5	75
17	K3_a	non-preserved solid collected on knife and wrapped in sterile gauze	2.06	0.5	75
18	K3_b		4.96	0.5	75
19	Sample 1 Location 4	non-preserved solid collected in	7.42	0.5	75

Methane producers

Methanosaeta, *Methanocalculus*

Direct electron transfer microbes

Coriobacteriaceae

Sulfate reducers

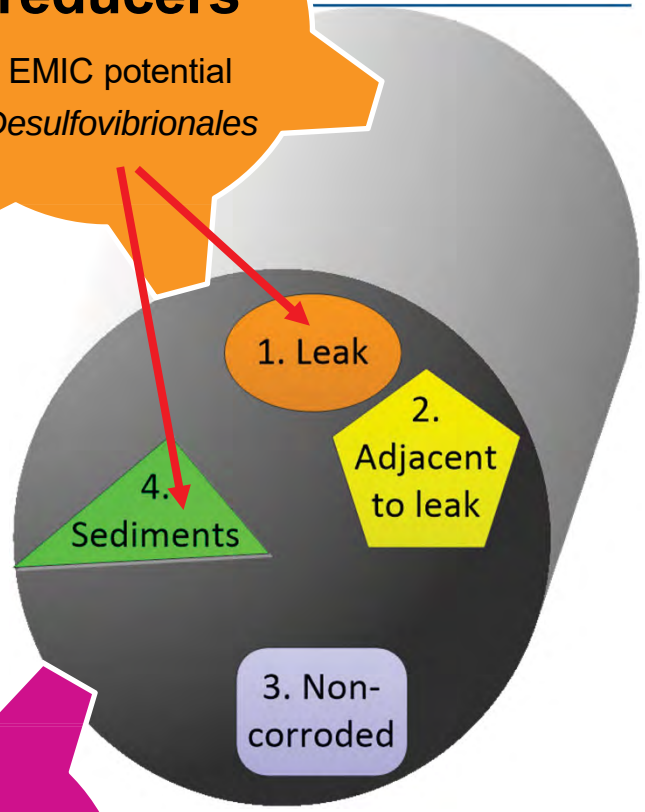
EMIC potential

Desulfovibrionales

Homoacetate Fermenters

Acetobacterium

MIC related metabolisms



Halophiles

Haloanaerobium

Ferment carbohydrates to acetate

reduce thiosulfate to sulfide

Biofilm formers

Pseudomonas

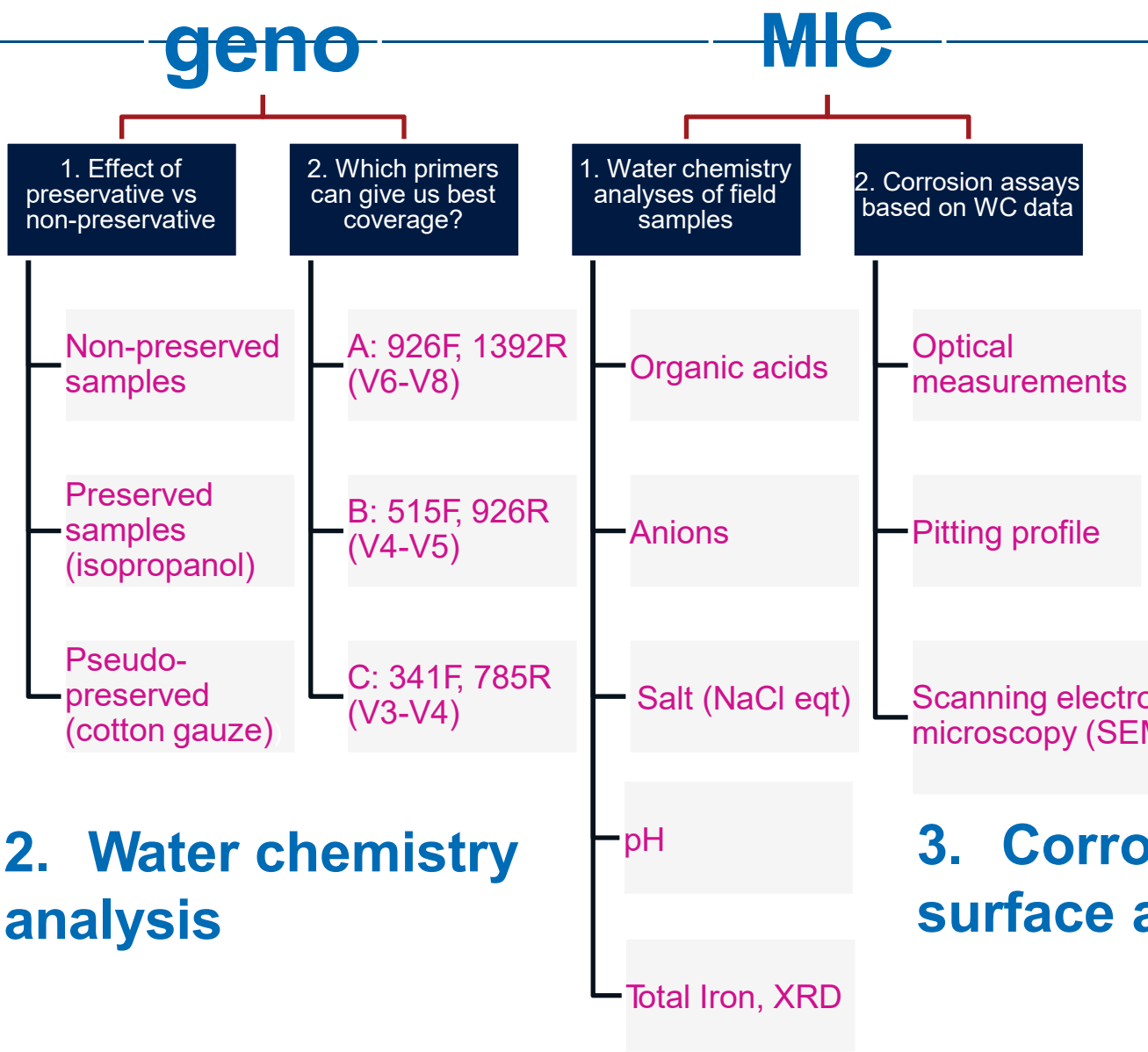
1. Genetic tests to identify microbes

Genetic tests to identify microbes:

- few differences between preserved and non-preserved samples
- testament to proper sampling and rapid shipping

geno-MIC

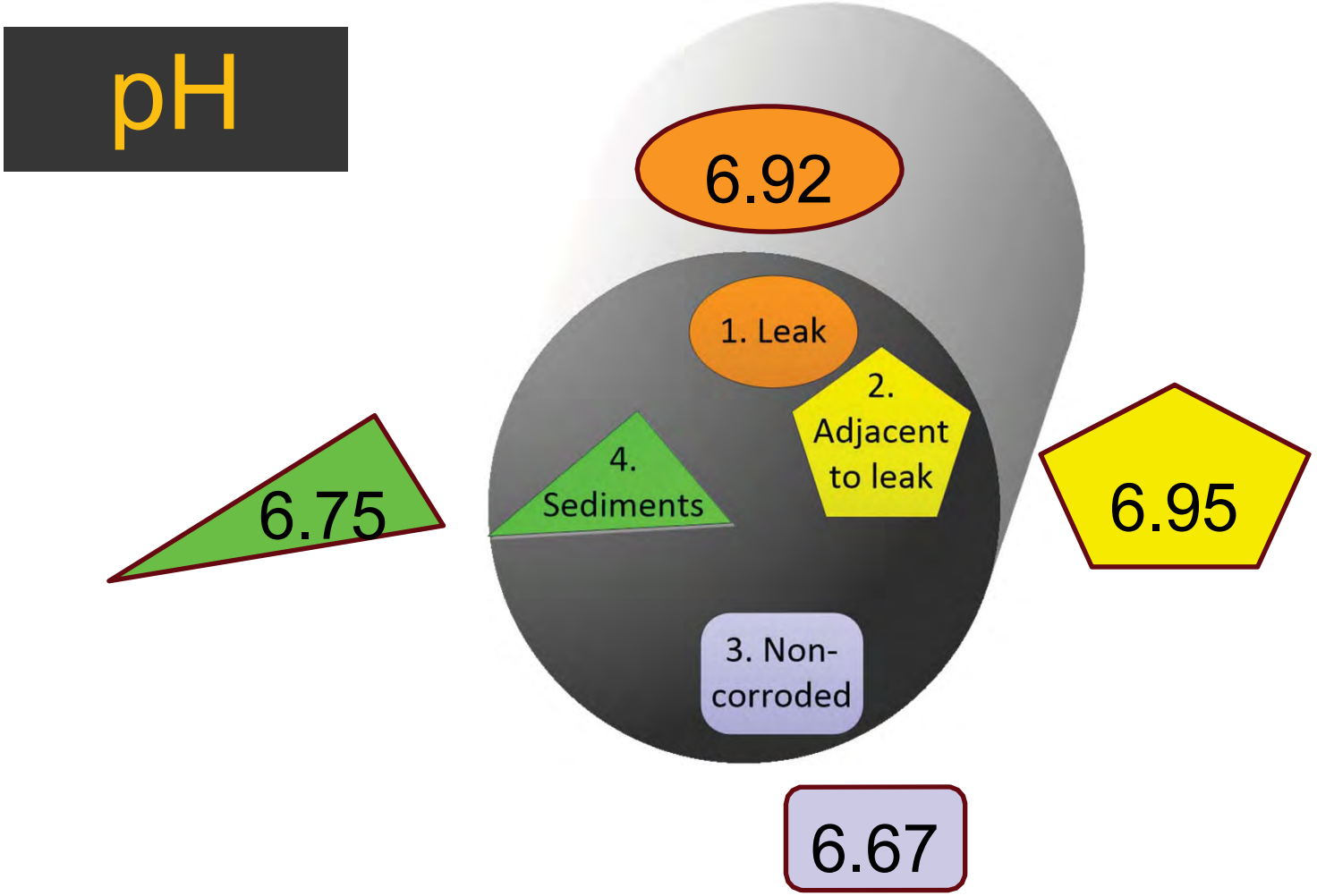
Holistic approach



2. Water chemistry analysis

3. Corrosion & surface analysis

2. Water chemistry analysis



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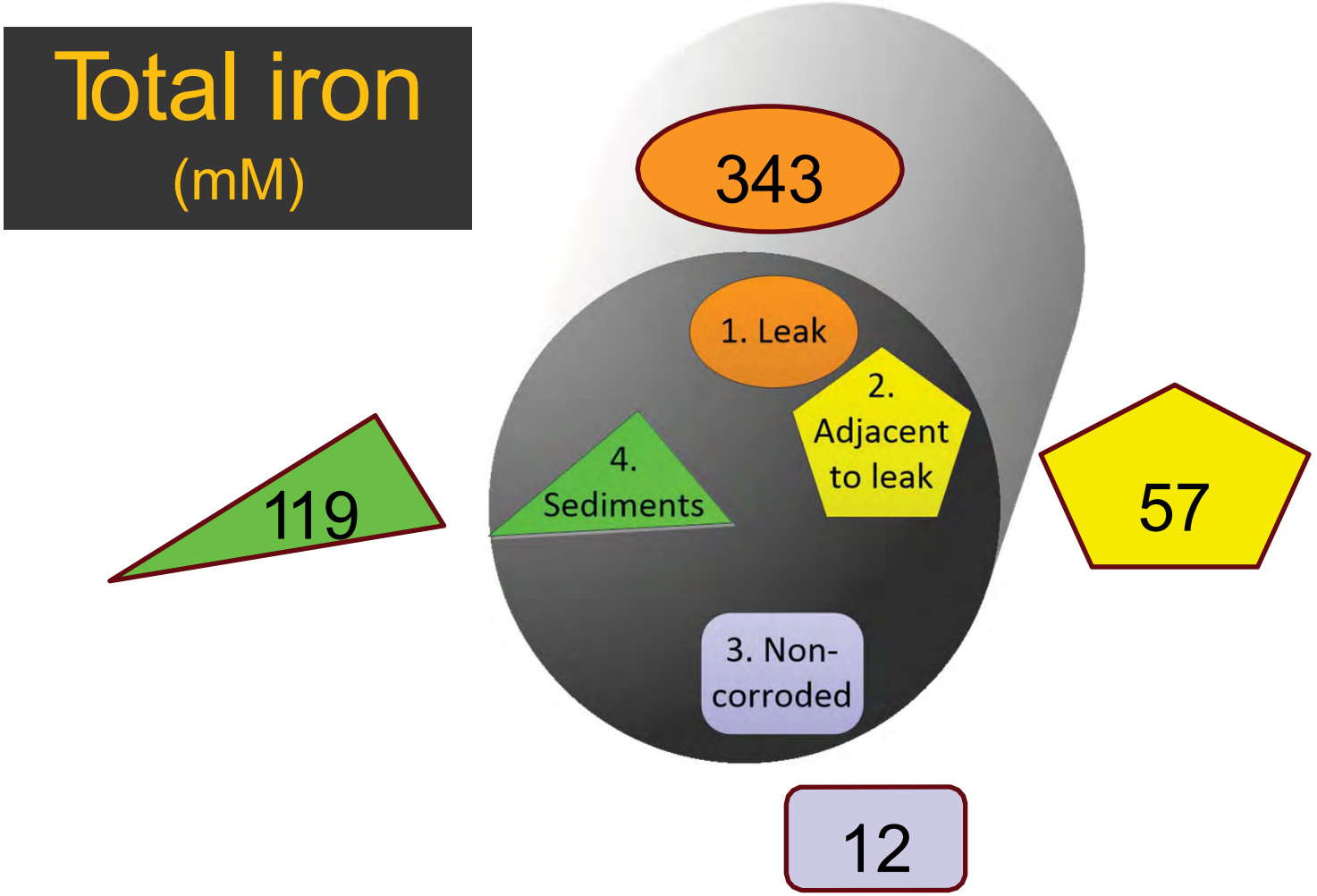

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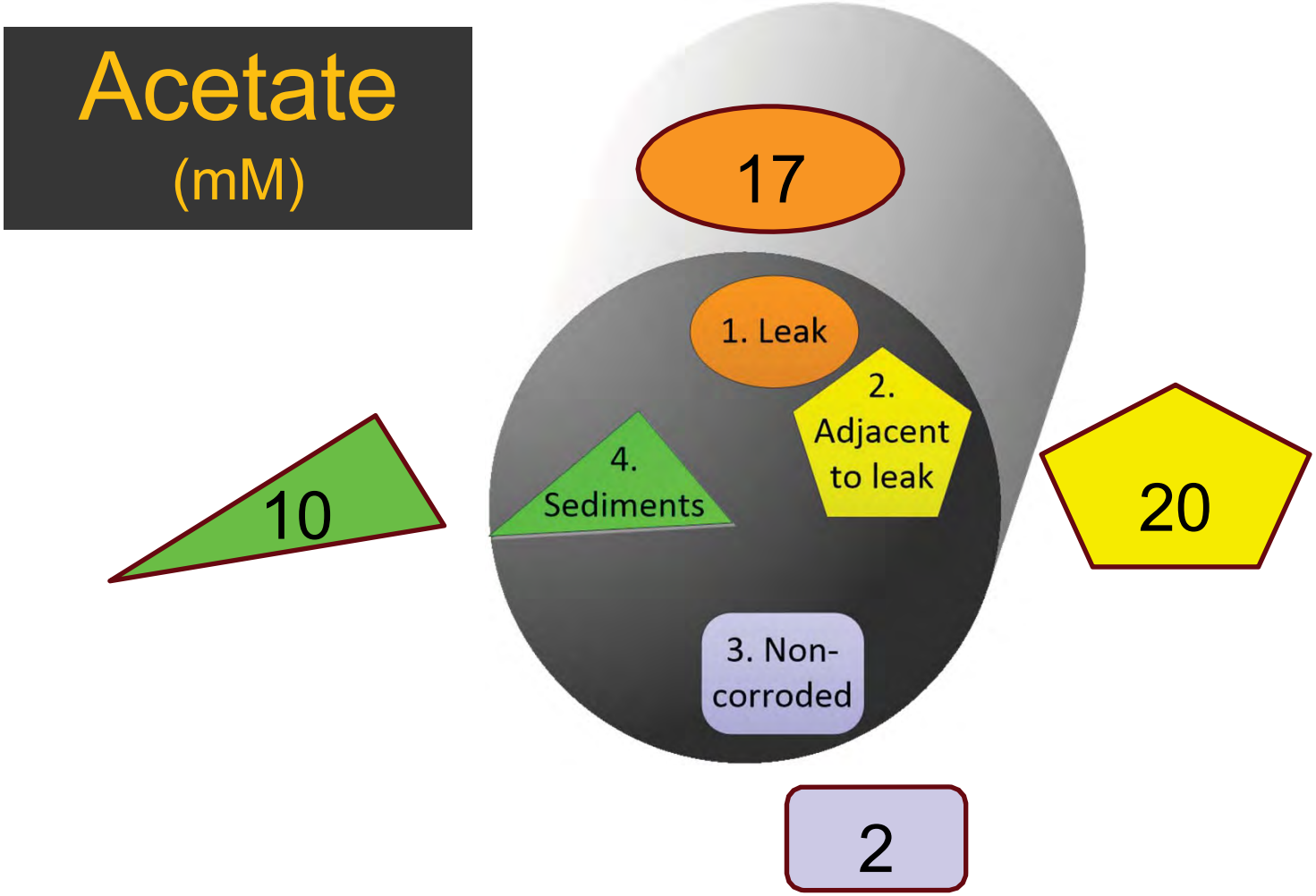
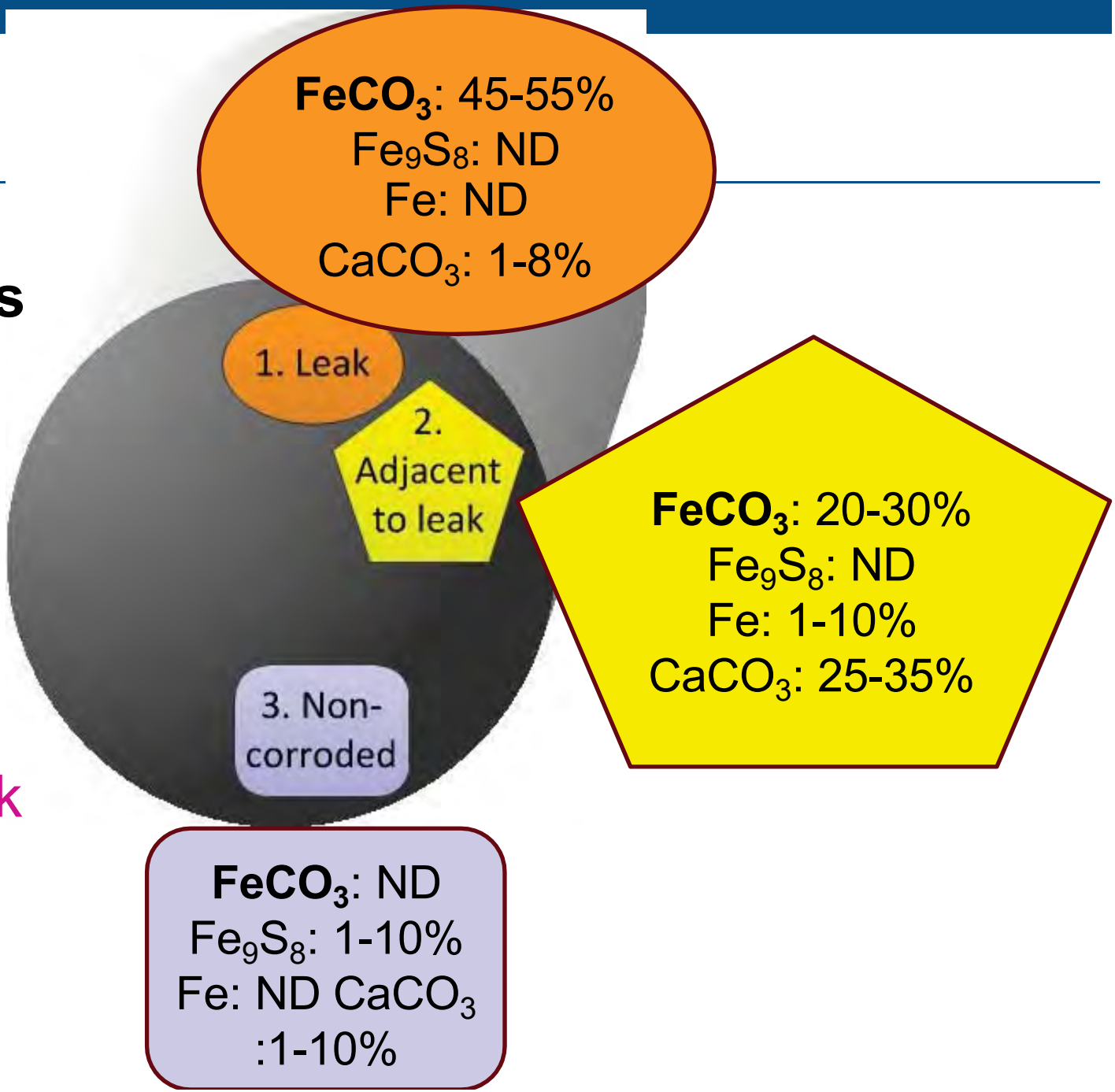


XRD results



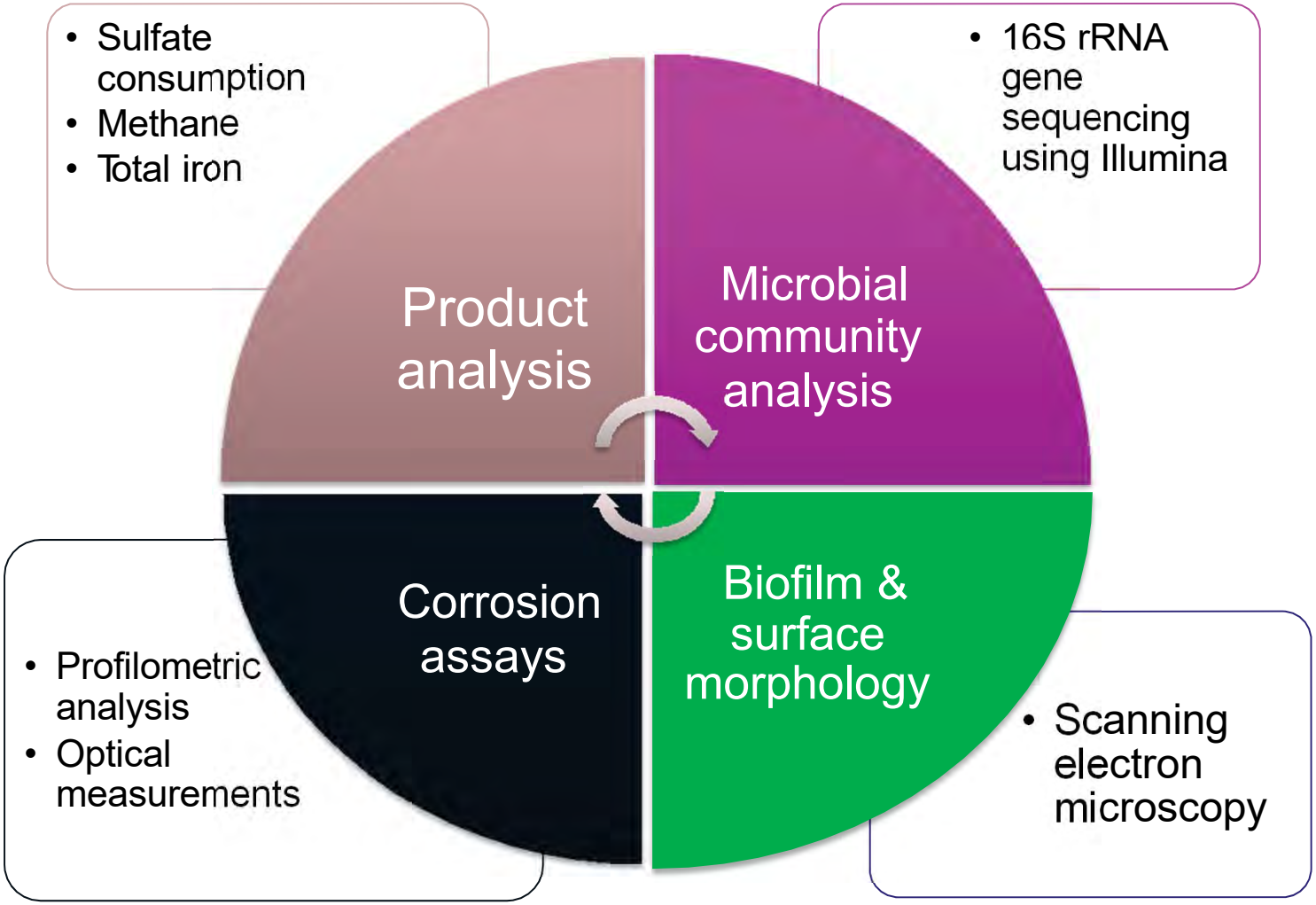
Elevated siderite at leak location 1

3. Corrosion and surface analyses

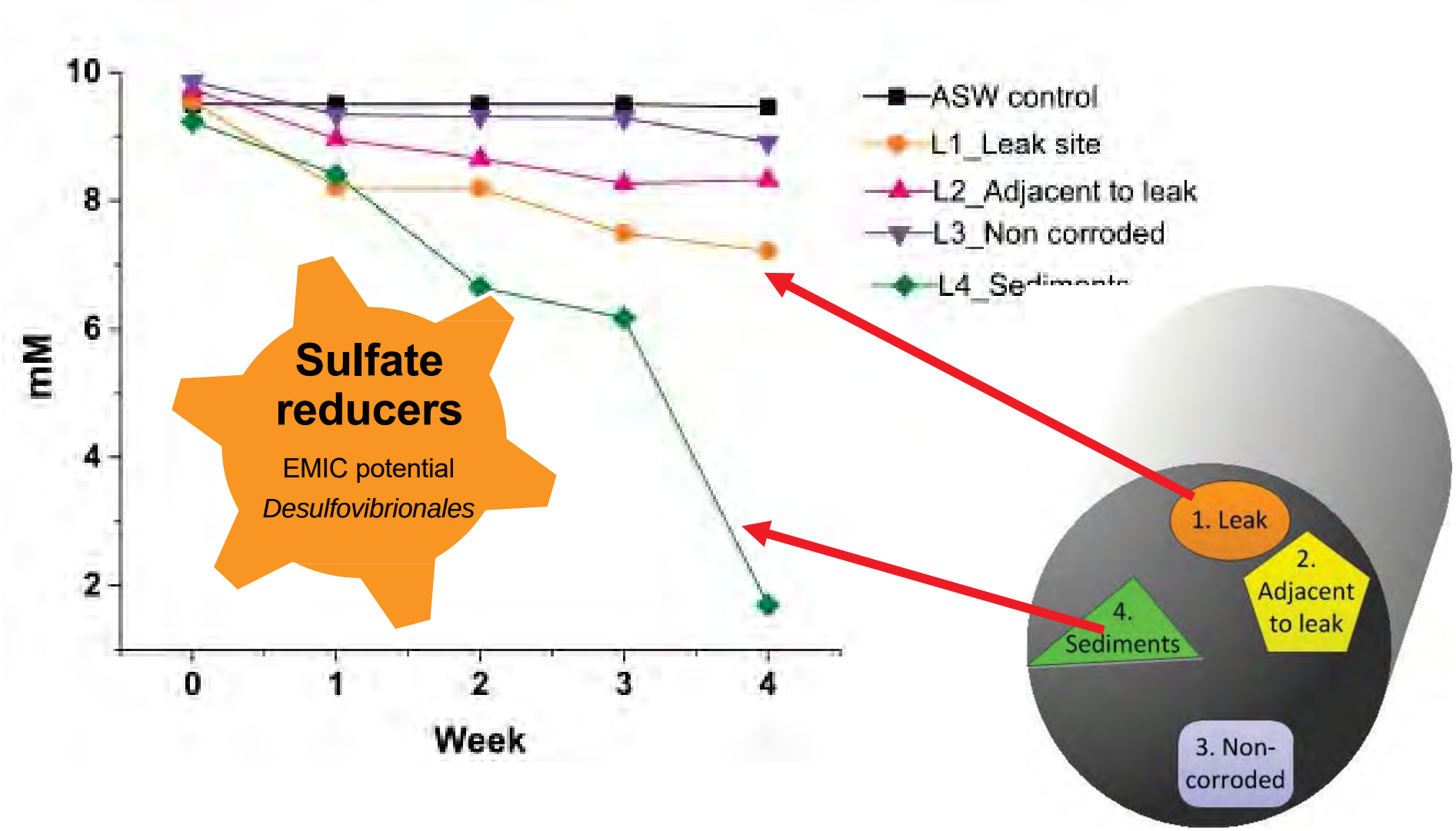
- **Methanogenic conditions**
  - *-sulfate*
- **Sulfate reducing conditions**
  - *+10 mM sulfate*

- **ASW (Artificial sea water) medium**
- **1mM acetate for cell biomass**
- **C1018 carbon steel coupon**
- **1 month: Incubation time**
- **N_2/CO_2 Headspace**

Methodology: corrosion assays

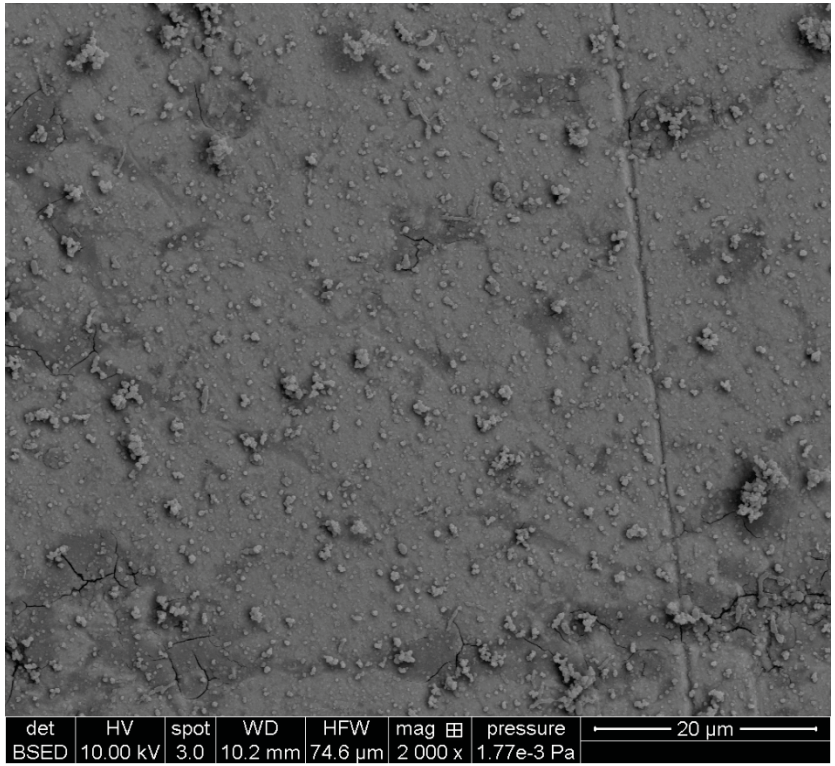


Sulfate consumption

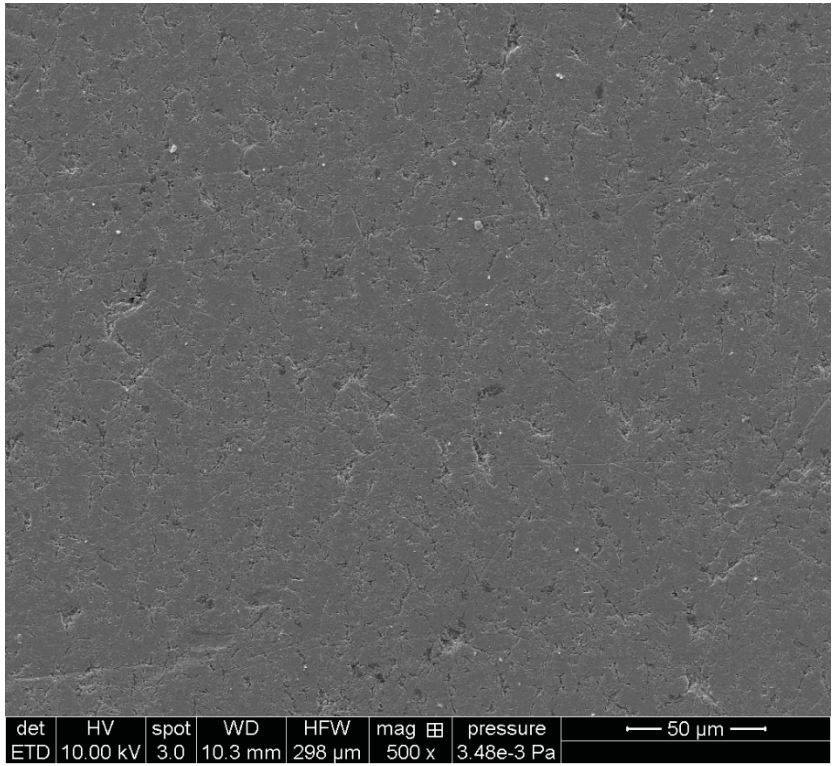


Surface analysis – control (no microbes)

Before cleaning



After cleaning



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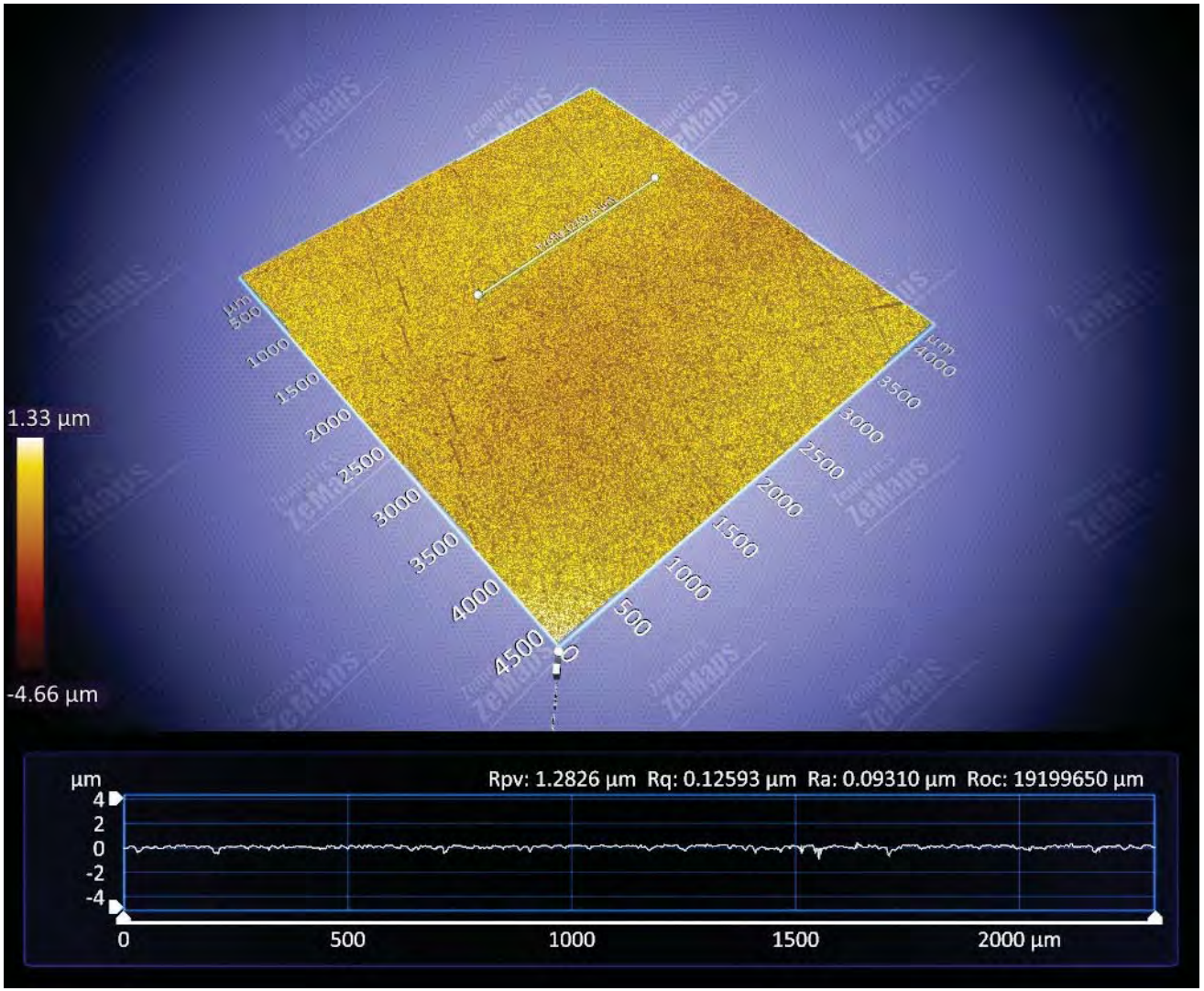
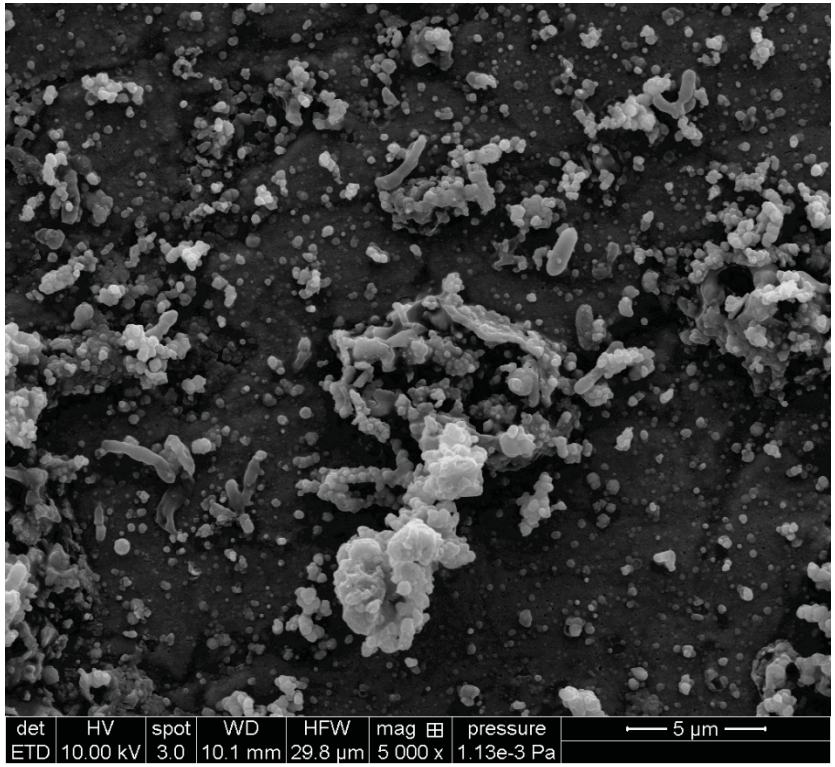
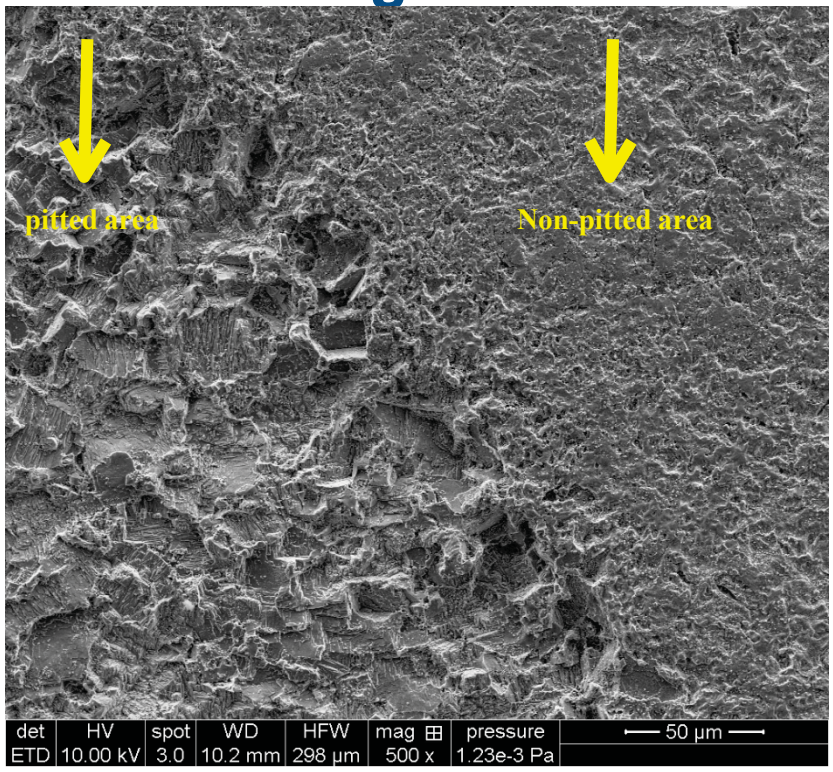


Location 1 (leak)

Biofilm on the coupon's surface



After cleaning



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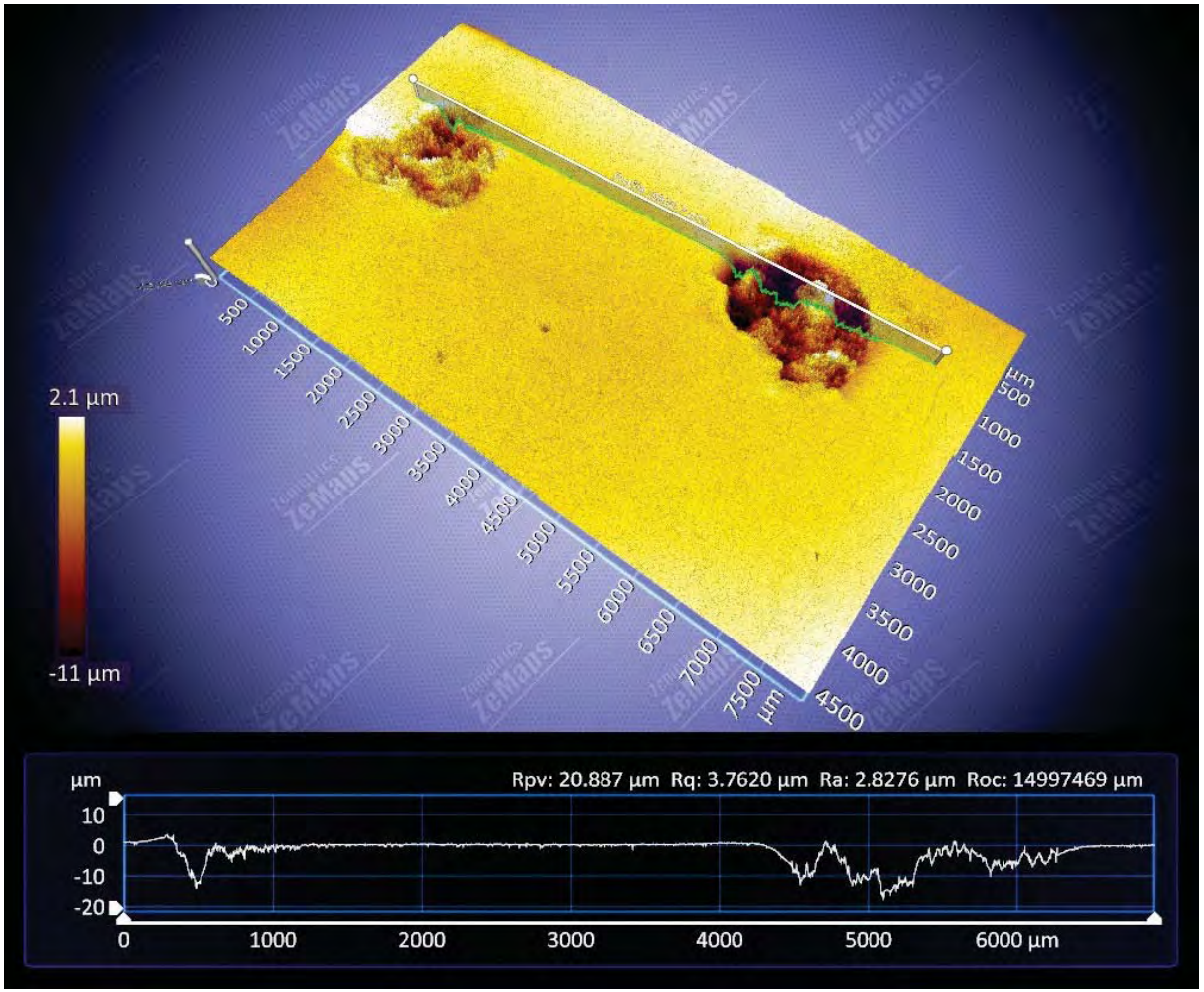
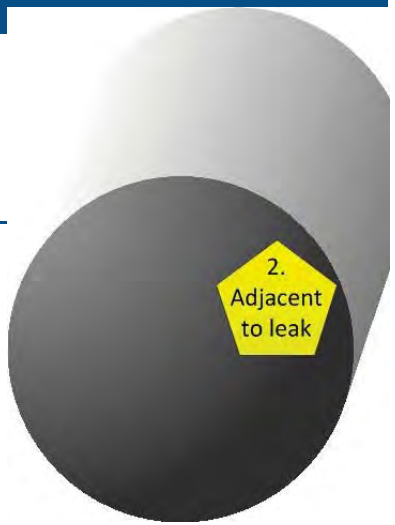
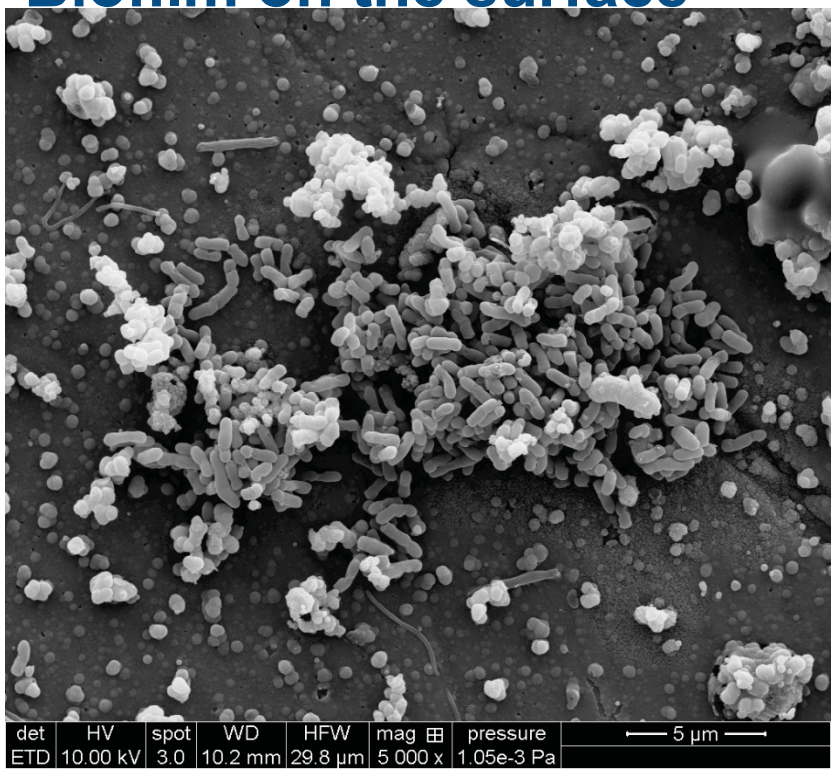


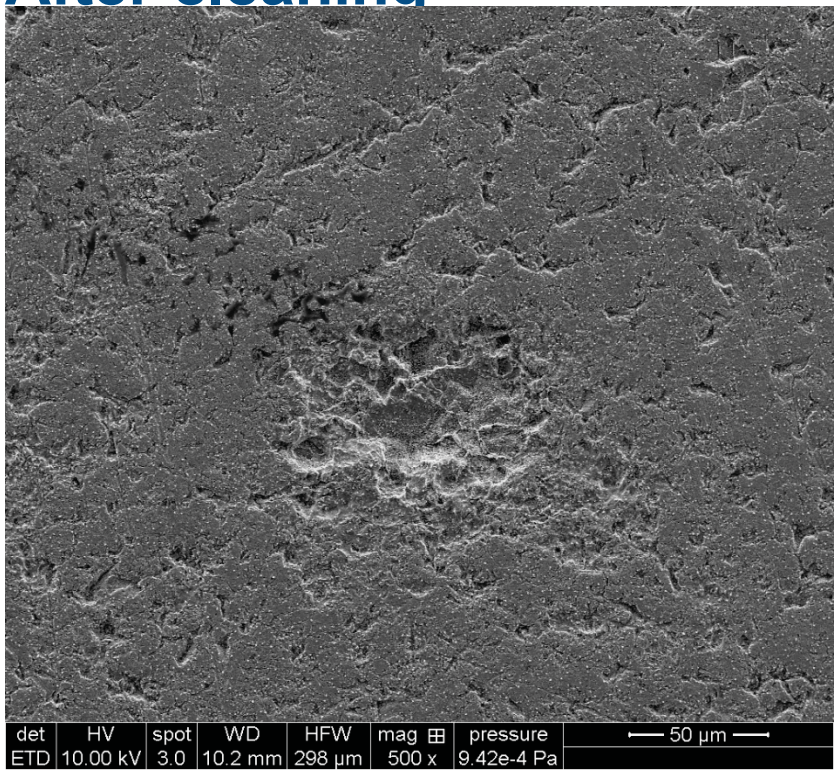
Location 2 (adjacent to leak)



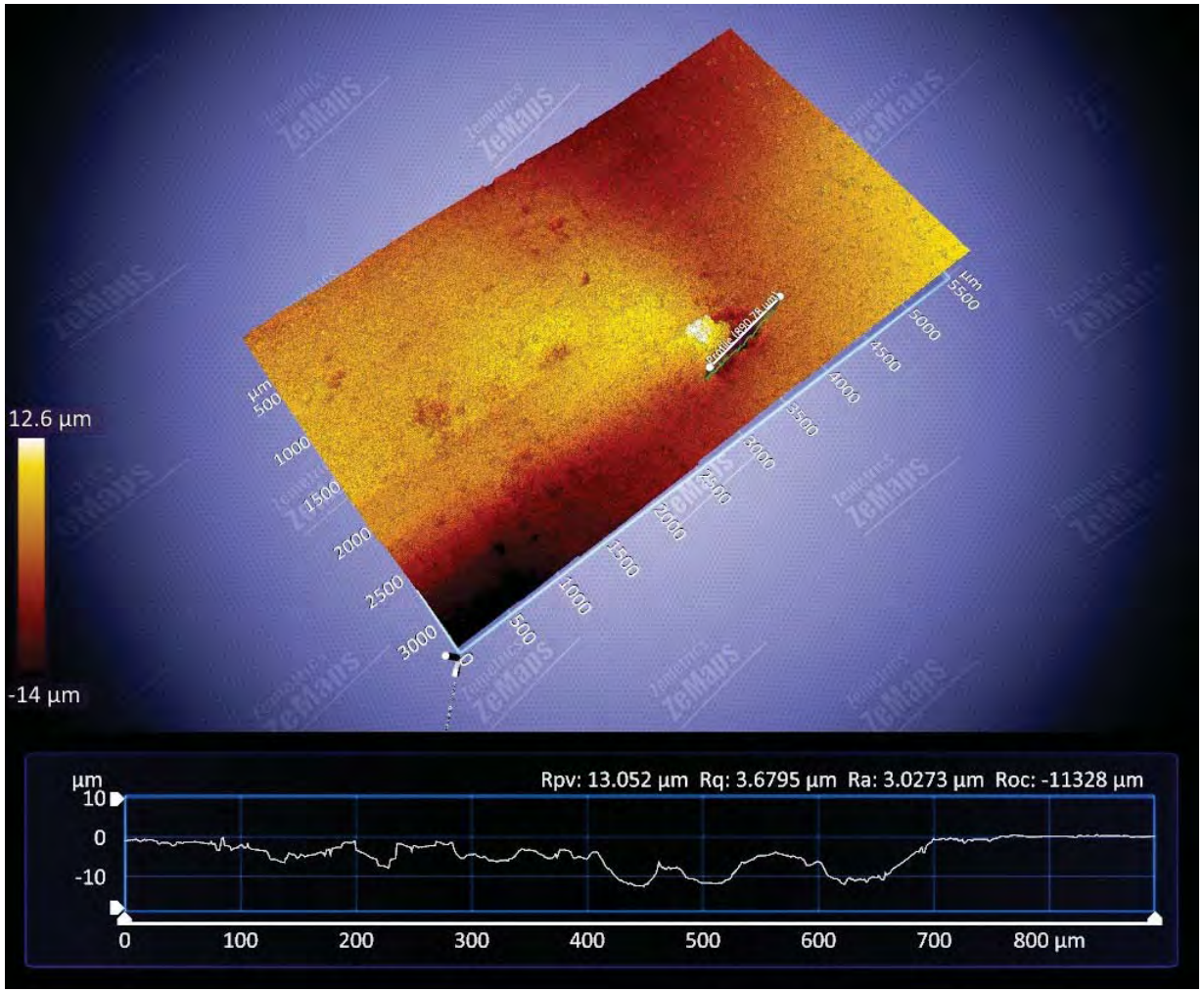
Biofilm on the surface

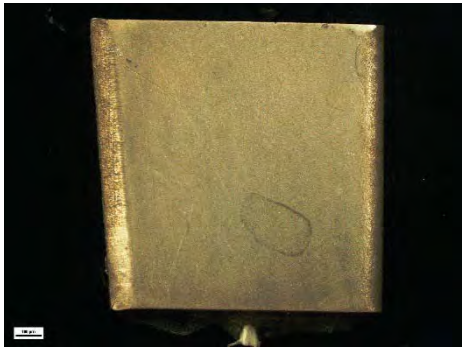


After cleaning

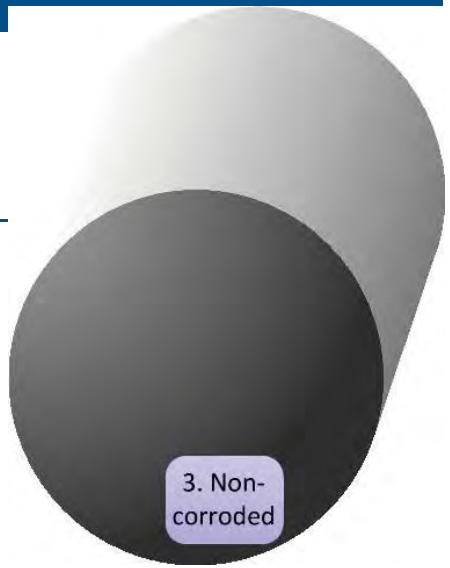


Location 2 (adjacent to leak)

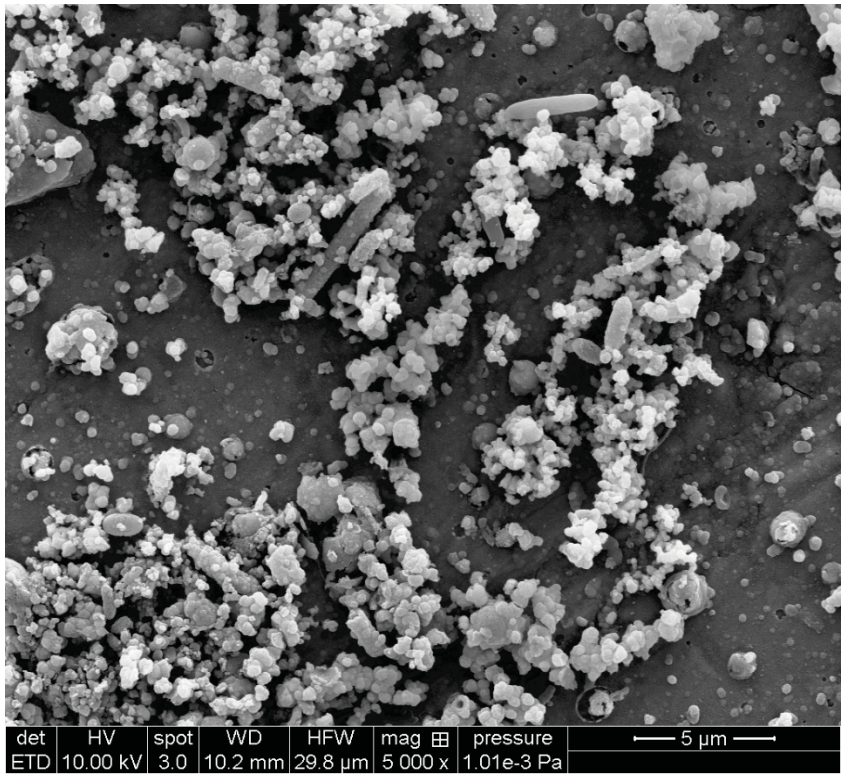




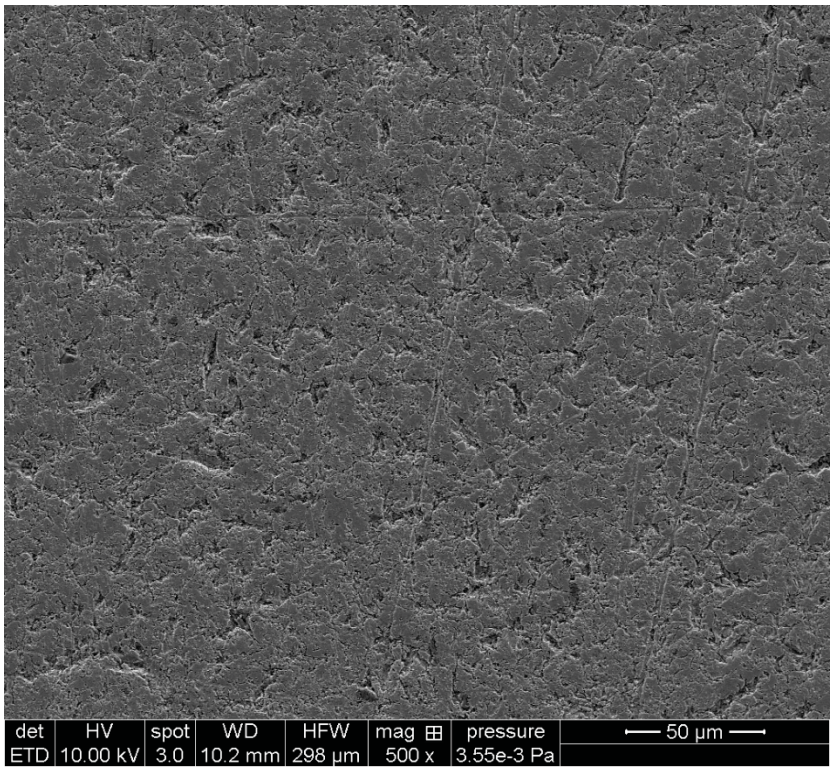
Location 3 (non-corroded area)



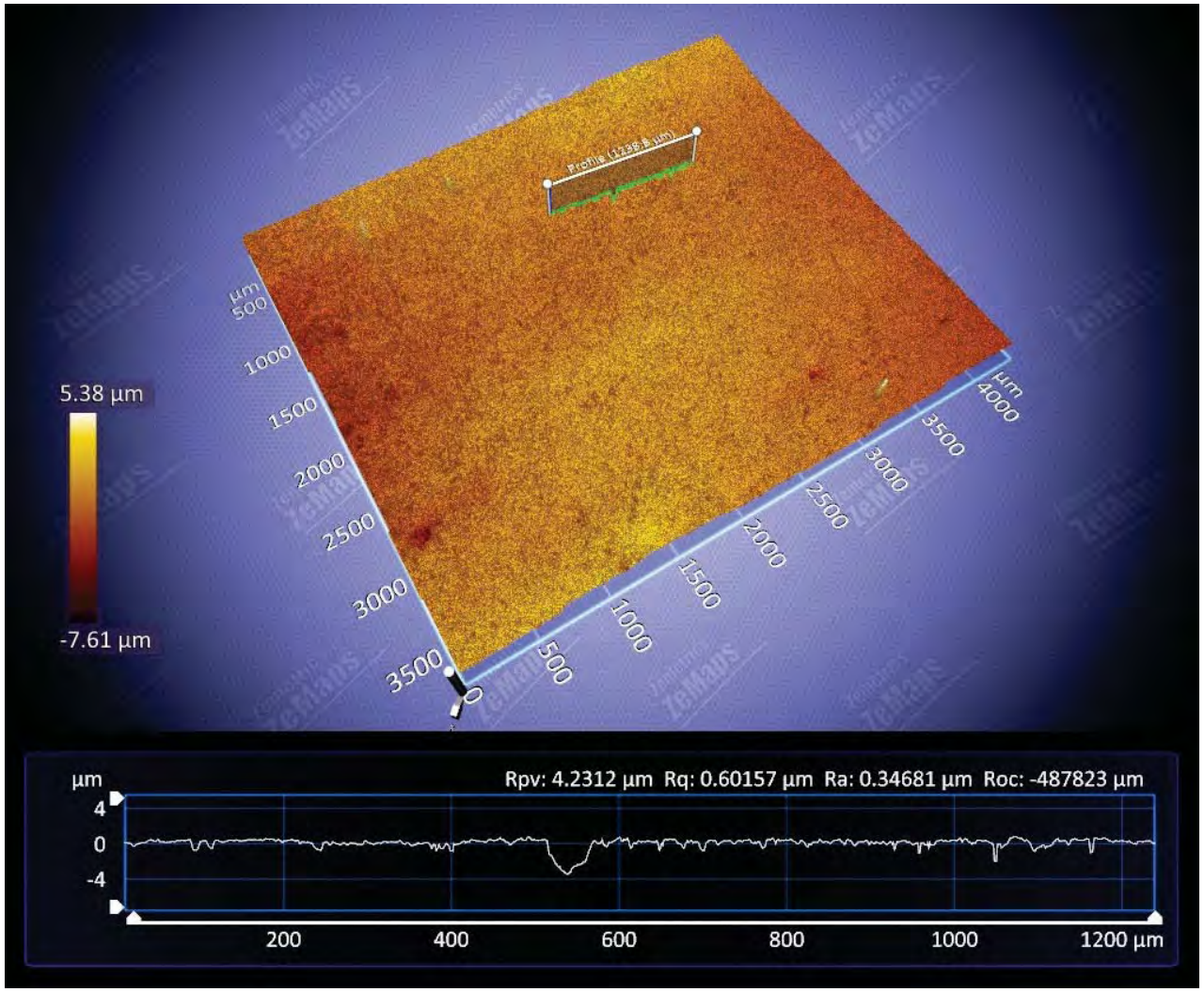
Biofilm on the coupon's surface

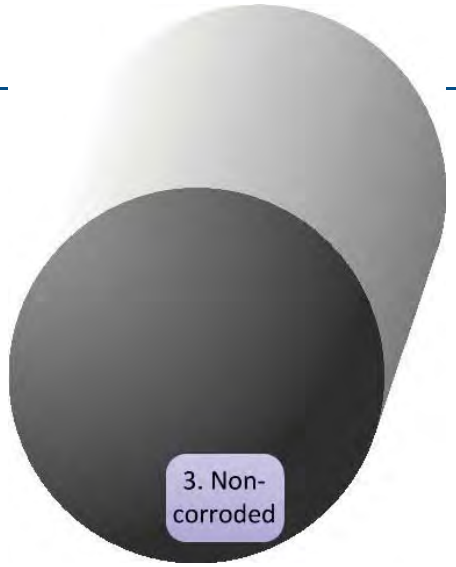


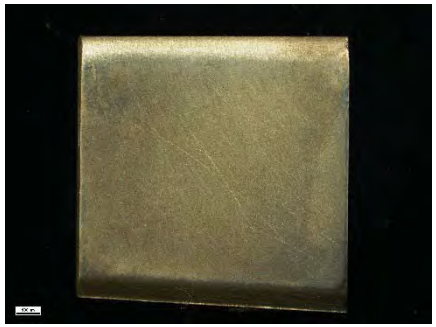
After cleaning



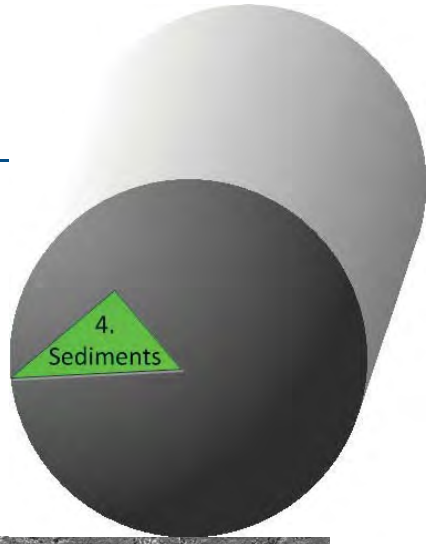
Location 3 (non-corroded area)



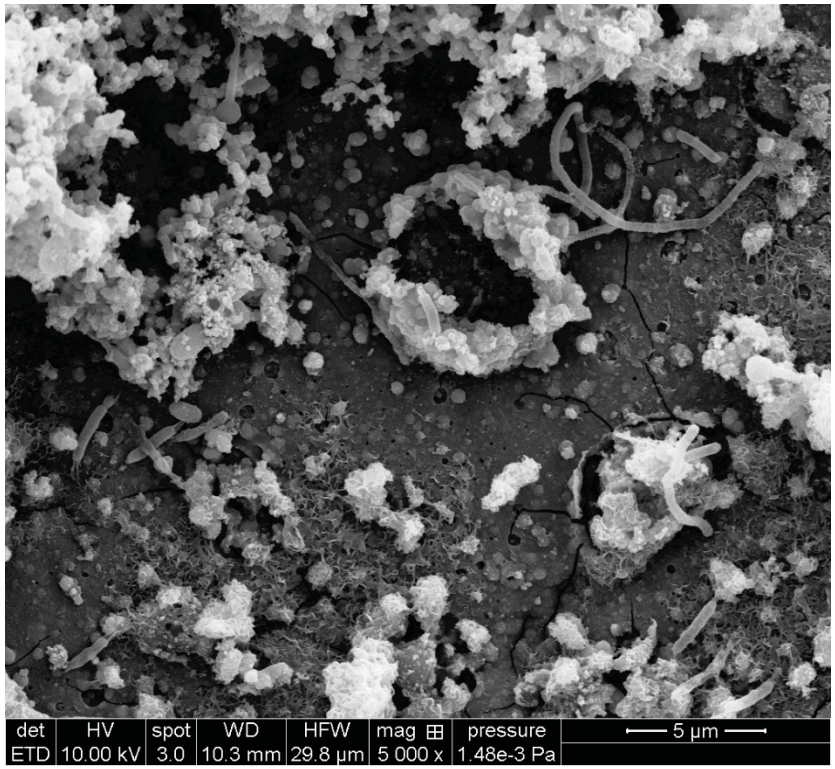




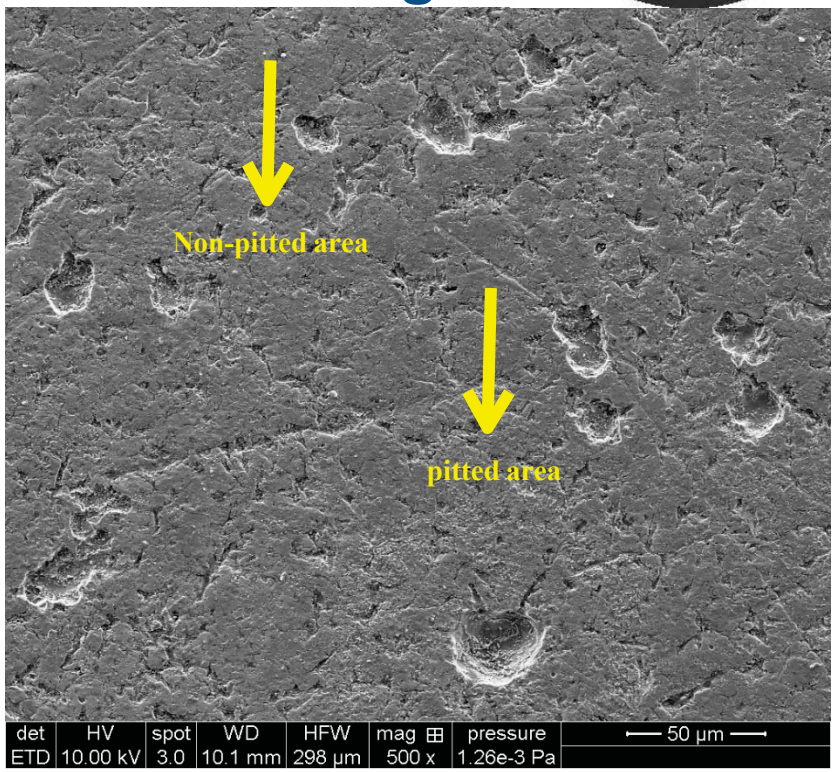
Location 4 (sediments)



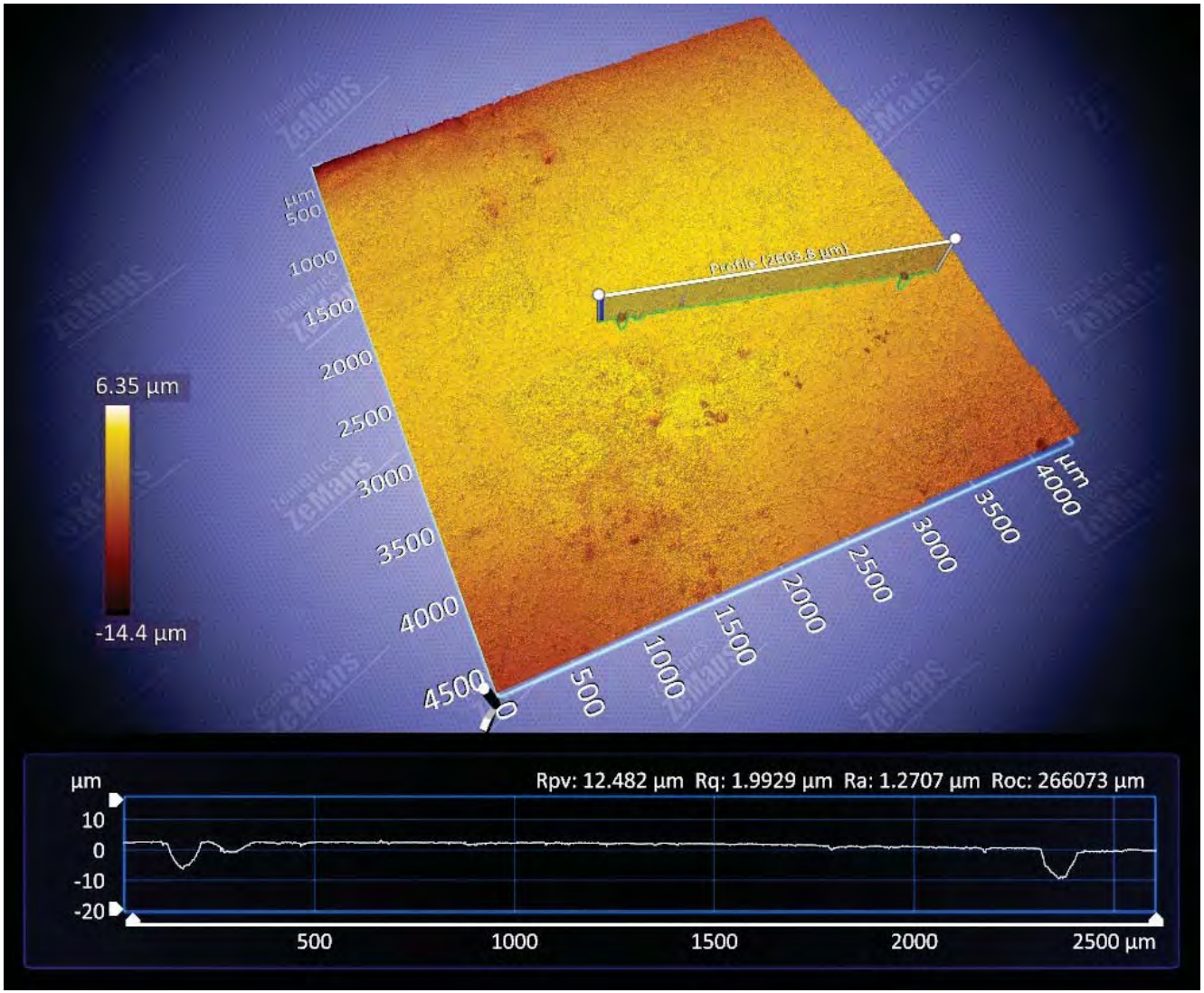
Biofilm on the coupon's surface

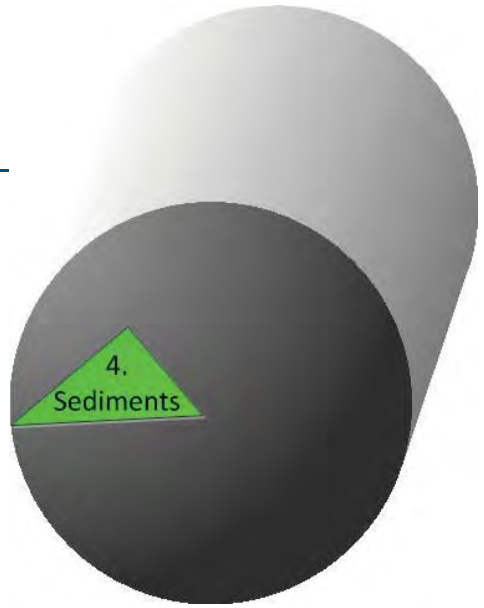


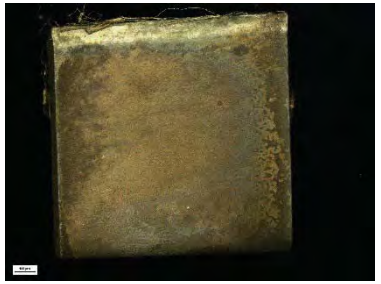
After cleaning



Location 4 (sediments)







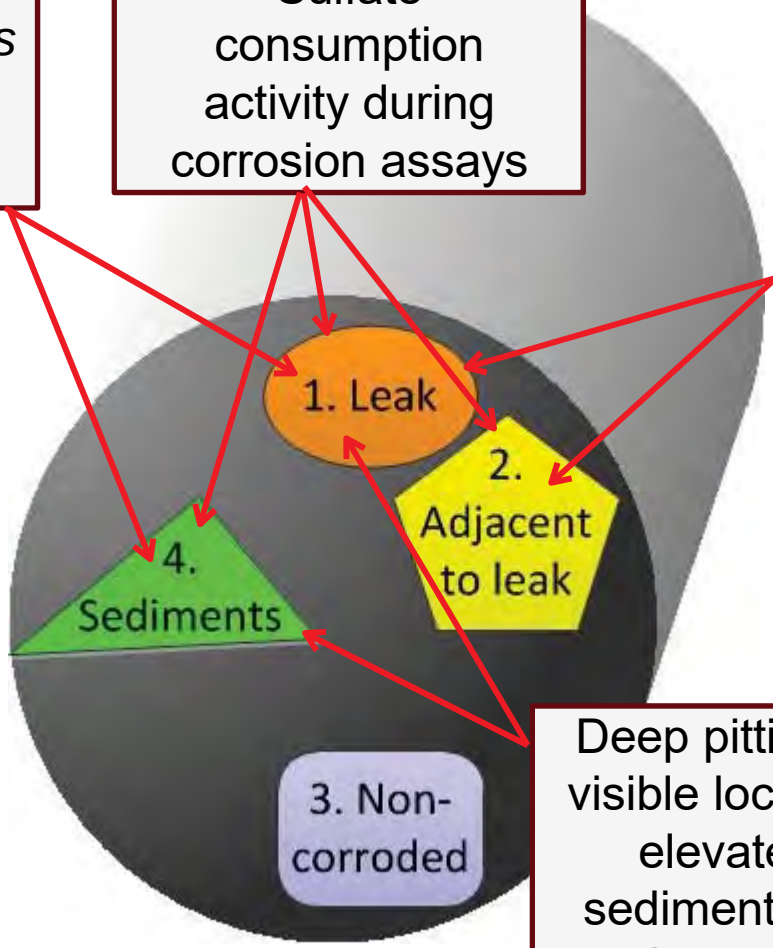
Case study – evidence of MIC

Elevated levels of *Desulfovibrionales* (potential EMIC organisms)

Sulfate consumption activity during corrosion assays

Elevated levels of siderite, acetate, salinity and numbers of cells/g

Preservatives did not affect microbial community



B-515F, 926R (V4-V5 region) gave best coverage including *Epsilonproteobacteria*

Deep pitting profiles and visible localized damage, elevated total iron, sediments may harbour MIC causing organisms

Limitations of this study

Coupon culturing analysis is to some extent artificial

- ✓ different than the pipe environment
- ✓ steel coupon did not benefit from the protective exposure to oil (it was not oil wetted)
- ✓ This may explain why sediments testing still produced pitting of the coupon –
  - even though these sediments were taken from an uncorroded area of the pipe.

Overall conclusions

- Unique opportunity to assess the potential for MIC at the site of a pipeline leak
- Sampling protocol allowed for comparisons between leak and non-leak locations
- Sampling for microbial analysis can be done well with minimal specialized sampling equipment – clear instructions are very important
- Minimal shipping times are best to maintain quality of sample
- Multiple lines of evidence – genetic testing, chemistry analysis, and microbial corrosion tests – are ideal to determine whether MIC is occurring

Thank you!

Questions?

UNIVERSITY OF CALGARY

geno-MIC
microbiologically influenced corrosion

www.geno-mic.ca

Pipeline Research Council International, Inc.

The PRCI MAT-8 Fracture Model: Recent Enhancements and Real-World Applications

Ted Anderson
TL Anderson Consulting

Jim Andrew
Flint Hills Resources

Taylor Shie
Shell Pipeline

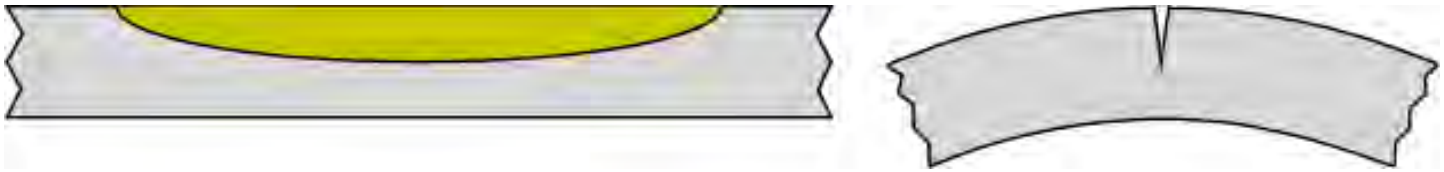
PRCI 2019 Research Exchange Meeting
Houston, Texas
March 6, 2019

Overview

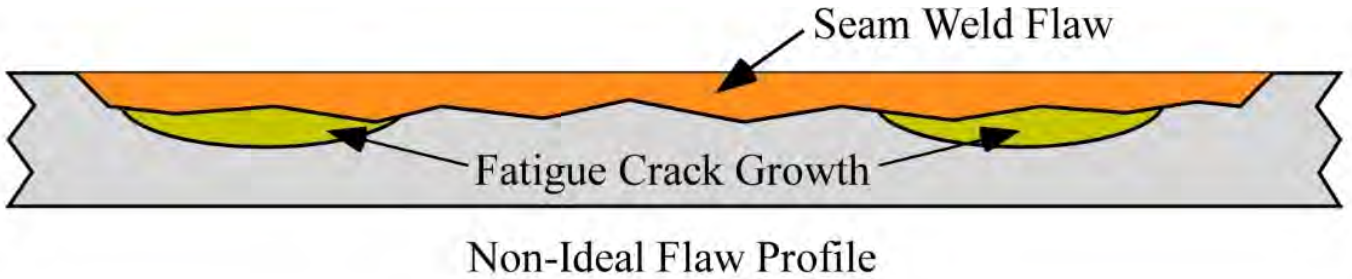
- **The PRCI MAT-8 fracture model has seen widespread use in the pipeline industry since it was published in 2015.**
  - Catalog No. PR-460-134506-R01
  - Over 200 3D elastic-plastic finite element simulations of axial cracks in pipes.
  - FEA results fit to a parametric equation.
- **Several major operators have supported enhancements to the MAT-8 technology.**
  - Flint Hills Resources
  - Shell Pipeline
  - ExxonMobil
- **Technological advances include:**
  - Accounting for non-ideal crack profiles.
  - Accounting for cycle-induced sharpening of seam weld flaws.
  - Implementation of MAT-8 in a probabilistic model.

Limitations of Most Fracture Models
Model Assumptions versus Reality

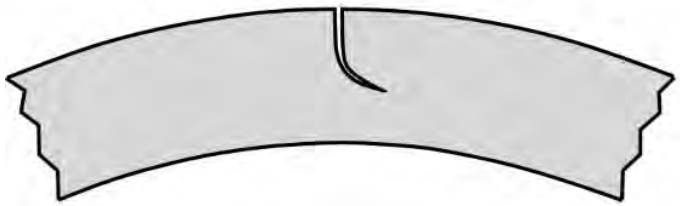
- **Idealized sharp planar crack with an elliptical profile.**



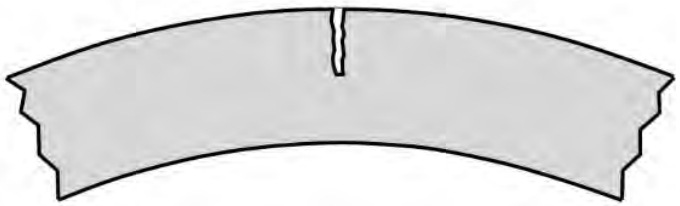
- **Real-world seam weld flaws.**



Non-Ideal Flaw Profile



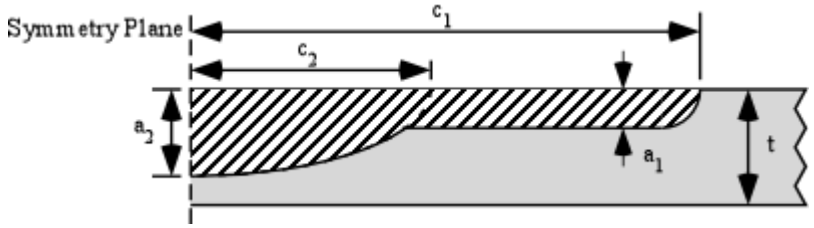
Hook Crack



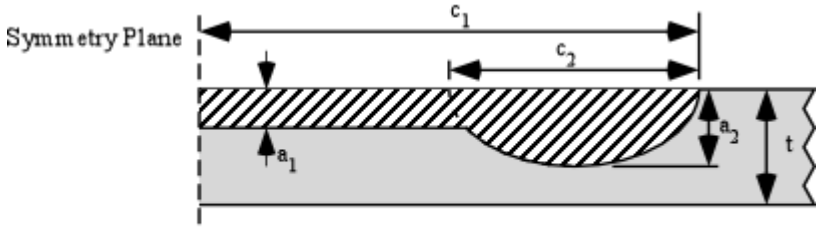
Lack of Fusion (Cold Weld)

Crack Profile Study
Compound Elliptical Cracks

Profile 1

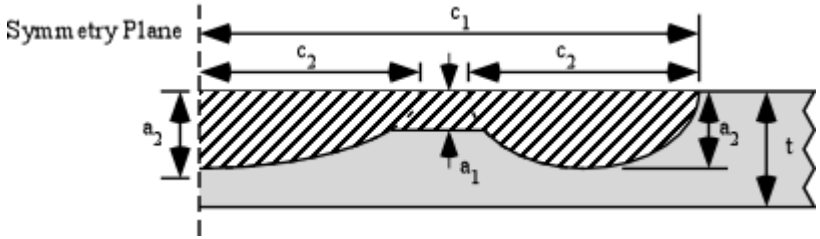


Profile 2

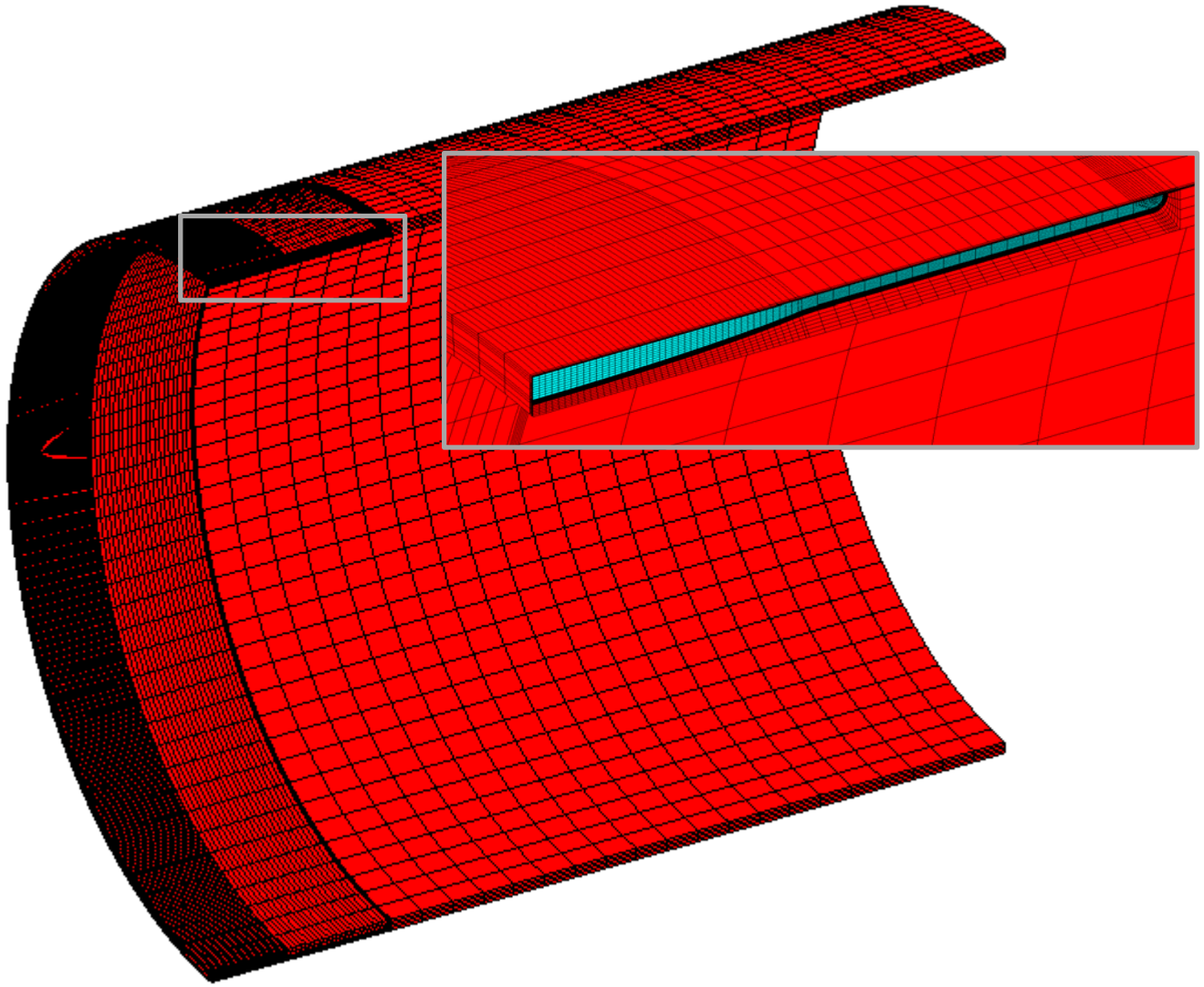


c1

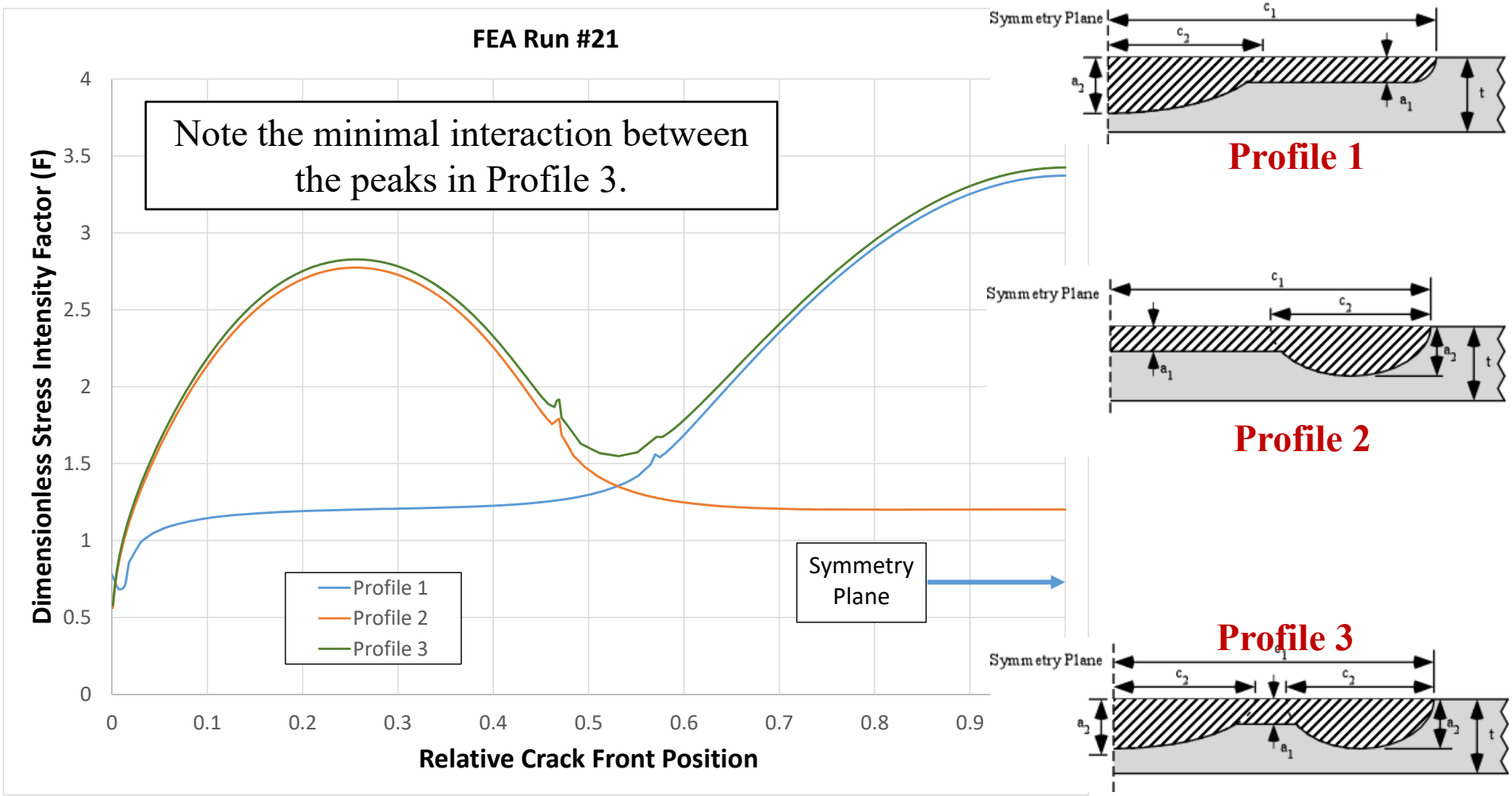
Profile 3



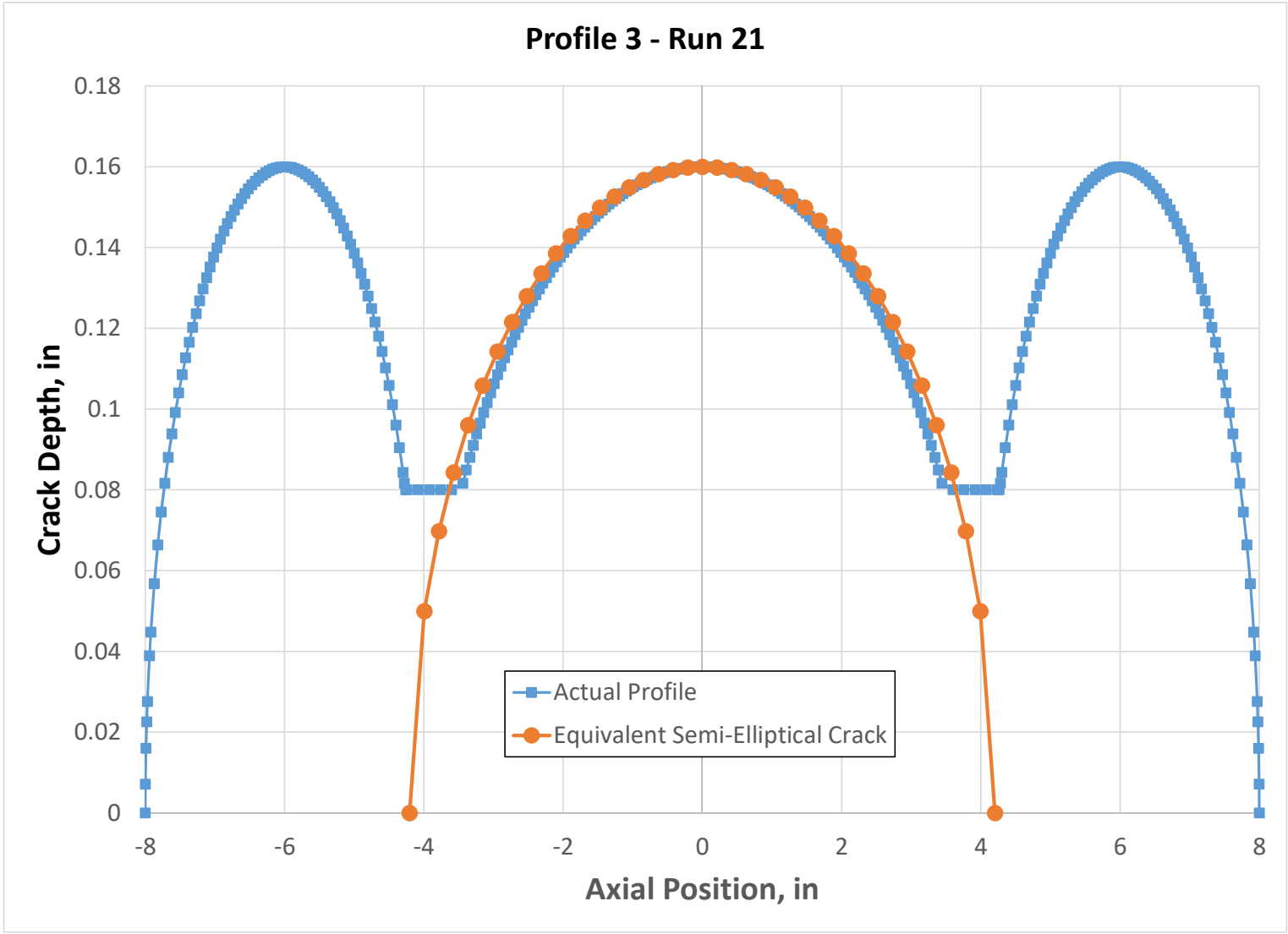
Typical FEA Mesh
Profile 1



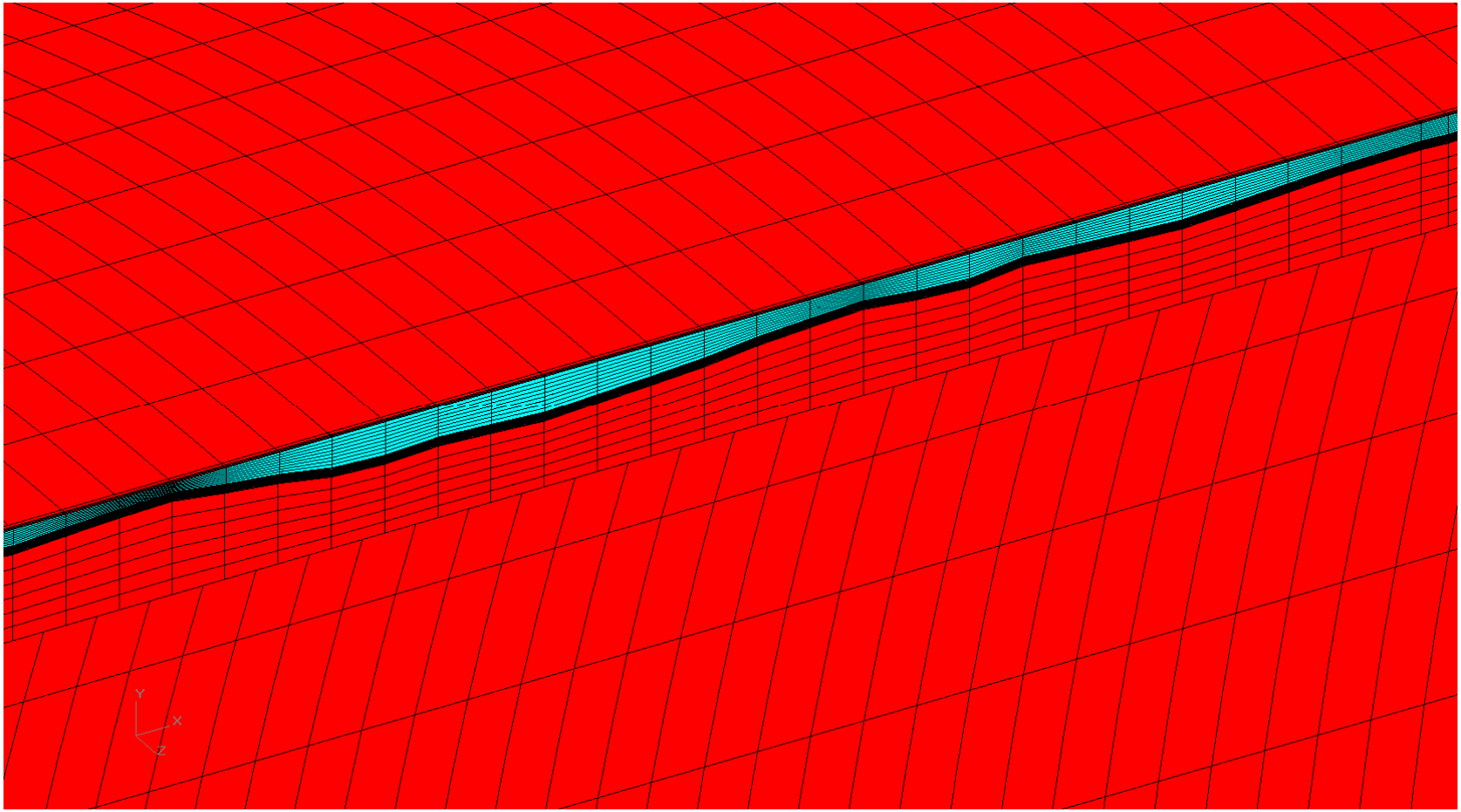
Elastic Stress Intensity Factor



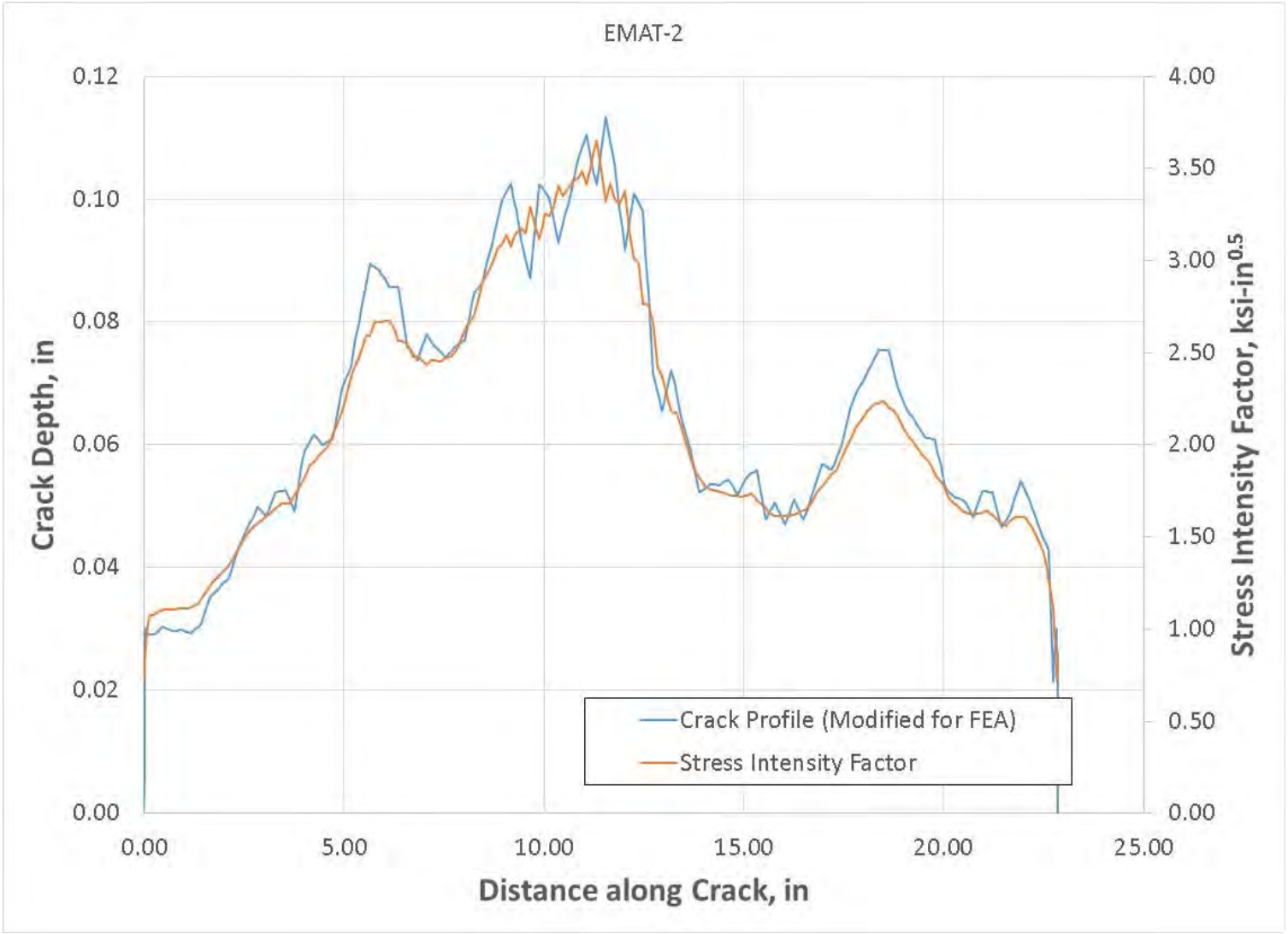
Equivalent Elliptical Crack
Matches the Peak K_I for the Profile



FEA Simulation of Crack Profiles from ILI

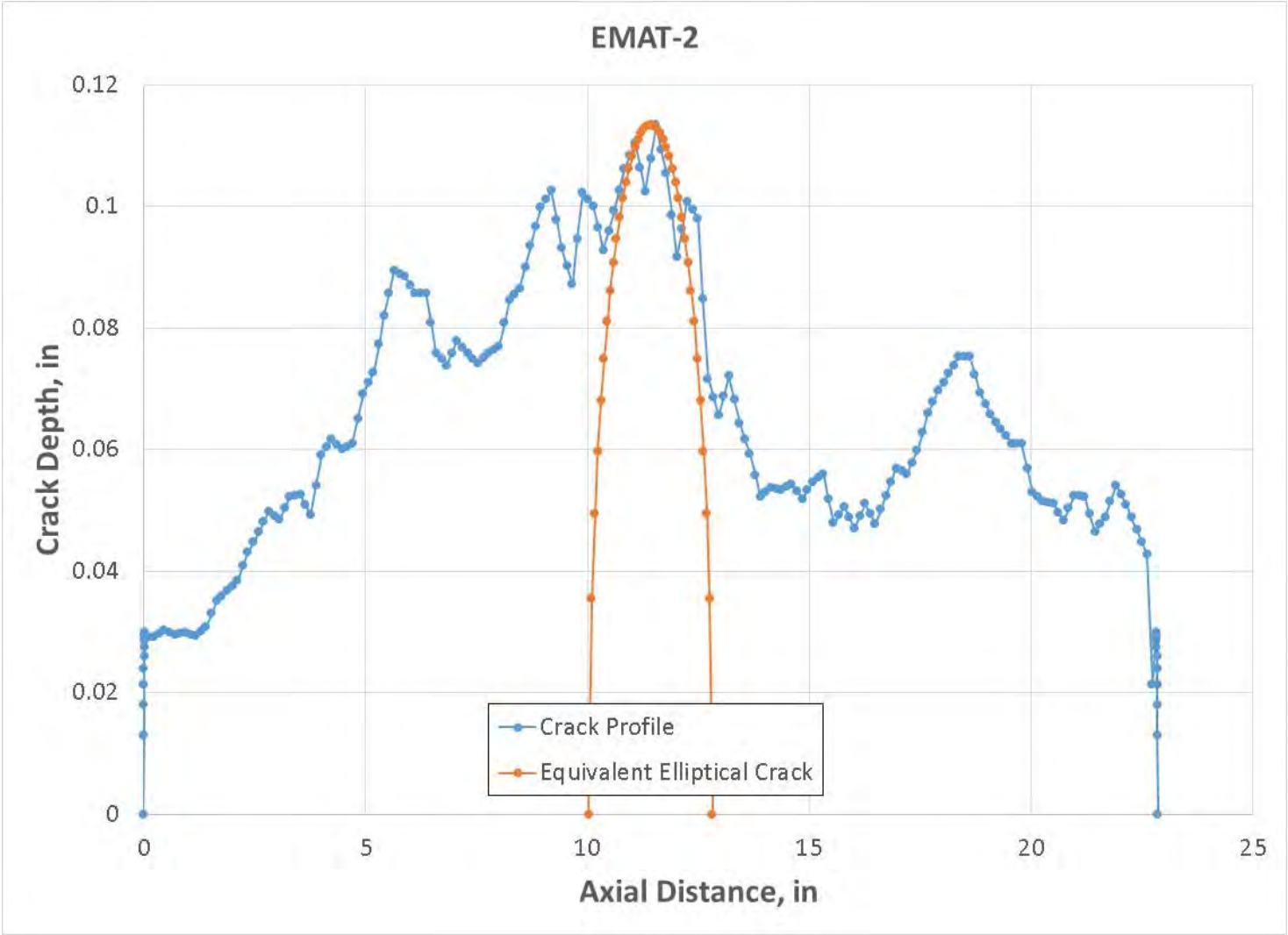


Real Flaw Profile from ILI
K_I Along the Crack Front

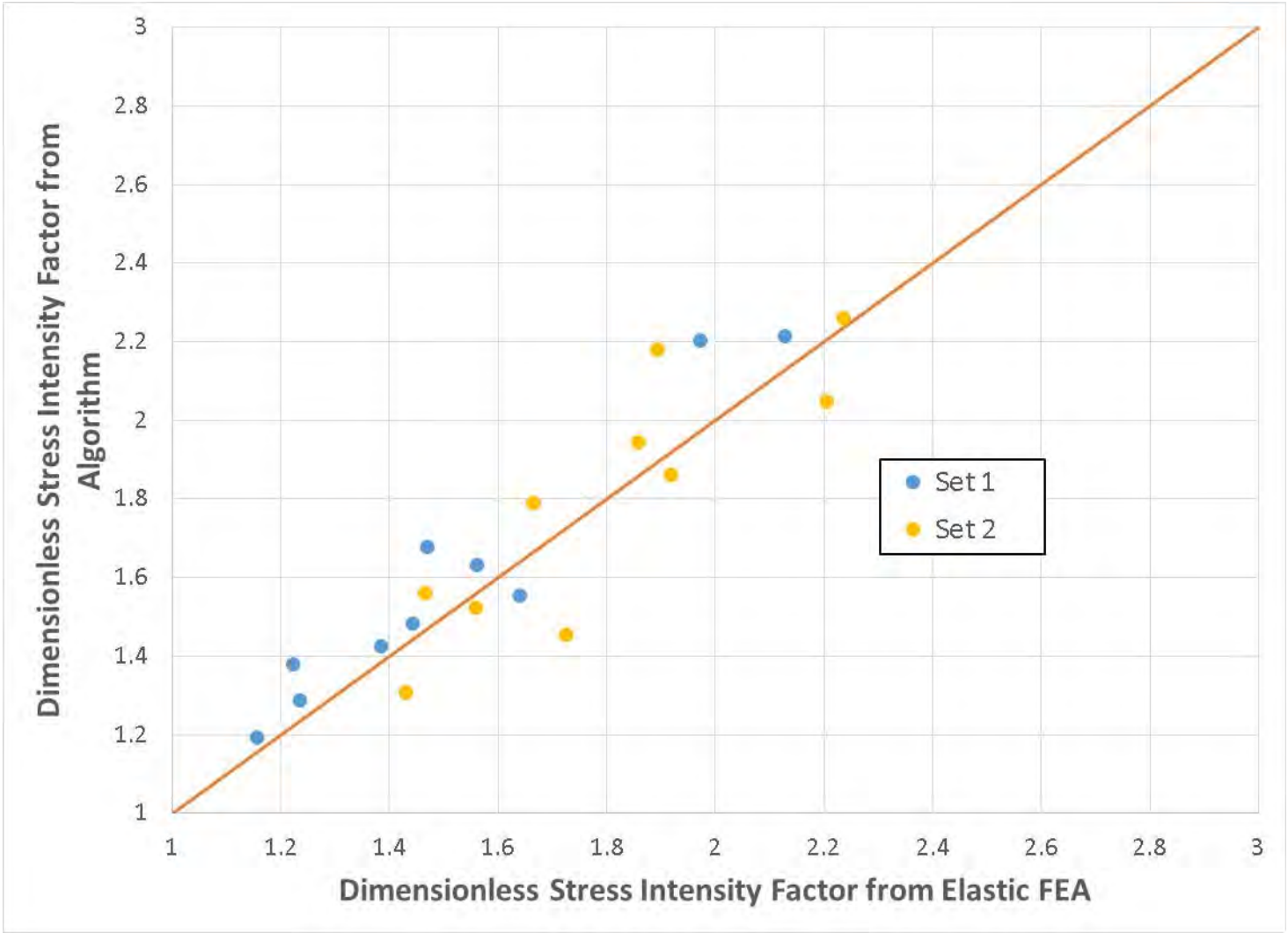


Real Flaw Profile from ILI

Equivalent Elliptical Crack based on Peak K_I



Algorithm to Estimate Equivalent Elliptical Crack Real Profiles from ILI



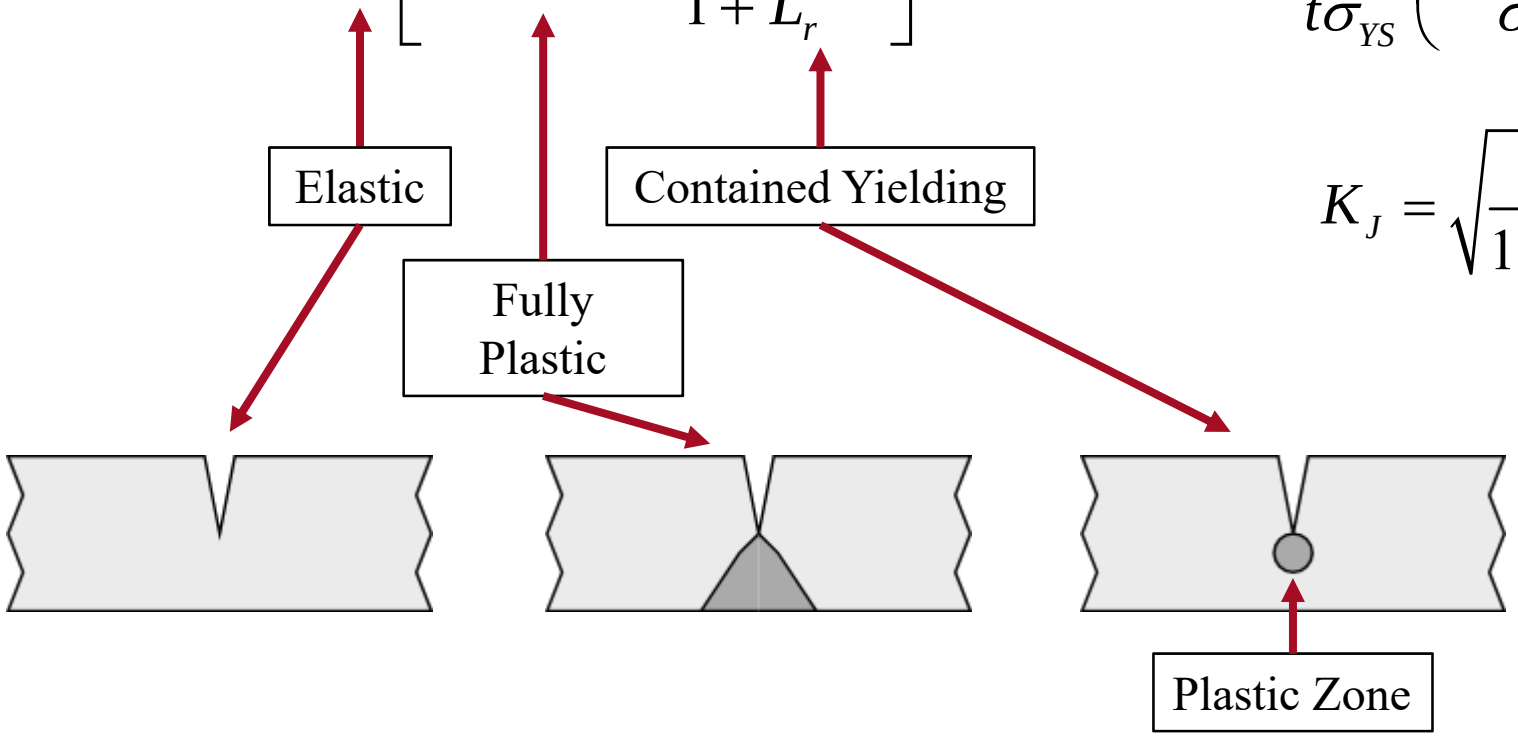
Elastic-Plastic Crack Driving Force
Original MAT-8 Equation

- **Applied J-Integral:**

$$J_{tot} = J_{el}\left[1 + L_r^{n-1} + \frac{\beta L_r^{2}}{1 + L_r^{n-1}}\right]$$

$$L_r = H\frac{pR_i}{t\sigma_{YS}}\left(\frac{0.002E}{\sigma_{YS}}\right)^{\frac{1}{n-1}}$$

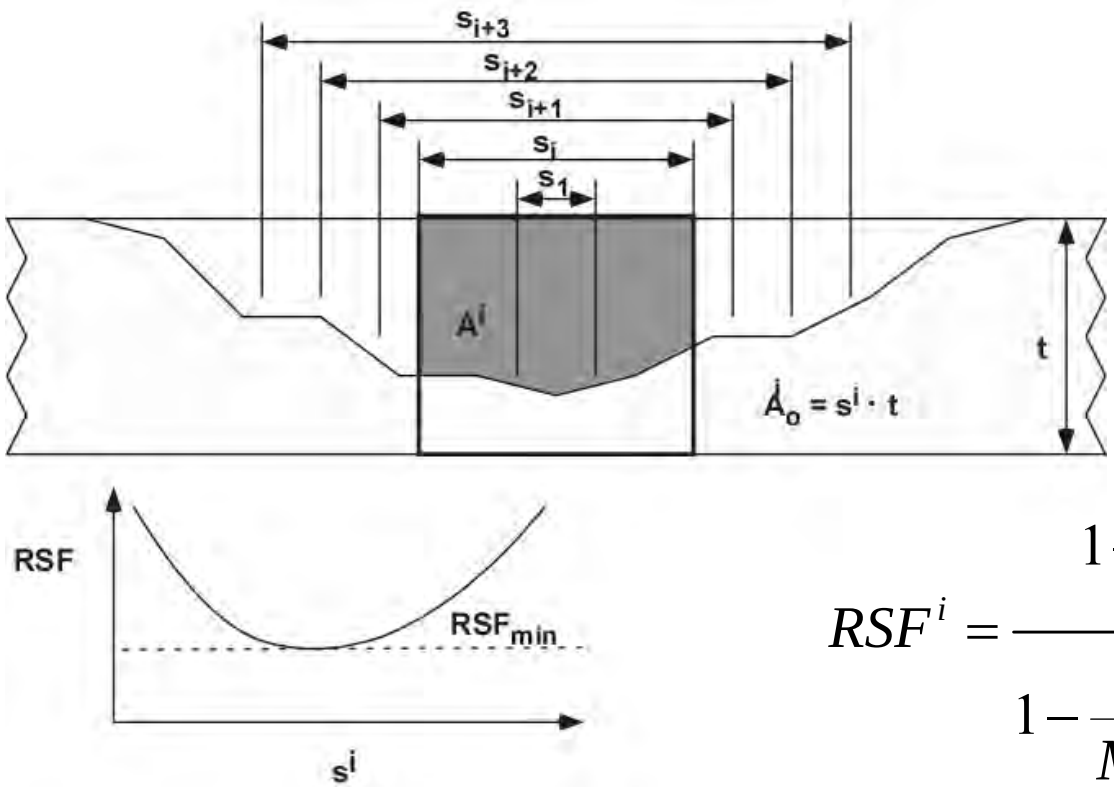
$$K_J = \sqrt{\frac{JE}{1-\nu^2}}$$



Fully Ductile Rupture

The Effective Area Criterion Governs Burst Pressure in the Fully-Plastic Regime

- **Effective Area Remaining Strength Factor (RSF):**



$$RSF^i = \frac{1 - \frac{A^i}{A_o^i}}{1 - \frac{1}{M}\left(\frac{A^i}{A_o^i}\right)}$$

Modified MAT-8 Equation

- **Incorporate Effective Area RSF in the Fully-Plastic Regime**

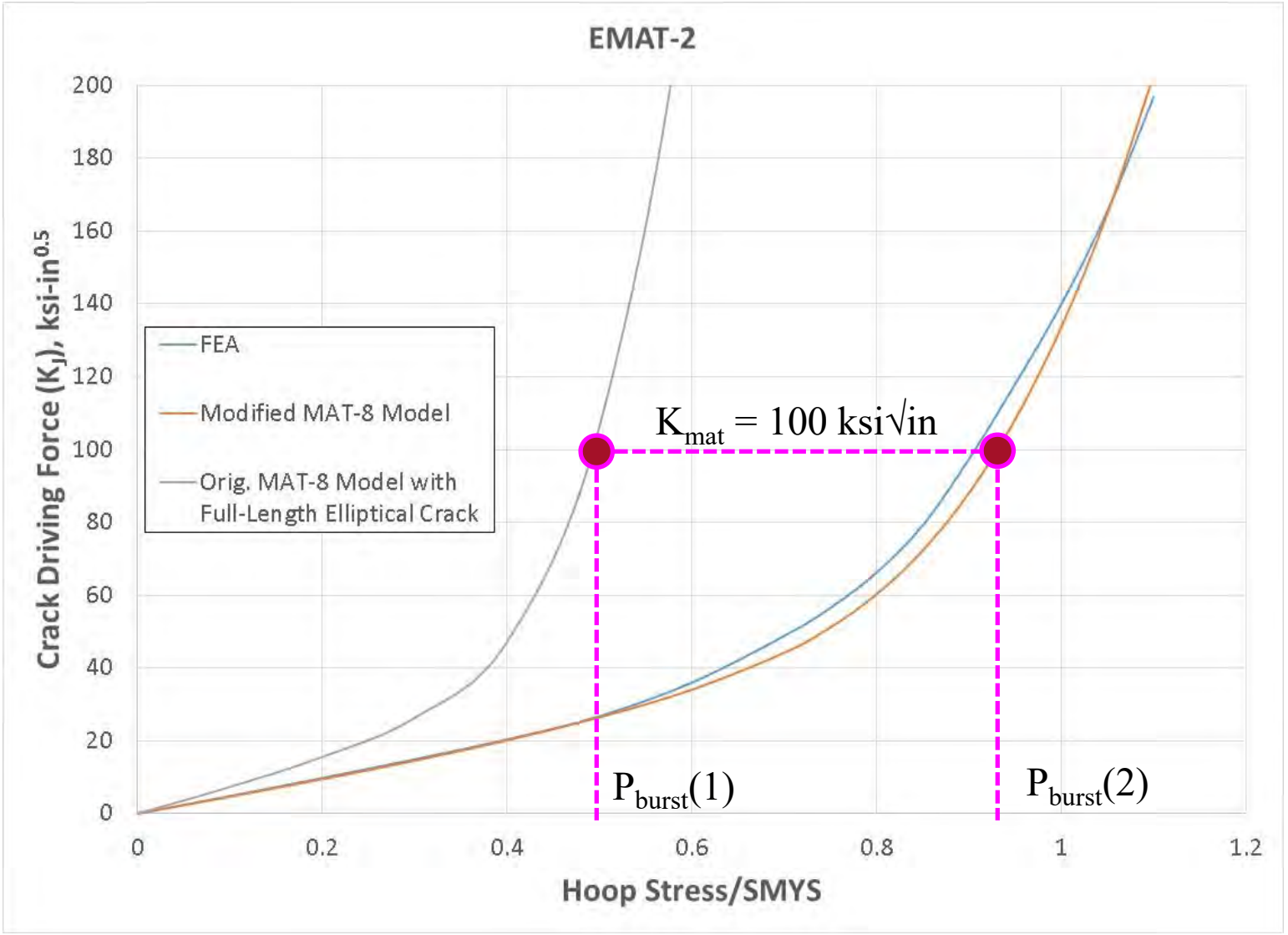
$$J_{tot} = J_{el}\left[1 + S_r^{\,n-1} + \frac{\beta L_r^{\,2}}{1 + L_r^{\,n-1}}\right]$$

$$S_r = \frac{1}{RSF}\left(\frac{pR_i}{t\sigma_{YS}}\right)C_1\left(\frac{E}{\sigma_{YS}}\right)^{C_2}$$

$$C_1 = -0.0028n^2 + 0.0896n - 0.0707$$

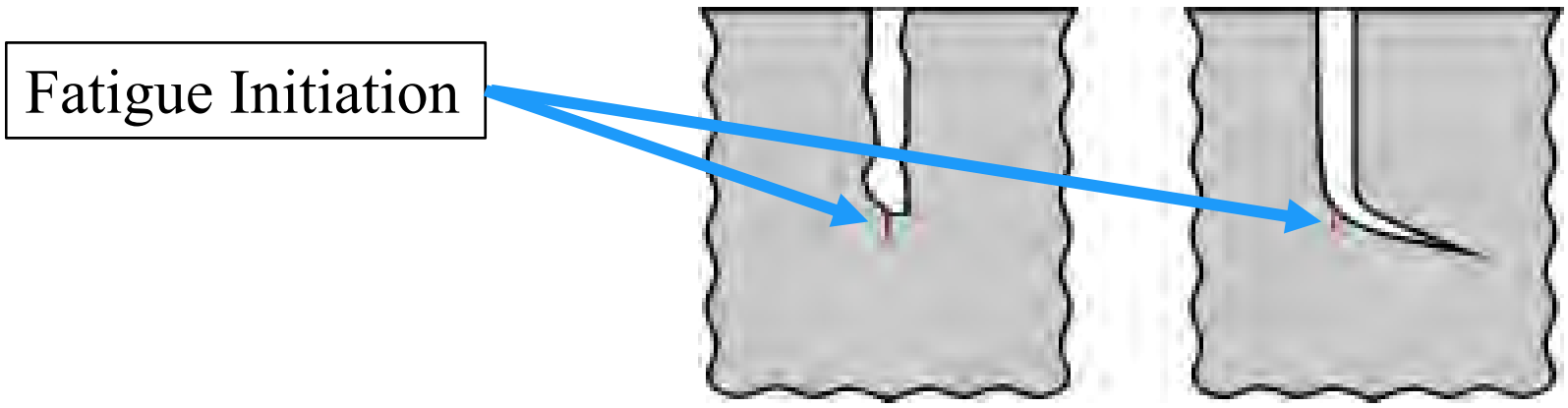
$$C_2 = \frac{1.4897}{n^{1.241}}$$

Benchmarking the Modified MAT-8 Eqn.



Fatigue-Induced Flaw Sharpening

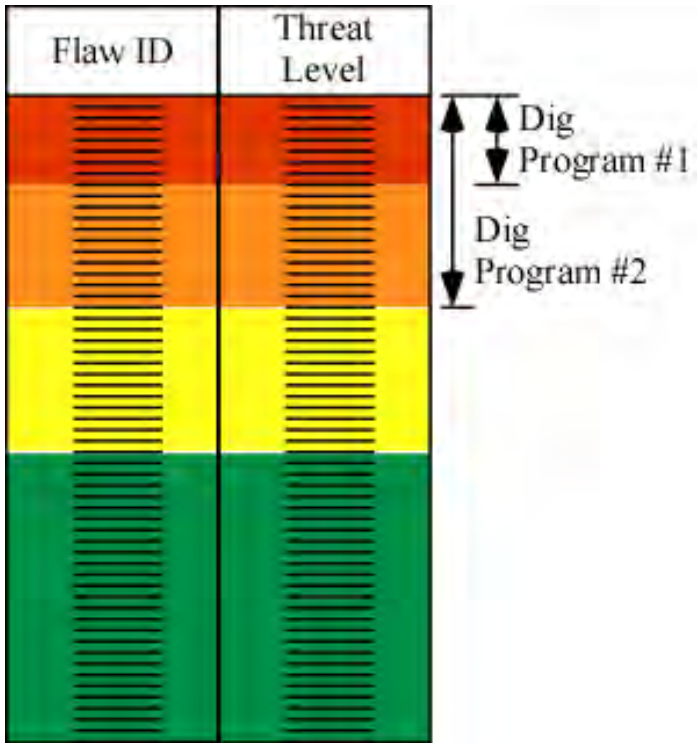
- Typical seam weld anomalies created during manufacturing have blunted tips (e.g. cold welds) or are not planar (e.g. hook cracks).
- Fatigue cracks initiate at manufacturing flaws after sufficient pressure cycles. This can result in an abrupt drop in burst pressure.
- Pressure cycle-induced sharpening can be handled probabilistically.



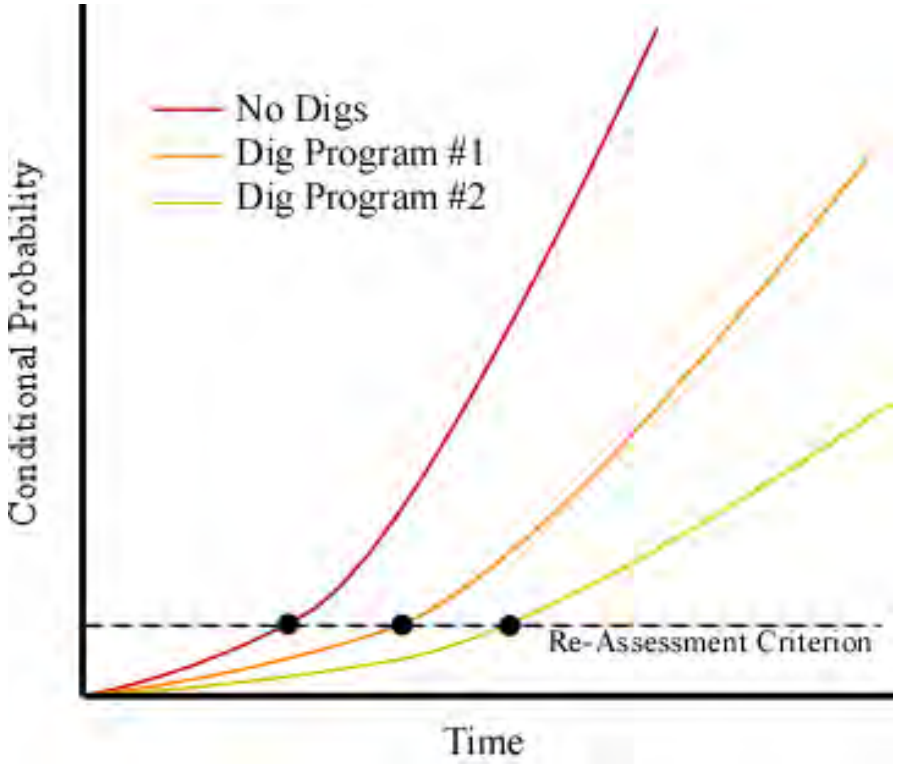
Probabilistic Assessment of ILI Data

- **Trade-off between the number of digs and the re-assessment interval.**

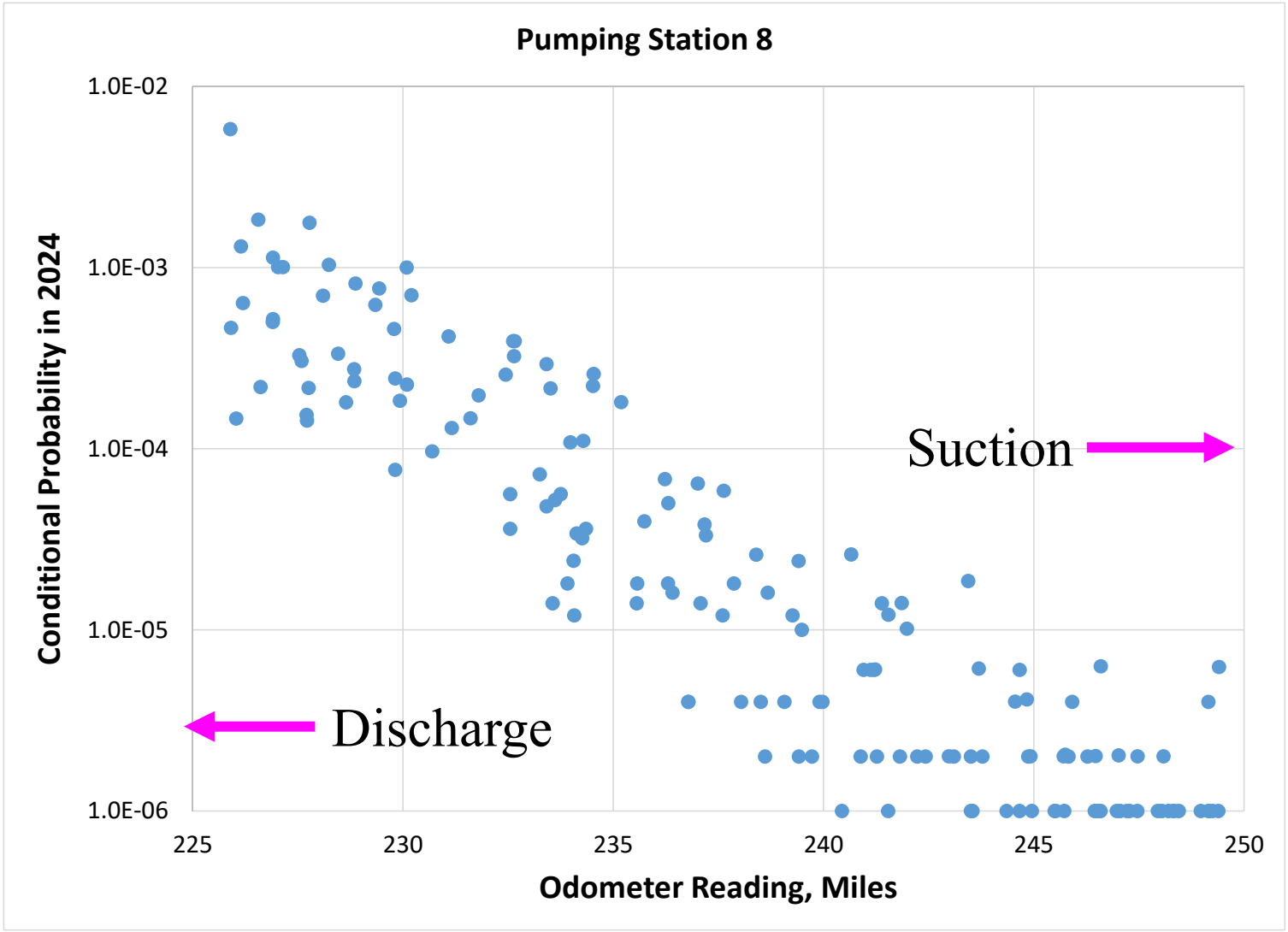
Probabilistic Flaw Prioritization



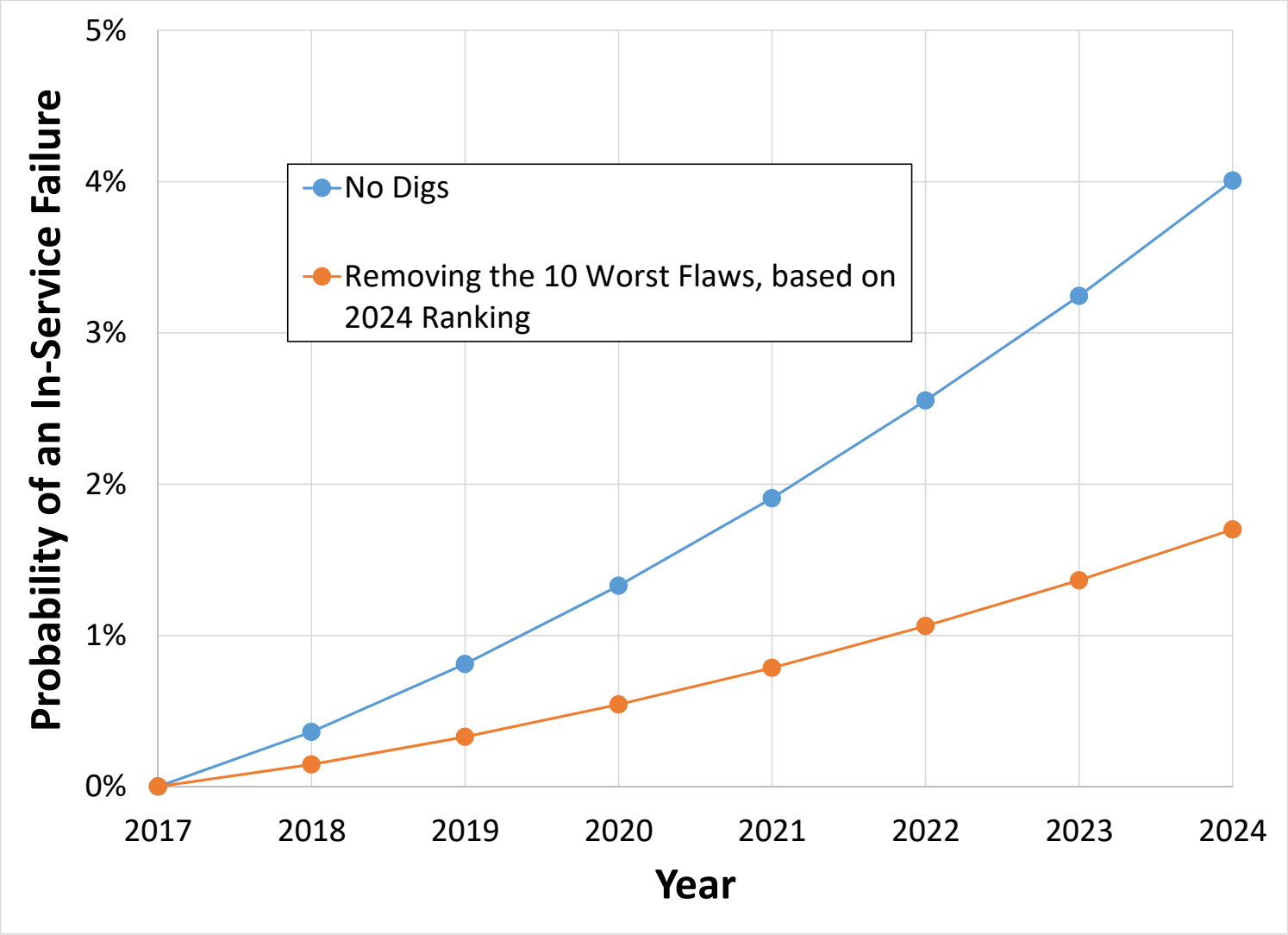
Probabilistic Fatigue Analysis



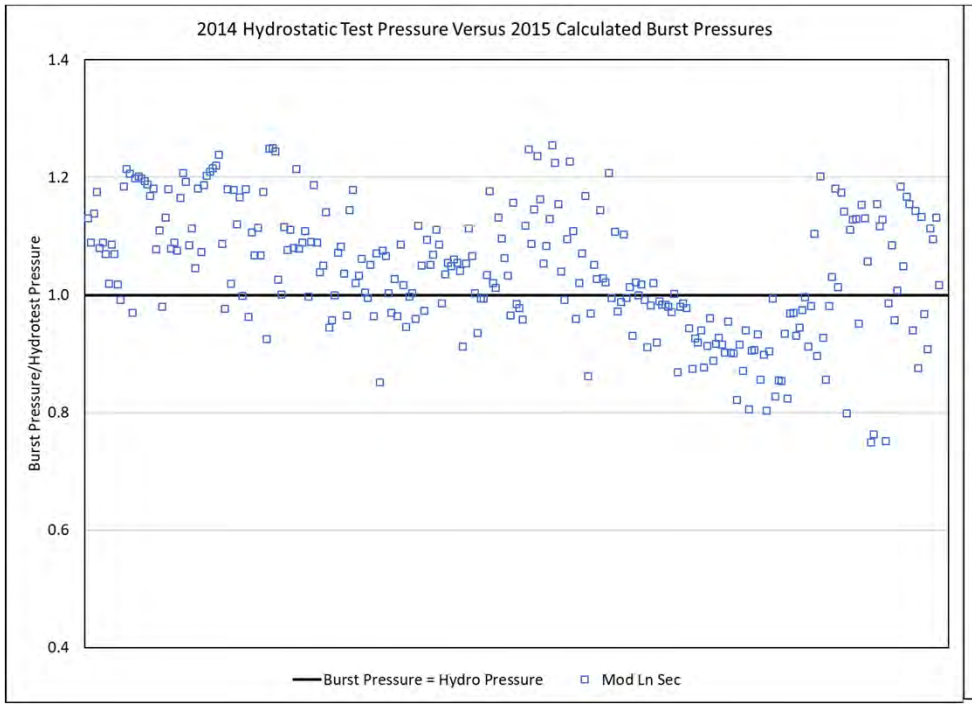
Conditional Probability of Individual Flaws
Correlation with Relative Position

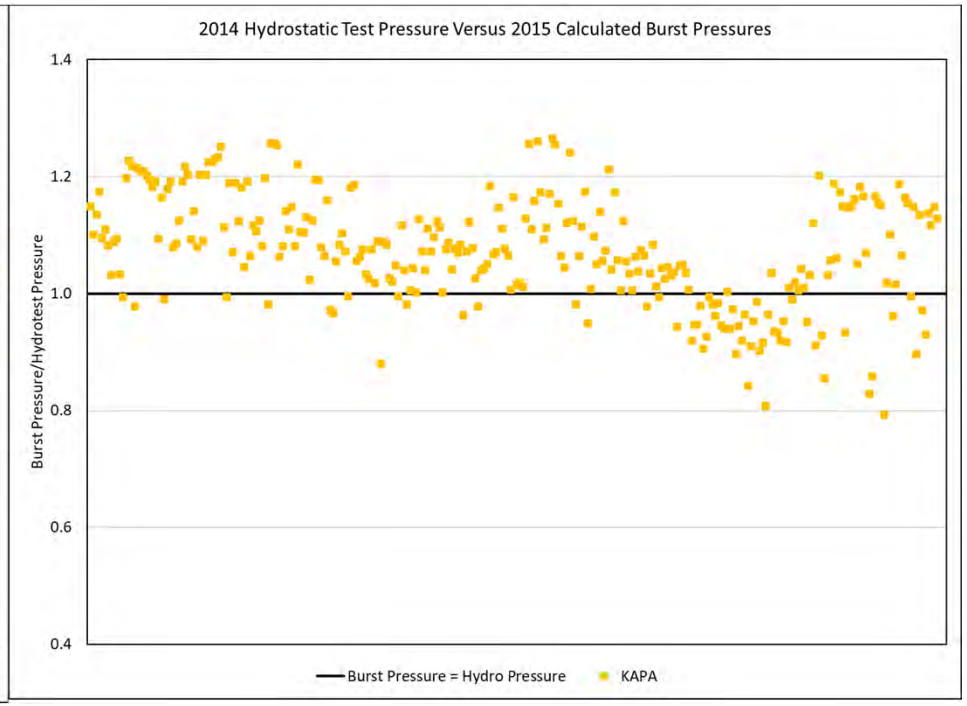


Effect of Digs on Future Risk



Case Study 1 – Comparison of P_{burst} Estimates (Flint Hills Resources)





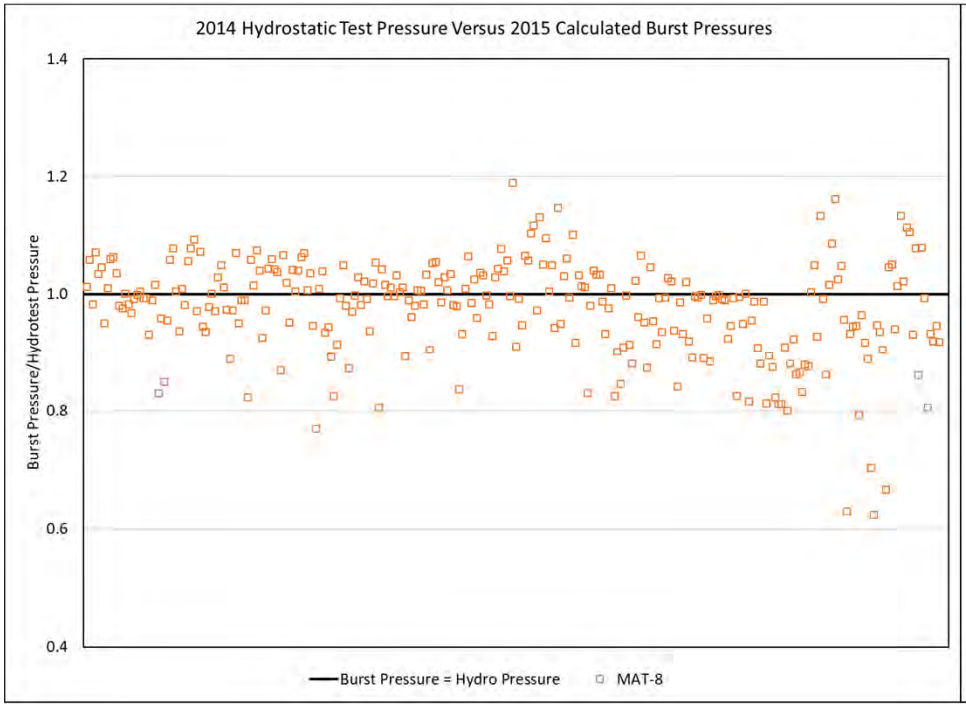
<u>Mod. Log-Secant</u>

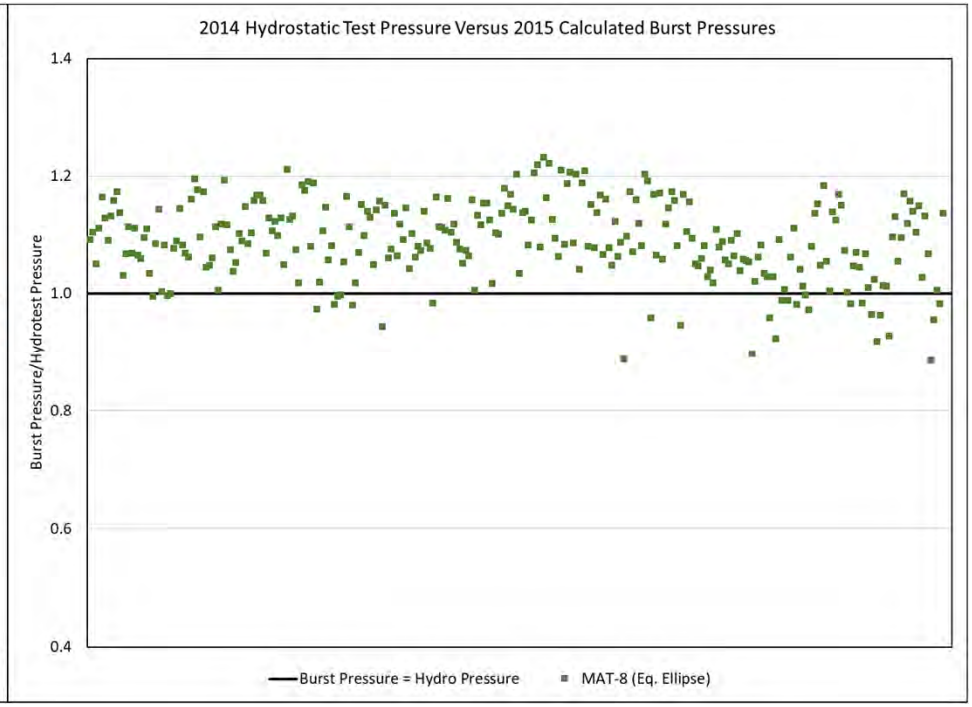
Predicted P_{burst} falls below hydro pressure in 110 cases (38%)

<u>KAPA</u>

Predicted P_{burst} falls below hydro pressure in 63 cases (38%)

Case Study 1 – Comparison of P_{burst} Estimates (Flint Hills Resources)





Orig. MAT-8

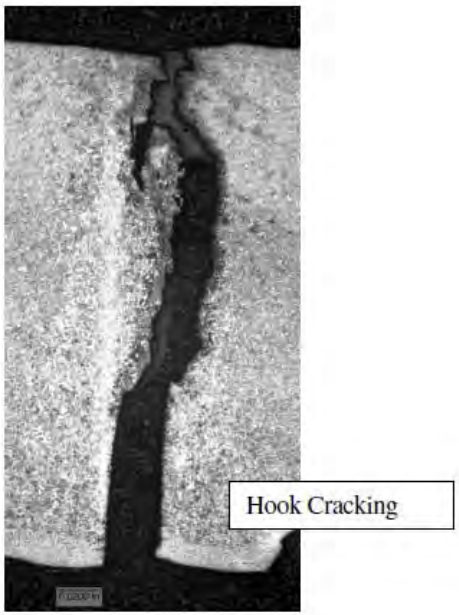
Predicted P_{burst} falls below hydro pressure in 168 cases (58%)

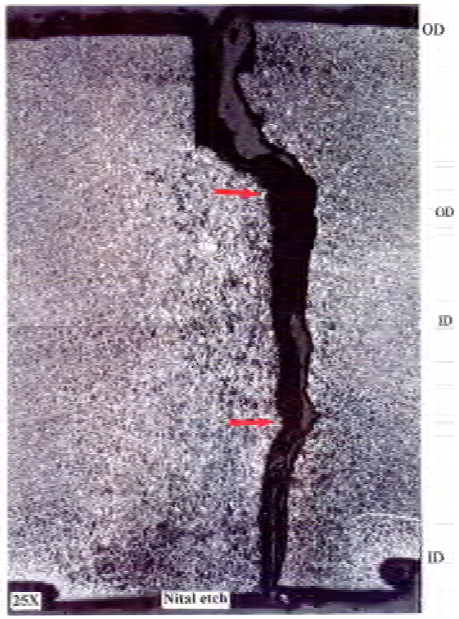
Mod. MAT-8

Predicted P_{burst} falls below hydro pressure in 29 cases (10%)

Case Study 1 – Comparison of P_{burst} Estimates (Flint Hills Resources)

Hydrostatic Test Failure #1





Hydrostatic Test Failure #2

Case	Actual P_{burst}, psi	Mod. LS P_{burst}, psi	KAPA P_{burst}, psi	Mod. MAT-8 P_{burst}, psi	
				Median Toughness Estimate	5% Lower-Bound Toughness
Failure #1	1330	1576	1583	1358	1261
Failure #2	1326	1492	1487	1377	1290

Case Study 2 – Probabilistic Assessment of ERW Seam Anomalies (Shell Pipeline)

- **6-mile long section.**
- **1958 low-frequency ERW Pipe from Republic Steel.**
- **16-inch OD, 0.25-inch wall, grade X52.**
- **Historical MOP = 960 psi.**
- **MOP recently reduced to 496 psi**
- **2018 UTCD results:**
  - 5 reported “crack-like” features.
  - 232 reported “mill anomaly” features.
  - 579 reported “weld anomaly” features.
- **All 816 Features were treated as crack-like in a probabilistic assessment.**
- **Flaw shape assumptions:**
  - Use the modified MAT-8 model on features where profile data was available.
  - Assume full length elliptical flaws for all other features.

Case Study 2 – Probabilistic Assessment of ERW Seam Anomalies (Shell Pipeline)

- **Probabilistic model assumptions.**
  - 60 prior years of operation at 960 psi.
  - Future operation at 496 psi.
  - Account for time-dependent damage from pressure cycling.
  - Using the concept of conditional probability, account for the effect prior successful operation (no failures in 60 years) on future risk.
  - 400,000 Monte Carlo trials x 816 features = 326,400,000 total trials.
- **Results**
  - Only **one** failure was predicted over the next ten years in 326,400,000 trials. (Failure probability ~1:300 million).
  - The combination of the MOP reduction and light pressure cycling results in negligible risk of failure over the next ten years.

Pipeline Research Council International, Inc.

PRCI Project: PRC-328-133702 (MD-1Q)

Full Scale Fatigue Testing of Crack-in-Dent and Development of Frame Work for Remaining Life Prediction

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Abstract

ASME B31.8 states that “Dents that contain stress corrosion cracking or other cracks are injurious to the pipeline” and therefore, requires immediate attention by the Operators. Dent containing crack fields (colonies) are often observed in liquid pipelines. The recently completed PRCI research project MD-1N “Study of the Mechanism for Cracking in Dents in a Crude Oil Pipeline” showed evidence of a combined mechanism of corrosion pitting and fatigue cracking from the fracture surface examination. Further, an attempt was made to estimate the crack growth rate as a function of stress intensity factor (K) using a fractographic (fatigue striation) based approach. However, due to lack of full-scale fatigue crack growth data, the success was limited.

This gap prompted PRCI to launch a further study (PRC-328-133702, MD-1Q) of full-scale experimental investigation of dent containing crack colonies under cyclic pressure to determine the crack growth rate. A combined micro-and macro-mechanics approach and FEA are used to establish a framework for remaining fatigue life prediction of cracks in dents in liquid pipelines. This would benefit Operators to better manage integrity of dents associated with corrosion fatigue cracking and mitigate in a timely manner incorporating with in-line-inspection (ILI) using combined dent geometry and crack tools.

Abstract (Cont'd)

A total of 6 pipe samples containing dents with cracks/corrosion excavated from a retired liquids transmission pipeline were used for the full-scale fatigue tests. The experimental test setup consists of four major components: (1) a computer-controlled hydraulic pressure cycling system, (2) an environment chamber containing NS4 solution mounted on the dent region to simulate field environment condition; (3) a crack growth monitoring system including Direct Current Potential Drop (DCPD), Clip gage and Strain gage; and (4) data acquisition and real-time data monitoring system. The cyclic pressure range used in the test was 78 to 780 psig (MOP = 72% SMYS) with R=0.1 based on historical operational pressure data & Rainflow/Miners Rule, and frequency of 0.0526 Hz (i.e., 19 sec a cycle).

The results from these six full-scale fatigue tests showed the cracks in dents exhibit leak-before-rupture behavior, which is predicted based on fracture mechanics using material toughness and through-wall crack size. However, subsequent pressure cycling after the leak could cause a rupture when the crack approaches to its critical size for rupture which was observed in one of the six tests.

Moreover, using historical operational pressure fluctuation data and the number of cycles to failure (leak or rupture) obtained from the present full-scale fatigue tests, the remaining in-service life for these six tested dents with cracks can be calculated and are presented. By combining micro-and macro-mechanics approach and FEA work, a framework for fatigue life prediction is being established and demonstrated with an example.

Outline

1. **Background** – Findings from MD-1N “Study of the Mechanism for Cracking in Dents in a Crude Oil Pipeline”
2. **Objective & Scope of Work** - MD-1Q “Full Scale Fatigue Cyclic Testing for Development of Frame Work for Life prediction for Crack-in-Dent in Liquid Pipelines”
3. **Experiment**: Full scale cyclic fatigue tests
   - Instrumentation, System development and Test results
4. **Experimental Data Analysis** – Cycles to failure and remaining in-service life estimate
5. **Macro Mechanic Analysis** – Fatigue crack growth rate da/dN
   - da/dN calculated from the DCPD (Macro)
6. **Finite Element Analysis** – K-solution and ΔK, $\ln(\Delta K)$ vs $\ln(da/dN)$
   - Example - Pipe#2 Test
7. **Micro Mechanic Analysis** – Local fatigue crack growth rate da/dN
   - da/dN estimated from fatigue striations (Micro)
   - Compare da/dN (Macro vs. Micro)
8. **Summary and work-in-progress**
9. **Value to Operators**

Background - MD-1N

Study of the Mechanism for Cracking in Dents in a Crude Oil Pipeline

- 24” crude oil pipeline, 0.250” wall, grade X52
- Constructed in 1973
- Asphalt enamel coating

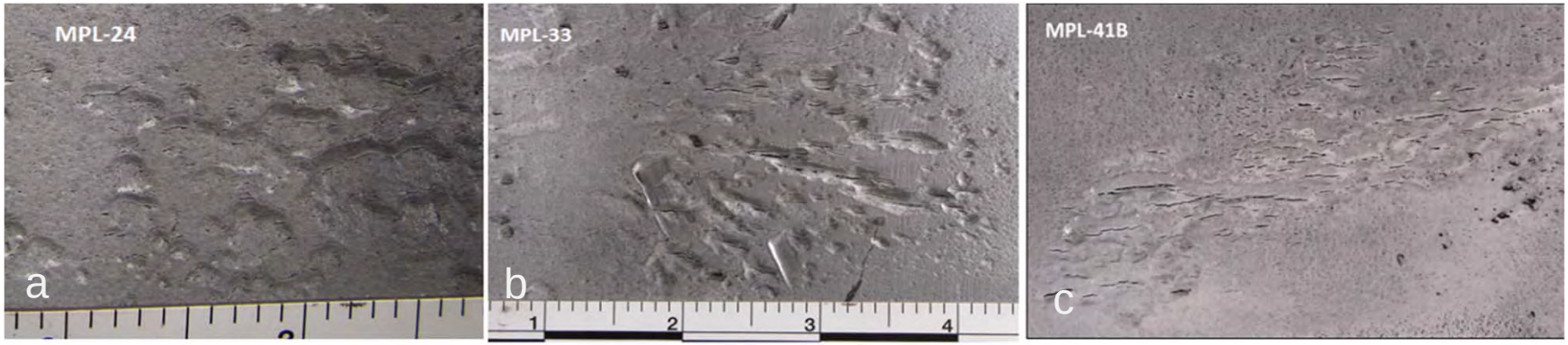
- Pipe manufactured by Republic, DSAW
- High Diameter vs. Wall Thickness ratio (D/t=96)
- 265 miles, more than 7000 dents, mostly shallow and at the bottom of the pipe

- 27 miles replaced in 2012, 11 of the 17 releases happened there
- Releases related to dents with cracks
- Failing dents are “shallow”
- Cracking mechanism in dent was not known at that time

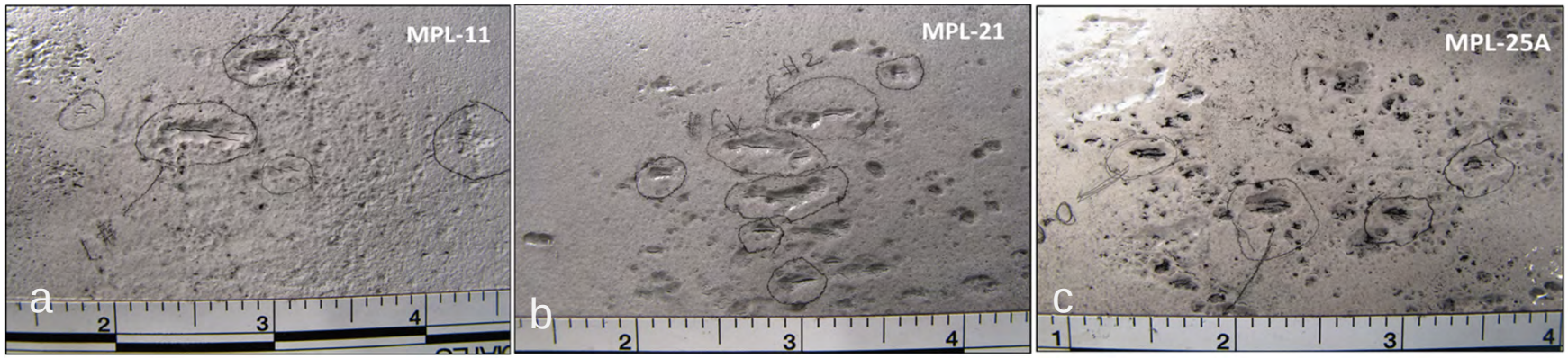
Background (Cont'd) – MD-1N

Six pipe samples containing dent with cracks were selected for MD-1N Study

Sleeved Dents with Pits and Cracks



Recoated Dents with Pits and Cracks

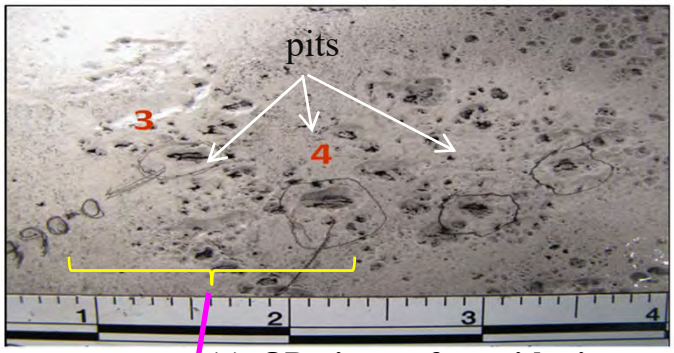


A total of 6 pipe samples containing dent with cracks/corrosion were investigated

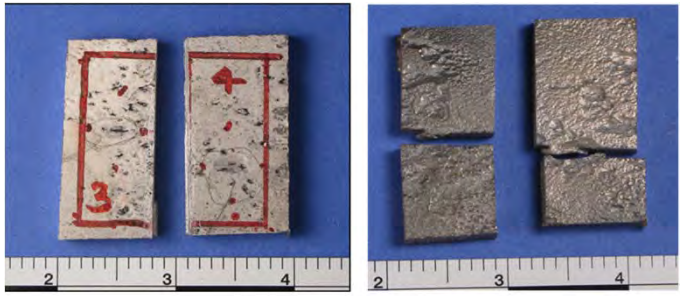
Background (Cont'd) MD-1N

MD-1N Study found well defined fatigue striations in 4 of 6 dent with crack samples. Other 2 samples showed evidence of fatigue striations but with heavily corroded crack wall

Example: Fatigue Striations observed MPL 25A

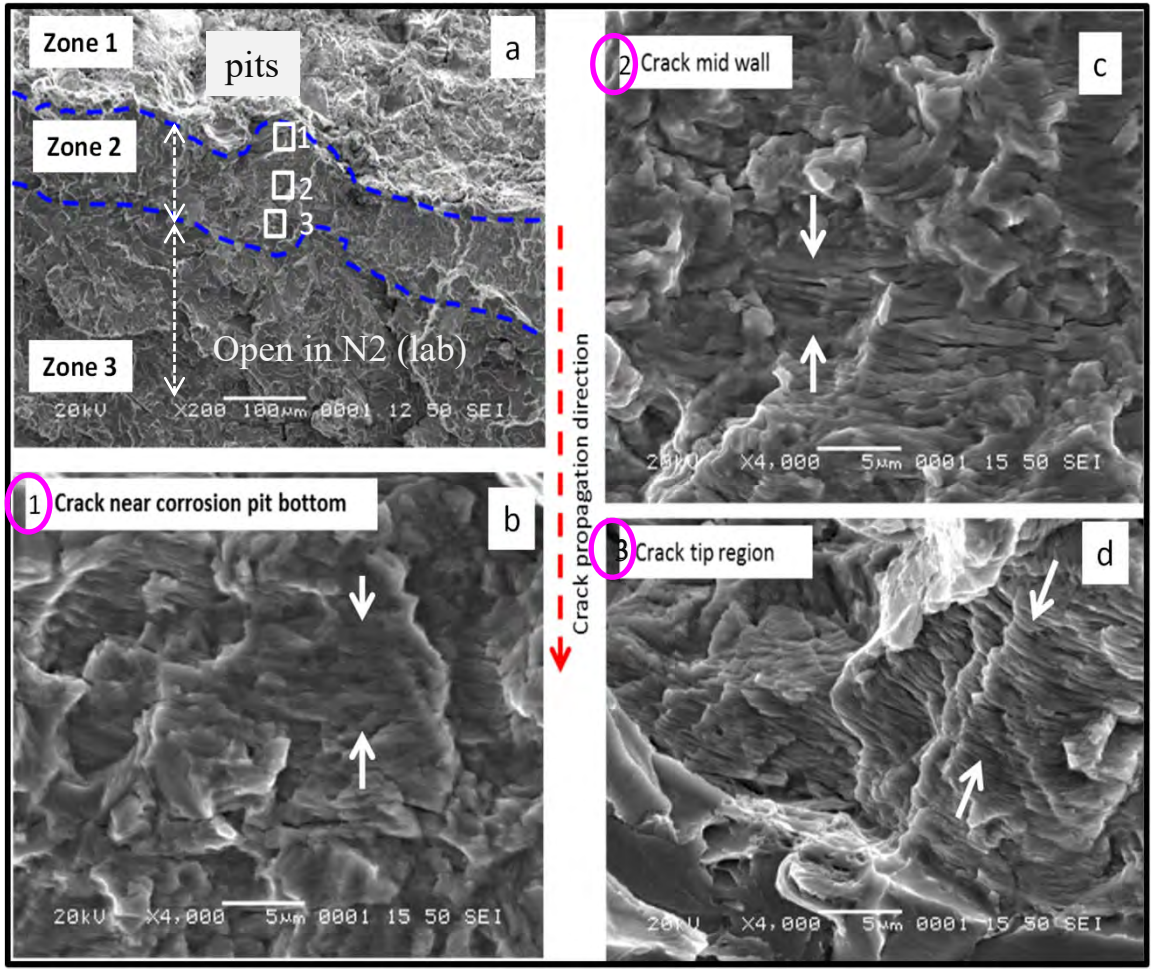


(a). OD pipe surface with pits



Crack Coupon 3 and 4

(b). Before Cleaning (c). After Cleaning



Background (Cont'd): MD-1N Findings

Cracking mechanism (initiation & propagation) in dent

- Corrosion pits are the initiation sites for cracks in dent (cracks in dent are all associated with pits but not all the pits had cracks)
- Growth of cracks in dent is driven by corrosion fatigue
- No evidence of SCC mechanism

Questions arising from this MD-1N Study:

- How to calculate the remaining life of dent with crack/corrosion?
- What is the fatigue crack growth rate in dent?
- How does the environment impact crack growth rate in dent?

MD-1Q Study

"Full Scale Fatigue Testing of Crack-in-Dent and Development of Frame Work for Remaining Life Prediction"

Approach and Objective

- Conduct Six Full Scale Fatigue Cyclic Pressure Tests & Calculate the remaining in-service life
- Calculate the fatigue crack growth rate using a combined macro- and micro-mechanics approach
- Establish a framework for life prediction of cracks-in-dents for liquid pipelines

MD-1Q – Workscope & Current Status

Tasks	Description	Current Status
1	Selection of 6 dent samples for fatigue testing	Completed
2	Detailed review of the existing corrosion initiation and kinetic models - Review of PRCI work on models for the prediction of delayed fatigue failure	Completed
3	Initial Test Setup & Perform full scale fatigue testing in air and NS4 solution environment	
	Full scale testing - sample #1	Completed
	Full scale testing - sample #2	Completed
	Full scale testing - sample #3	Completed
	Full scale testing - sample #4	Completed
	Full scale testing - sample #5	Completed
	Full scale testing - sample #6	Completed
4	FEA numerical approach to determine the K-solutions of cracks in dents	Completed
5	Experimentally estimate fatigue crack growth rates (C and m) and striation spacing and determined fatigue crack growth rate as a function of K	In-progress
6	Establish a frame work for predicting remaining life. Submit draft report for comments.	March/ April 2019

Full-Scale Fatigue Test

Six pipe samples containing dents with cracks were tested in 2018. Followed consistent steps:

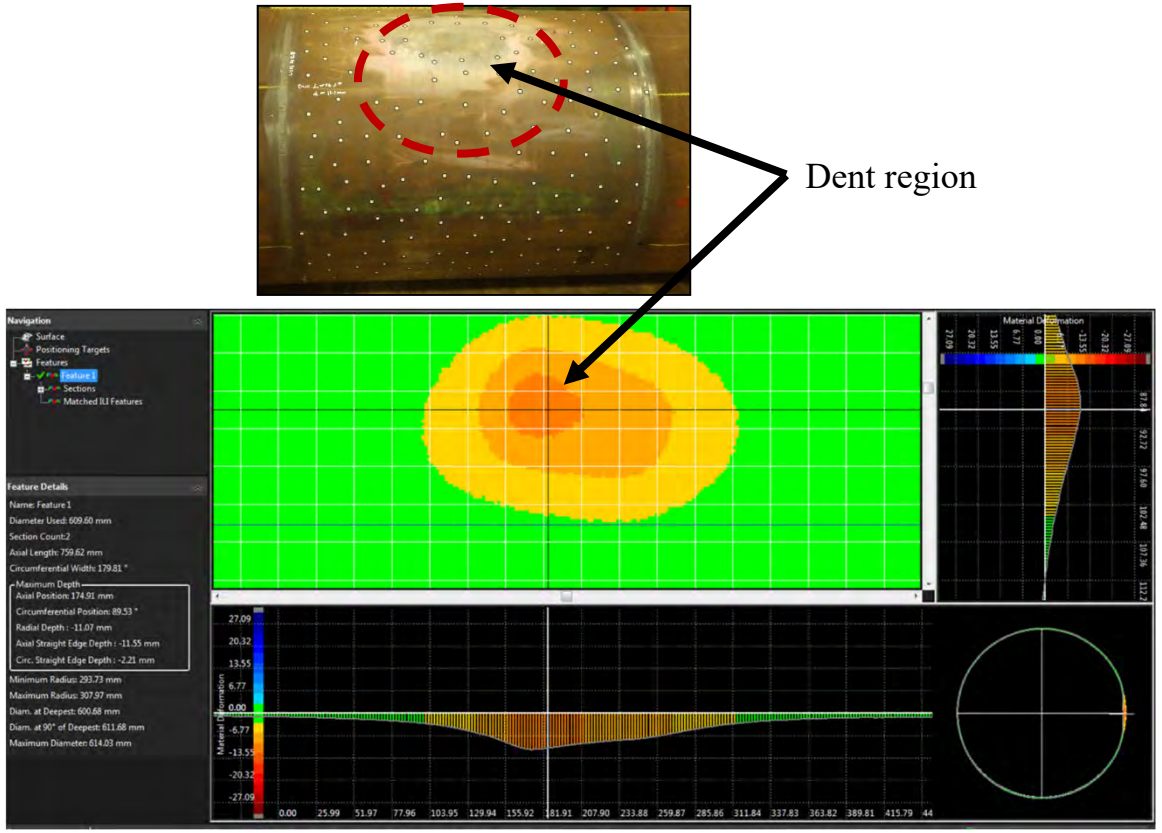
- Laser Scanning of Dent Geometry
- Sample Preparation – NDE, endcaps welding and instrumentations
- Selection of Crack Growth Monitoring System
- Environment Cell (in-air, in NS4 solution)
- Pressure Cycling with water
- Control System & Data Acquisition
- Leak Detection Method
- Post-Processing of Experimental Data (DCPD, Clip Gage, SG)
- Leaked Crack Sample Extraction for Metallurgical Analyses
- Remaining Fatigue Life Calculation

Laser scan to capture dent 3D geometry

3D laser scanning was performed to accurately measure surface defects, metal loss or geometrical deformations of dent, pipe ovality.

With a 3D laser scanner (1x1mm2), one can obtain a complete dent 3D shape with high resolution

- Length = 12.3-inch
- Width = 8.7-inch and
- Depth = 0.452-inch

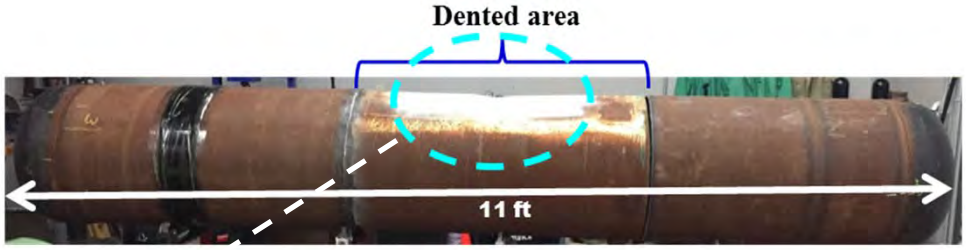


3D dent geometry was accurately captured to be utilized for FEA modeling of dent with crack

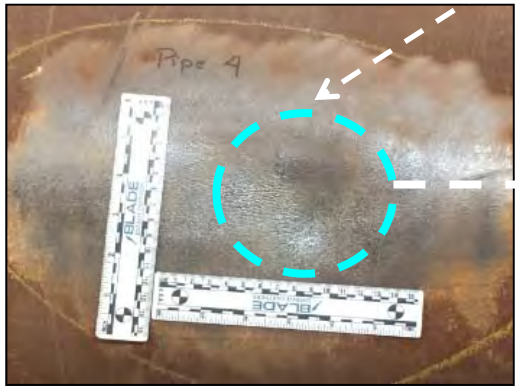
Sample Preparation – Example: Pipe#4

NDE

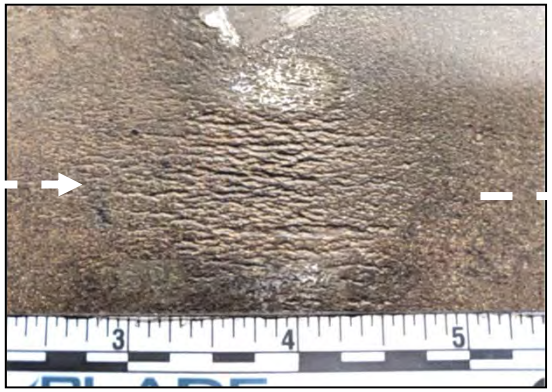
- The pipeline surface was prepared locally prior to NDE inspection and laser scan. Dirt, scale and rust was removed without damaging the pipe surface. Cleaning the area of interest ensures meaningful results.
- Three tiny cracks detected with depth sizing close to NDE detectable threshold.



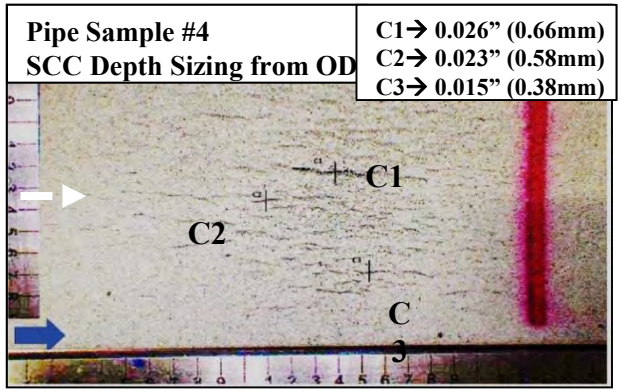
Full-scale pipe prepared for fatigue test



Dent region



Dent with corrosion grooves

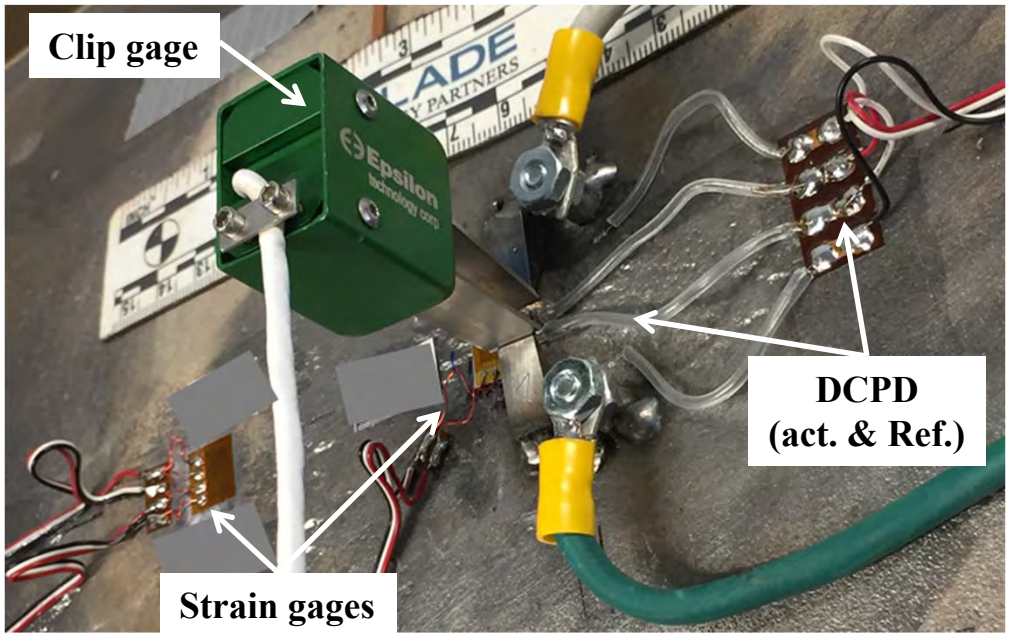


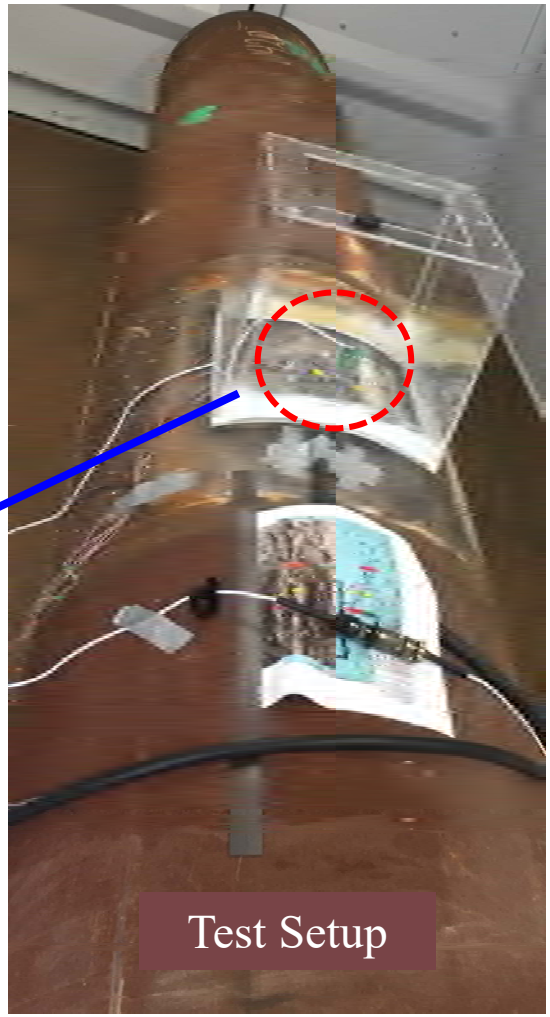
Dent with three tiny cracks (C1, C2, C3)

Crack Growth Monitoring Systems

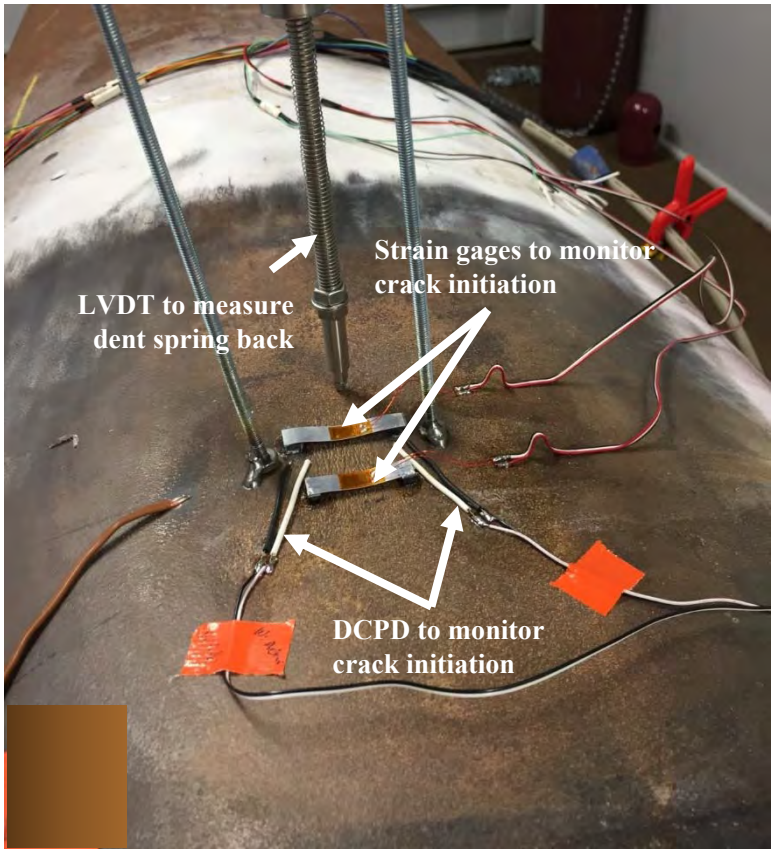
Crack growth was monitored using three different techniques:

1. Direct Current Potential Drop (DCPD) method,
2. Clip gage, and
3. Strain gage

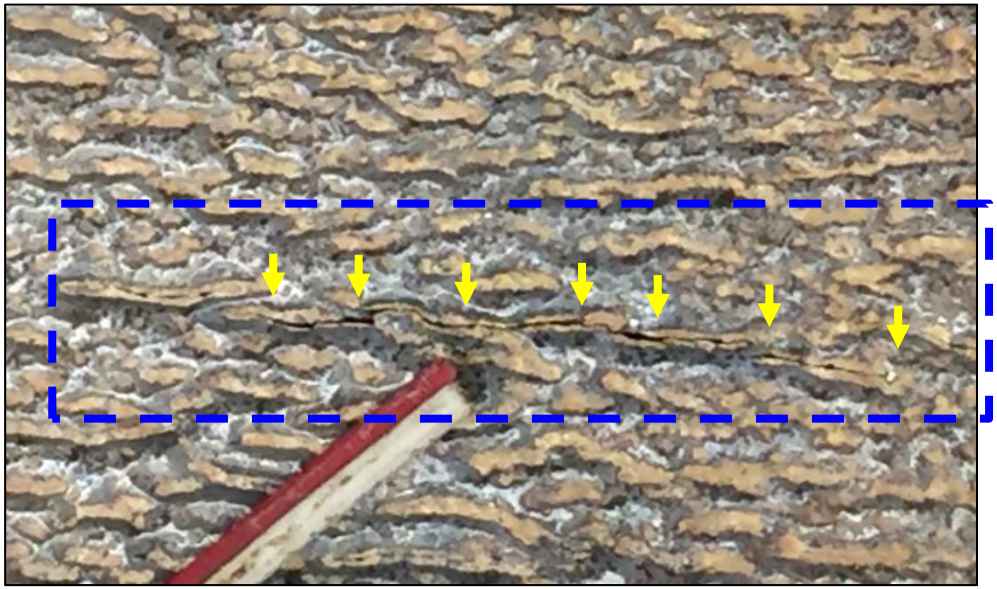




Crack Extension by pressure cycling in air



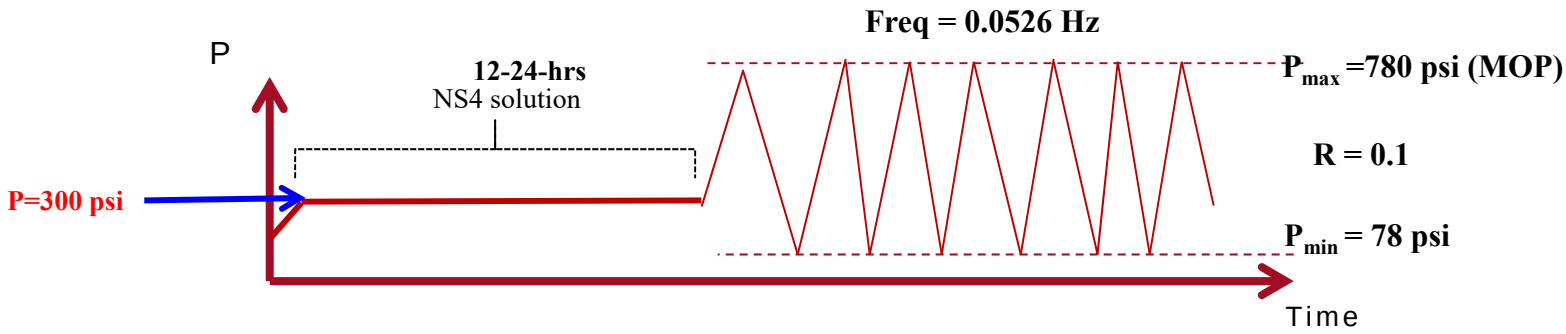
Experimental set-up for crack extension in dent



- Crack extension in air: P_{max}=780psi (@72%SMYS); P_{min}=78psi
- Visible long enough crack observed in the dent region. This helps to place the crack growth monitoring sensors (DCPD, Clip gage) at a right and critical place.

Loading Spectrum - Pressure Cycle

- Before fatigue cyclic, the sample was held under sustained load (constant pressure) around ~40% MOP (~310 psi) just enough stress **allowing the environment to access crack** for 12-24 hours (see figure). Then, the fatigue cycling testing with environment was continued with environment.

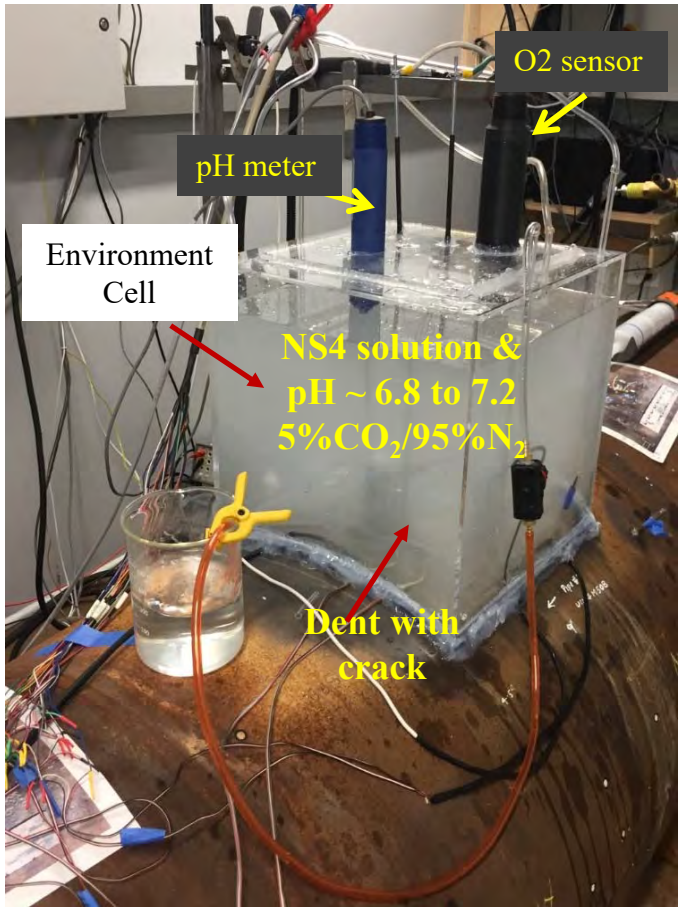


- After the pressure holding, the test was performed with cyclic pressure ranging from 78 to 780 psi (MOP = 72% SMYS) with R=0.1 based on historical operational pressure data & Rainflow/Miners Rule, and frequency of 0.0526 Hz

Liquid (Water) was used in the fatigue test

Procedure for Test – Environment Cell

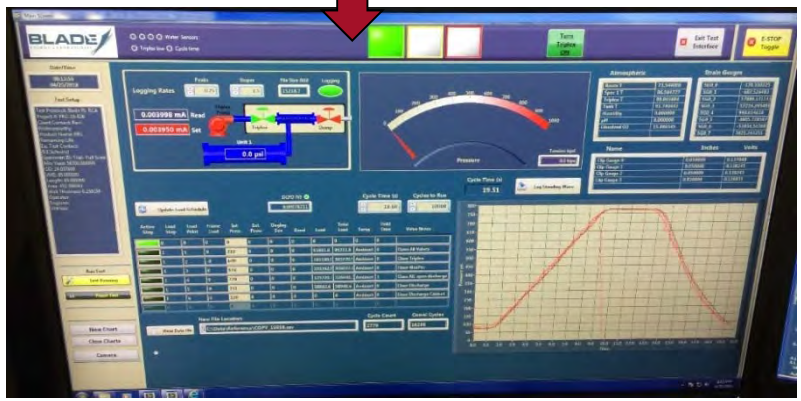
- During the fatigue test in NS4 solution, the environmental cell was securely mounted on the OD pipe surface and well sealed.
- DCPD, Strain gages, and Clip gage were attached on the pipe surface and immersed in environment solution.
- To avoid any galvanic corrosion between strain and clip gages as well welding wires of the DCPD system; special coating was applied on all connection to avoid corrosion at the point of electrical contact and, more importantly at the crack site.
- Similar issue is expected in using the Clip gauge and Strain gauge due to galvanic effect. Additionally, the method of fixture have to be able to withstand test environment (corrosive) attack and retain its integrity of operation throughout the test.
- At the Blade Energy, a reliable system was developed to make sure of the integrity of equipment as well experimental results.
  - ❑ The equipment for monitoring crack propagation → DCPD, and Strain gauges were connected and calibrated, including clip gauge.
  - ❑ pH-meter sensors was added in the environment chamber.
  - ❑ Special attention was paid to ensure the NS4 solution was saturated with mixed gas (5%CO2+95%N2) and the pH was about 6.8 to 7.2.
  - ❑ Ensure no air/leak source of presence of oxygen in NS4 solution, and during the entire test, the air-tight environmental chamber shall ensure no leak or air from outside admitted to the test solution
  - ❑ A food color (Black dye) was added to the water in the pipe specimen which allows to easily detect leak from the pipe specimen into the environment chamber.



Electrolytic charging cell mounted on the dent area on the OD pipe surface

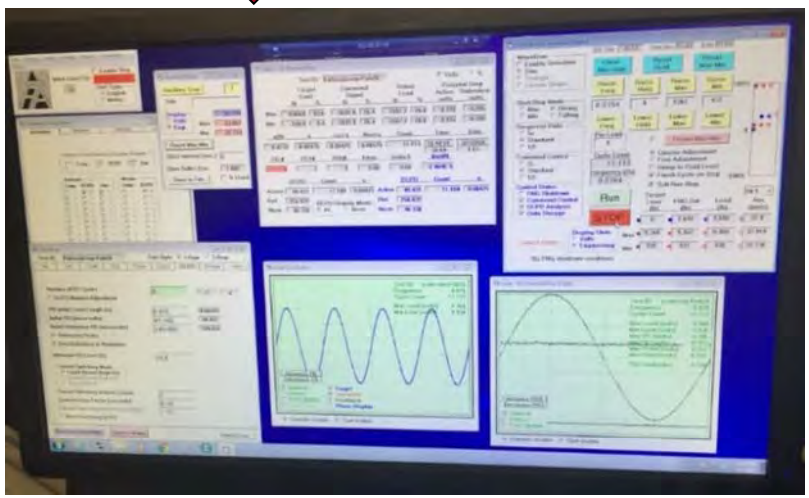
Control System & Data Acquisition

Pressure Test System – Control, Data Acquisition and real-time monitoring



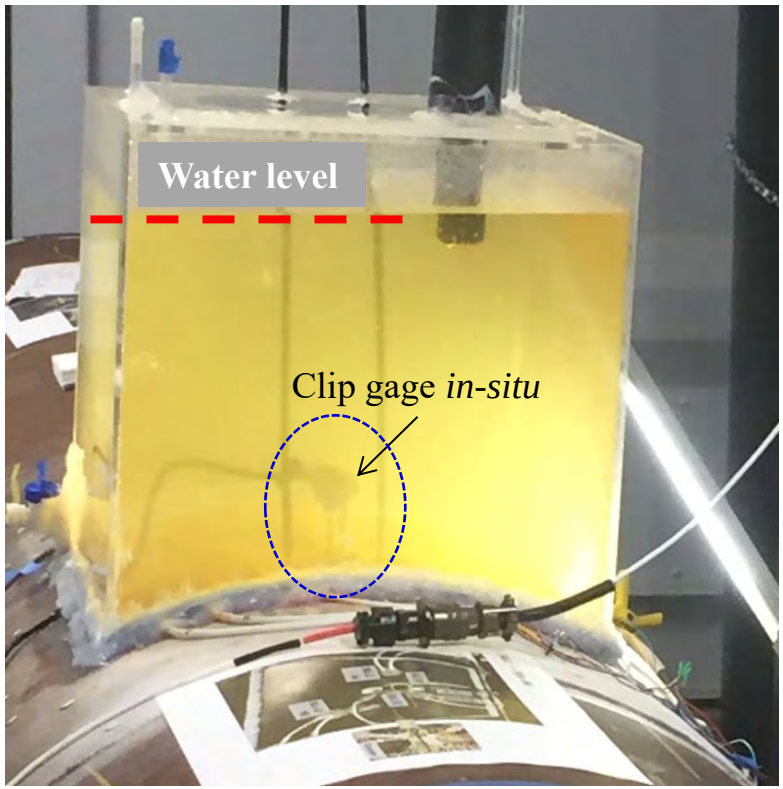
Set P_{max}, P_{min}, freq.
Track # of cycles

DCPD System –
Track potential drop, dent depth, pipe temperature



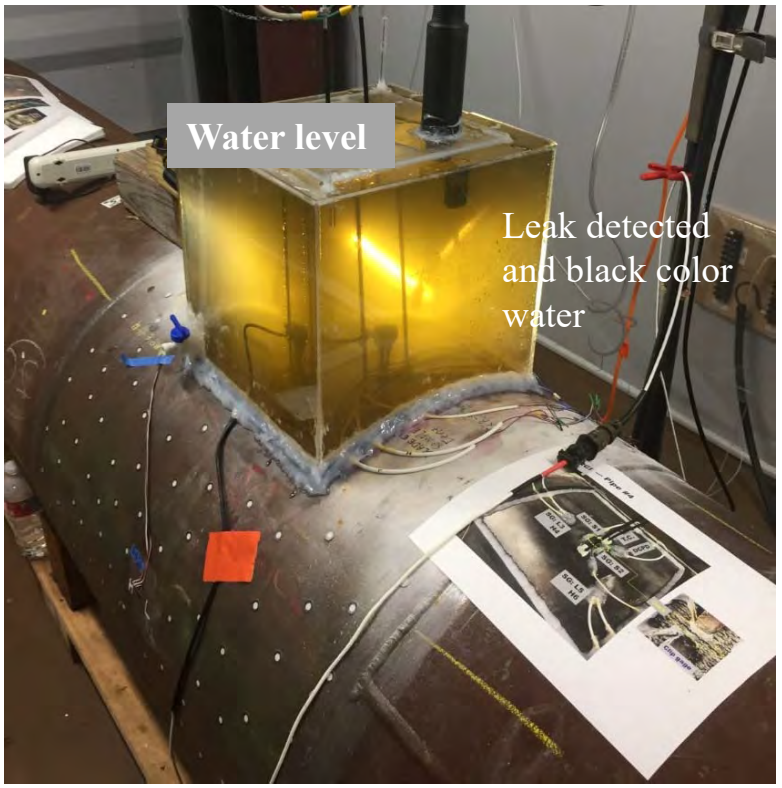
Tracking Clip and strain gages data

Pipe #4 (Dent with cracks) – Full-scale Test Result



Before Leak

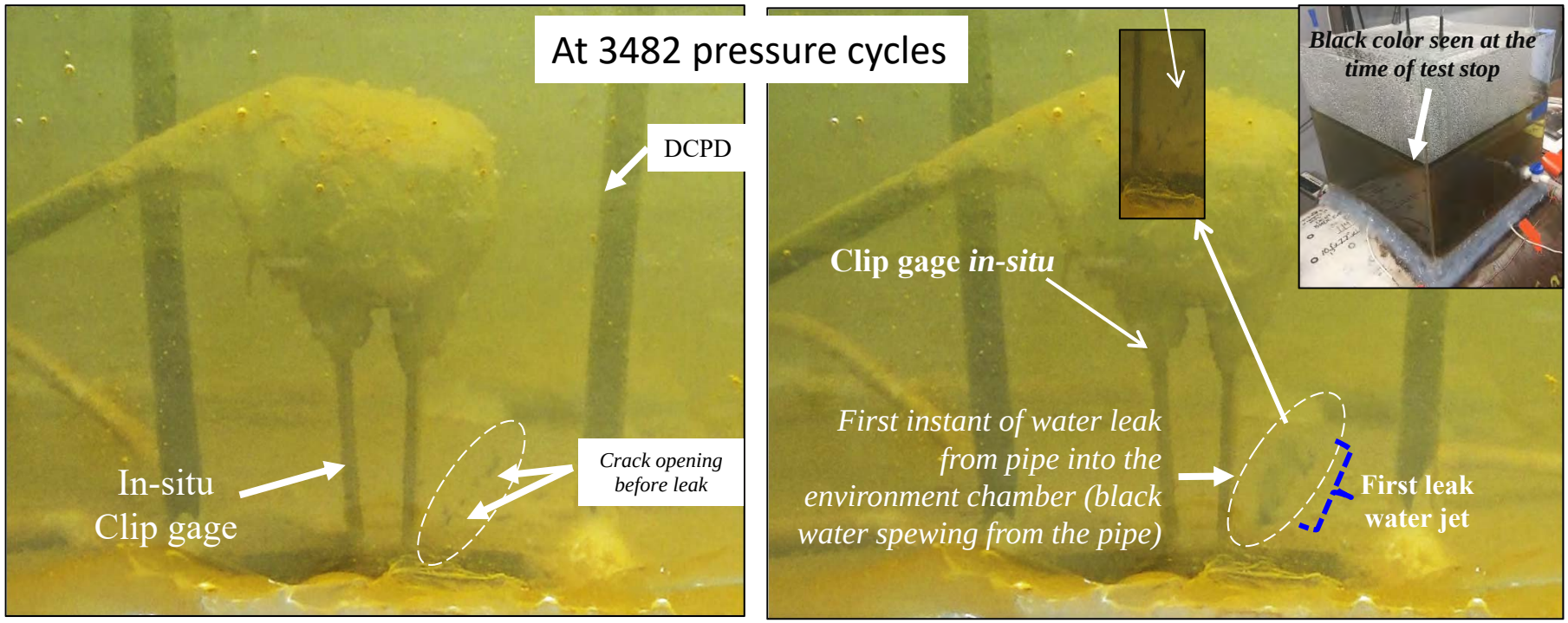
The color and level of NS4 solution remain clear, indication of no leak



After Leak

The color (black) and level of solution changed, visually indicating the crack grew through wall and leak occurred from ID of the pipe into chamber, which is consistent with DCPD/Clip gage/strain gage detection

Example: Pipe #6 (Dent with cracks) – Leak Detection



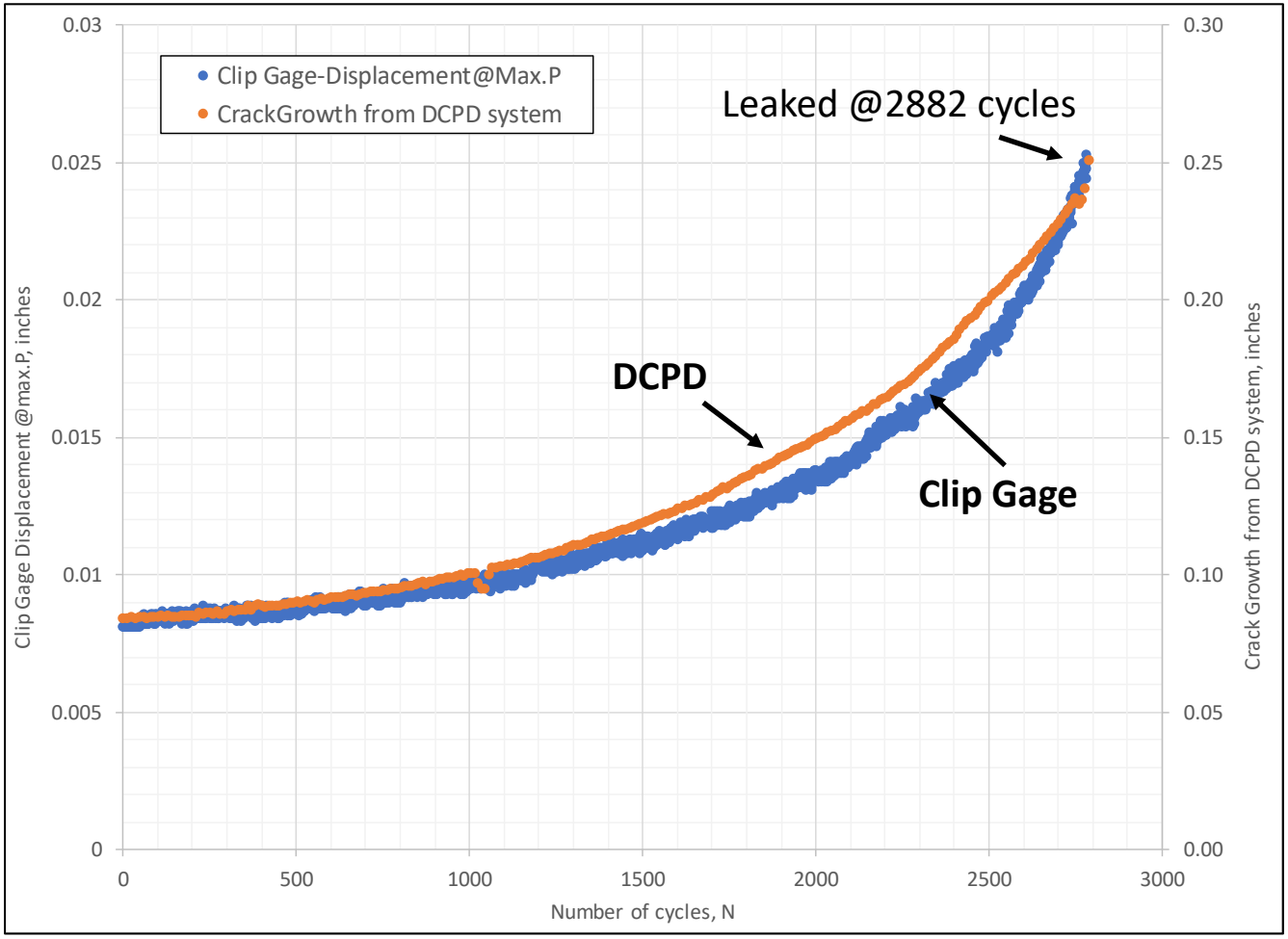
Before Leak

Crack opening seen during pressure cycling

At Leak

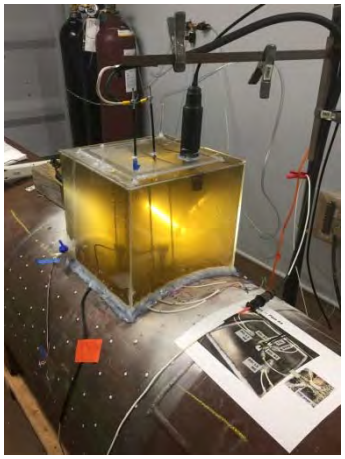
Black water spewing (leak) from the pipe to environment chamber, indication of crack in dent grew through-wall

DCPD & Clip Gage Post-Processed Data – Example: Pipe #2 (Dent with cracks)

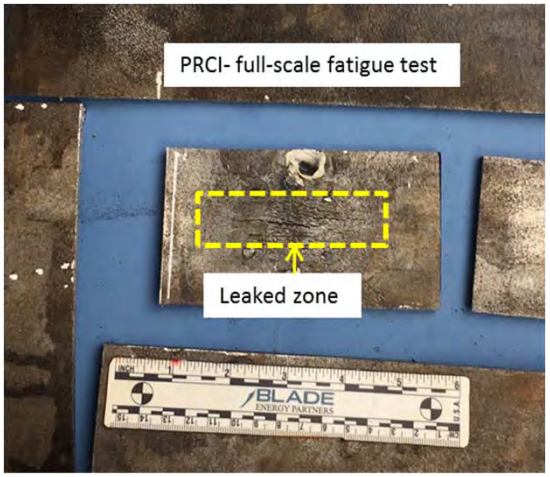


Plot showing the clip gage displacement & DCPD crack growth data during the test of Pipe#2

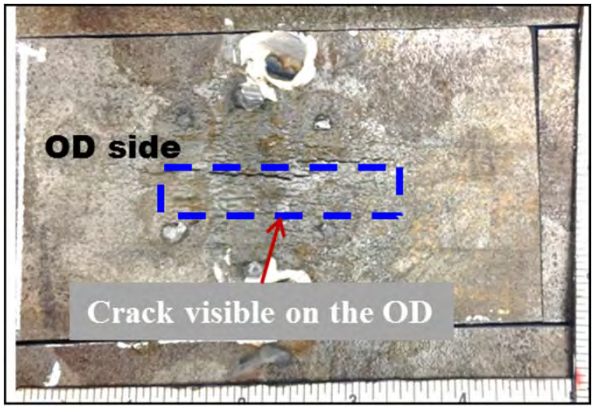
Leaked Crack Sample Extraction for Metallurgical Study

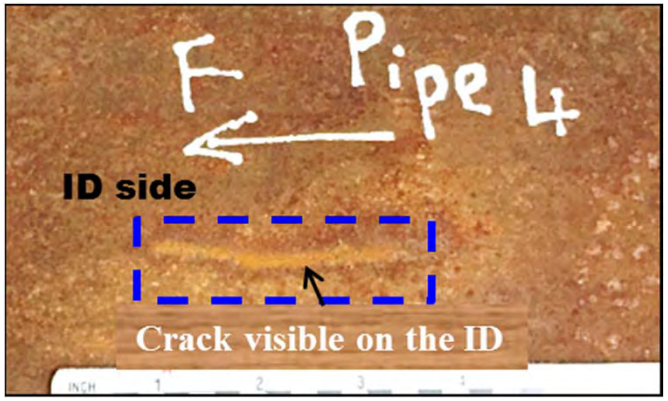


Leakage is detected by the change of water color in black (access of water from the inside of pipe to the cell). In addition, the cell is flooded



Extraction of the leakage zone by cutting with a saw

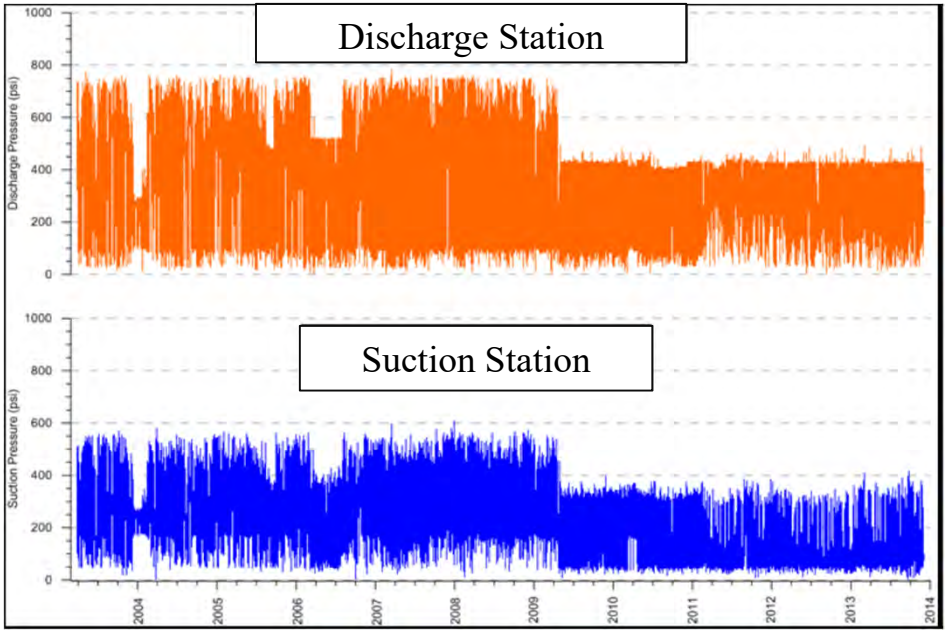


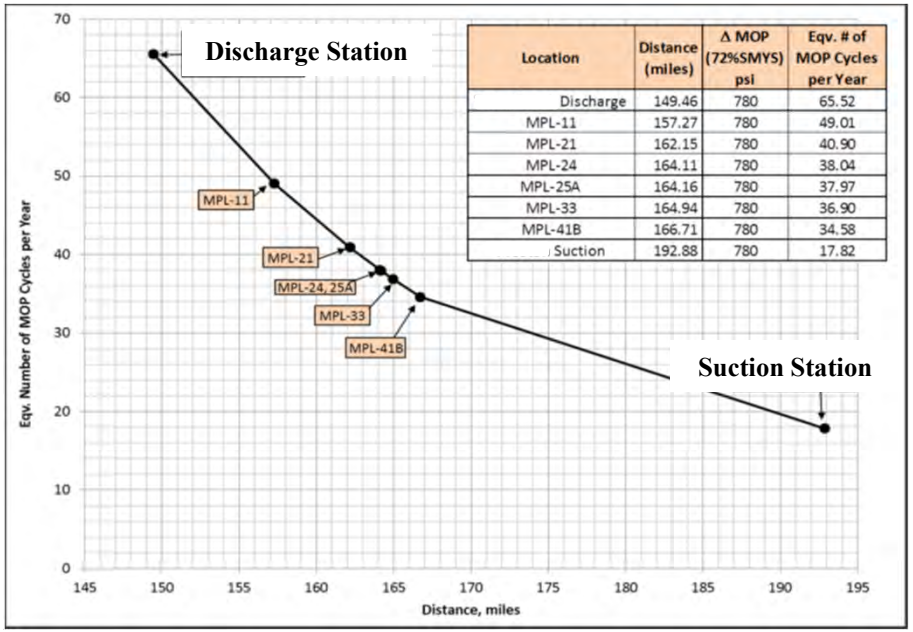


Evidence of crack after leak on **OD** as well on **ID**

Remaining Life Calculation – Dent with Crack

- Obtained 10 years of historical pressure data from this pipeline section
- MOP = 780 psi
- Performed Rainflow & Miners Rule Analysis
- Calculated Eqv. # of cycles per year for MOP pressure range





Location	Distance (miles)	Δ MOP (72%SMYS) psi	Eqv. # of MOP Cycles per Year
Discharge	149.46	780	65.52
MPL-11	157.27	780	49.01
MPL-21	162.15	780	40.90
MPL-24	164.11	780	38.04
MPL-25A	164.16	780	37.97
MPL-33	164.94	780	36.90
MPL-41B	166.71	780	34.58
Suction	192.88	780	17.82

Remaining Fatigue Life Calculation

- Calculated the remaining fatigue lives from Six Full-scale Fatigue Tests of Dent With Cracks

Test #	Pipe Specimen #	Feature Type	Dent Depth, %OD	NDE Reported Max. crack depth[4], %WT	Test Environment	Number of cycles to failure (cycles)	Remaining Life (years)	Comments
1	Pipe #2	Dent with crack	1.5%	34.0%	Air	2,882	44.0	Leak detected and stopped the test
2	Pipe #3	Dent with crack	0.9%	53.6%	NS4 solution	2,779	42.4	Leak detected first and kept running test until rupture
3	Pipe #4	Dent with possible crack	1.6%	10.4%	NS4 solution	2,294	35.0	First performed crack extension by pressure cycling in air and then, tested until leak in NS4 solution
4	Pipe #7	Dent with crack	3.5%	24.9%	NS4 solution	2,272	34.7	Leak detected and stopped the test
5	Pipe#6	Dent with cracks	1.1%	9.1%	NS4 solution	3,200	48.8	Leak detected and stopped the test
6	Pipe#5	Dent with possible crack	0.9%	5.2%	NS4 solution	21,263	> 100	Leak detected and stopped the test

Note:

1. The line MOP of the specimen was 780 psi
2. Pipe parameter: **24-inch OD; WT=0.25, X52 grade**
3. Test Parameter: **Max. Pressure = 780 psi; Min. Press = 78 psi, R =0.1, f=0.0526 cycle/sec, T=19 seconds**
4. The NDE reported crack depth includes corrosion pit depth and crack depth
5. Conservative Eqv. Number of cycles for the pressure range of **78 to 780 psi = 65.52 cycles/yr.**

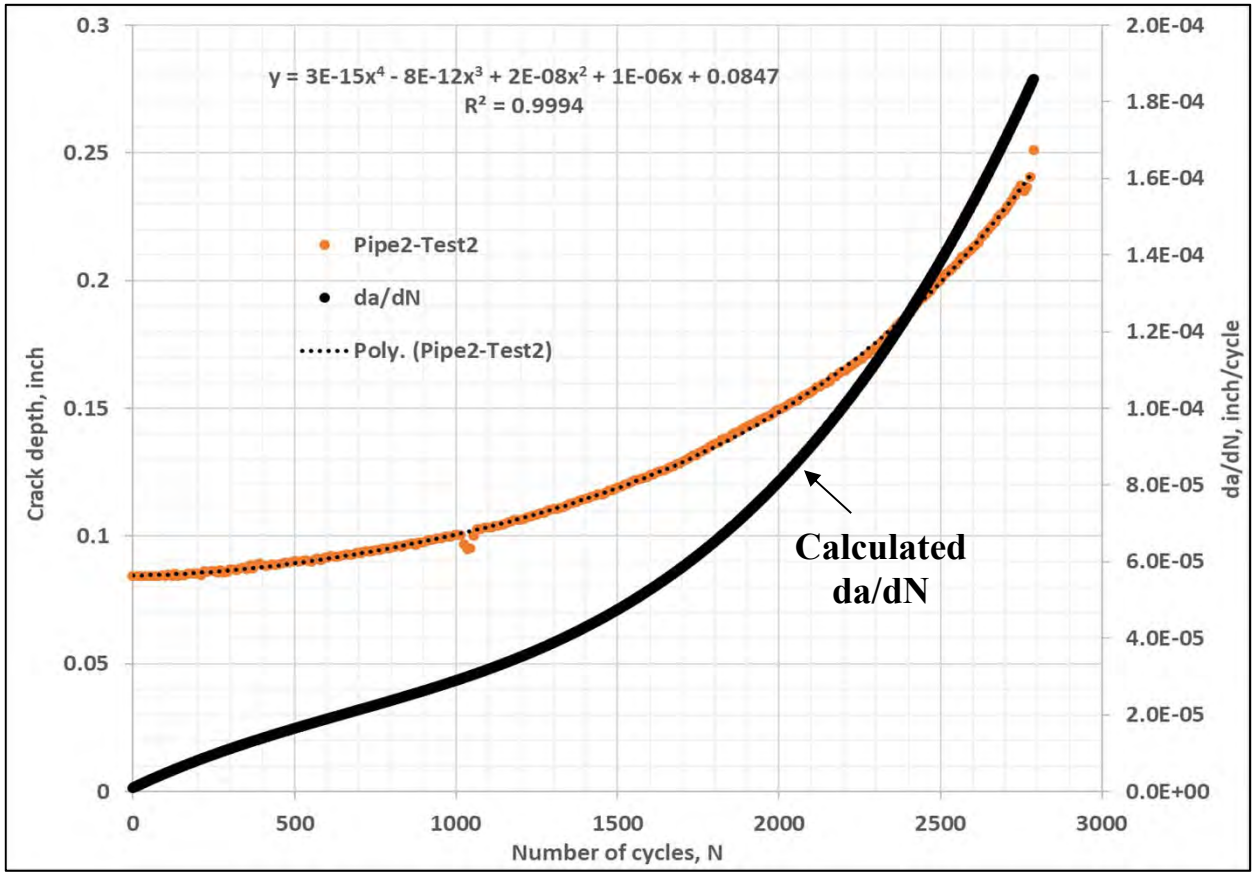
- Dents with cracks leaked between 2200 - 3200 cycles
- Dent with no crack (plain dent) leaked at 21,000 cycles
- Full-scale fatigue tests demonstrated minimum of 34 years remaining life

Macro and Micro-Mechanics Analyses

1. Calculated fatigue crack growth rate (da/dN) using DCPD data - Macro growth rate
2. Performed FEA of dent with crack and determined Stress Intensity Factor (ΔK) under cyclic pressure load
3. Plotted ΔK vs da/dN, and estimated fatigue crack growth coefficients, ***C and m*** in air and NS4 for dent with crack
4. Measured fatigue striation spacing using leaked fracture sample (Local growth rate-Micro) and compared against Macro (DCPD) growth rate – Work-in progress

Fatigue Crack Growth Analysis – Pipe#2 Test DCPD data (in-air)

- Total number of cycles to failure (leak) = 2882 cycles
- Experimental data was best curve-fitted and obtained the equation (4th degree polynomial). Then, calculated the fatigue crack growth rate (da/dN) by taking first derivative and plotted
- The calculated fatigue crack growth rate is non-linear 4th degree polynomial. The calculated maximum crack growth rate 1.85E-04 inch/cycle, just prior to the leak

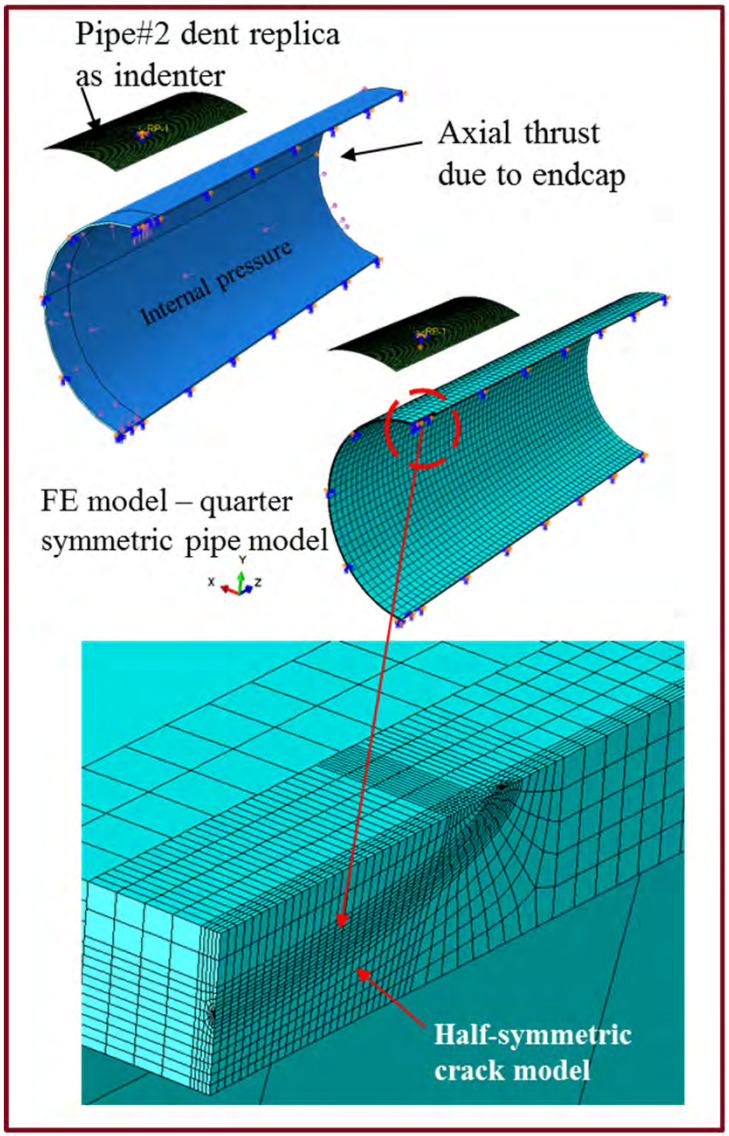


Fatigue crack growth rate was calculated using DCPD data obtained from full scale fatigue test

Finite Element Analysis – Dent With Crack K-solution and ΔK

Procedure to calculate the stress intensity factor for dent with crack:

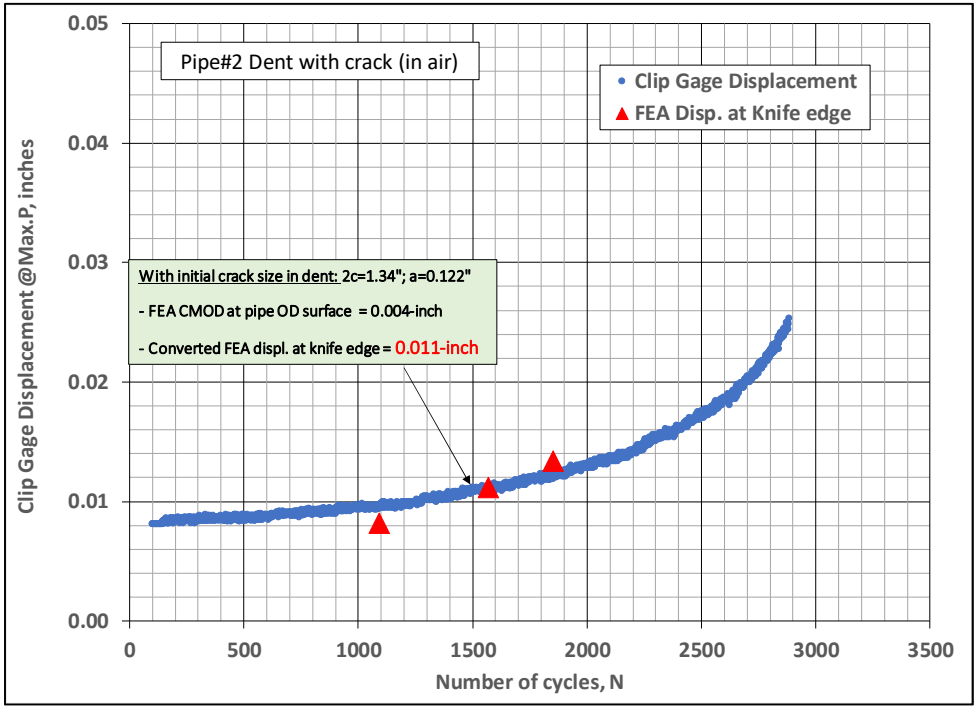
1. Created FEA model of 24-inch OD pipe with 9 different crack depths range from 20% to 85%wt, i.e., covering Stage I, Stage II and Stage III of fatigue crack growth
2. Modeled rigid indenter using the pipe#2 dent deformation from 3D laser scan data. Assembled both the FEA pipe model with crack and rigid indenter. Defined contact between them. Used X52 elastic-plastic material curve.
3. Pushed the indenter against the pipe wall such that it made dent of depth measured at zero pressure in the laboratory. This denting process created a residual stress due to bending in the pipe (i.e., deactivate the crack definition during denting process)
4. Then, using the residual stress due to denting as initial condition and activated the crack definition**.** Applied internal pressure **of P_{min} = 78 psi and P_{max} = 780 psi**. Obtained **J-integral** and K_I for these two load steps and calculated $\Delta K_{I\text{-dent}}$
5. Further, validated the FEA prediction of CMOD and dent depth against experimental results.



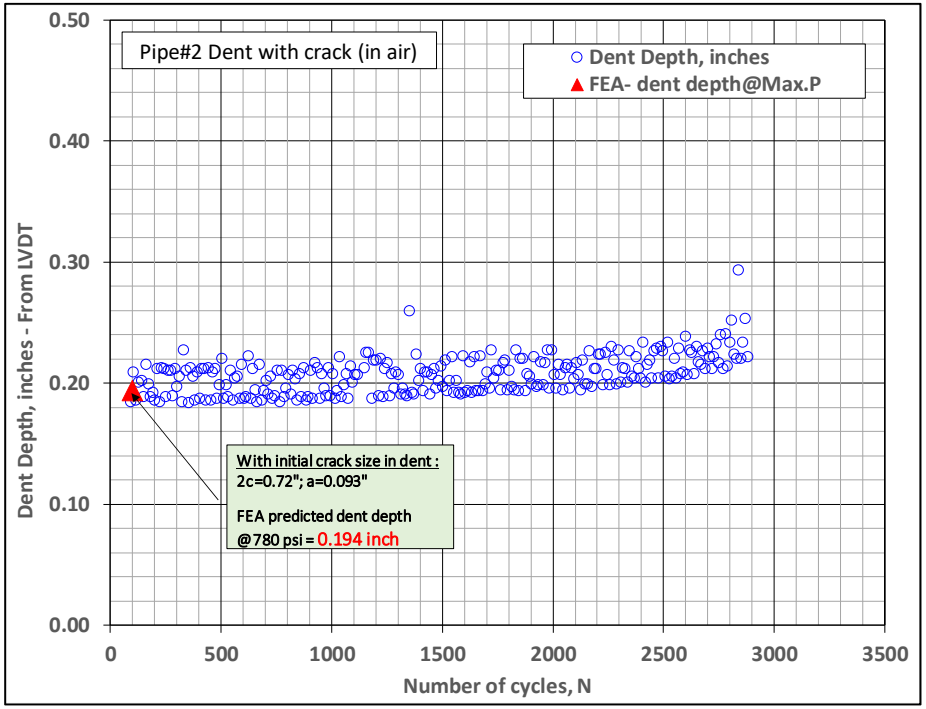
Validation – FEA vs.Test Data

(Pipe#2 Test - 1.5%OD Dent with external surface crack)

CMOD – FEA vs Clip Gage Displacement at the knife edge



Dent Depth @ 780 psi – FEA vs LVDT



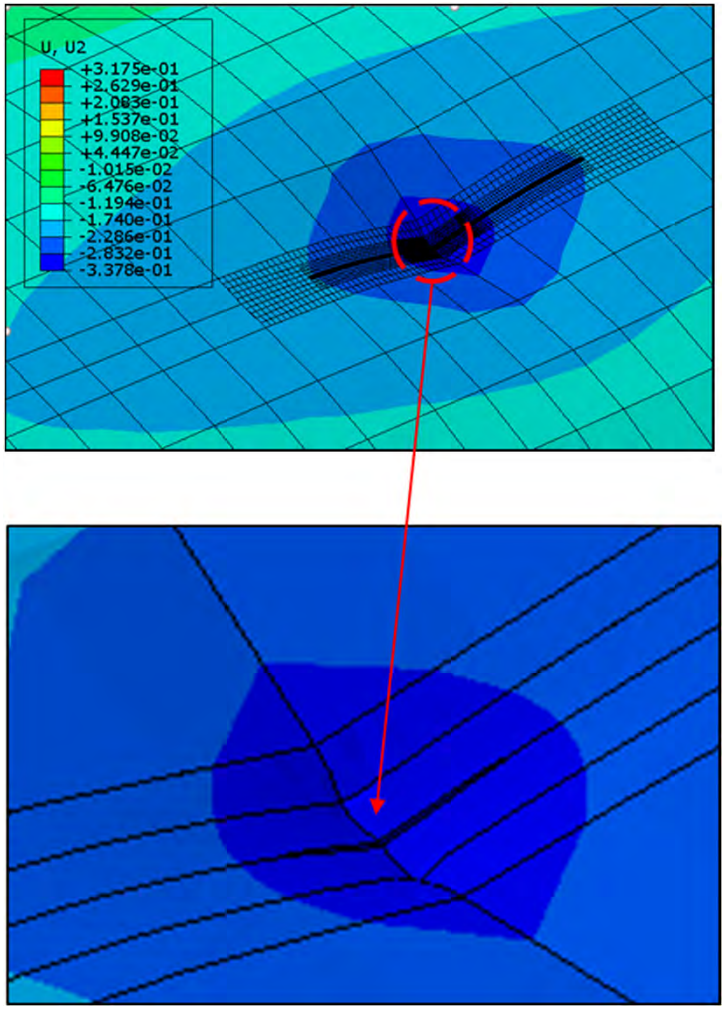
FEA predicted dent depth and CMOD agreed well with full-scale fatigue test results

Stress Intensity Factor – Crack-in-dent vs. No dent

(1.5%OD Dent with external surface crack, *cs#5*:1.34" long and 50.8% wt)

1) Crack-in-1.5%OD Dent

Applied Internal Pressure, psi	With end cap	
	FEA	
	J-integral (klbf/in)	K_I (ksi*in$^{0.5}$)
78	0.00478	12.56
780	0.16720	74.24
	ΔK	61.68

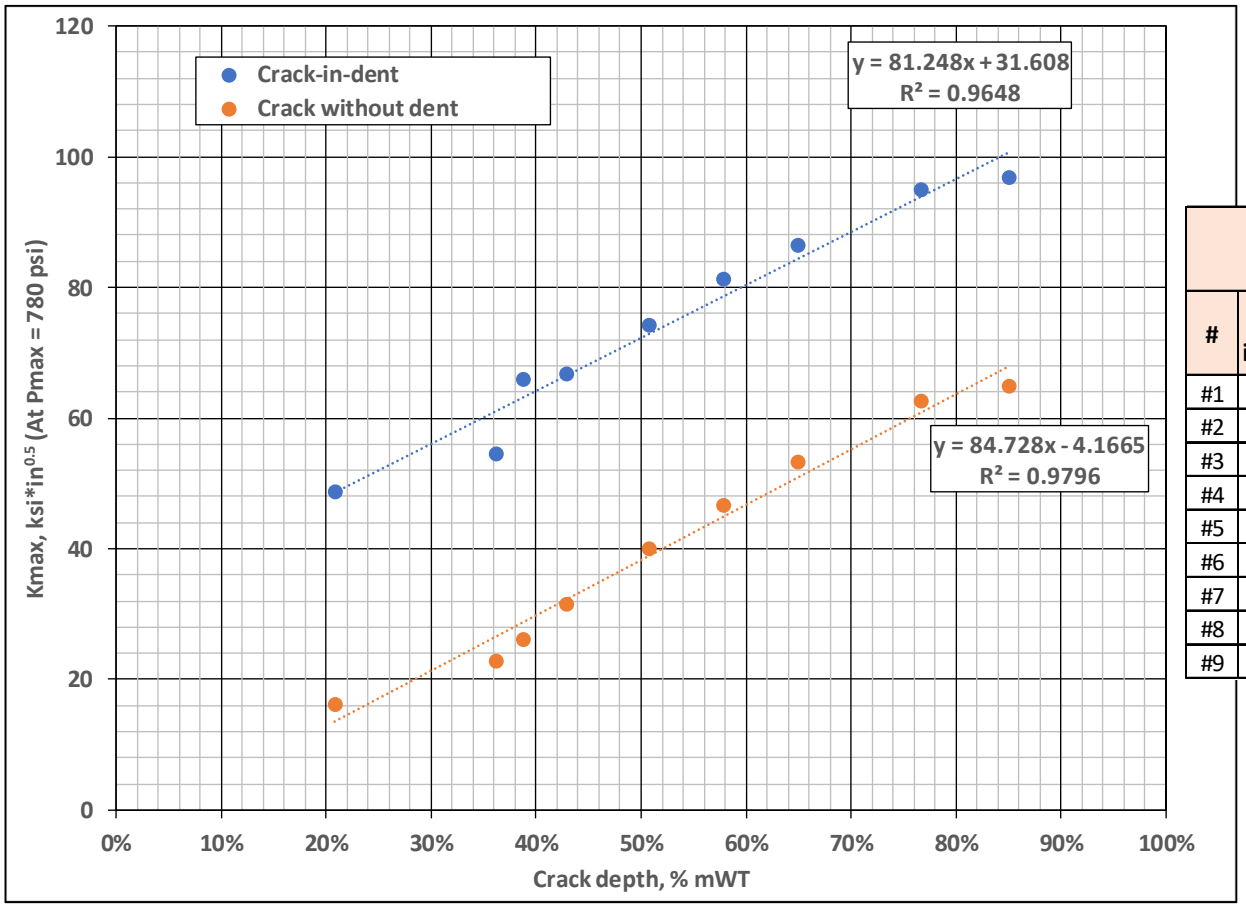


2) Crack-in-pipe body without dent

Applied Internal Pressure, psi	With end cap		No end cap			
	FEA		FEA		API 579, K_I	% of K_I difference (FEA vs API579)
	J-integral (klbf/in)	K_I (ksi*in$^{0.5}$)	J-integral (klbf/in)	K_I (ksi*in$^{0.5}$)		
78	0.00034	3.36	0.00034	3.36	3.88	
780	0.04630	39.07	0.04727	39.48	38.80	1.7%

For a given dent and crack size, the stress intensity factor of crack-in-dent is about 1.9 times higher than K_I of crack in pipebody without dent

Stress Intensity Factor– Crack-in-dent and No dent (1.5%OD Dent with external surface crack, *9 different crack sizes*)

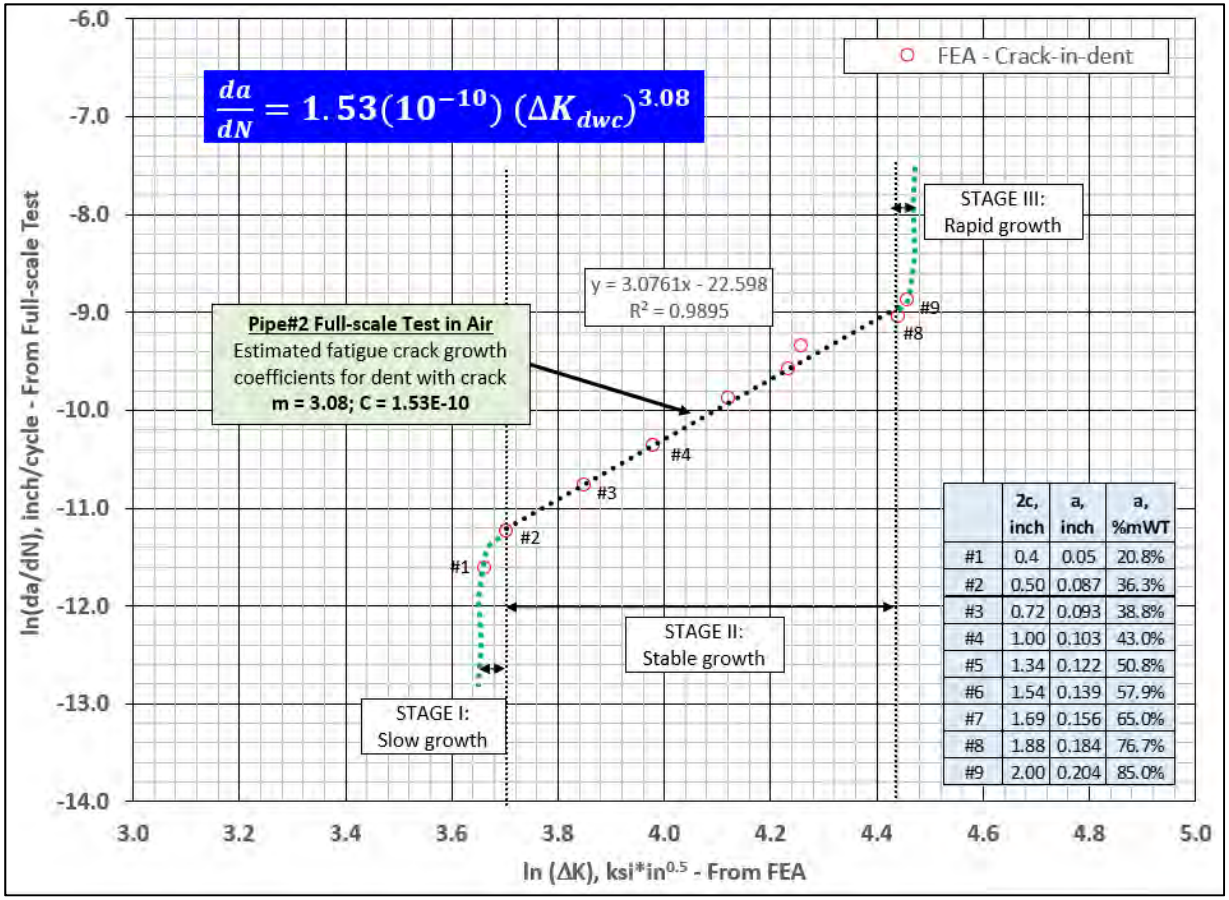


Crack size				FEA Stress Intensity Factor ($K_{I\text{-}max}$, ksi*in$^{0.5}$)		
#	2c, inch	a, inch	a, %mWT	With Dent	Without Dent	K ratio = $K_{I\text{-}dent}/K_{I\text{-}no\ dent}$
#1	0.4	0.05	20.8%	48.63	16.2	3.0
#2	0.50	0.087	36.3%	54.49	22.869	2.4
#3	0.72	0.093	38.8%	65.99	26.136	2.5
#4	1.00	0.103	43.0%	66.79	31.581	2.1
#5	1.34	0.122	50.8%	74.24	39.996	1.9
#6	1.54	0.139	57.9%	81.34	46.728	1.7
#7	1.69	0.156	65.0%	86.47	53.262	1.6
#8	1.88	0.184	76.7%	95.02	62.667	1.5
#9	2.00	0.204	85.0%	96.78	64.845	1.5

The stress intensity factor ($K_{I\text{-}max}$) ratio of crack in dent and without dent ranges from 1.5 to 3.0 depending on the crack size

Pipe#2 Test - 1.5% OD Dent with crack in Air
ln(ΔK) vs. ln(da/dN) plot

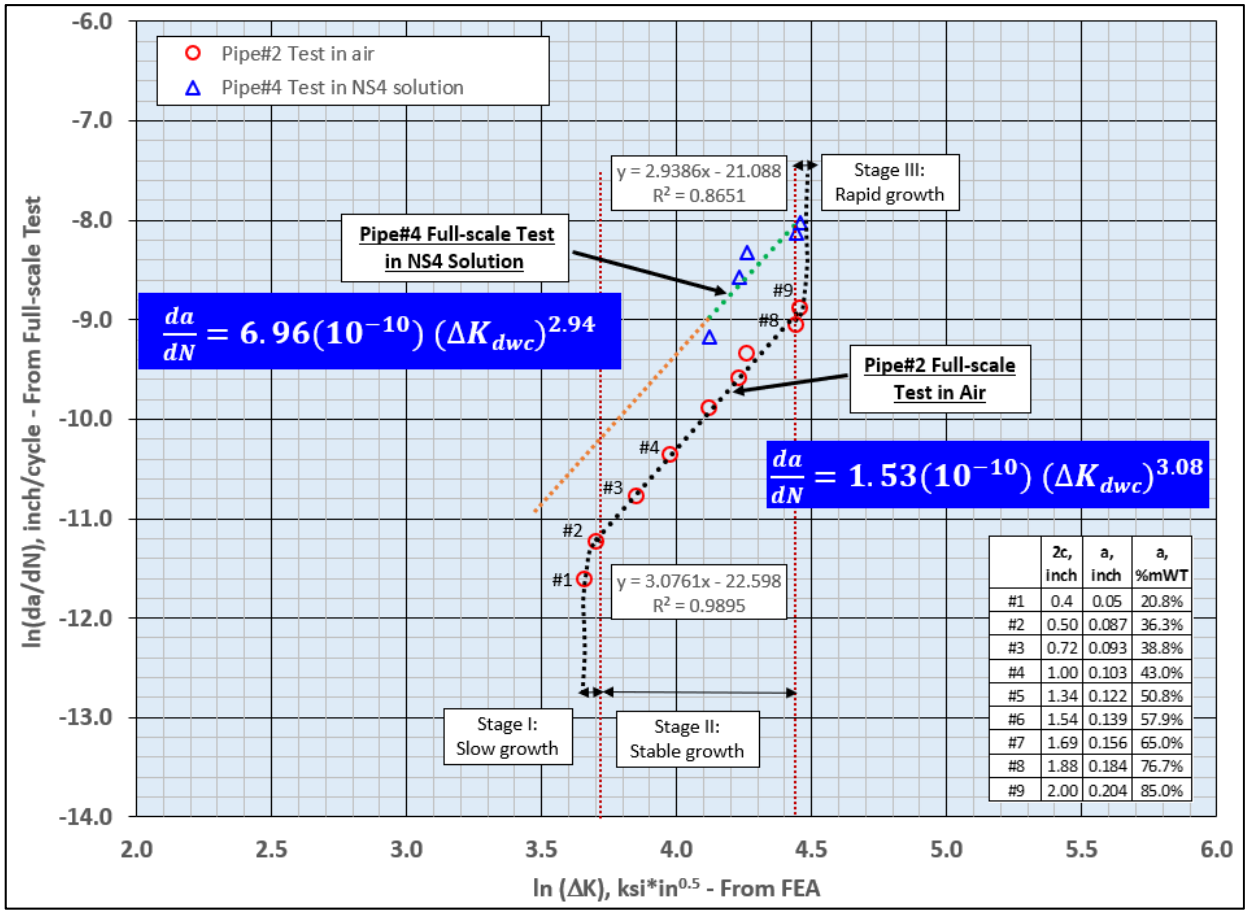
- Calculated ΔK under the cyclic internal pressure load using FEA for 9 different crack sizes in dent.
- Extracted the fatigue crack growth rate for the given crack sizes from full-scale test (DCPD) data.
- Plotted the ln(ΔK) vs. (da/dN), which exhibits three stage mechanisms (Stage I,II and III), and consistent with the literatures.
- Finally, the fatigue crack growth coefficients were estimated in air and can be used with Paris Equation.



	2c, inch	a, inch	a, %mWT
#1	0.4	0.05	20.8%
#2	0.50	0.087	36.3%
#3	0.72	0.093	38.8%
#4	1.00	0.103	43.0%
#5	1.34	0.122	50.8%
#6	1.54	0.139	57.9%
#7	1.69	0.156	65.0%
#8	1.88	0.184	76.7%
#9	2.00	0.204	85.0%

Estimated fatigue crack growth Coefficients for pipe#2: m=3.08, C=1.53E-10

Pipe#2 & Pipe#4 Test: Dent with crack - ΔK vs da/dN plot (Different environment but same dent depth)



	2c, inch	a, inch	a, %mWT
#1	0.4	0.05	20.8%
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#7	1.69	0.156	65.0%
#8	1.88	0.184	76.7%
#9	2.00	0.204	85.0%

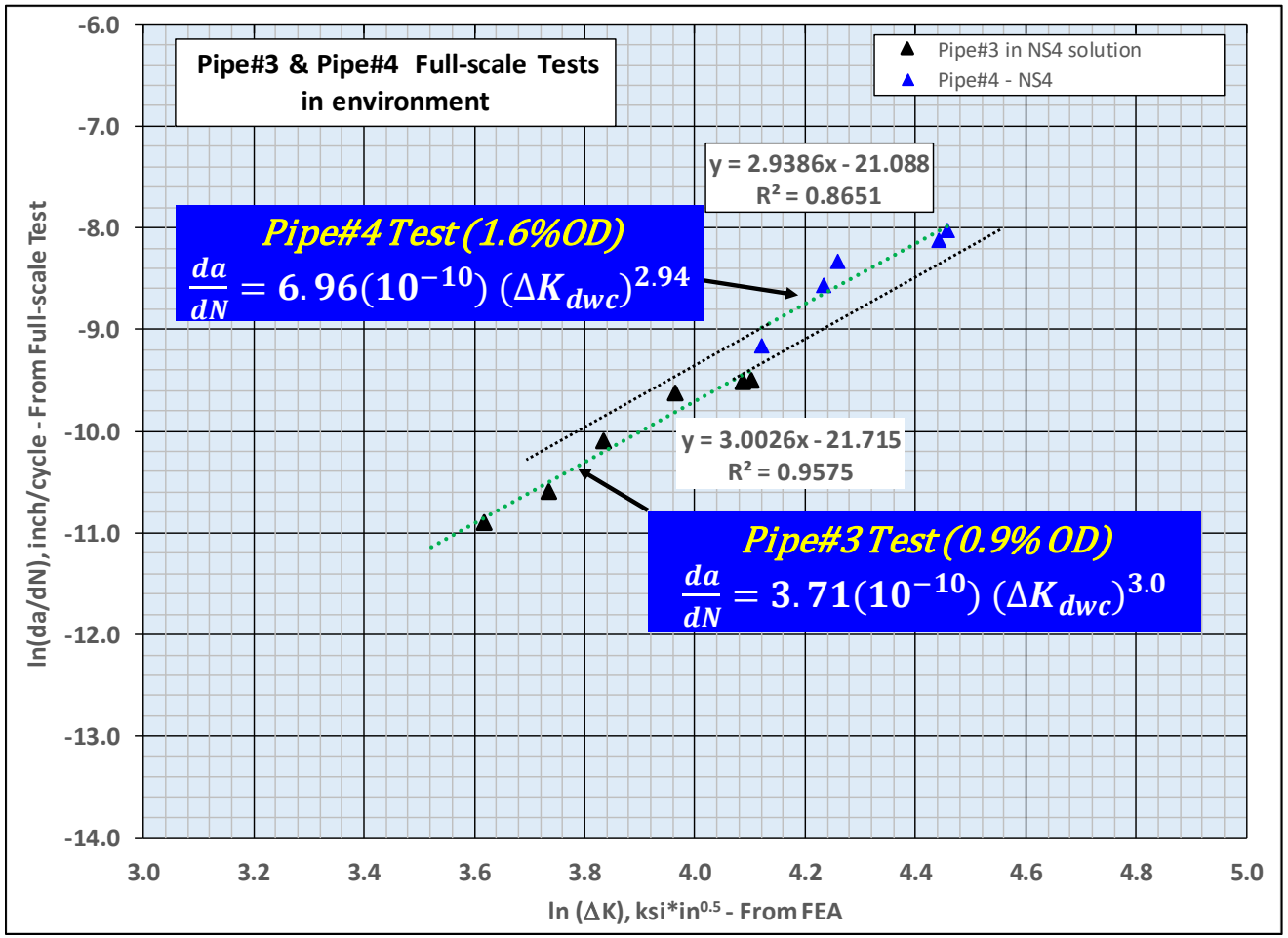
P_{max} = 780 psi
P_{min} = 78 psi
ΔP = 702 psi
R = 0.1

Dent depth:

Pipe#2 = 1.5%OD (in air)
Pipe#4 = 1.6%OD (in NS4)

For a given dent depth, the crack in dent can grow 4.5 times faster in NS4 than in air, i.e., as expected the growth coefficient "C" depends on the environment

Pipe#3 & Pipe#4 Tests: Dent with Crack - ΔK vs da/dN plot (Same environment but different dent depth)



P_{max} = 780 psi
P_{min} = 78 psi
ΔP = 702 psi
R = 0.1

Dent depth:

Pipe#3 = 0.9%OD (in NS4)
Pipe#4 = 1.6%OD (in NS4)

For given environment, crack growth coefficient "C" depends on initial dent depth

Dent With Crack – Fatigue Crack Growth Coefficients(C and m)

- For given material type, it appears that
  - Growth coefficient "m" values are relatively same, i.e., constant, m=2.9; 3.0; 3.1
  - However, growth coefficient "C" depends on the environment type and initial dent depth

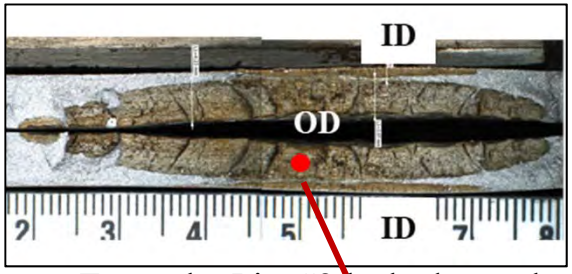
$$C_{dwc} = f\{\ material,\ environment,\ dent\ depth\ \}$$

Note: Estimated **corrosion fatigue** crack growth coefficients (C and m) are limited to **shallow dents** with cracks

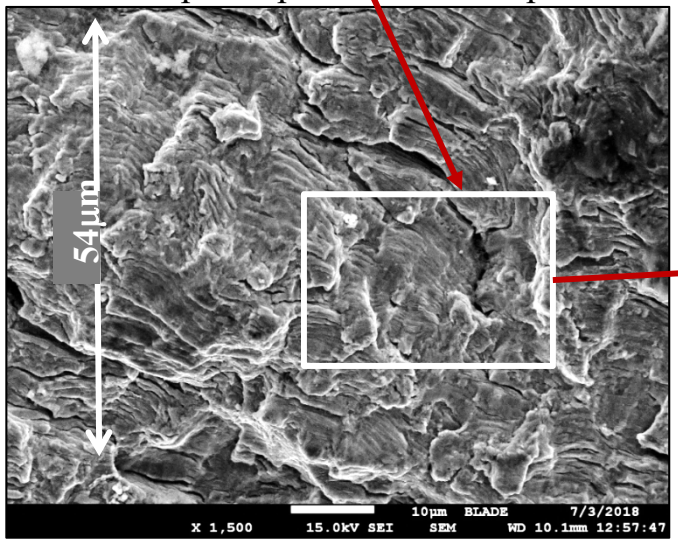
Summary

- Performed 6 full-scale fatigue tests of pipe containing **shallow dents** < 2% with cracks in Air and NS4 environment
  - Except one test, all other tests leaked between 2200 – 3200 cycles (applied ΔP =780-78 psi, R=0.1, f=0.0526Hz)
  - Demonstrated minimum of 35 years remaining life, based on the historical operational pressure fluctuation loads
- Established the fatigue crack growth rate in dent (Macro growth rate)
- Developed procedure to calculate stress intensity factor for dent with crack using numerical method
- Established **corrosion fatigue** crack growth coefficients, C and m for dent with crack in air and environment, which are used with Paris' Equation to calculate remaining life of dent with crack

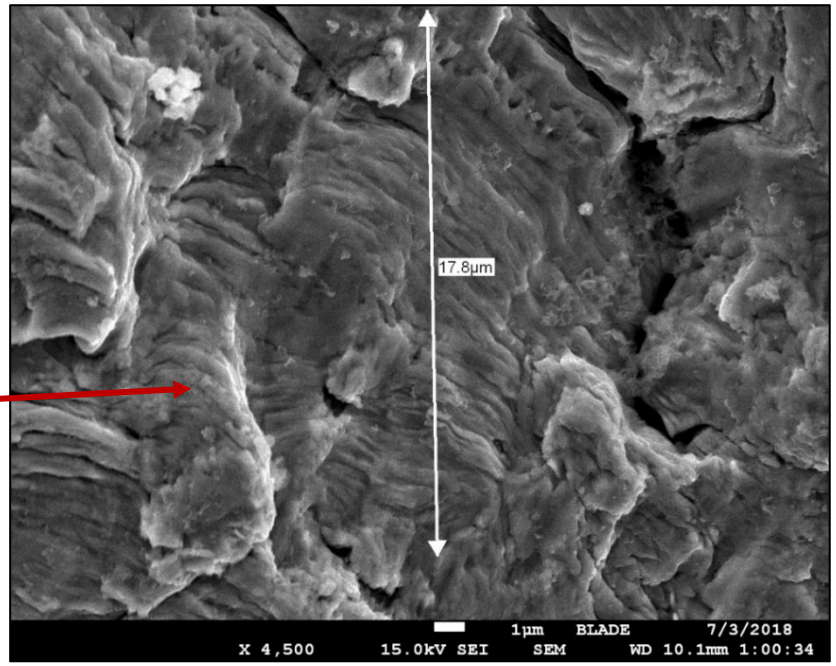
Fatigue Crack Growth Rate Analysis – Work in progress (Micro Mechanics Approach)



Example: Pipe#2 leaked sample



Fatigue crack produced by full-scale fatigue testing. The fracture surface shows evidence of well defined fatigue striations.



- Fatigue striation spacing will provide the local crack growth rate
  - Estimated local fatigue crack growth rate (da/dN)
  - Established correlation between Macro (DCPD) vs Micro (SEM) growth rates
  - The preliminary result showed large scatter with low correlation coefficient. This is consistent with literature finding for the low carbon steel.

Next Steps

- Establish a framework (procedure) for remaining life prediction utilizing the results from full-scale fatigue test and Macro/Micro mechanics analyses
- Submit a draft report (April 2019)

Value to Operators

This research provides a framework for remaining life prediction by fatigue for dent with cracks. The framework will serve as a basis for developing a guideline and procedure to calculate the remaining life using the historical operation pressure fluctuation data, dent geometry and crack size

Outcome of this research would benefit members to better manage integrity of dents associated with corrosion fatigue cracking and mitigate in a timely manner incorporating with in-line-inspection (ILI) of combined dent geometry and crack tools.

Questions

Thank You

Pipeline Research Council International, Inc.

Towards a Reliability-Based System-Wide Integrity Management Approach for Pipeline Dents

Nader Yoosef-Ghodsi
Enbridge Liquid Pipelines

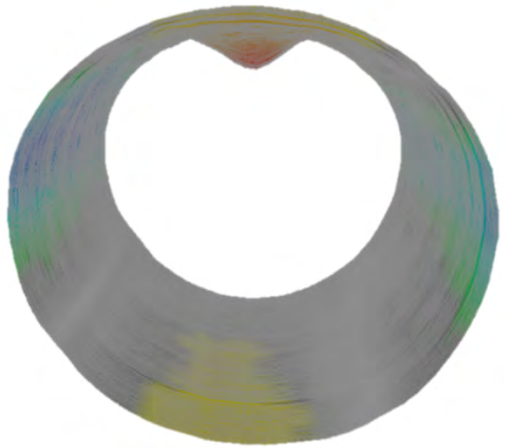
PRCI 2019 Research Exchange Meeting
Houston, Texas
March 5, 2019

Overview

- Objective
- Motivation
- Developed Models
  - Semi-Quantitative Model (SQuAD)
  - Quantitative Model (QuAD)
- Validation and Results
- Proposed Framework
- Example Process
- Future Work
- Use by Other Operators
- Summary

Objective

- Develop a reliability-based framework to support dent analysis for pipeline systems;
- Include complex feature morphologies and dents associated with stress risers (i.e. crack, corrosion, etc.);
- Allow system-wide analysis in a reasonable timeframe for integrity management.

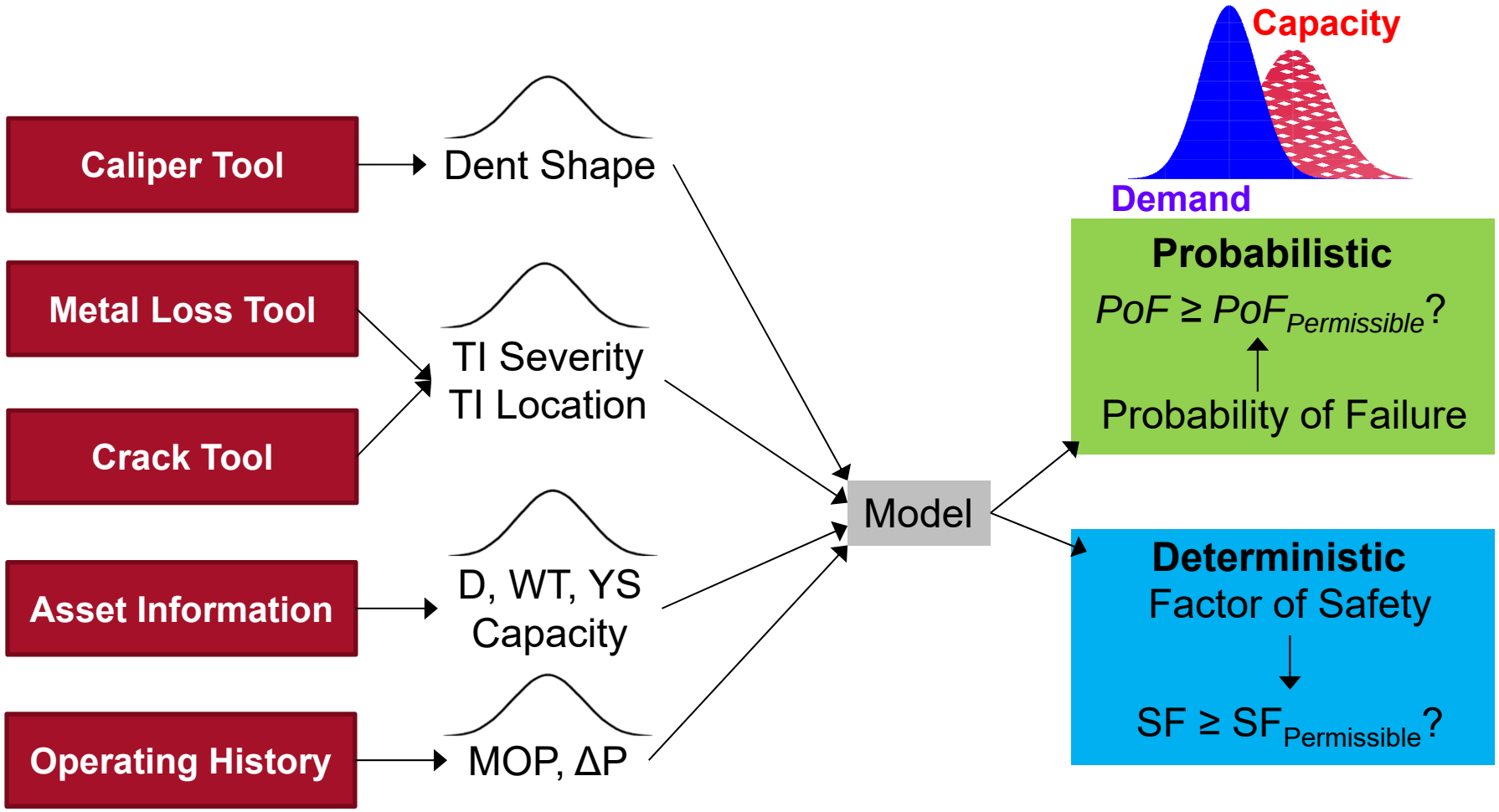


Motivation

- Recent industry dent failures
- Current Regulations
- Limitations of existing methodologies
- Resultant efficiency
- Optimize without compromising safety

Analysis Model

5



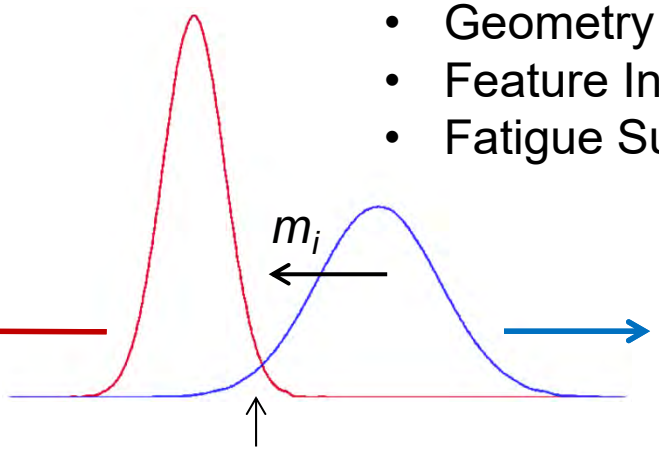
Developed Models

Semi-**Qu**antitative **A**nalysis of **D**ents (**SQuAD**)

- Strain-based ranking method
- All dents + TI
- System-wide

m_i are penalty terms which account for:

- Geometry
- Feature Interaction
- Fatigue Susceptibility



Plain Dent Strain Demand (ASME B31.8)

Conservative Strain Capacity (SME Choice based on mix of API 5L and CSA Z662)

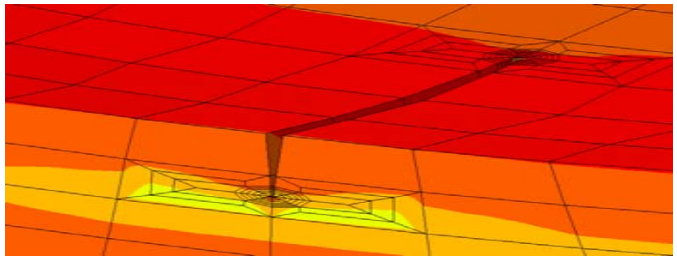
Leak Failure Mode

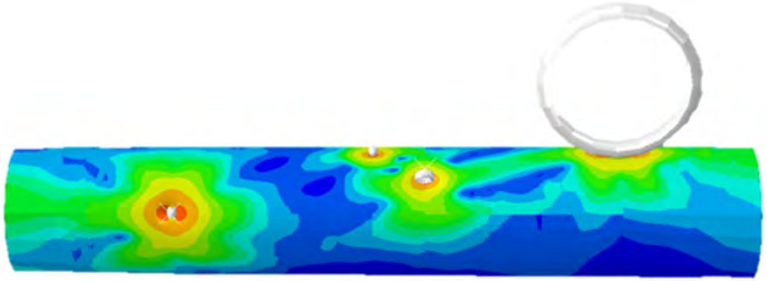
PoE ≅ *PoF* = P(strain demand > strain capacity)

Developed Models

Quantitative **A**nalysis of **D**ents (**QuAD**)

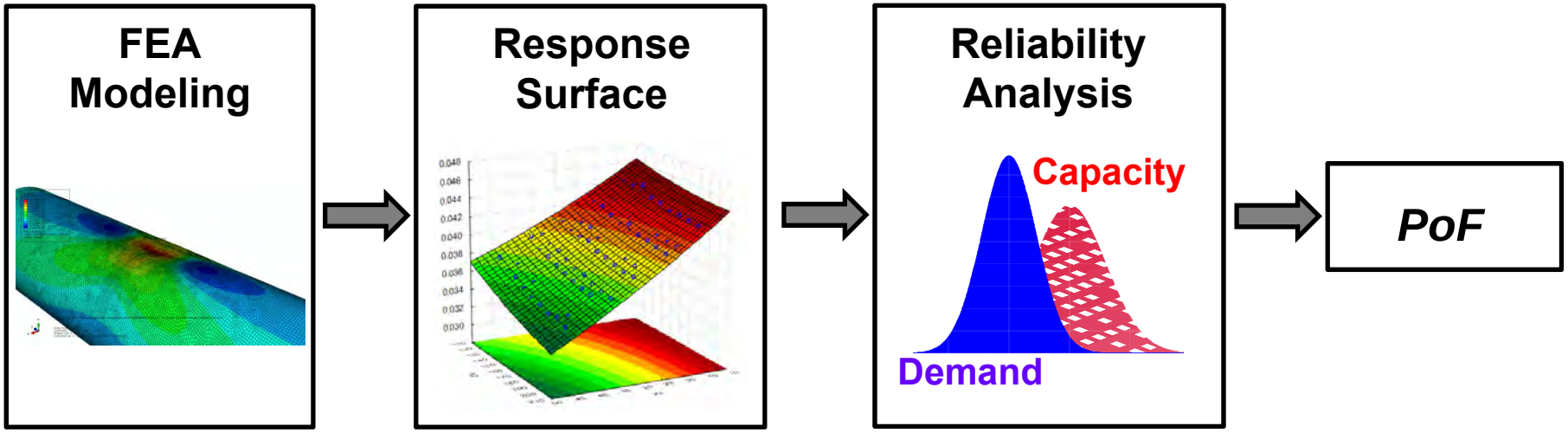
- Strain, Fatigue (cycling), Stress (burst) Limit States
- Complex interactions
- Load Sequencing
- Individual features





Developed Models

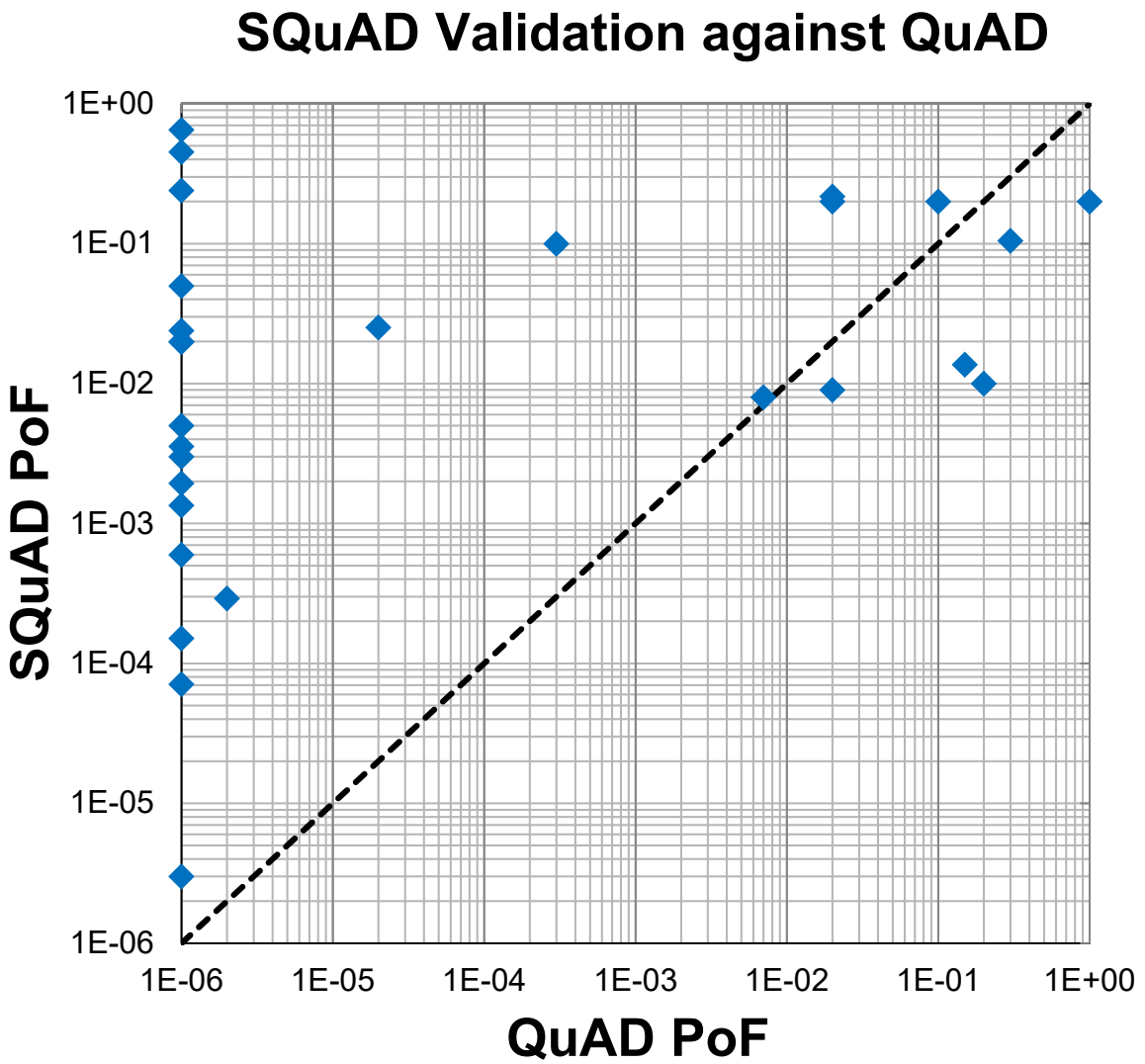
Quantitative **A**nalysis of **D**ents (**QuAD**)



$PoF \cong PoE$ = P(**strain demand > strain capacity**)

Validation and Results

- Analysis time
- Accuracy
- Model capabilities
- Conservatism



Validation and Results

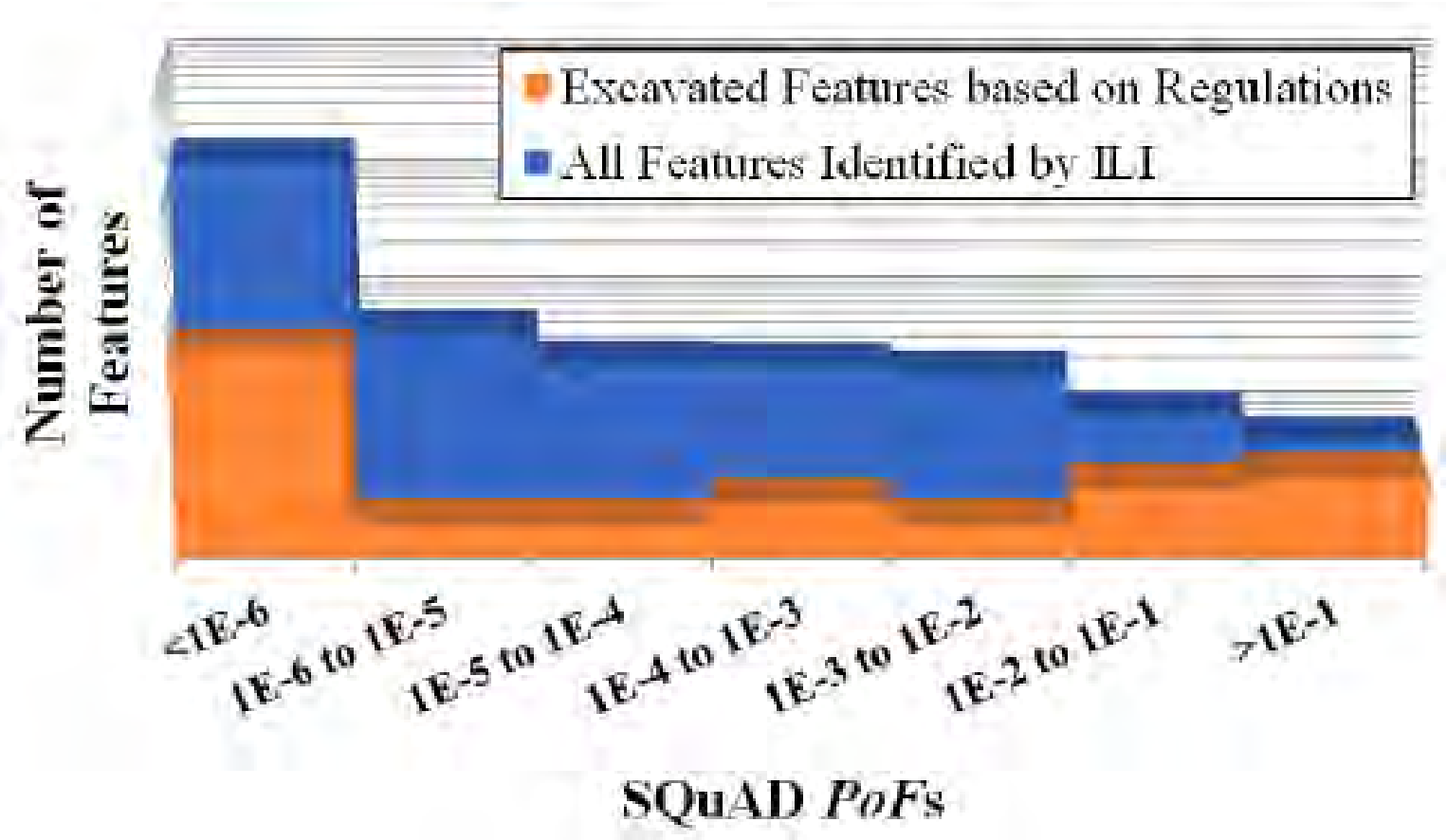
SQuAD Validation against Field Findings

- Difficult to validate models using field findings alone

Industry Failure Experience

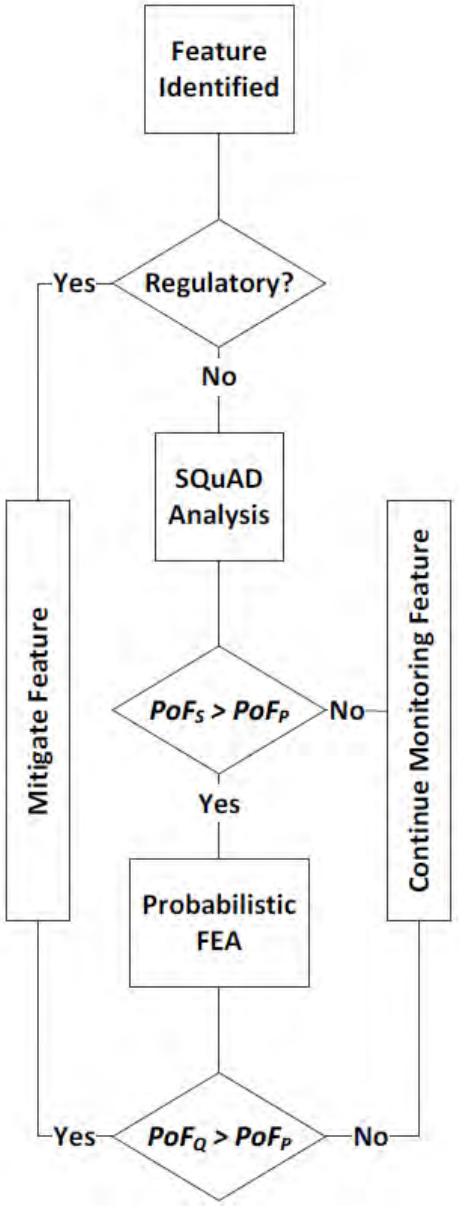
#	Depth (%OD)	ILI Call	Failure Mode	Strain (%)	PoF_{SQuAD}
1	0.9	Multi-Apex, DICP, Metal Loss	Leak	3.7	1.2E-1
2	3.5	Metal Loss	Leak	4.8	4.7E-2
3	2.7	Metal Loss	Leak	4.7	4.7E-2
4	1.4	Multi-Apex, DICP, Metal Loss	Leak	2.8	1.1E-2
5	4.2	Dent with Crack	Leak	3.2	6.1E-3

System Results

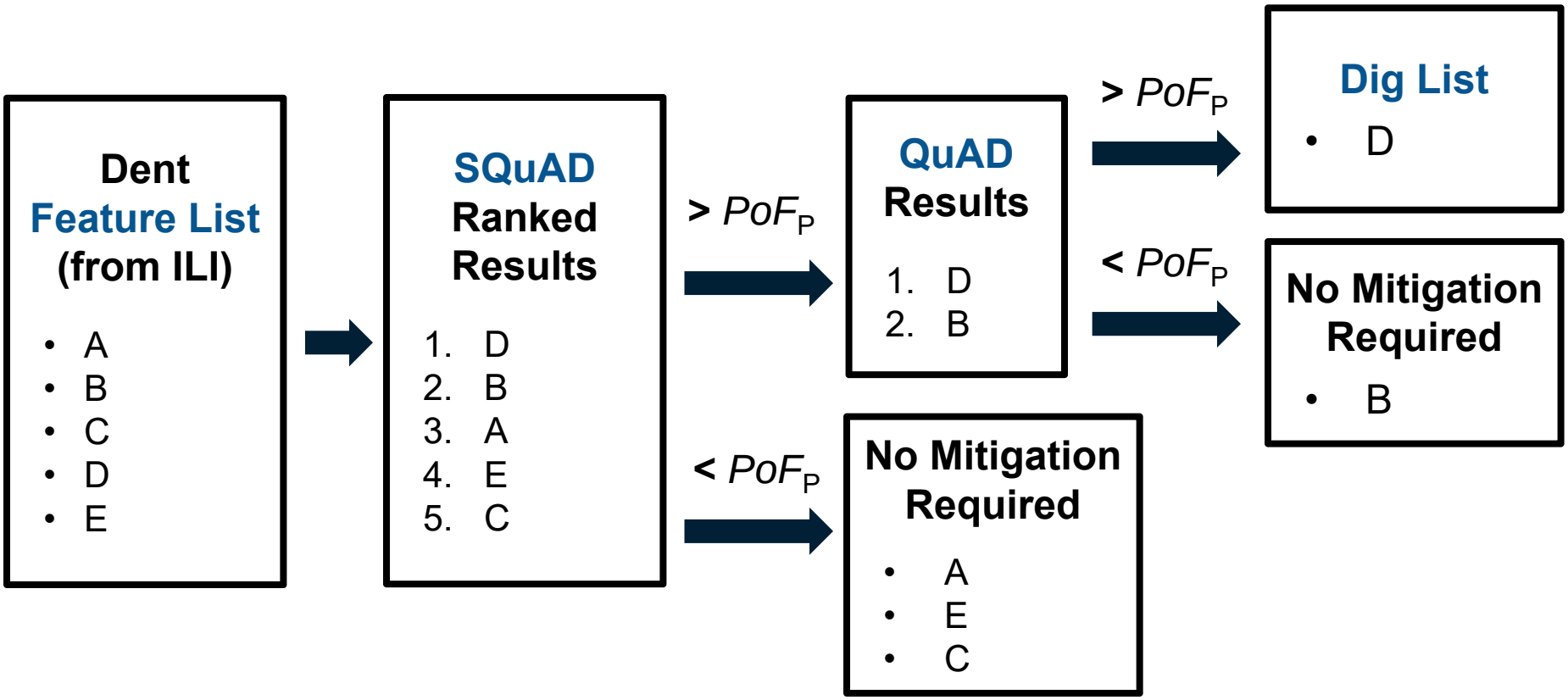


Framework

- Augments existing regulations
- Feature Ranking (SQuAD)
- Detailed Review (QuAD)
- Selection of PoF_P
- Mitigation Options



Example Process



Future Work

- Enhanced fatigue analysis (SQuAD)
- Improved uncertainty quantification
- Additional calibration & validation
- Recommended permissible *PoF* values
- Expand analysis to gas pipelines

Summary

- Developed SQuAD and QuAD models for dents + TI
- System-wide dent assessment framework
- Benefits of quantitative probabilistic analysis

Pipeline Research Council International, Inc.

NDE-4E, NDE-4-7

Leveraging Industry Data Sharing to Support Improved Crack Management Programs at a Liquids Operator

Steven Bott
Enbridge, Liquids Pipelines

PRCI 2019 Research Exchange Meeting
Houston, Texas
Date [March 5 OR 6, 2019]

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Overview – Goals of NDE-4E

- Enhance crack management programs by understanding ILI sizing capability for flaws below the critical size to establish the population of near-critical flaws
- Transfer experience and performance data from operators with significant crack ILI experience to those with limited or no crack ILI experience to improve the overall reliability of the industry; and
- Allow a common understanding of crack ILI performance across the industry including operators, regulators, and other stakeholders.

History of PRCI Crack ILI Data Gathering

- **2012-2015: NDE-4E Phase 1**
  - Initial data collection included construction of a database structure and collection of primarily UTCD data
  - Significant time for data collection and cleaning
- **2016-2017: NDE-4E Phase 2**
  - Additional data collection for EMAT
  - Additional analysis of available UTCD data
- **2017-2018: NDE-4E Tech Transfer Document**
  - A concise document to enable effective tech. transfer of the detailed technical reports
- **2018: NDE-4-7 ("NDE-4E Phase 3")**
  - Collection of more recent UTCD data
  - Focus on data with profiles as well as repeat inspection data to develop and test advanced analytics

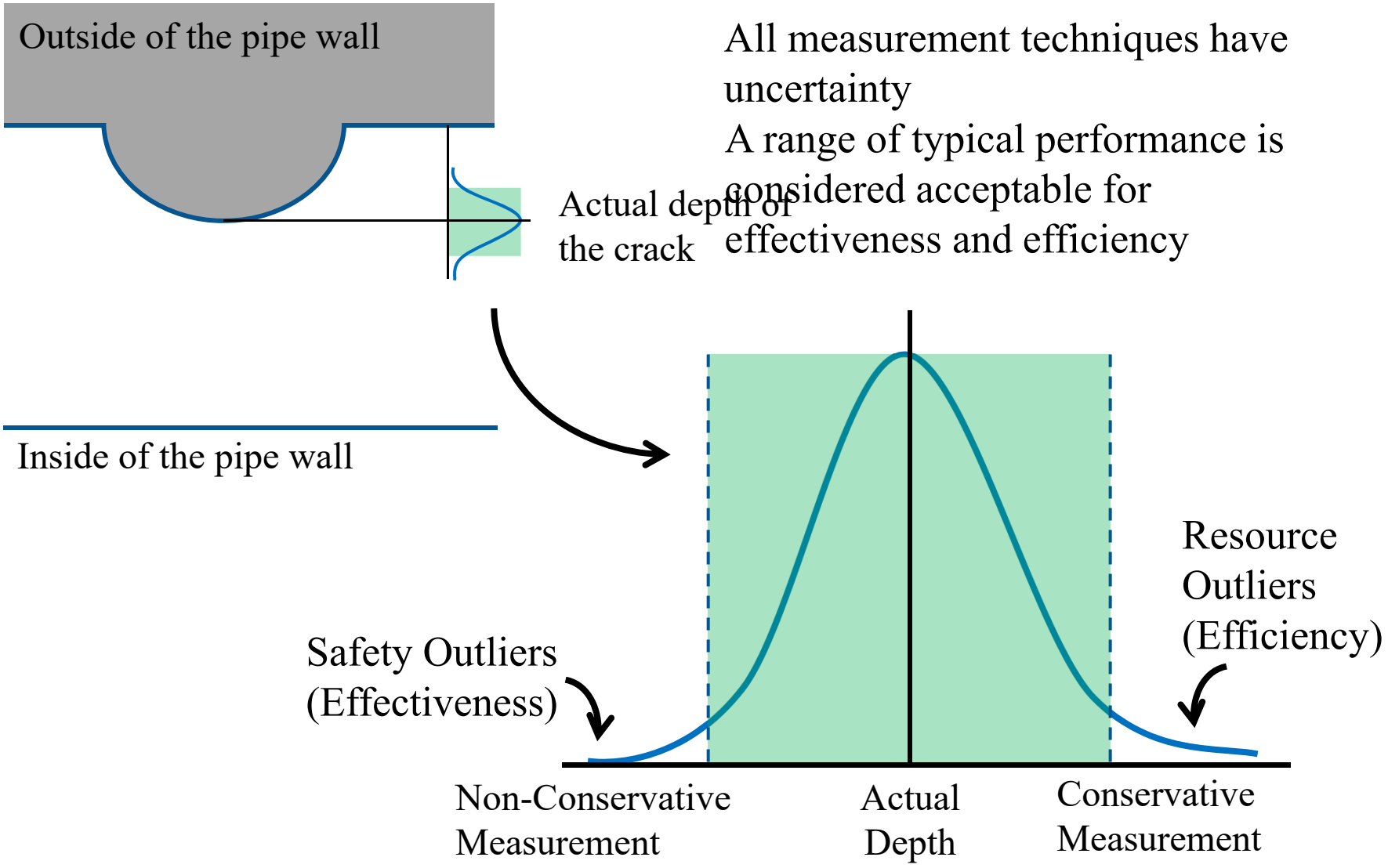
Key Results and Outcomes

- A database of over 60,000 NDE records correlated with ILI results to leverage for industry learning and continuous improvement
- Demonstrated range of detection, identification, and sizing performance for UTCD and EMAT
- Importance and impact of high quality NDE on the assessment of inspection and program performance
- Impact on sizing accuracy of repeat inspections
- A robust guideline to provide support for operators both experienced and inexperienced in leveraging crack ILI for the purpose of crack management
- Crack ILI can be used for effective crack management

Leveraging Results for Crack Management

- Intro to effectiveness and efficiency?
- Rate of detection
- Identification
- Sizing accuracy
- Repeat inspection benefits

Illustration of Effectiveness and Efficiency



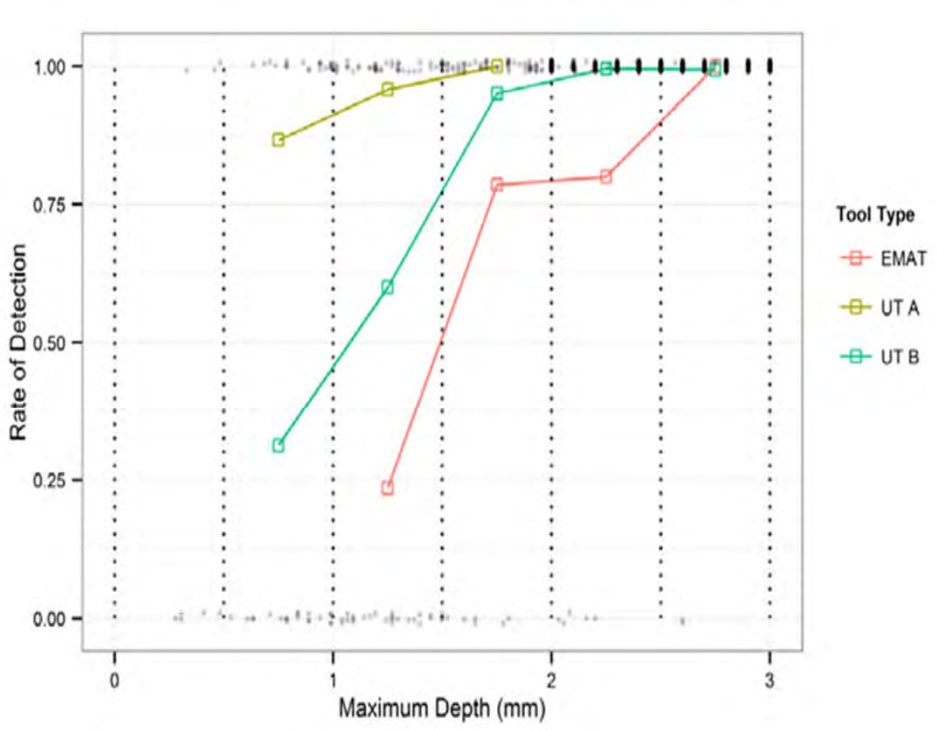
All measurement techniques have uncertainty

A range of typical performance is considered acceptable for effectiveness and efficiency

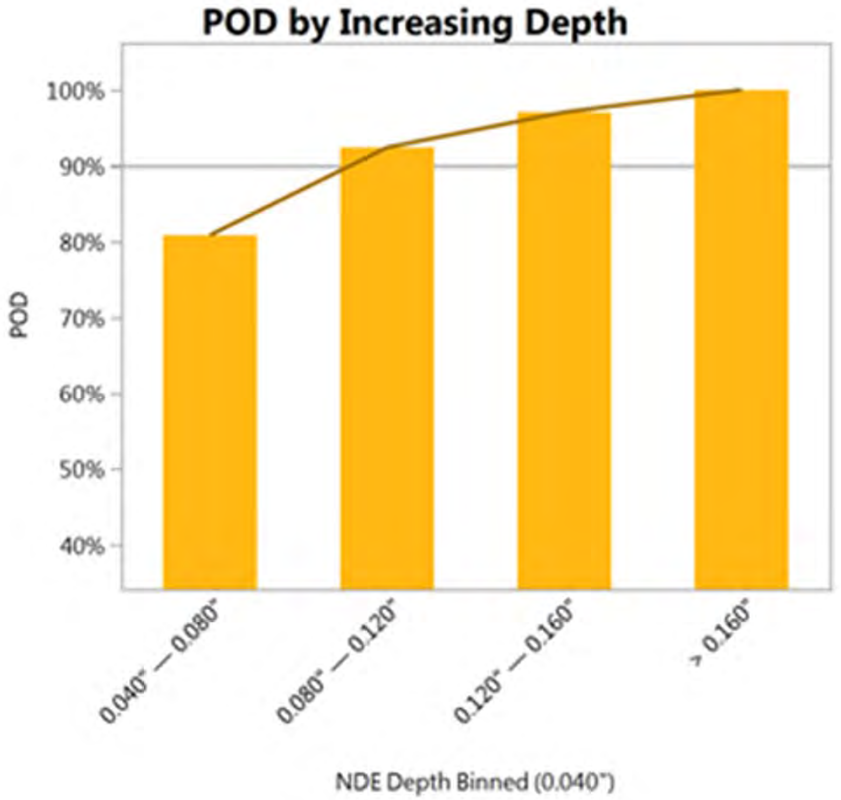
Rate of Detection Example

- **Results support that detection increases with crack size**

NDE-4E Example Results

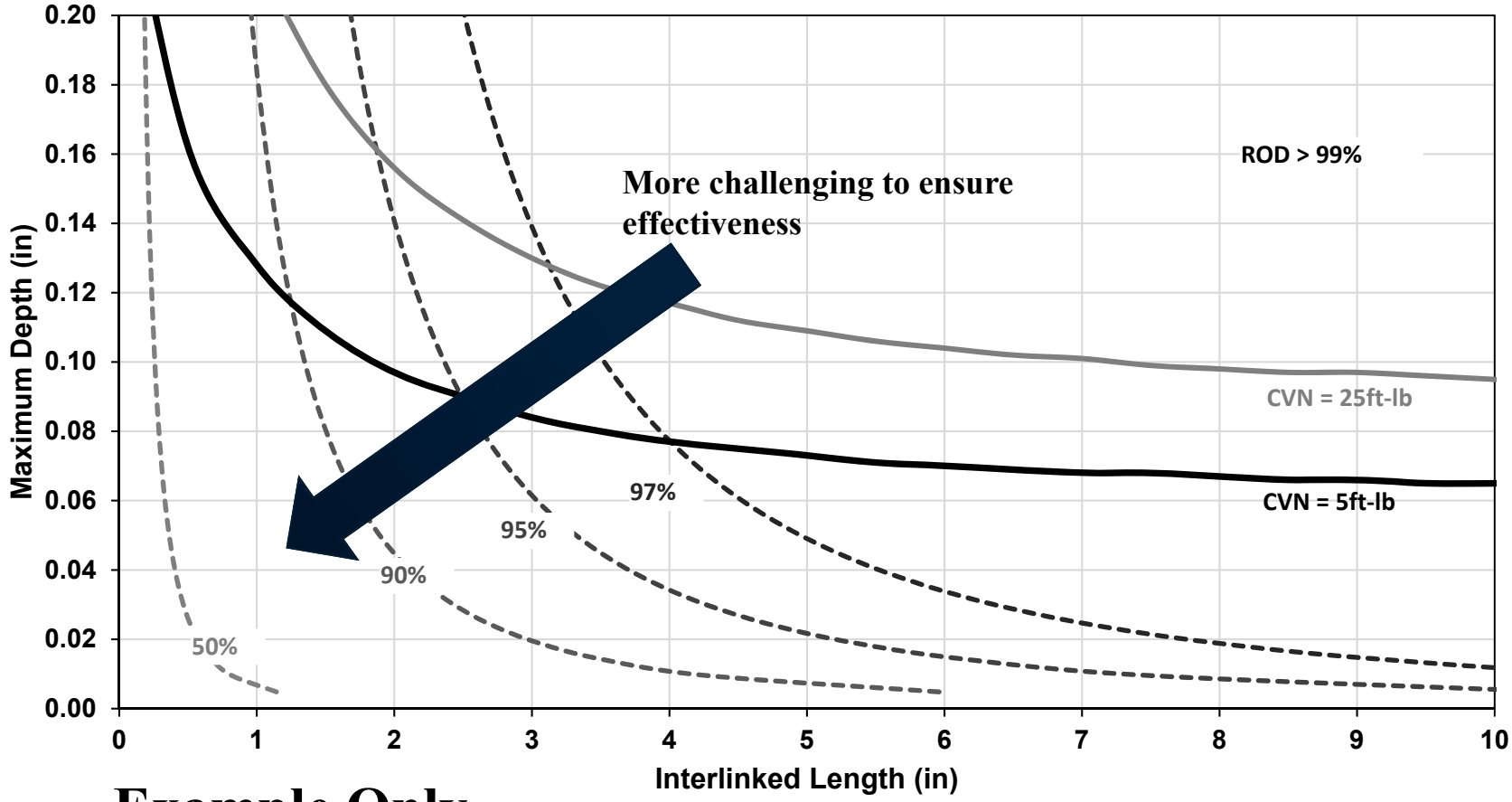


Enbridge Results (2014-2017 UTCD)



Implications of Rate of Detection

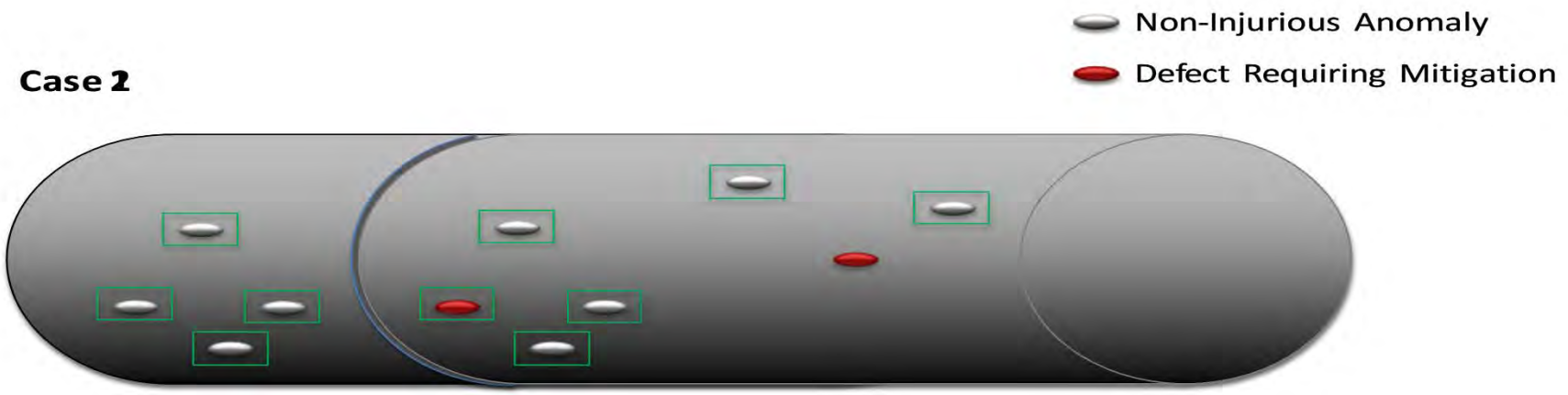
- **Effectiveness and efficiency based on operating conditions and pipe characteristics**



Example Only

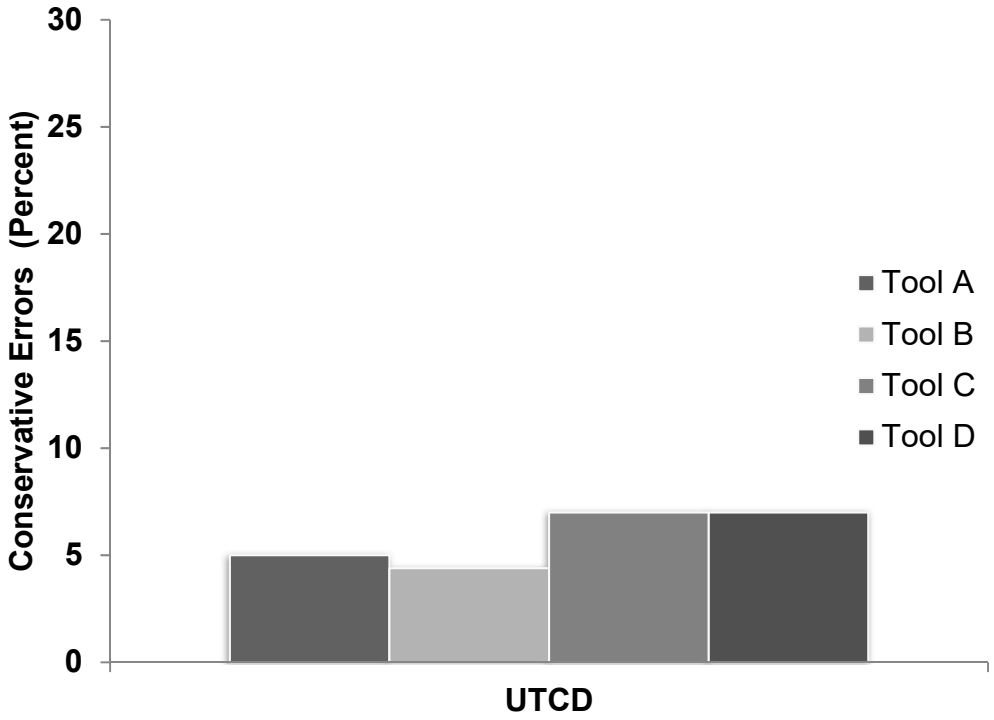
Implications of Rate of Detection

- Concept of ‘Missed Defects’ as an additional performance check
- If a crack defect is not properly selected by the program, it may be an indicator that inspection performance does not meet expectations

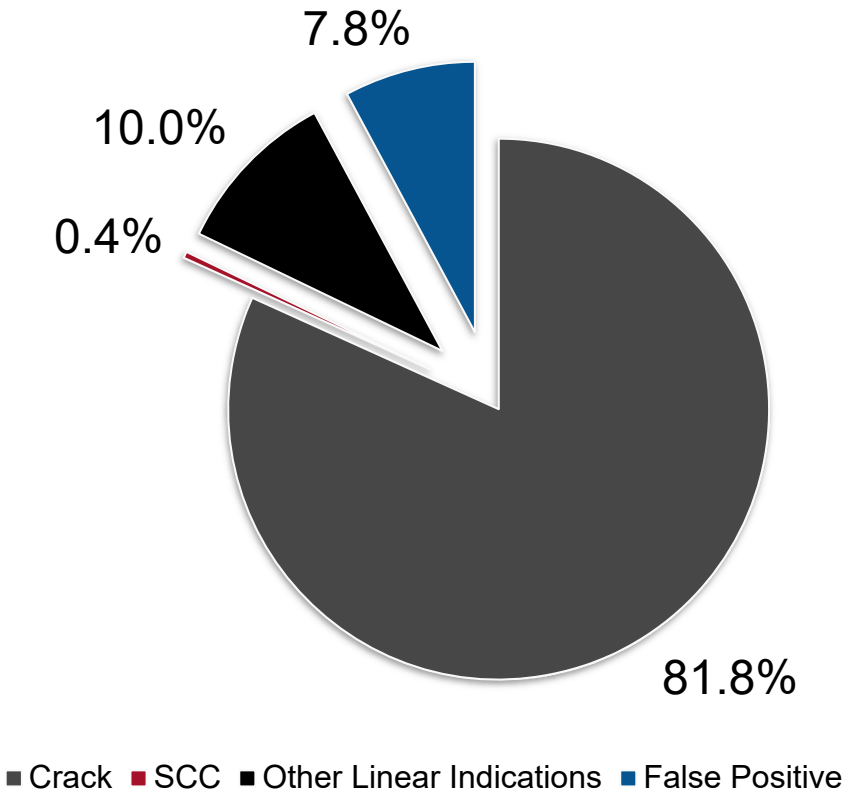


Identification Example

- **POI is typically high**
- **POFC may be high in certain cases**
  - Efficiency impact, not necessarily effectiveness



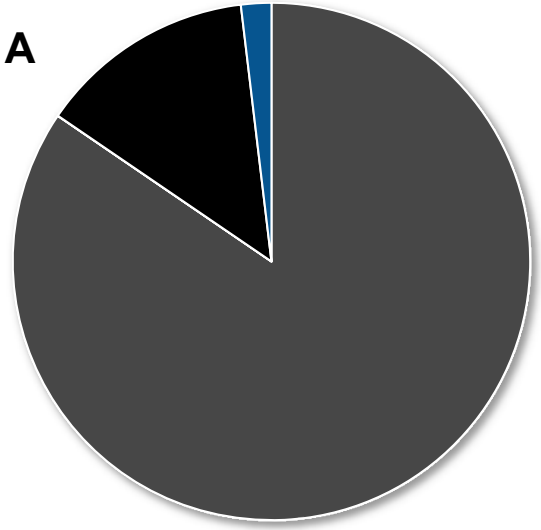
Example NDE-4E Results



Enbridge Results (2014-2017 UTCD)

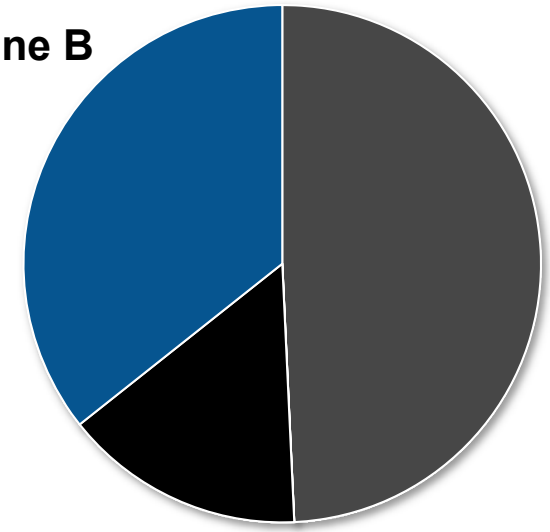
Implications of Identification

Line A



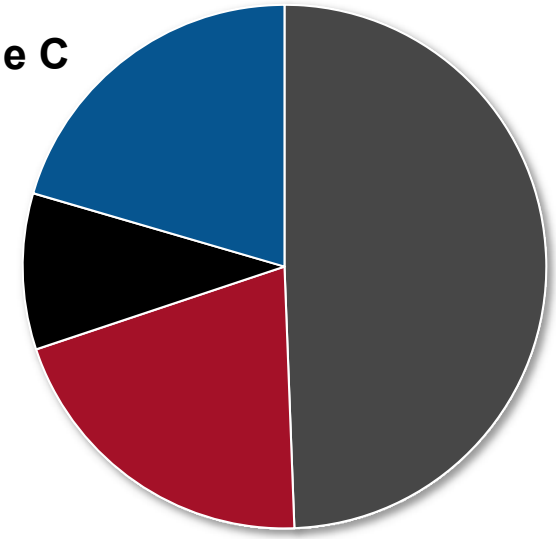
- Need to monitor POI and POFC
- Enbridge data supports that the line segment has impacts beyond overall trend
- Sizing algorithms and response criteria may be different
- API 1176: Likely vs. unlikely cracks

Line B



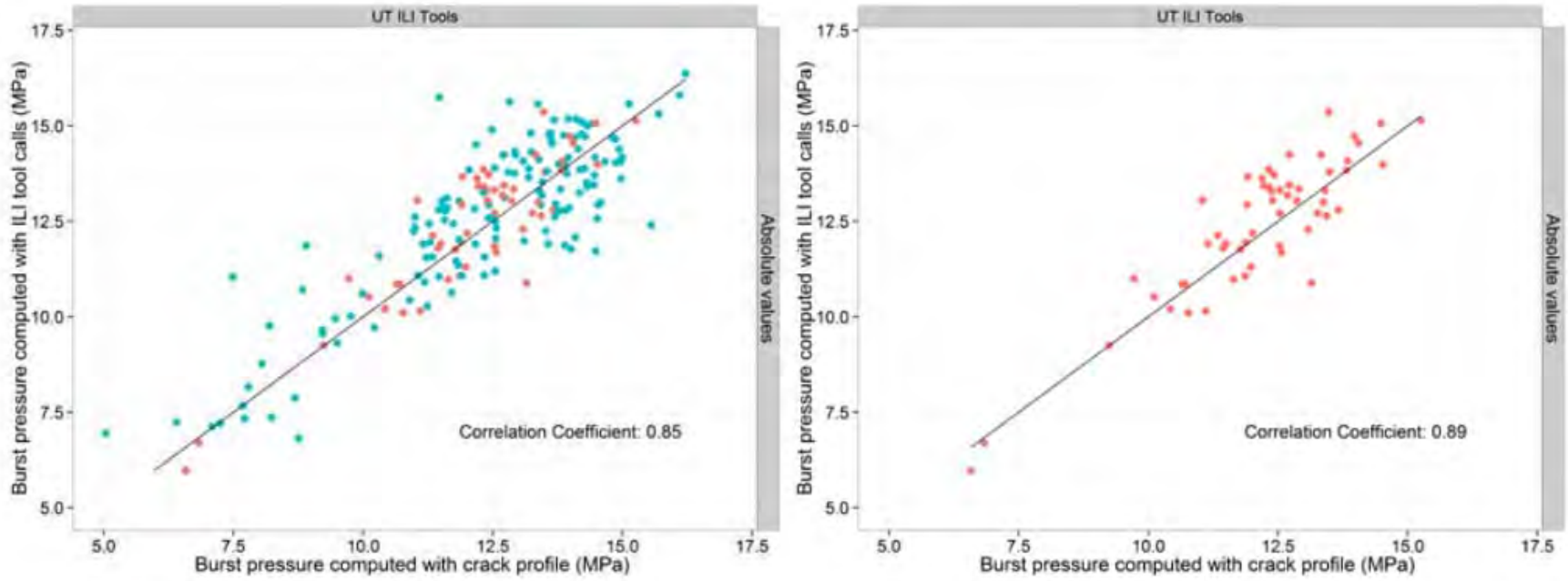
- Crack
- SCC
- Other Linear Indications
- False Positive

Line C



Sizing Accuracy Example

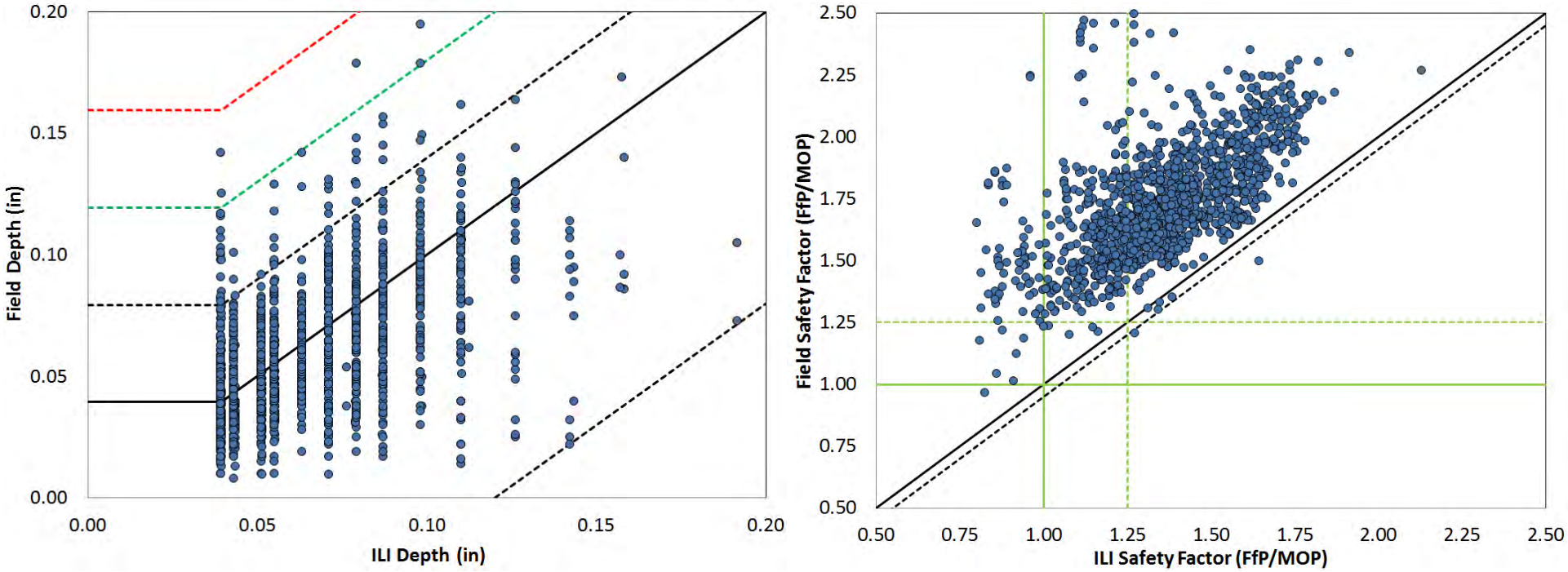
- Sizing typically meeting the vendor specifications or conservative
- Limitation of NDE-4E is that most of the data is based on peak depth and length, which limits the current dataset with respect to burst pressure performance



Burst Pressure Unity Plot for Feature Profile Data, NDE-4E, Phase 1

Implications of Sizing Accuracy

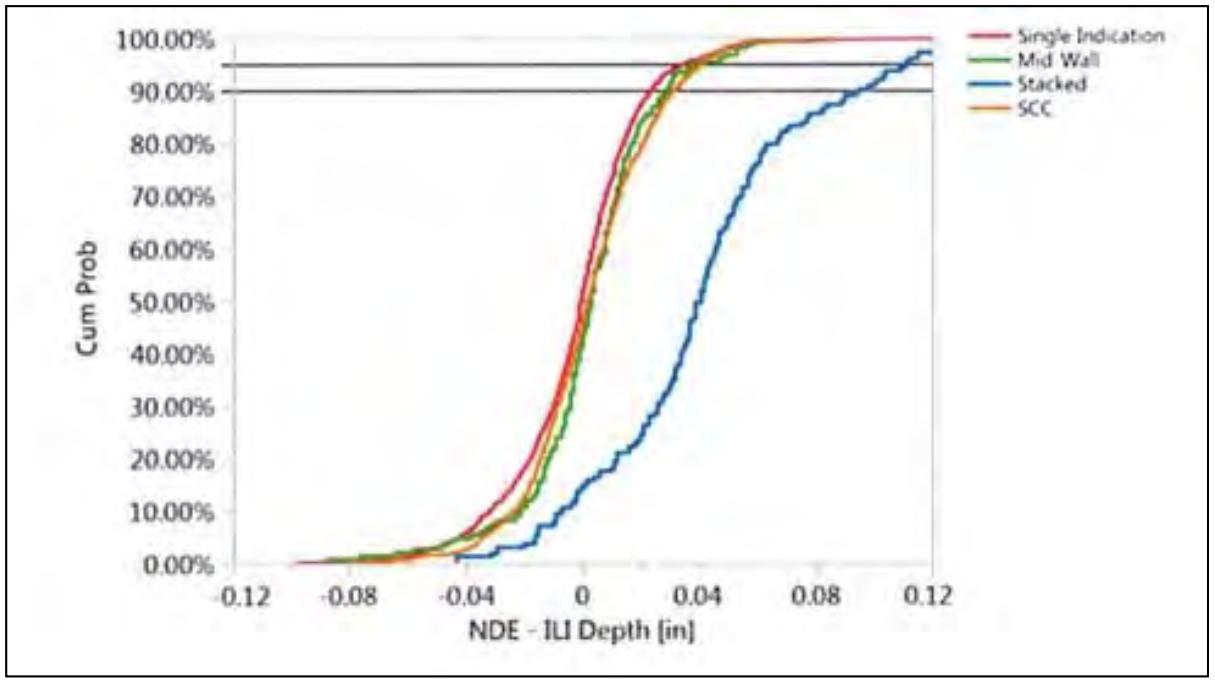
- Profiles mean that sizing under-calls may not lead to non-conservative fitness-for-purpose assessments
- Your burst pressure assessment performance should be tested as well as individual attributes



Example Depth and Safety Factor Data (Enbridge 2014-2017 UTCD)

Implications of Sizing Accuracy

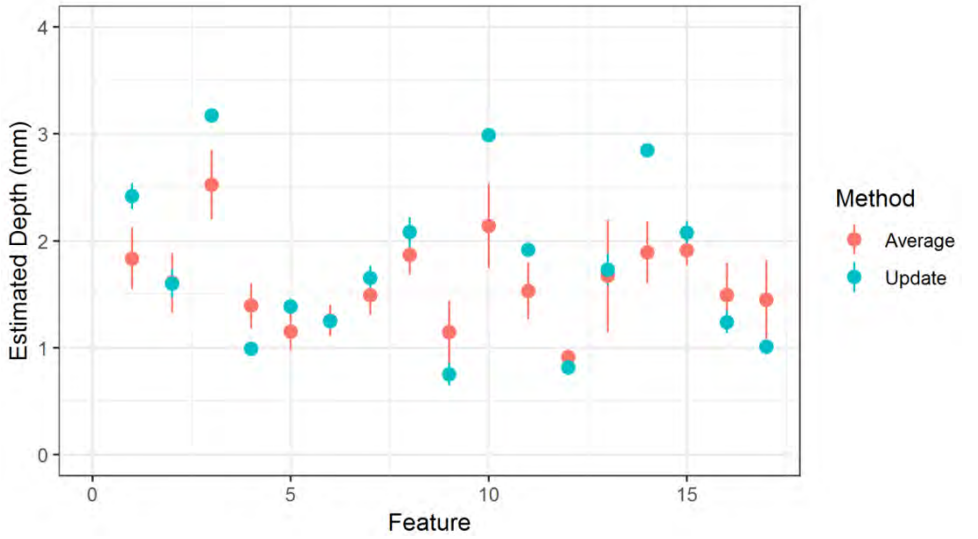
- Different flaw morphologies and locations affect sizing accuracy
- The ‘spec’ is an overall measure, and some flaws types might exceed the specification while others do not meet the specification

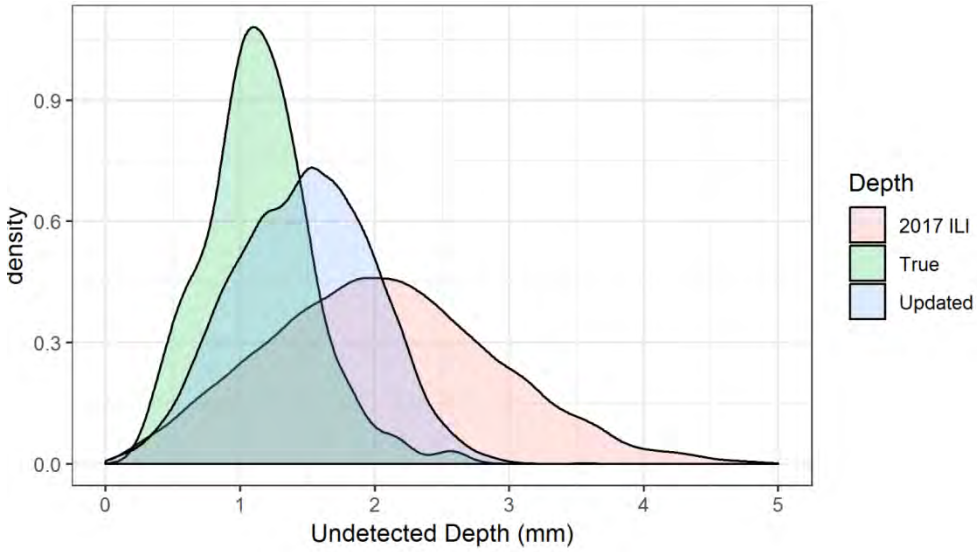


Example Data for Different Flaw Radial Locations, (Enbridge UTCD)

Benefit of Repeat Inspections

- Potential improvements in detection and sizing
- Improved understanding of unreported crack population
- Crack ILI becomes more efficient with increased experience
  - Discussed in API 1176
- Potential to improve growth analysis based on tighter sizing uncertainties





Summary

- **Crack ILI can be used for effective crack management**
- **Demonstrated performance can support Enbridge experience and supports continuous improvement**
  - More access to severe flaws and wider range of pipe properties and crack morphologies than a single operator
  - Demonstration of best practices available for assessment of tool performance
- **Enbridge and industry experience demonstrates that specific cases where program performance may be impacted by crack ILI performance can be identified and managed**
  - NDE-4E provides a mechanism to learn about other operators experiences and use of crack ILI
- **Repeat inspections with crack ILI can improve the confidence in sizing and detection, as well as the characterization of the unreported crack population**

Pipeline Research Council International, Inc.

Research for ERW Seam Management

Mark Piazza, Colonial Pipeline

PRCI 2019 Research Exchange Meeting

March 5, 2019

Presentation Overview

- Roadmaps – benefit and value
- Project Champions
- Flexible and adaptable approach
- Working across projects and Technical Committees
- The benefits and how to maximizing high-value samples from former –in-service pipe
- Truth Data and the Pursuit of Truth

Background Information

- **Project was initially part of IM-3 Program – *Comprehensive Approach for Integrity Management of ERW Pipe***
  - *Prompted by PHMSA R&D Work and NTSB Recommendations*
  - *Later de-coupled into individual projects*
  - *PHMSA analysis of ERW seam failures occurred was significantly lacking in depth and rigor*
- **IM-3 Program funded recovery of vintage ERW pipe with known seam anomalies – makes up a significant portion of pipe now in flow loop**
  - ILI data review of segment to be abandoned in place
  - Other relevant data on pipe conditions; metallurgical testing
- **Initial NDE screening to confirm presence of seam features and high-value samples**
- **NDE screening through IM-3C used to identify additional threats**

PRCI Research – Crack NDE Technology Evaluation

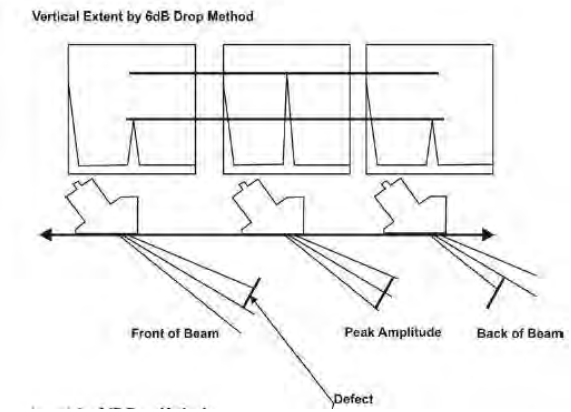
Method	Average Absolute Error (in.)	Average Error % of Compo-nent Thick-ness*	Standard Deviation of Absolute Error (in.)	Average Error % of Aver-age Crack Depth	Slope of Linear Regression Unity Line Slope: 1	Correlation Coefficient (*R*) of Linear Regression
PAUT 2	0.020	7.90%	0.016	22.70%	0.33	0.587
PAUT 4	0.023	9.30%	0.021	26.80%	0.43	0.424
PAUT 1	0.024	9.50%	0.019	27.80%	0.58	0.535
SWUT	0.026	10.30%	0.021	30.00%	0.19	0.233
IWEX	0.031	12.50%	0.022	36.00%	0.21	0.206
PAUT 3	0.032	12.70%	0.026	36.70%	0.59	0.459
FAST	0.034	13.70%	0.024	39.50%	0.31	0.379
ECT	0.042	16.90%	0.023	50.10%	0.29	0.504
micro-TOFD	0.045	18.20%	0.028	53.40%	0.39	0.447
ECHO 3D	0.050	19.90%	0.028	57.90%	0.17	0.196

UT in general lower average error than electromagnetic/ eddy current techniques

3 of 4 PAUT providers demonstrated lowest Average Error (8-10% of Through Wall Depth)

NDE Truth Data Investigation Strategy

- **Learning from NDE-2-2**
  - Significant error remains in SOTA for UT amplitude based depth profiles for both ERW and SCC
    - *Why?*
      - Potential for oversizing is well established, relationship of flaw size to beam size
      - Lack of relevant calibration standards, performance criteria
      - Real Hook Cracks likely very irregular, out of plane



  - Destructive sizing is Truth, but how to conserve samples?
    - *Investigate potential for new technologies; Computed Tomography*

The Research Process for ERW Seam Management

2014: Recover ERW Pipe with known flaws

2016: NDE technology evaluation – round robin study (IM-3C)

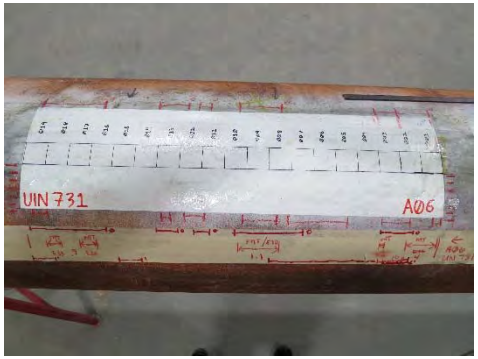
2016 - 2017: PRCI commissions 12-inch ILI flow loop & ILI tool runs

2018: Truth Data for ILI and NDE technologies

- **CT scanning of all segments – prototype system**
- **Selection of segments for "truth data"**
- **Lab-scale CT scanning of seam selected sections and sectioning**

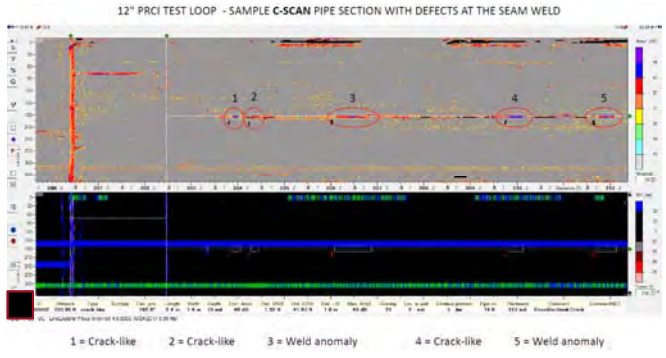
2019: Data compilation and analysis (ongoing) and Reporting

2015

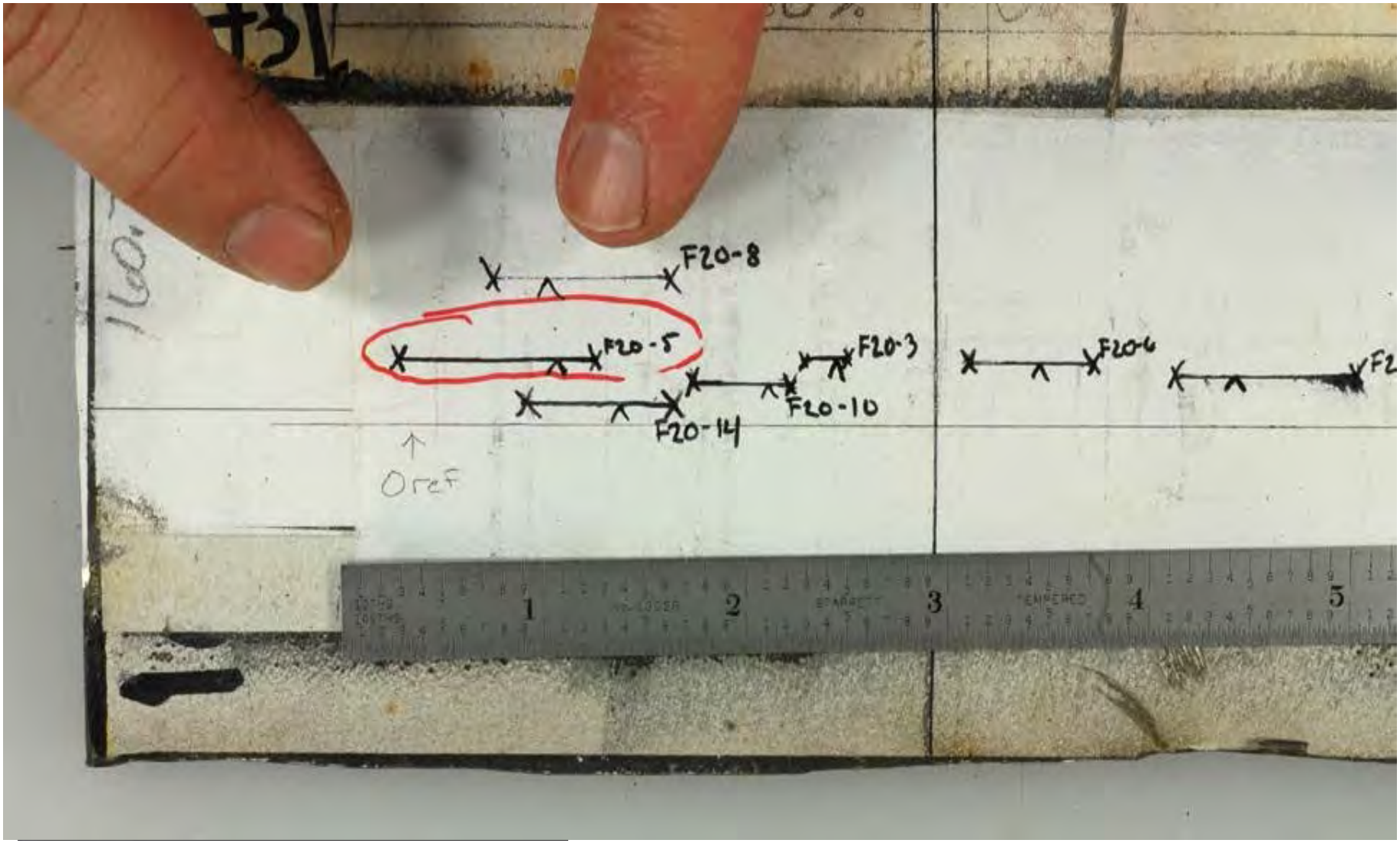


2017

2017 - 2018

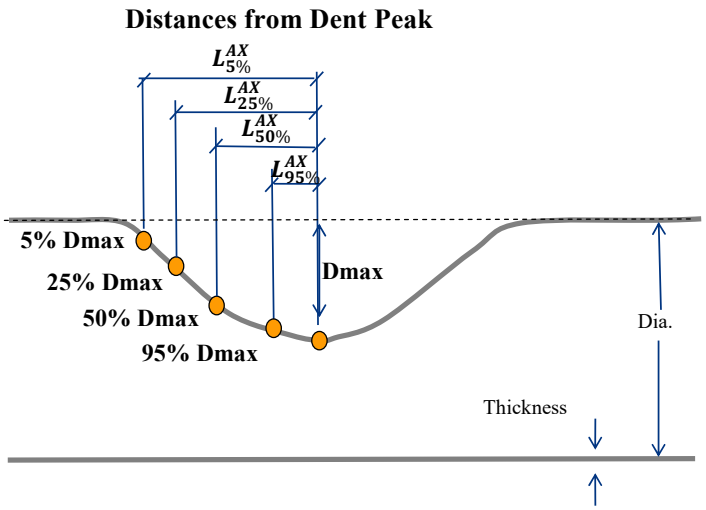


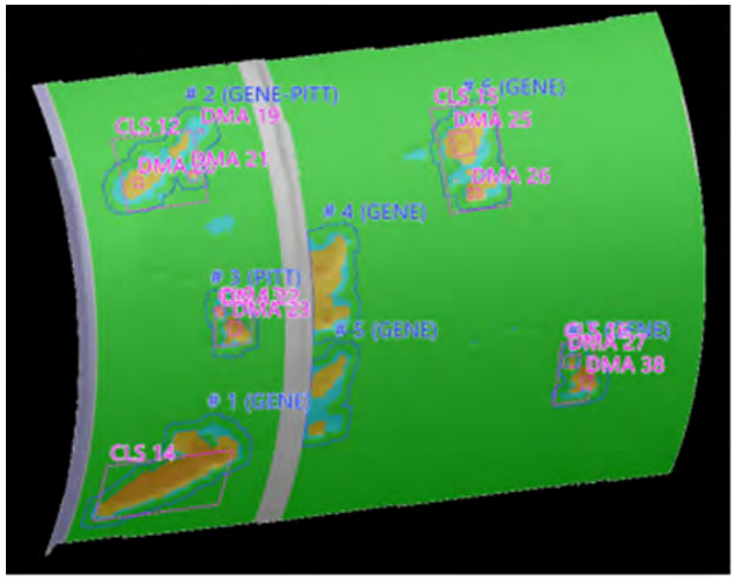
The Research Process for ERW Seam Management



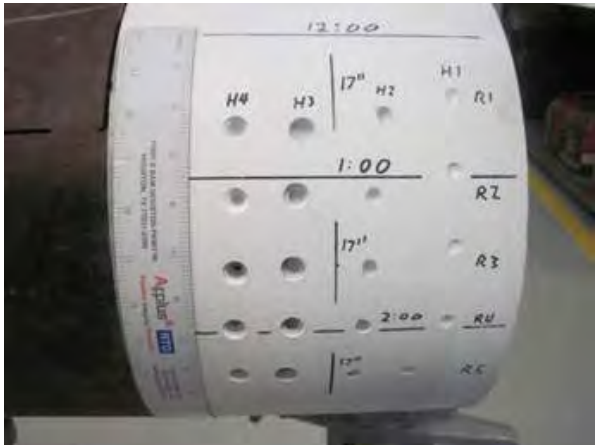
So What's Next?

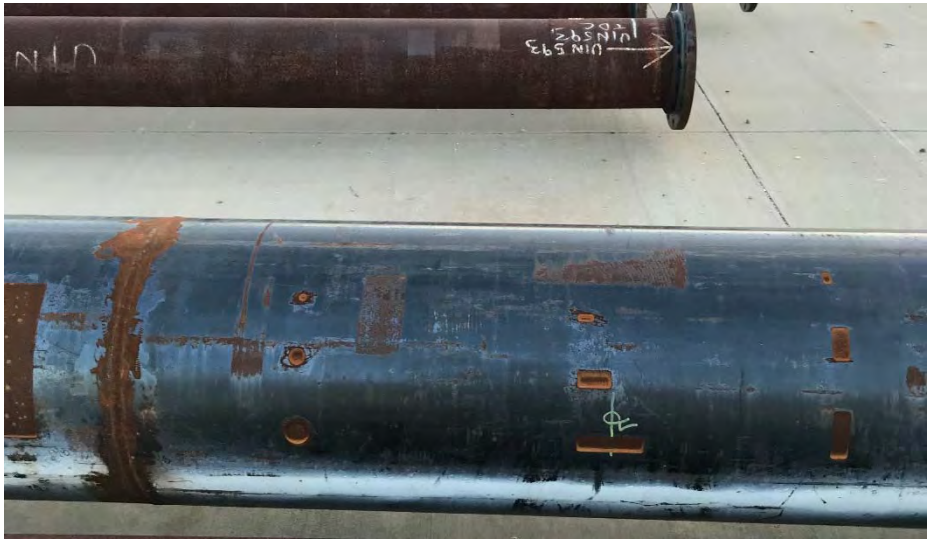
- The Pursuit of Truth
- ILI and NDE technology evaluations
- Benchmarking and technology development using calibration and reference standards
- Seam anomaly and crack focus

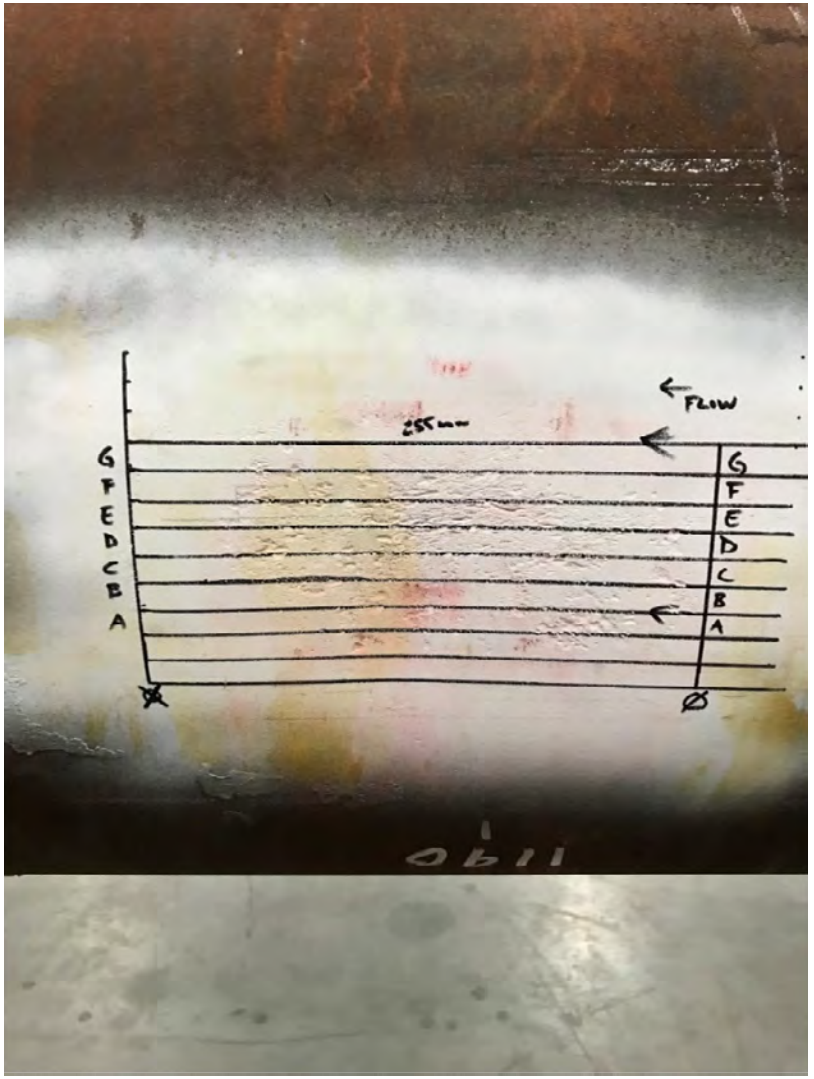




Machined Calibration Standards….





….vs. The Real World

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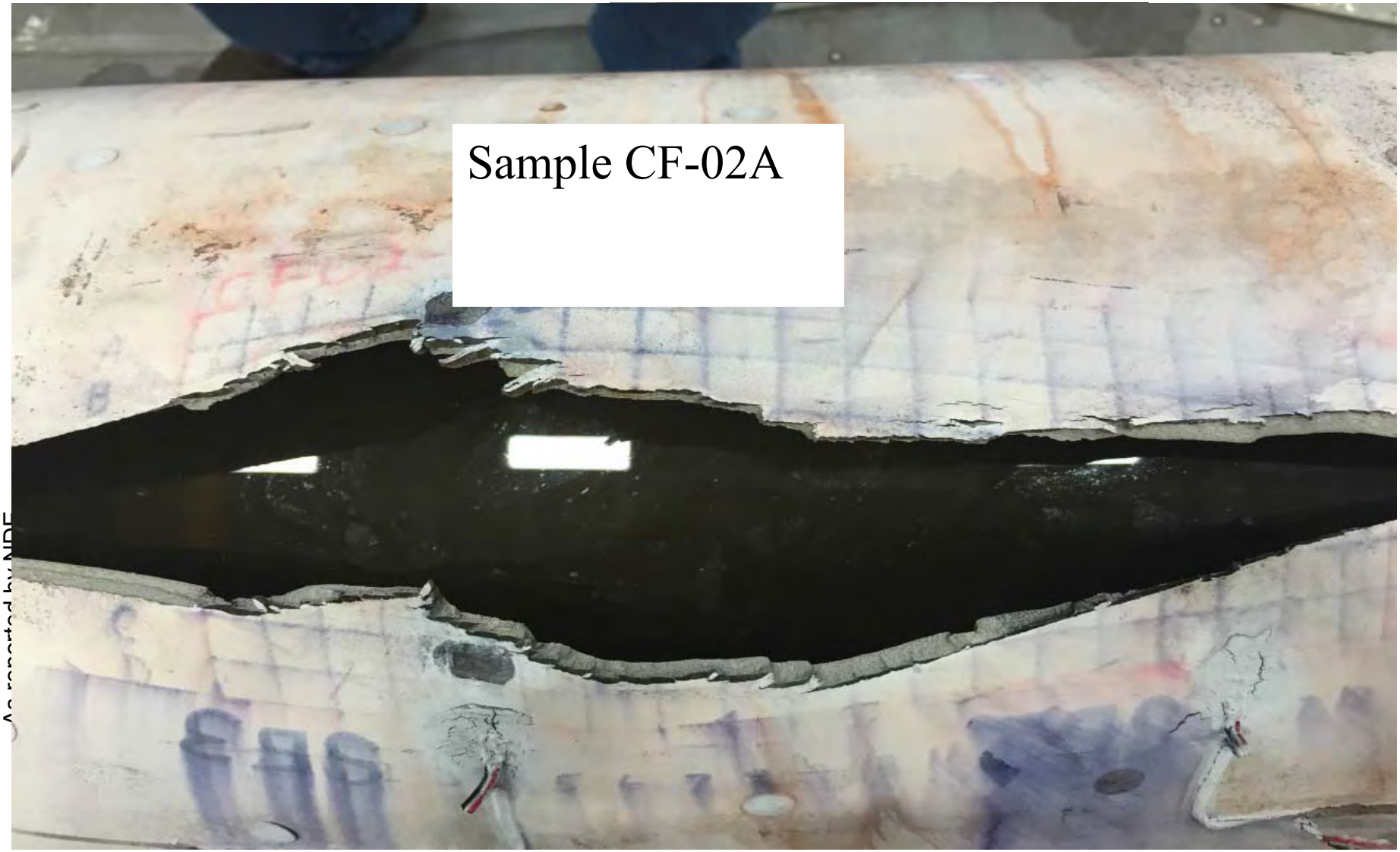
Characterizing Crack Features

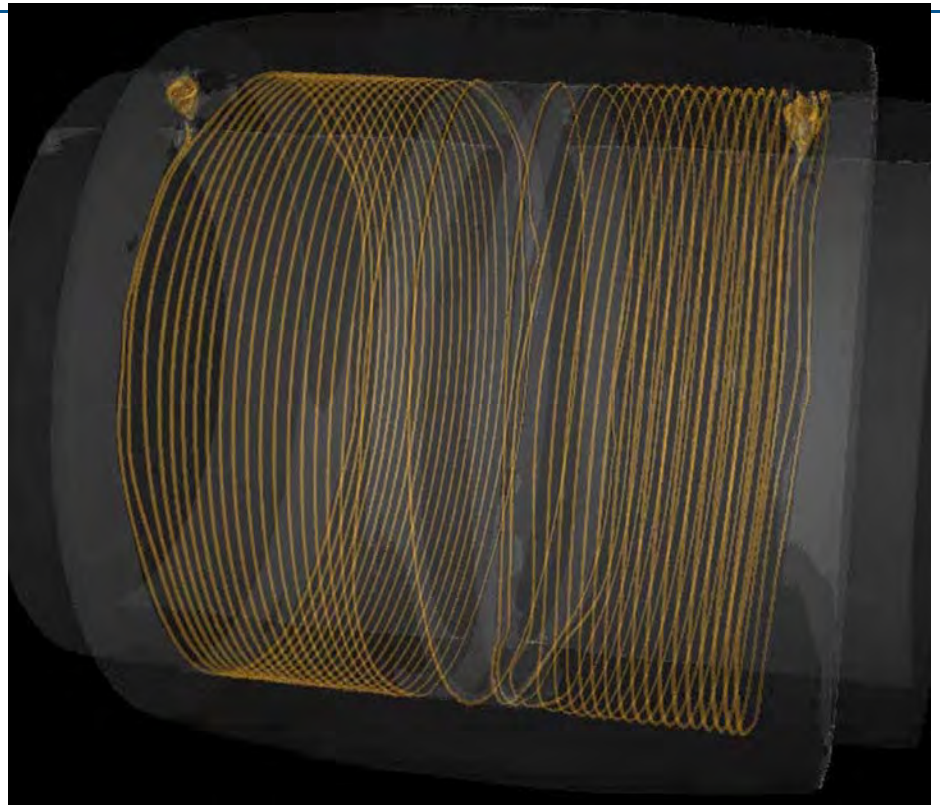


As reported by NDE

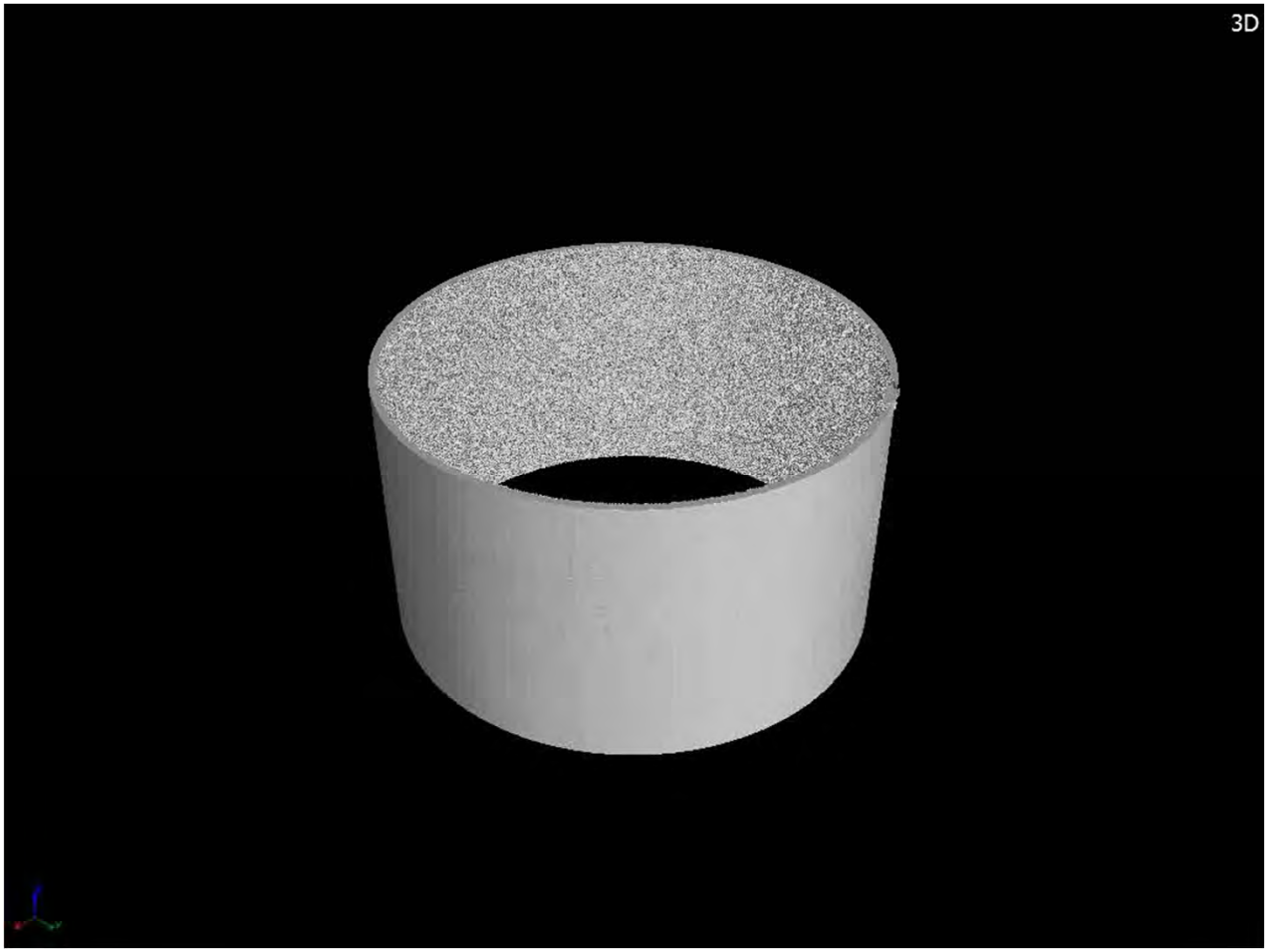
NDE Truth – Driving New Technology

- **Ultimate Crack Truth by metallographic section**
- **Role of Computed Tomography?**
  - Precisely identify the locations for metallographic sections based on CT profile data
  - Recognizing the TRL for on-shore full pipe CT
  - Prototype system by Inspection Associates
  - Ongoing evaluation by PRCI – reference stds.

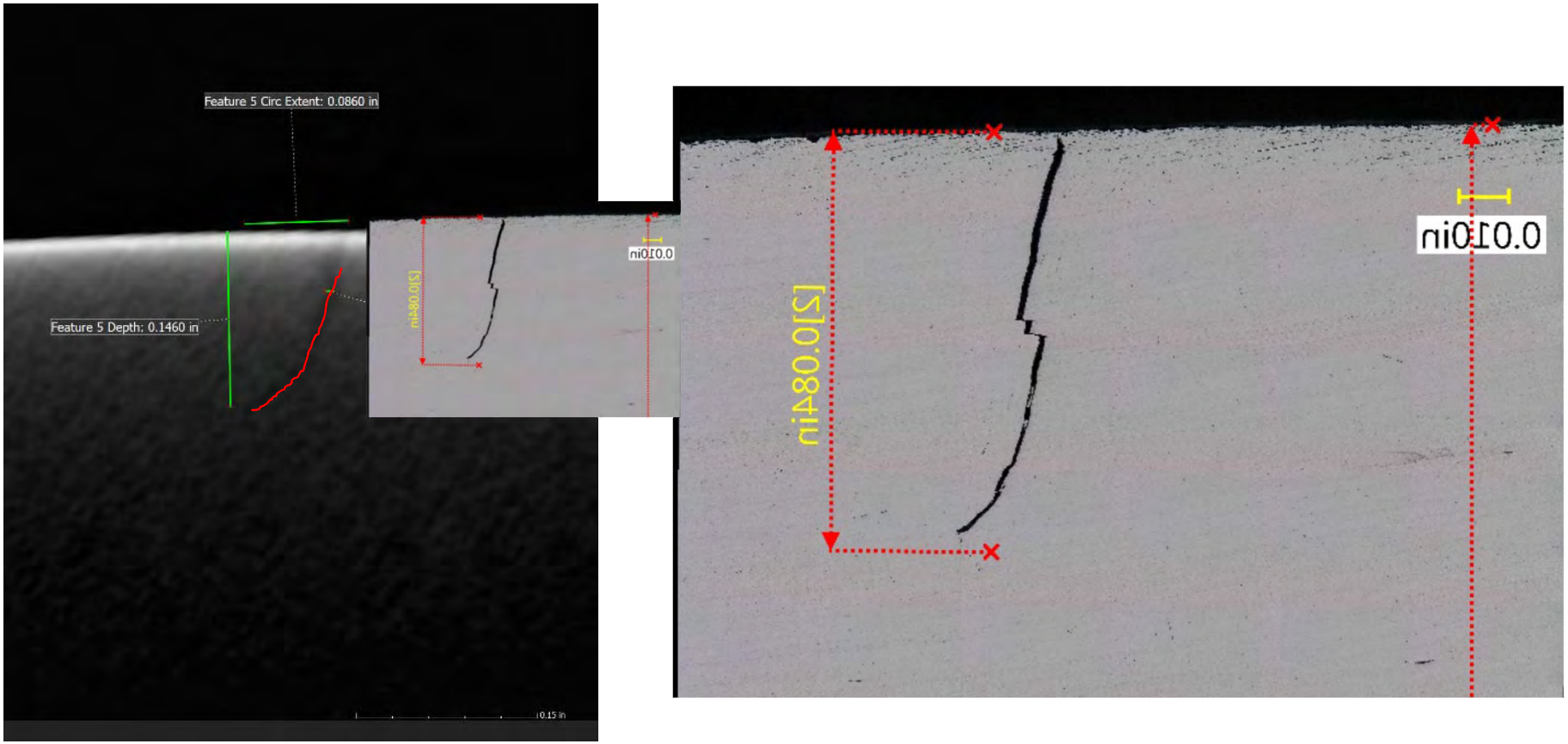
What's Next?



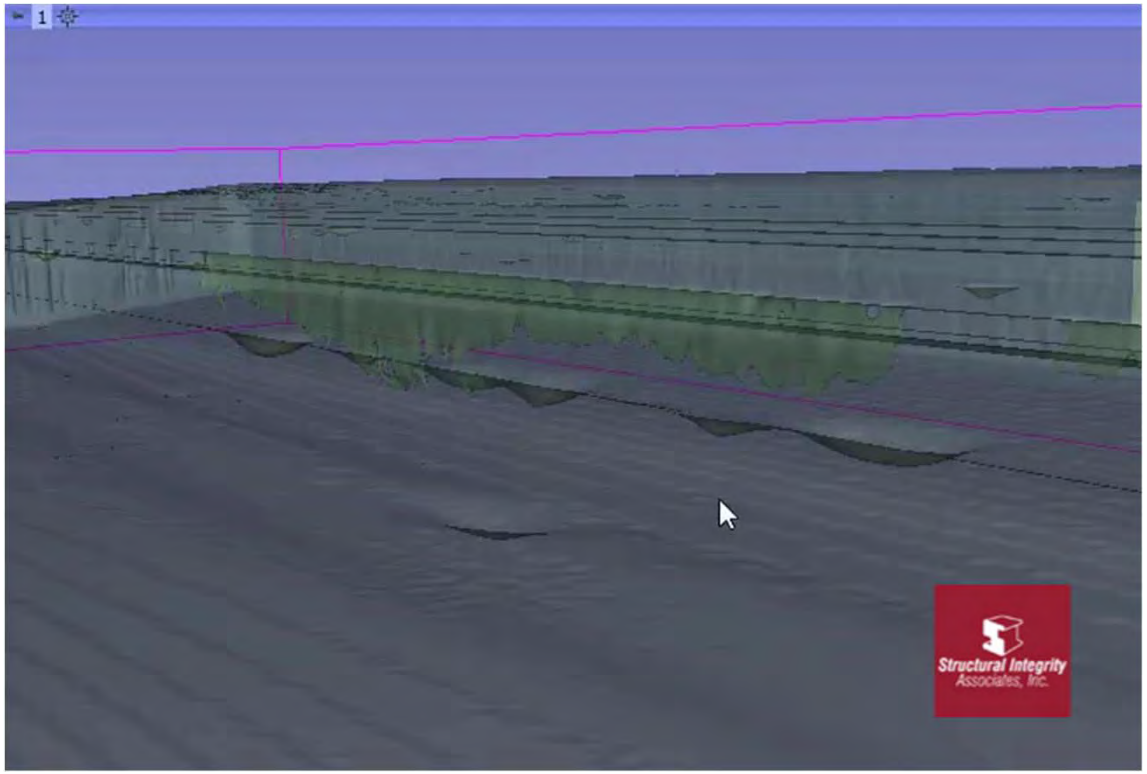
What's Next?

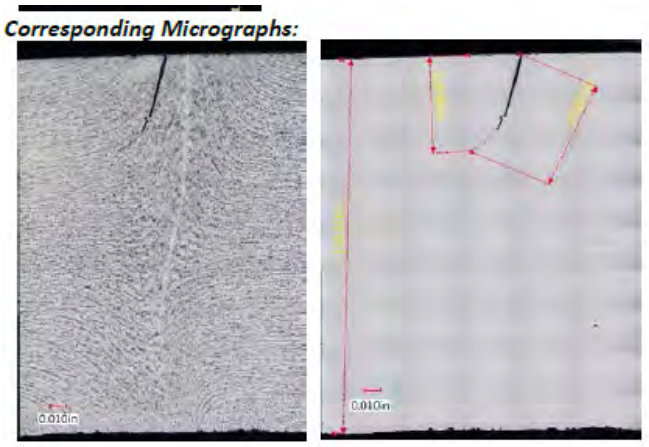


What's Next?

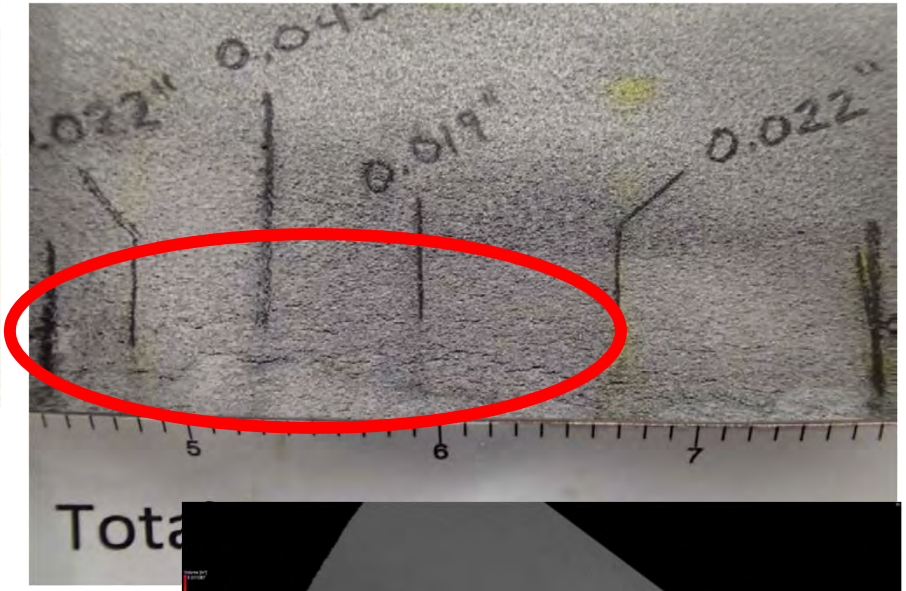

Feature 5 Circ Extent: 0.0860 in
Feature 5 Depth: 0.1460 in
0.15 in
0.080in
0.013in

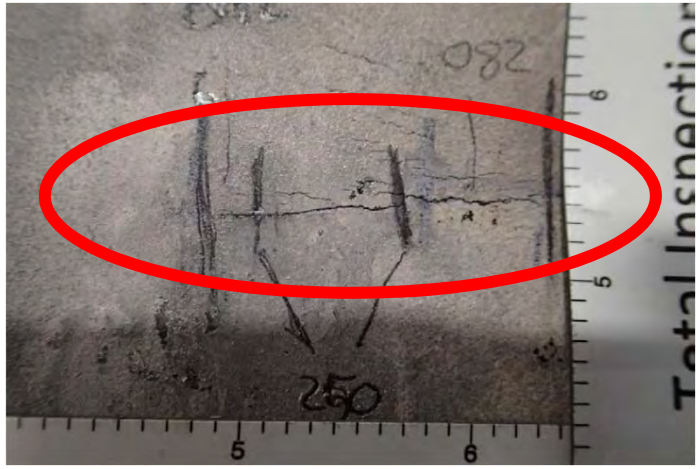
What's Next?

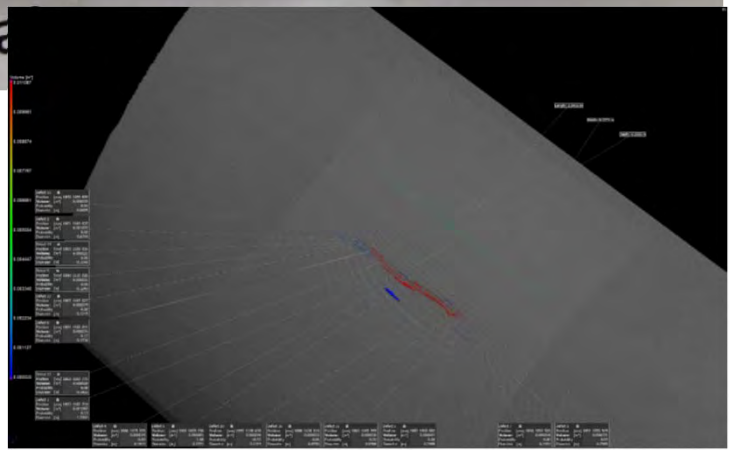

1
Structural Integrity
Associates, Inc.


Corresponding Micrographs:

Dents with Fatigue Cracks







Related Work

- **New Funding Model – *Develop Industry Reference Standards for NDE Technology Evaluation***
- **2 related projects in PRCI – NDE 4-6 and NDE 4-10**
  - *Both using small-scale CT as the basis to evaluate NDE technologies performance for crack sizing*
  - *SCC focus (vs ERW)*
- **PRCI NDE-4-6A – expanding modeling, developing best practices for NDE crack inspection**
- **Encoder development for SCC that is technology agnostic (planned)**
- **Use small-scale CT to validate/certify NDE & ILI technologies**
- **Continue to develop full-scale protoype systems and establish a basis for industry reference standards**

Conclusions

- Computed Tomography and the pursuit of the “Truth” – continued research
- Industry recognition of the need for calibration & reference standards and ILI and NDE certification – **the future is now**
- Continue industry benchmarking
- Drive industry research
  - ILI & NDE Performance evaluations for cracks – SCC, cracks in dents, hook cracks
  - Next generation ILI and NDE systems
  - Strategic Research focus and funding models - need change to achieve industry objectives

Leverage PRCI TDC

PRCI Crack Consortium

Pipeline Research Council International, Inc.

A Novel Method in Assessment of Corroded Steel Pipe in Water Lines

Ashkan Khalili, Ph.D.
Ali Alavi, Ph.D., P.E.
Xylem

PRCI 2019 Research Exchange Meeting
Houston, Texas
Date March , 2019

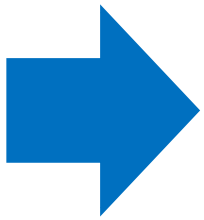
xylem
Let's Solve Water

Defects in Steel Pipe

Flower Mound TX

Motivations and Objectives

- **Level 1 methods mostly developed for oil/gas industry:**
  - High grade
  - High pressure
- **Common Level 1 methods:**
  - Highly conservative



- **Developing a new method in order to:**
  - More suitable for water industry
  - Decrease level of conservatism
  - Reduce error
- **Analyze its sensitivity to parameters**

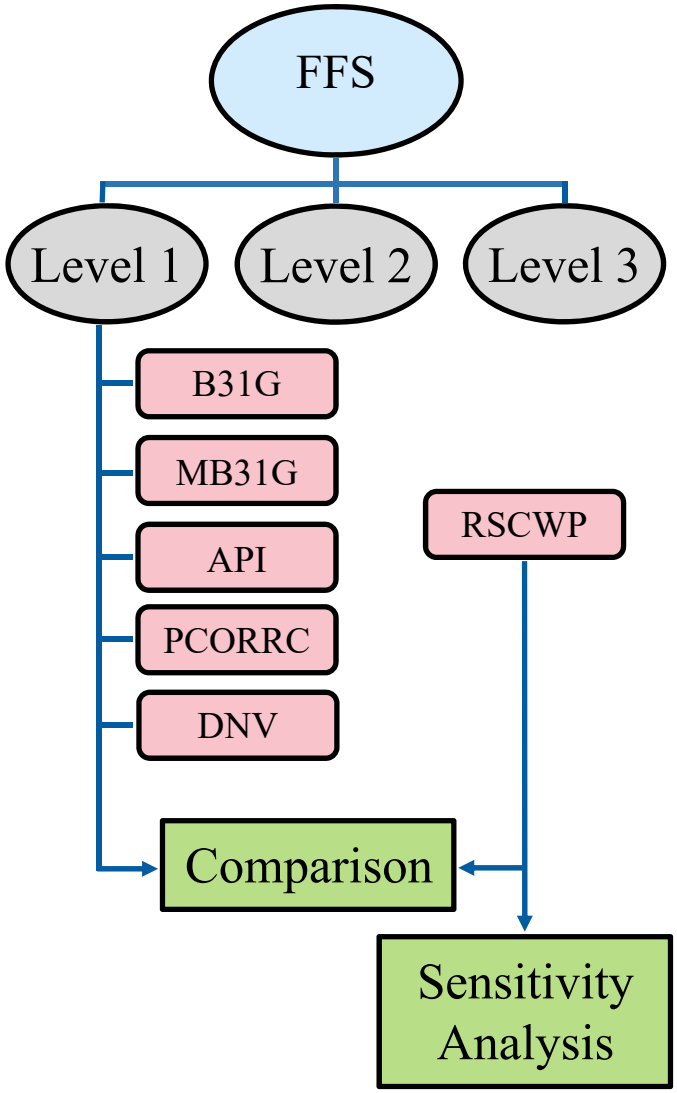
Steel Pipe in Water Pipeline

- **Water industry uses different material standard in comparison to Oil and Gas industry**
- **Water industry rarely uses any material with SMYS above 52,000 psi (only exception is ASTM A572 GR60)**

ASTM Material Designation[1]	Grade	Minimum Yield Strength ksi (MPa)	Minimum Tensile Strength ksi (MPa)
Steel Sheet (Coil or Flat)			
A139	B	35 (242)	60 (415)
	C	42 (290)	60 (415)
	D	46 (315)	60 (415)
	E	52 (360)	66 (455)
Steel Plate			
A36/A36M		36 (248)	58 (400)
A572/A572M	42	42 (290)	60 (415)
	50	50 (345)	65 (449)
A516/A516M	55	30 (205)	55 (380)
	60	32 (220)	60 (415)
	65	35 (240)	65 (450)
	70	38 (260)	70 (485)

Outline

- **Fitness for Service (FFS)**
- **Level 1 Assessment**
  - ASME B31G
  - Modified ASME B31G
  - API RP 579
  - PCORRC
  - DNV RP F101
- **Remaining Strength of Corroded Water Pipe (RSCWP)**
- **Results and Discussion**
- **Conclusion**



Fitness for Service (FFS)

- **A quantitative engineering evaluation for in-service equipment to determine its fitness for continued service.**
- **A rational base to define the flaw acceptance limit**

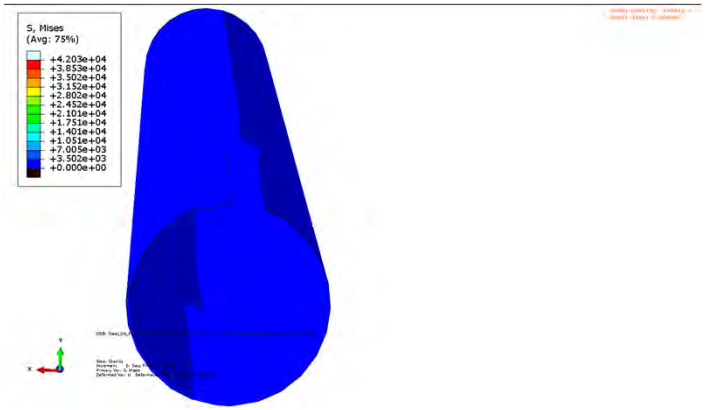
Complexity

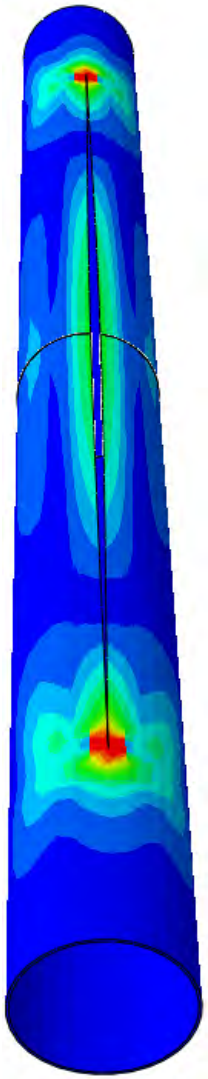
Level 1:
Requires basic inspection data

Level 2:
Requires more detailed inspection data

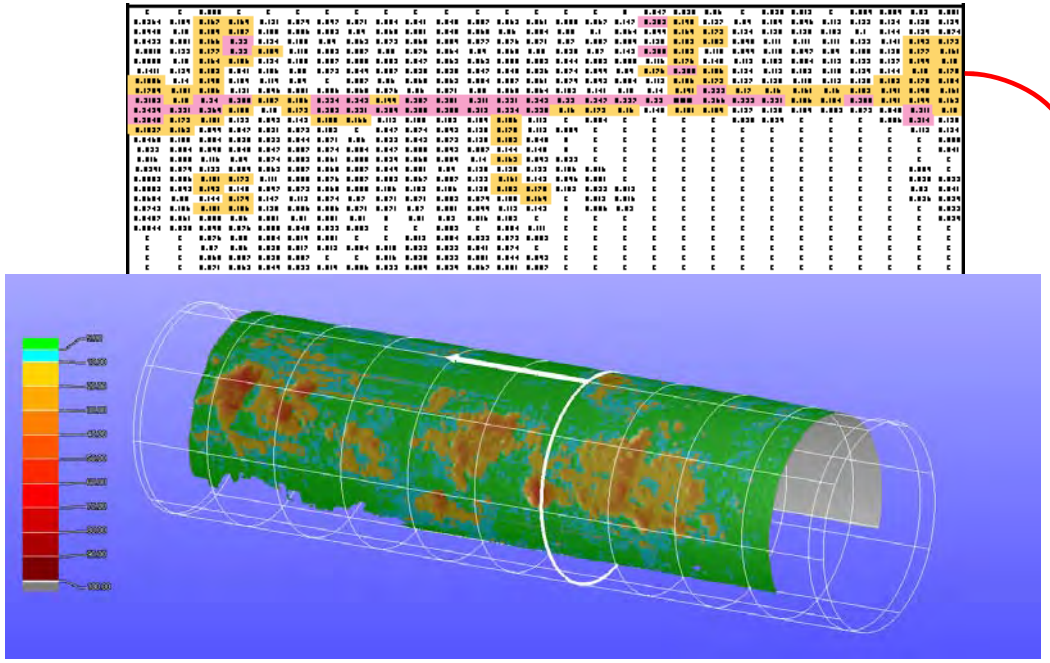
Level 3:
Requires enhanced data collection

Conservatism





Insulate Component Testing (InCoTest)



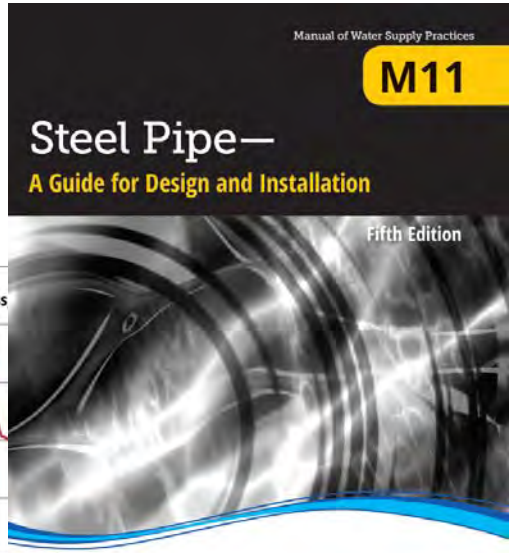
Yellow Zone: Corrosion **>15%**
Pink Zone: Corrosion **>20%**

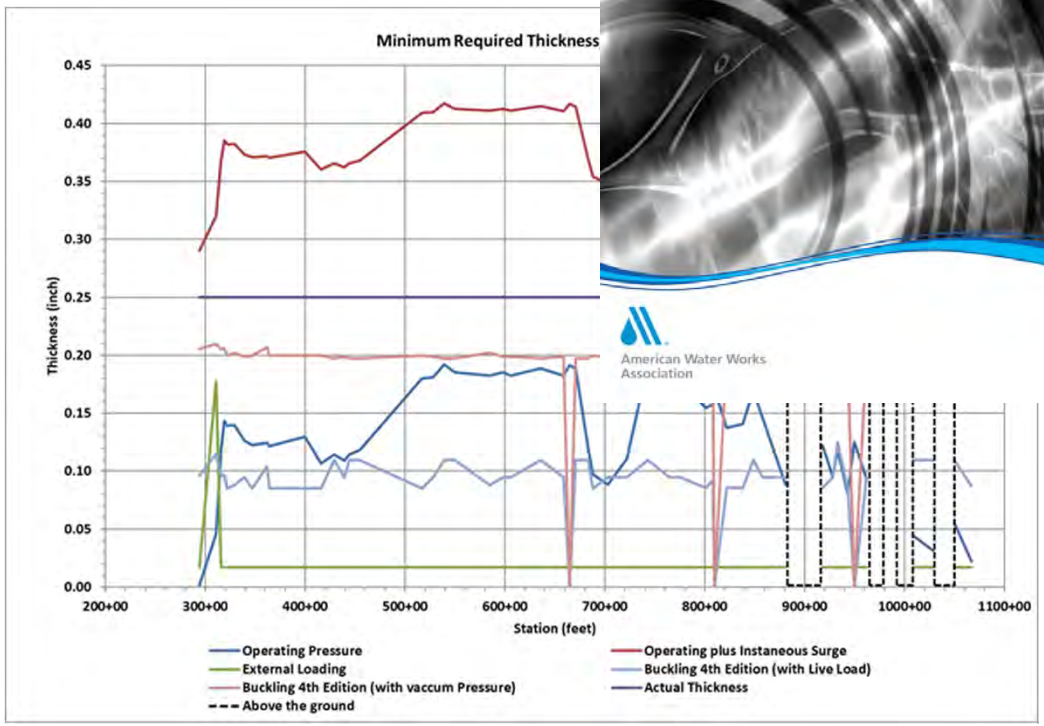
0.1410909	0.192	0.1730909
0.1381818	0.1774545	0.1614545
0.1367273	0.1992727	0.1803636
0.144	0.1803636	0.1745455
0.1527273	0.1745455	0.1541818
0.1905455	0.1949091	0.1614545
0.1905455	0.1992727	0.1629091
0.048	0.2109091	0.1803636
0.0058182	0.2138182	0.1381818

Scanning Results

Level 1 Assessment

- **Experimental data (found in literature) were filtered to have a better match with water industry material standards:**
  - Any pipe with SMYS above 52,000 psi were filtered
- **A new method developed to have a better match with water industry needs and standards**





Level 1 Assessment

- **Level 1 Assessment – Common methods in industry**
  - ASME B31.G
  - Modified ASME B31.G

$$(SMYS + 10000) \times \left[\frac{1 - 0.85 \times \frac{d}{t}}{1 - 0.85\frac{d}{t}M_T^{-1}}\right]$$

$$M_T = \begin{cases} \sqrt{1 + 0.6275\frac{L^2}{Dt} - 0.003375\frac{L^4}{D^2t^2}} & ; \quad \frac{L^2}{Dt} \leq 50 \\ 3.3 + 0.032\frac{L^2}{Dt} & ; \quad \frac{L^2}{Dt} \geq 50 \end{cases}$$

  - API RP 579
  - PCORRC
  - DNV RP F101

RSCWP

- **Remaining Strength of Corroded Water Pipe (RSCWP)**
  - Uses the same structure as Modified ASME B31.G
    - *Uses depth of flaw and its length*
    - *Not applicable for wall loss (d/t) greater than 80%*
    - *Calculates the critical Hoop stress*

$$S = (UTS) \times \left[\frac{1 - 0.85 \times \frac{d}{t}}{1 - 0.85 \frac{d}{t} M_T^{-1}} \right]$$

$$M_T = \begin{cases} \sqrt{1 + 0.6275 \frac{L^2}{Dt} - 0.003375 \frac{L^4}{D^2 t^2}} & ; \quad \frac{L^2}{Dt} \leq 50 \\ 3.3 + 0.032 \frac{L^2}{Dt} & ; \quad \frac{L^2}{Dt} \geq 50 \end{cases}$$

RSCWP

- **Remaining Strength of Corroded Water Pipe (RSCWP)**
  - Uses the same structure as Modified ASME B31.G
    - *Uses depth of flaw and its length*
    - *Not applicable for wall loss (d/t) greater than 80%*
    - *Calculates the critical Hoop stress*
  - Uses tensile strength as criteria

$$S = (UTS) \times \left[\frac{1 - 0.85 \times \frac{d}{t}}{1 - 0.85 \frac{d}{t} M_T^{-1}} \right]$$

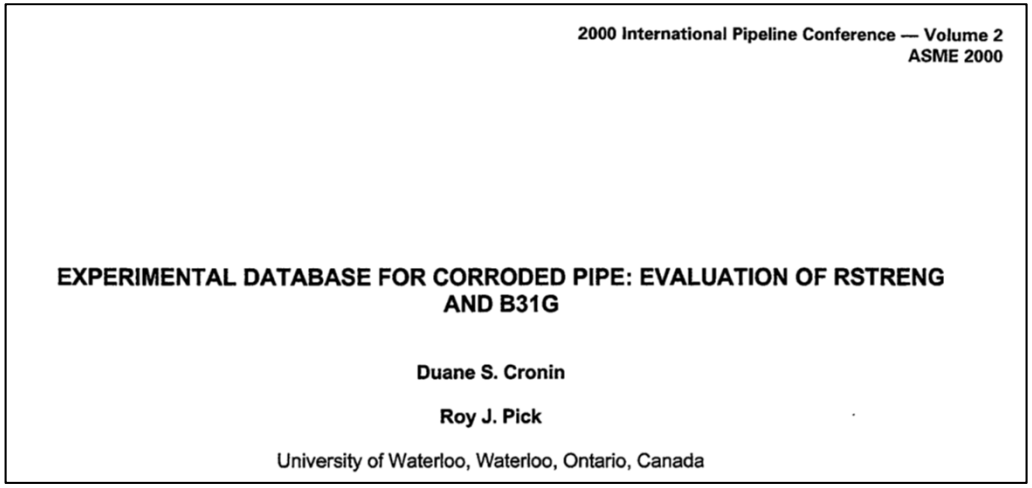
$$M_T = \begin{cases} \sqrt{1 + 0.6275 \frac{L^2}{Dt} - 0.003375 \frac{L^4}{D^2 t^2}} & ; \quad \frac{L^2}{Dt} \leq 50 \\ 3.3 + 0.032 \frac{L^2}{Dt} & ; \quad \frac{L^2}{Dt} \geq 50 \end{cases}$$

Results and Discussion: Methods

- **Introduced methods are used to predict failure pressure**
  - ASME B31.G
  - Modified ASME B31.G
  - API RP 579
  - PCORRC
  - DNV RP F101
  - RSCWP
- **Predictions are compared to experimental data**
- **Average error is calculated for each method**
- **Sensitivity analysis**

Results and Discussion: Database

- **Experimental Database**
  - Diameter: 10-inch to 34-inch



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ASME 2000

EXPERIMENTAL DATABASE FOR CORRODED PIPE: EVALUATION OF RSTRENG AND B31G

Duane S. Cronin

Roy J. Pick

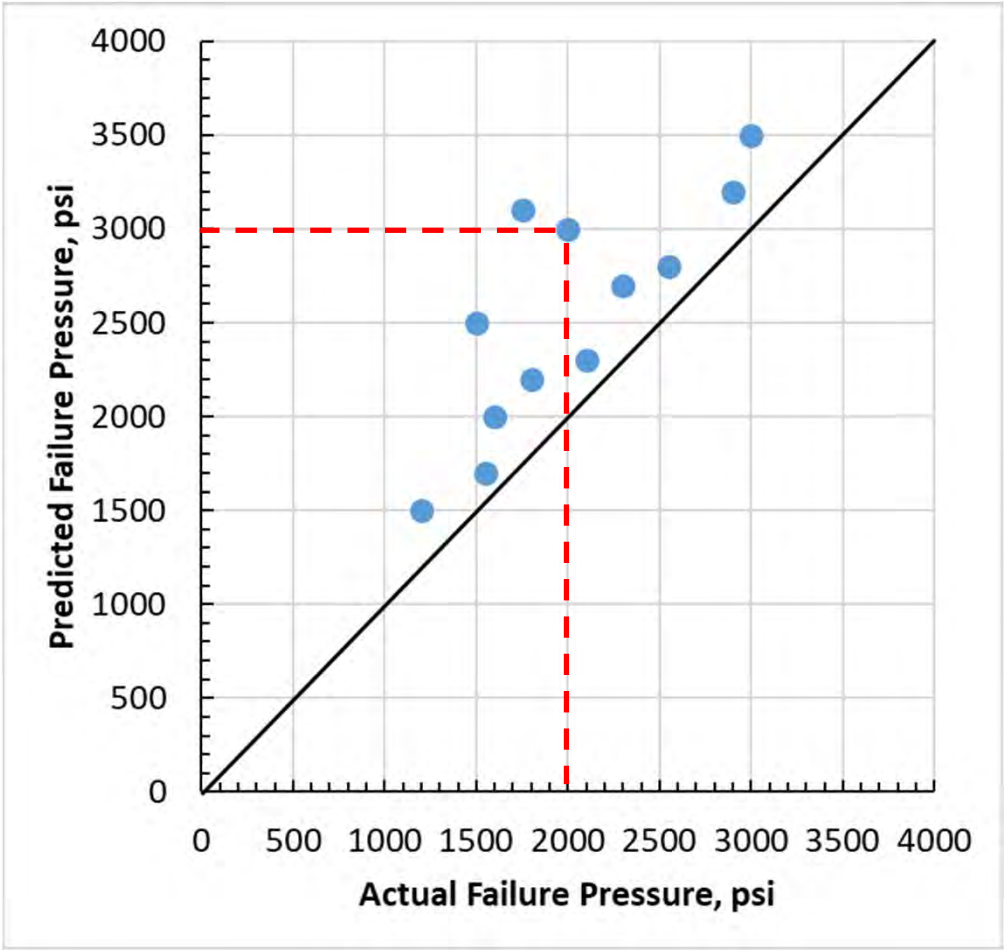
University of Waterloo, Waterloo, Ontario, Canada

SMYS above 52,000 psi were not considered

Test ID	Outside Diameter (in)	Wall Thickness (in)	SMYS (psi)	YS (psi)	UTS (psi)	Failure Pressure (psi)	Max. Defect Depth (mil)	Defect Length (in)
SOL-1	12.740	0.335	46000	51689	68062	3635	0	0.0
SOL-2	12.730	0.340	46000	51689	68062	3535	85	2.5
SOL-3	12.740	0.340	46000	51689	68062	3545	0	0.0
SOL-4	12.720	0.338	46000	51689	68062	3351	117	8.0
SOL-5	12.760	0.336	46000	51689	68062	3627	0	0.0
SOL-6	12.720	0.340	46000	51689	68062	3659	106	2.4
SOL-7	12.660	0.328	46000	51689	68062	3258	0	0.0
SOL-8	12.740	0.344	46000	51689	68062	3469	0	0.0
SOL-9	12.760	0.332	46000	51689	68062	3375	0	0.0
SOL-10	12.740	0.339	46000	51689	68062	3471	130	5.7
SOL-11	12.740	0.340	46000	51689	68062	3154	105	5.0
SOL-12	12.720	0.336	46000	51689	68062	3127	86	2.0
SOL-14	12.750	0.340	46000	51689	68062	3556	0	0.0
NOR-1	10.750	0.206	52000	56376	72845	2423	73	16.1
NOR-2	10.750	0.207	52000	56376	72845	2619	68	5.5
NOR-3	10.750	0.208	52000	56376	72845	2501	0	0.0
TNG-01	10.750	0.325	46000	59364	69780	3076	156	9.5
RLK-1	24.069	0.258	52000	58381	77524	1370	130	35.5
RLK-2	24.116	0.253	52000	58381	77524	1143	140	56.4
RLK-3	24.075	0.252	52000	58381	77524	1423	101	54.0
BCG-1	10.760	0.195	42000	50852	65825	1994	130	7.2
BCG-2	10.747	0.184	42000	50852	65825	2000	103	1.9
BCG-3	10.769	0.188	42000	50852	65825	1988	64	1.2
BCG-4	10.752	0.192	42000	50852	65825	2201	86	4.0
BCG-5	10.783	0.194	42000	50852	65825	2174	63	1.8
BCG-6	10.793	0.197	42000	50852	65825	1936	85	4.9
BCG-7	10.805	0.180	42000	50852	65825	1838	108	2.6
BCG-8	10.792	0.196	42000	50852	65825	2147	107	1.5
BCG-9	10.808	0.190	42000	50852	65825	1831	83	6.2
ESS-01	12.750	0.200	46000	54058	68512	1412	144	3.9
NOV01	19.950	0.226	55000	67055	85184	1556	119	5.2
NOV02-2	19.880	0.223	55000	67055	85184	1168	128	18.2
NOV03-2	20.000	0.224	55000	67055	85184	1244	148	24.4
NOV04	20.000	0.226	55000	67055	85184	1434	151	21.0
NOV04-2	20.000	0.226	55000	67055	85184	1582	120	16.4
NOV05	20.010	0.221	55000	67055	85184	1167	132	23.5
NOV06	20.000	0.222	55000	67055	85184	1669	97	6.7
TCP01	34.000	0.379	46000	58050	73680	1567	143	8.4
TCP02	34.000	0.373	46000	58050	73680	1531	118	7.3
TCP03	34.000	0.369	46000	58050	73680	1330	182	3.6

Results and Discussion: Comparison

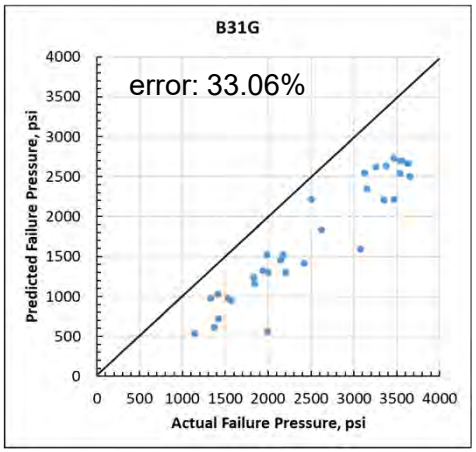
- **Predicted failure pressure vs. actual failure pressure**

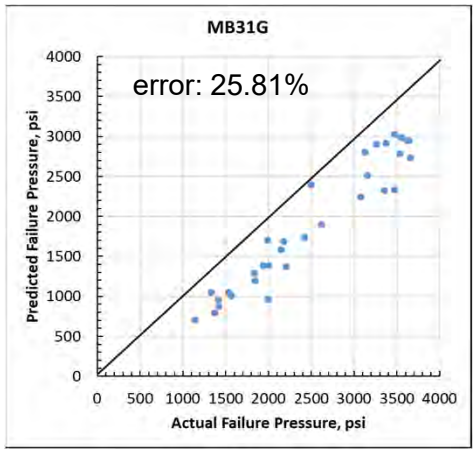


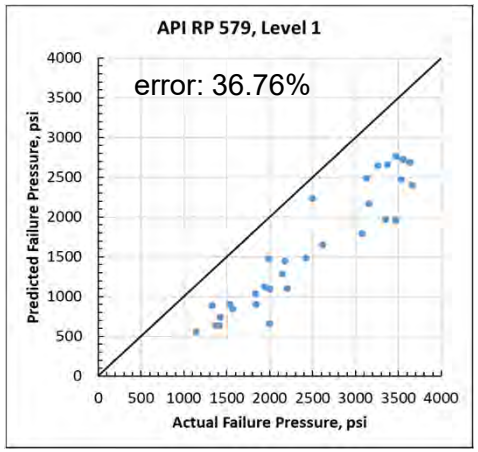
- Exact Prediction
- Conservative
- Acceptable
- Highly Desirable

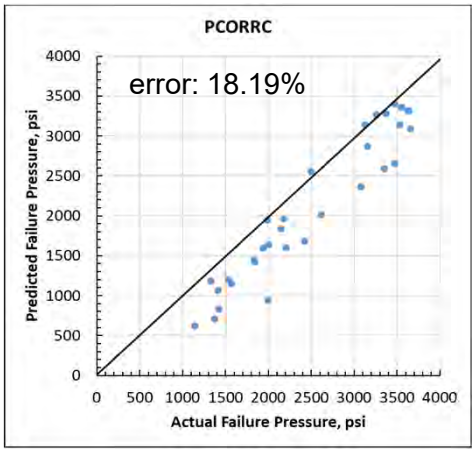
Results and Discussion: Comparison

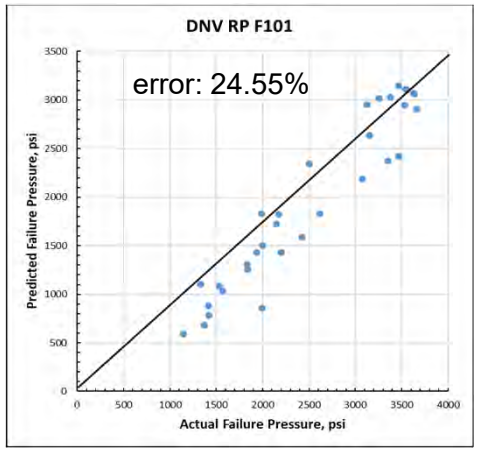
- **Predicted failure pressure vs. actual failure pressure**

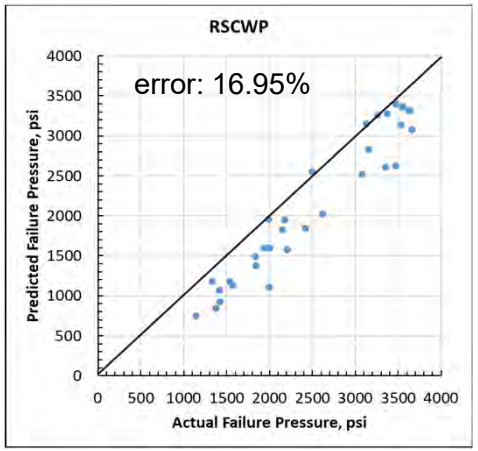






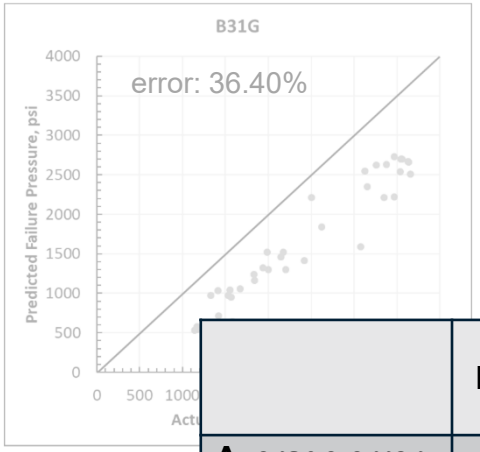


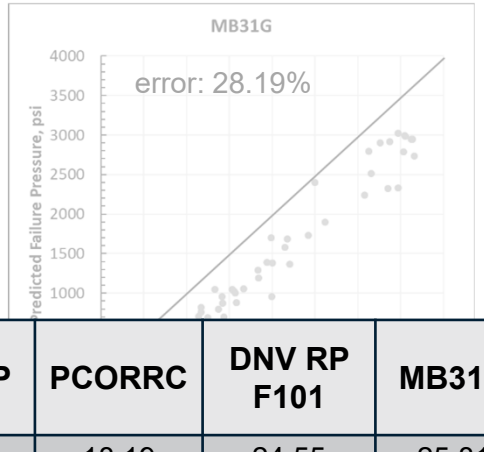


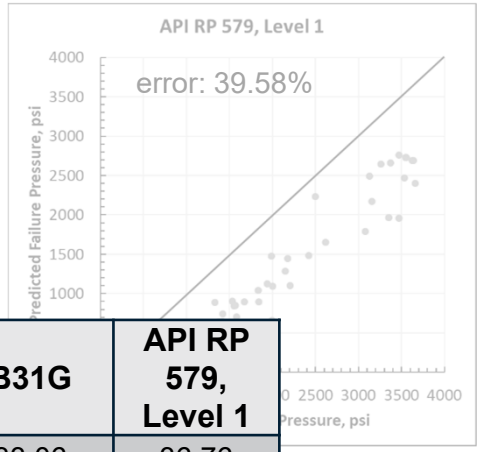


Results and Discussion: Comparison

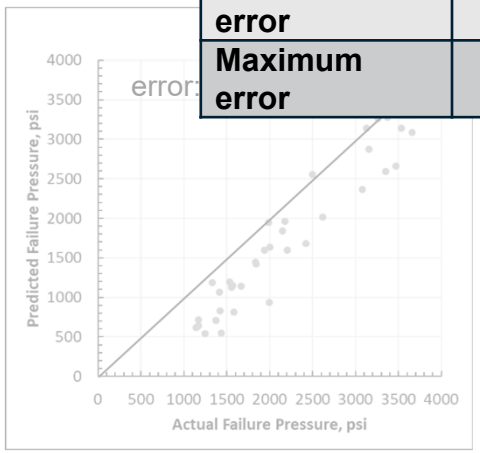
- **Predicted failure pressure vs. actual failure pressure**

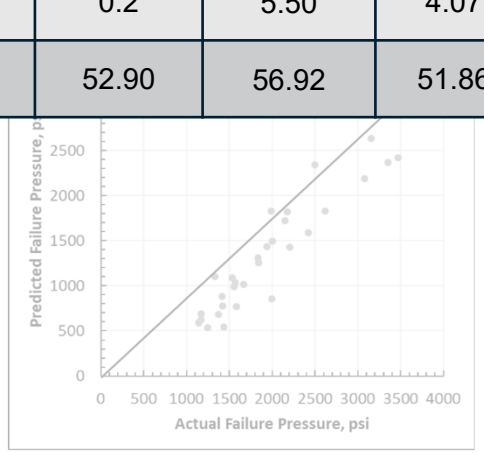


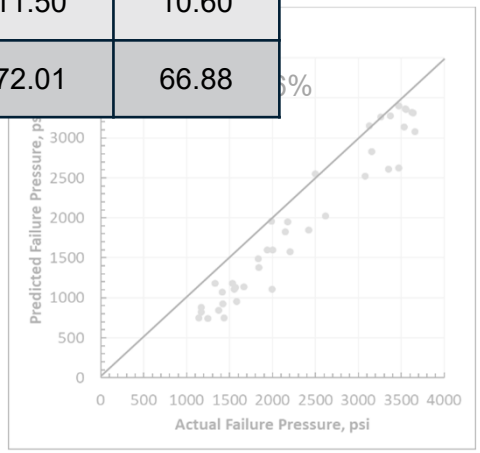




	RSCWP	PCORRC	DNV RP F101	MB31G	B31G	API RP 579, Level 1
Average error	16.95	18.19	24.55	25.81	33.06	36.76
Minimum error	0.20	0.2	5.50	4.07	11.50	10.60
Maximum error	44.46	52.90	56.92	51.86	72.01	66.88







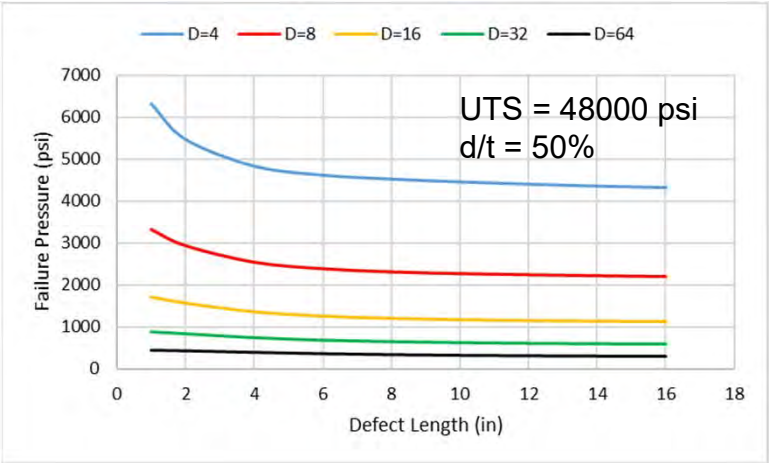
RSCWP- Sensitivity Analysis

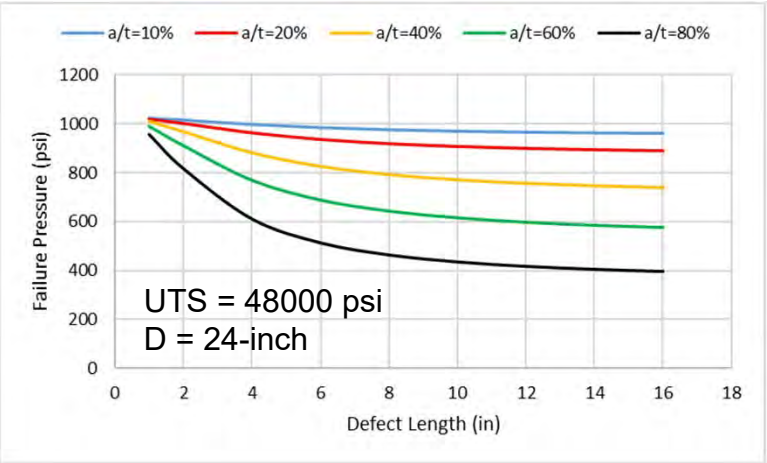
- **Remaining Strength of Corroded Water Pipe (RSCWP)**
  - Diameter, D
  - Defect length, L
  - Wall loss, d/t

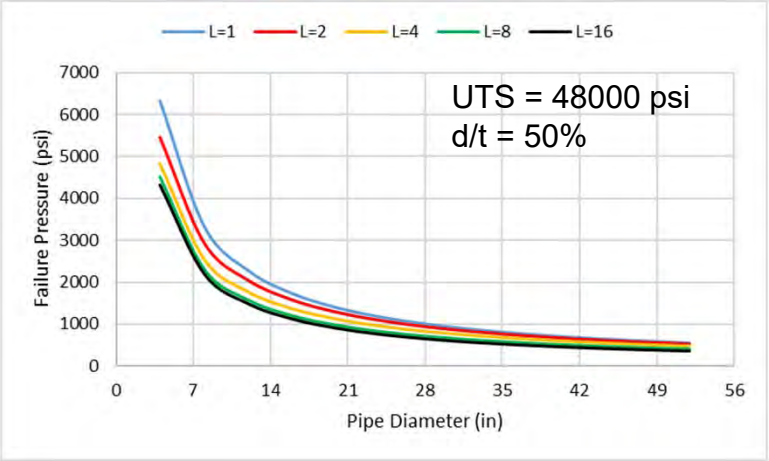
$$S = (UTS) \times \left[\frac{1 - 0.85 \times \frac{d}{t}}{1 - 0.85 \frac{d}{t} M_T^{-1}} \right]$$

$$M_T = \begin{cases} \sqrt{1 + 0.6275 \frac{L^2}{Dt} - 0.003375 \frac{L^4}{D^2 t^2}} & ; \quad \frac{L^2}{Dt} \leq 50 \\ 3.3 + 0.032 \frac{L^2}{Dt} & ; \quad \frac{L^2}{Dt} \geq 50 \end{cases}$$

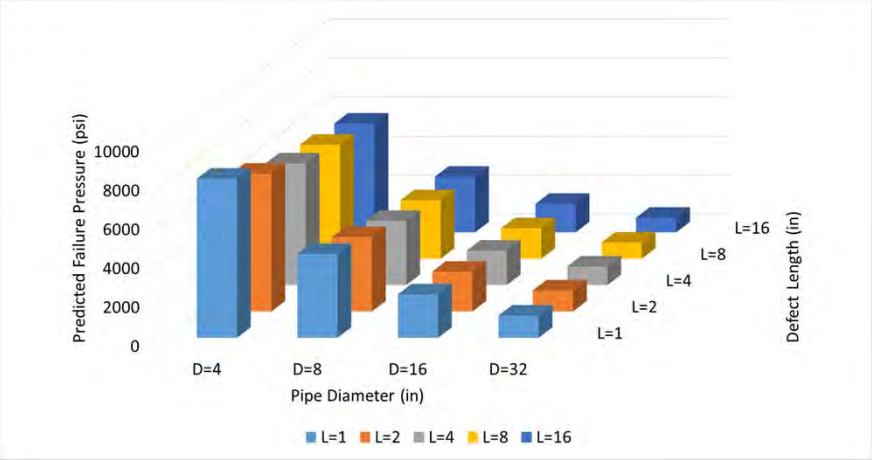
Results and Discussion: Sensitivity Analysis

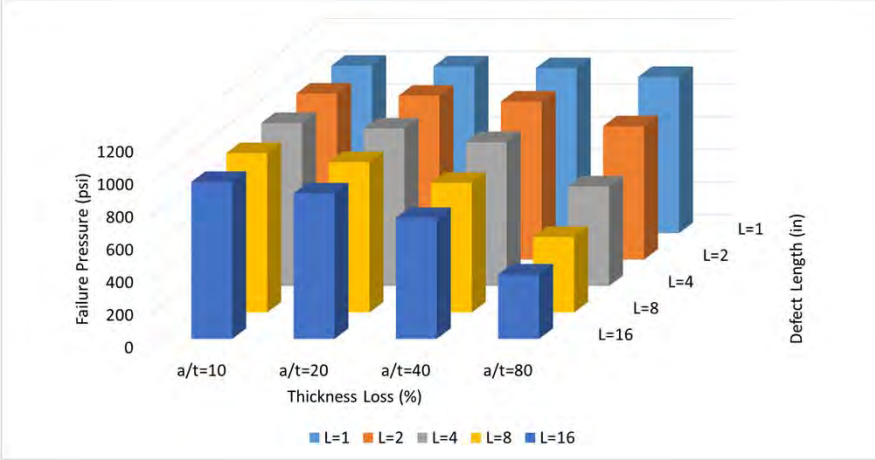


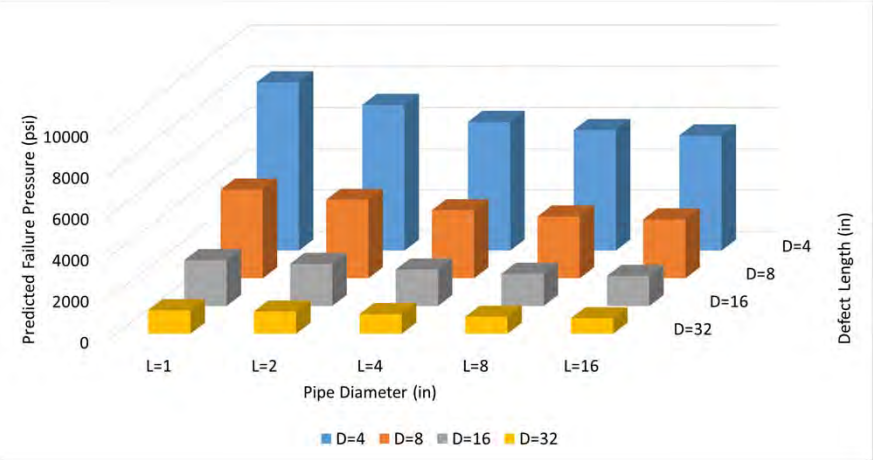




Results and Discussion: Sensitivity Analysis

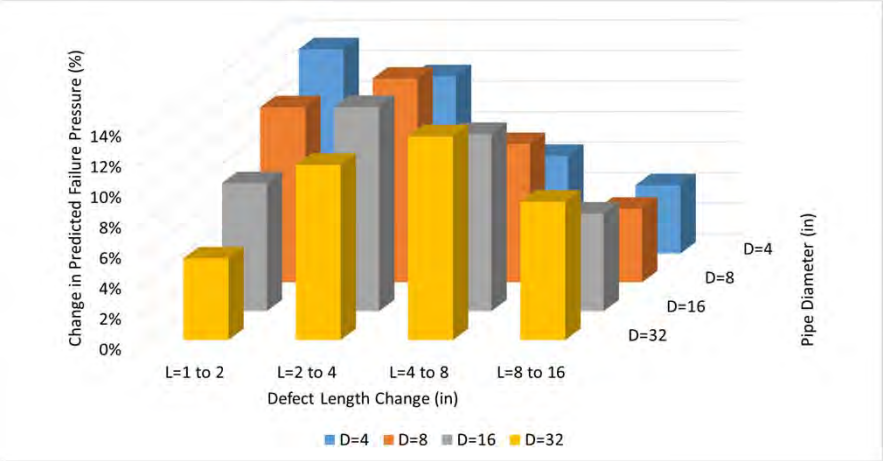




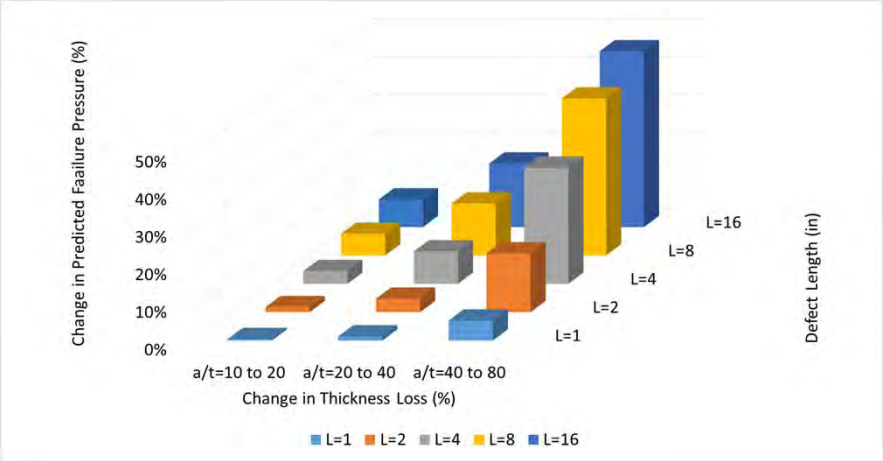


Results and Discussion: Sensitivity Analysis

Sensitivity to defect length change depends on diameter



More sensitive to higher wall thickness loss



Conclusion

- There is some opportunities for condition assessment of water pipelines
- AWWA vs ASME, different design requirements/ how about risk tolerance of the damaged pipes
- RSCWP modified based on literature review and currently common methods in industry to predict the failure pressure of steel water pipeline
- RSCWP more accurate failure pressure prediction
- RSCWP is more sensitive to higher wall loss
- RSCWP's sensitivity to defect length depends to the diameter

Questions?

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Pipeline Research Council International, Inc.

Project NDE-4-10
Evaluating SCC in Pipelines with IWEX

Integrity Assessment of Crack Colonies with the Aid of Advances in NDE including EMAT and Ultrasonic Imaging

Harvey Haines – Applus
Ben Hanson – Kinder Morgan

PRCI 2018 Research Exchange Meeting
Houston, Texas
March 6, 2019

PRCI™

Applus®

NDE-4-10 Objective and Deliverable

- **Project Objective**
  - Developing the means to determine accurate failure pressure prediction for SCC using
    - *in-ditch NDE*
    - *In-line inspection (ILI)*
- **Project Deliverable:**
  - Validated, more accurate means for evaluating SCC
    - *determining effective crack length*
    - *leading to accurate predicted failure pressure*
- **Result**
  - a more accurate remaining life calculation for SCC colonies,
    - *given the capabilities and limitations of current EMAT technology.*

3 Year Project

1. Developing processes for gathering accurate SCC images

- Samples – examined 30 coupons
- Scanning – coupons scanned in a water tank because of small size
- Analysis – compared to XCT data and a few lab analyses

2. Field scanning and comparison to EMAT ILI data

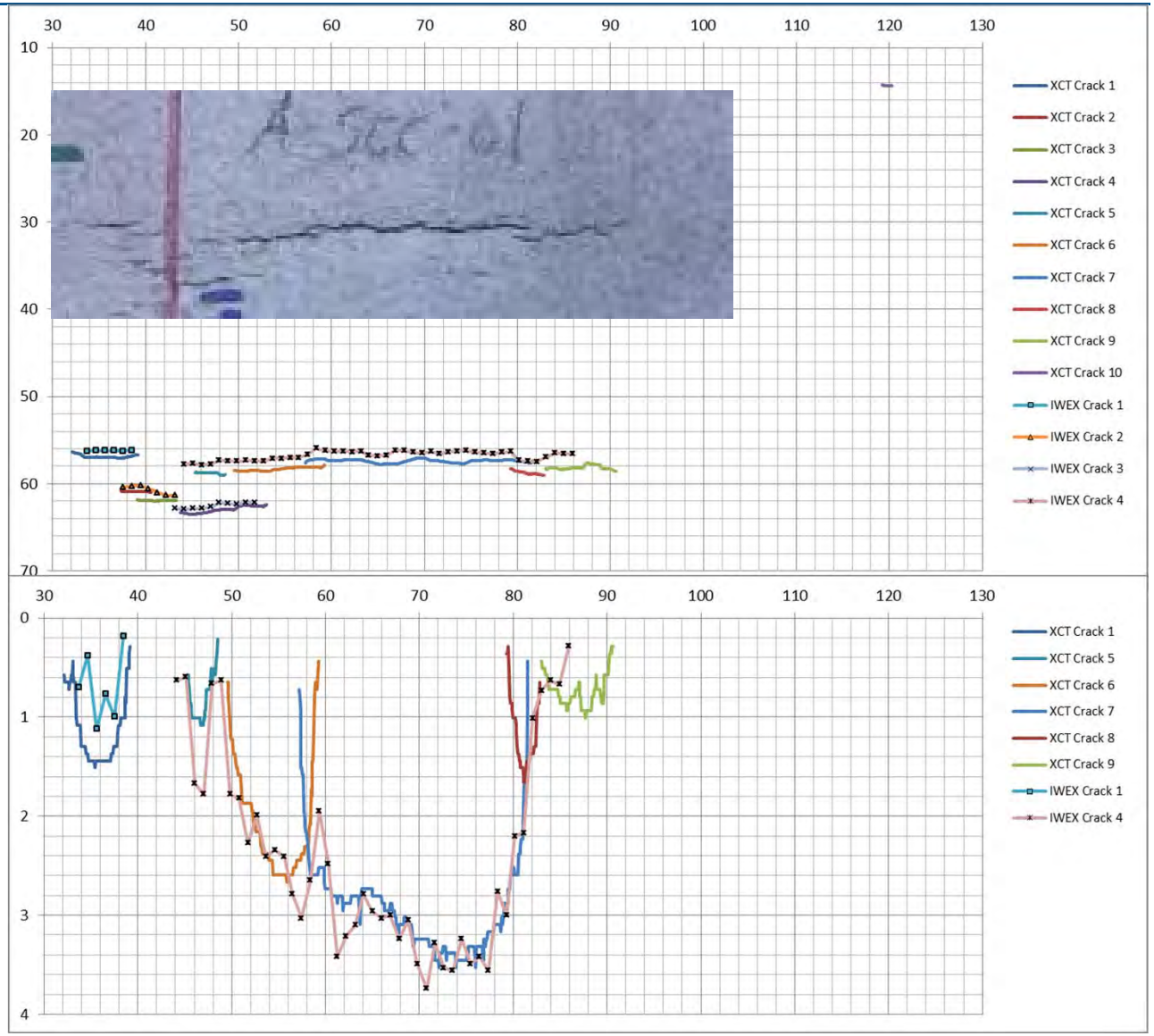
- Sites – examined colonies on full joints
- Analysis – developing procedures to compare IWEX to EMAT results
- P_{burst} predictions – Selected samples for burst tests in year 3

3. Examine burst pressure predictions

- Plan to perform burst tests on 4-5 samples
- Compare predicted burst pressures to actuals
- Cooperate with SIA-1-5 on developing improved methods

Example 16-062 best sizing results (all units in mm)

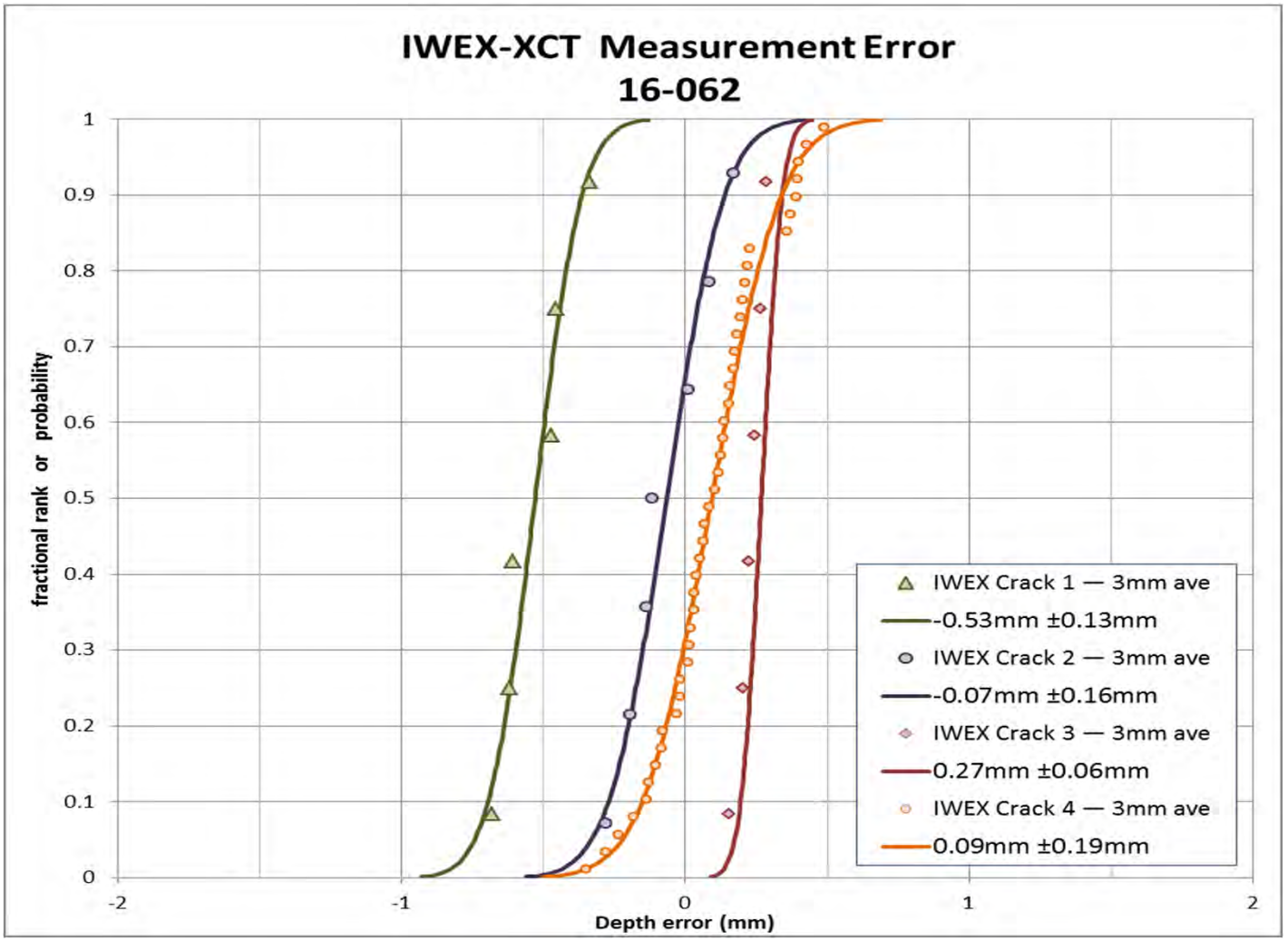
- Surface correlation can be performed semi-automatically
- Axial adjustments can be made from Depth correlation
- 16-062 is an example with a narrow colony >1-2 cracks wide
- UT scanning in 1 strip (<1-in wide)
- Max Depth 3½ mm
  Very close to XCT depths



Example 16-062 IWEX vs XCT differences

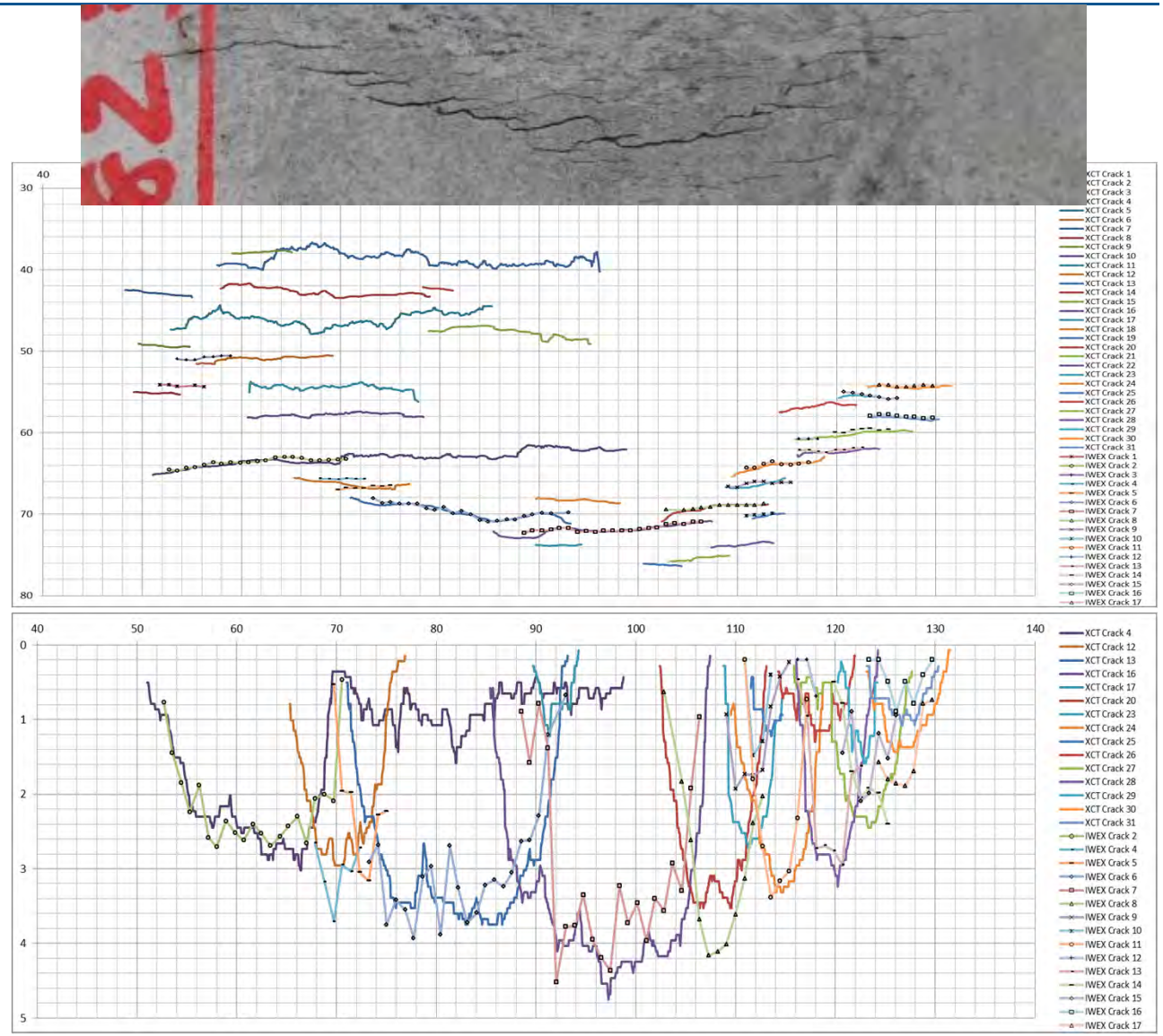
For the longest crack IWEX Crack 4 accuracy is: ±0.2mm

80% certainty -0.34 – +.34mm



Example 16-405 3rd best sizing results (all units in mm)

- Surface correlation can be performed semi-automatically
- Axial adjustments can be made from Depth correlation
- 16-405 is an example with a wide colony >1-in (25mm) wide
- Requires UT scanning in 2 strips (2nd strip shown)
- Note: Least significant cracks are <2mm deep
- Max Depth: 4 ½ mm
  most within ±0.2mm
  some within ±0.5mm

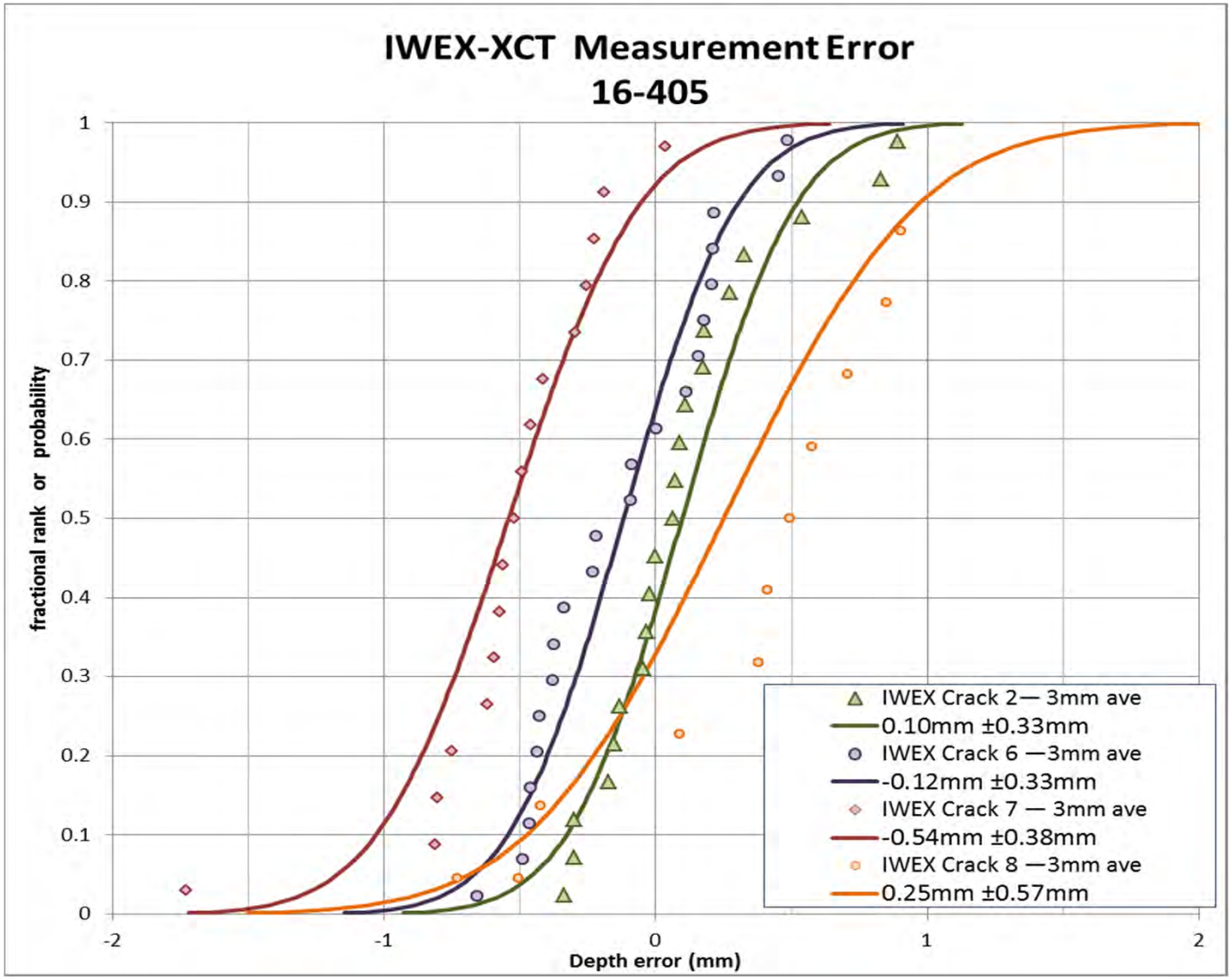


Example 16-405 (4 sample cracks)

Sizing accuracy for sample cracks is not as good.

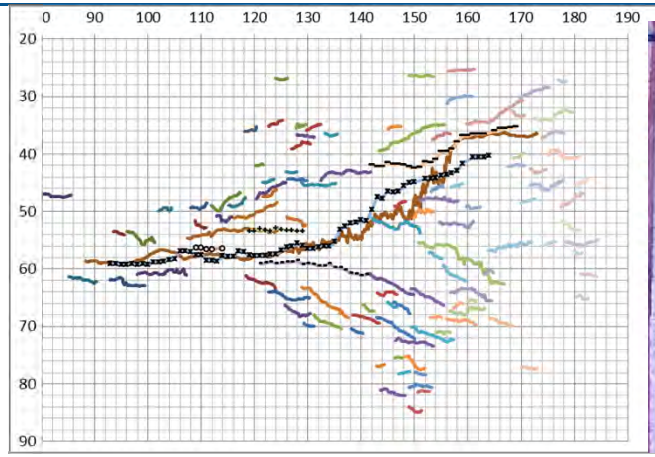
Ranges from: undercall of ½mm ±0.6mm to best data of ±0.3mm

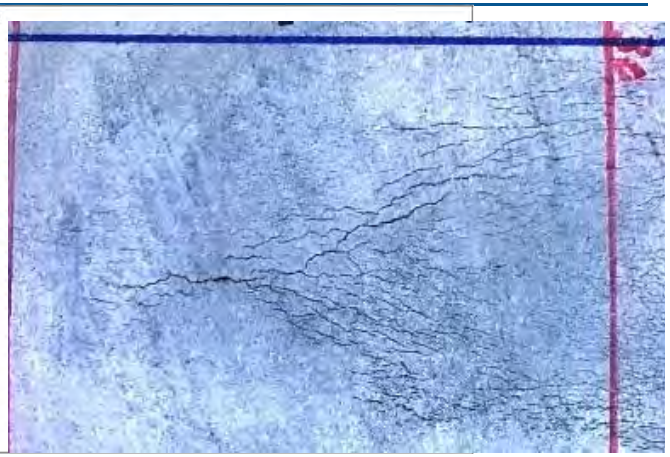
80% certainty -0.6 – +0.5mm

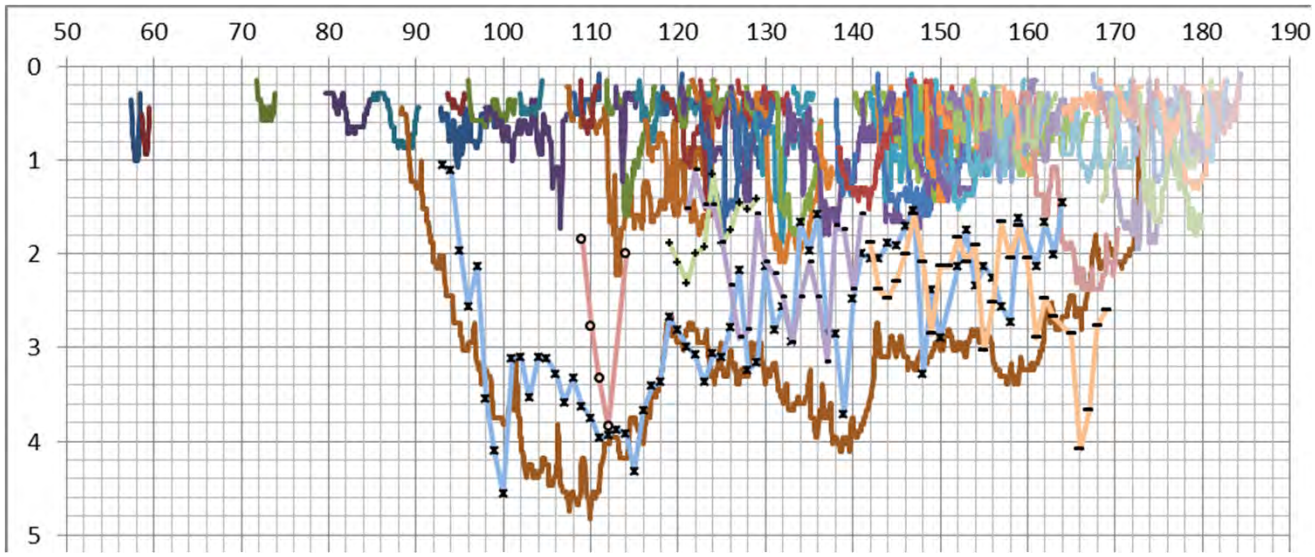


Example 16-027 deep crack in middle of large colony

- Most difficult colony to correlate
- Wide colony
  - Deepest crack in the middle
- 384 XCT cracks
- 387 IWEX cracks
- Sizing
  - Auto detection did not size well
  - Manual tip detection for significant crack sized much better
- Note: all cracks <2mm deep (except 1 long deep crack)
- Max Depth 4½ mm
  sizing correct for max depth
  undersized by 1mm
  for much of crack





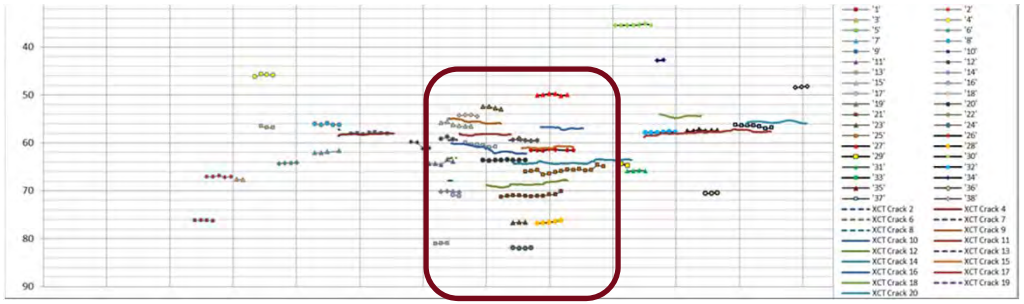


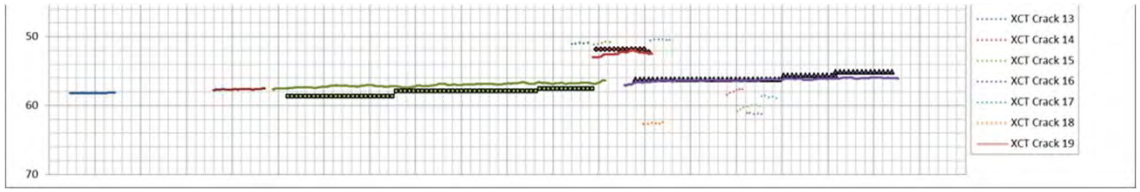
1.6 Make improvements to automatic detection and sizing algorithms

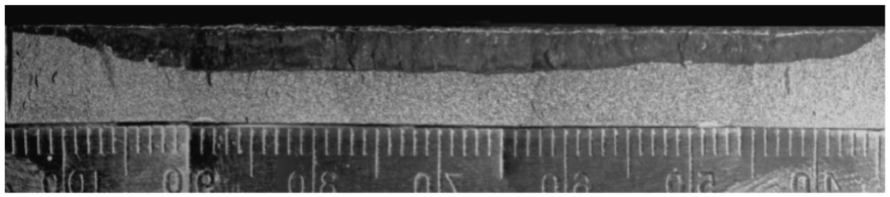
- **Accomplishments**
  - Automatic detection is making it much easier to follow cracks through a colony
    - *Reduces evaluation time from days/weeks to hours/day*
  - Automatic sizing algorithms are not detecting tips and require manual sizing
  - This is still much faster than 1st set of tests as they required manual detection in addition to sizing
  - Automatic Excel plotting of cracks allowed comparison of colonies with large numbers of cracks
- **Goals**
  - Automate tip diffraction sizing to make depth sizing more consistent and remove human error

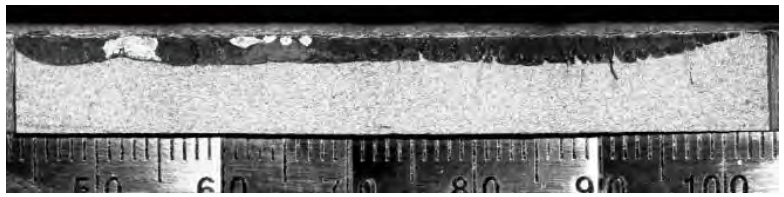
Two Samples Destructively Tested

- **Destructive Testing (Task 1.4)**
  - XCT and UT generally agree
    - *Deeper than lab*
    - *Evaluating possible causes*
      - Blur at OD or crack tip
  - Sectioning 16-909
    - *26 X-Sections*
    - *50-60 cracks, many very short*
    - *Closely spaced cracks are harder to size*
      - Following multiple cracks?
  - Freeze break 16-912
    - *2 large cracks*

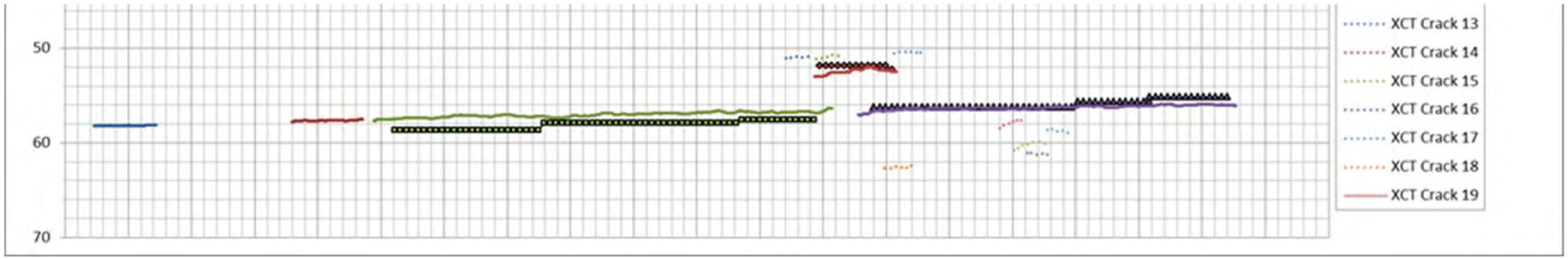


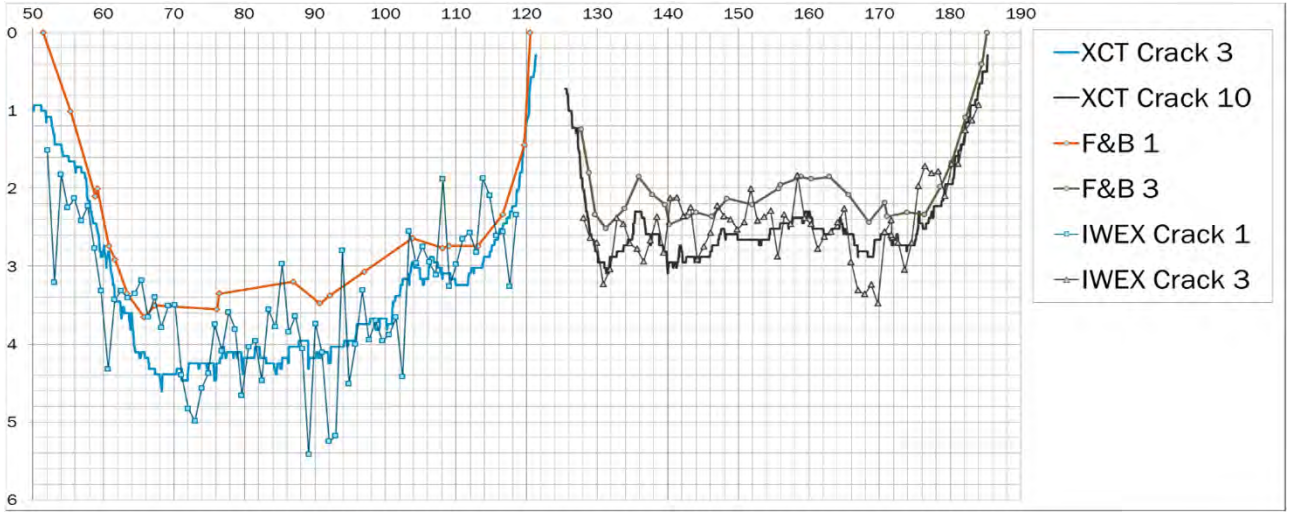


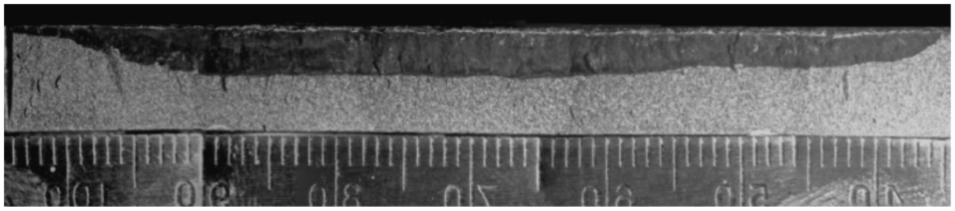


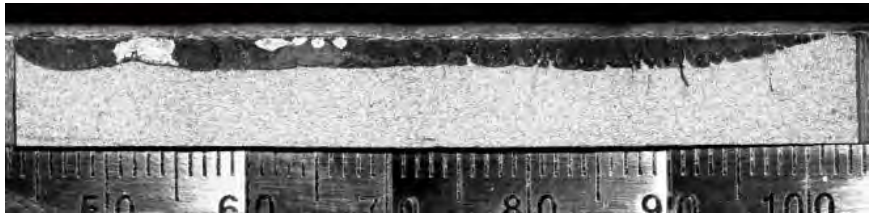


Freeze Break 16-912

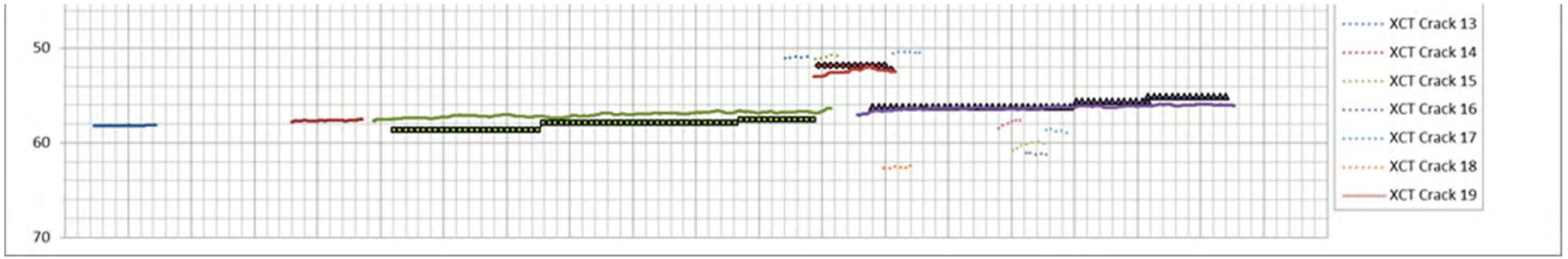


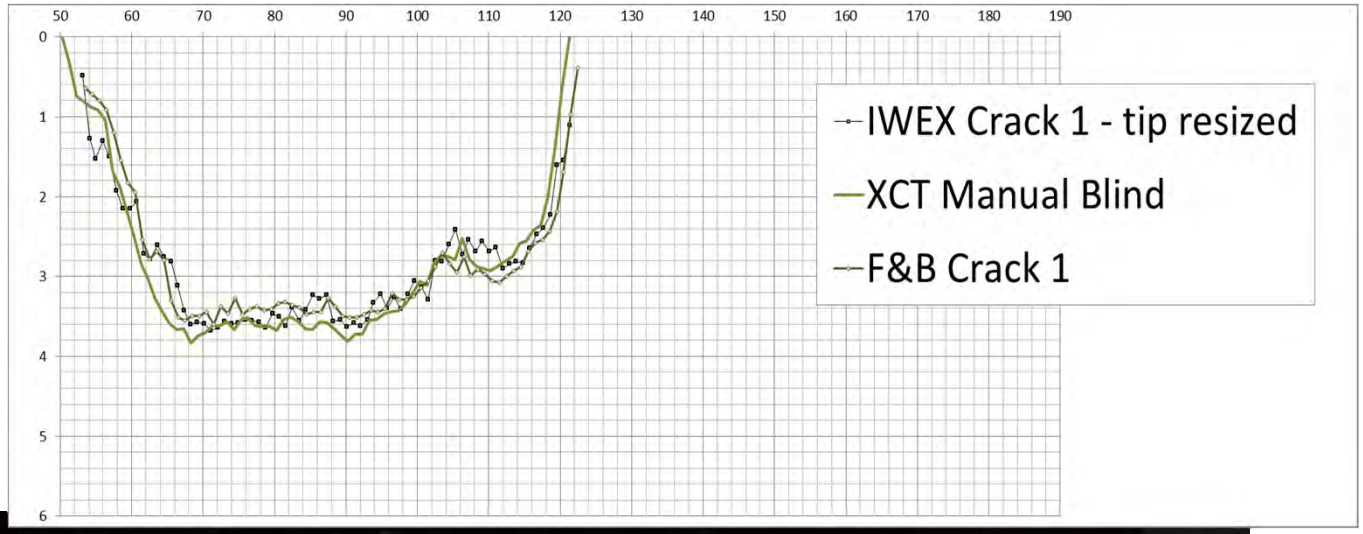


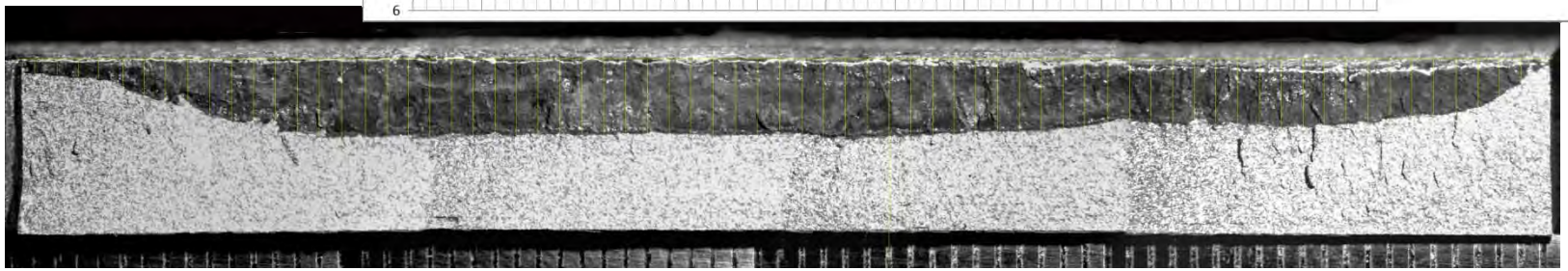




Improvements in Evaluation of 16-912

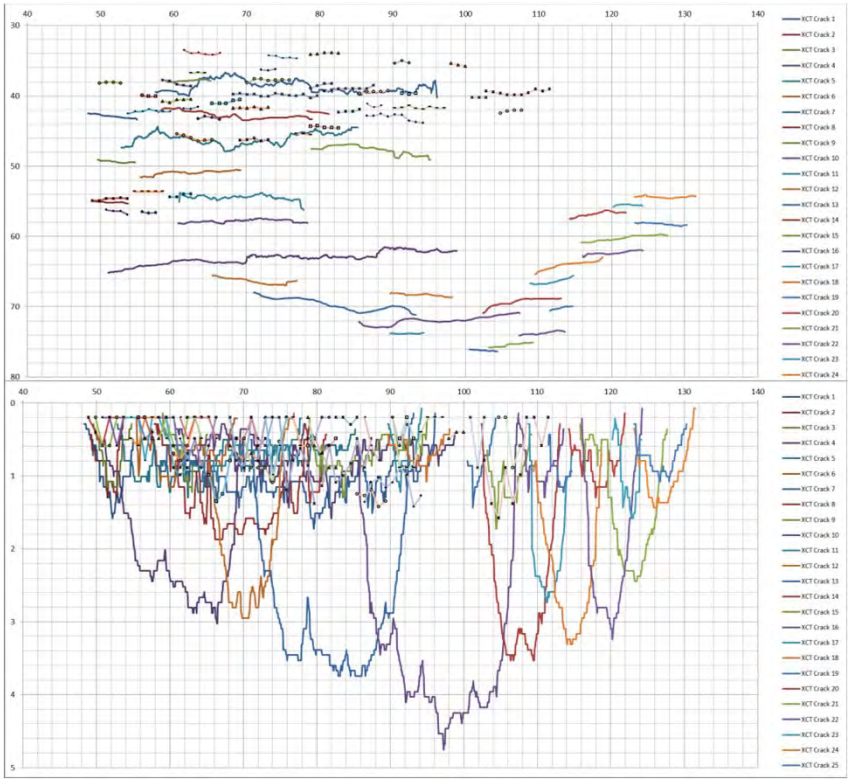


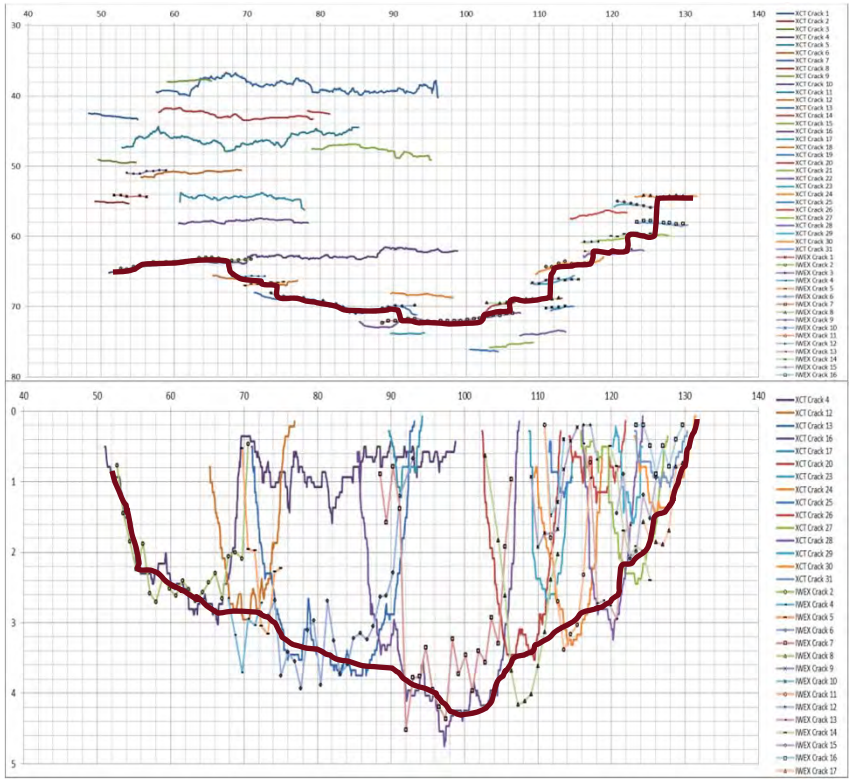




Estimate Effective Crack Length

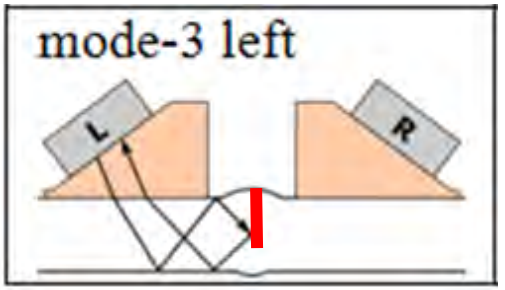
- We've noticed in 3-4 examples the effective length is fairly easy to estimate for the deepest crack (cracks >2mm deep)
- This is much easier to evaluate than using a surface breaking interaction rule *(such as 1mm circumferential spacing)*





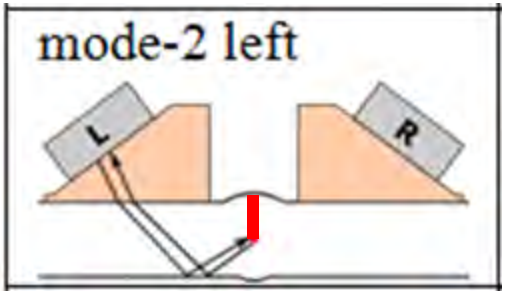
1.8 Procedure for Measuring SCC using IWEX

- **Scan SCC colony axially in strips**
  - Move scanner 15mm circumferentially between scans for ~25% overlap
  - Process (interpret) scan images separately and merge interpreted results
- **Process scans**
  - Perform automated detection using tandem modes for detecting cracks



tandem mode*

  - Size cracks using tip diffractions using individual slices
    - *Slices are spaced every 1 mm*



tip diffraction*

  - Cracks can be grouped (interacted) using deepest crack profile

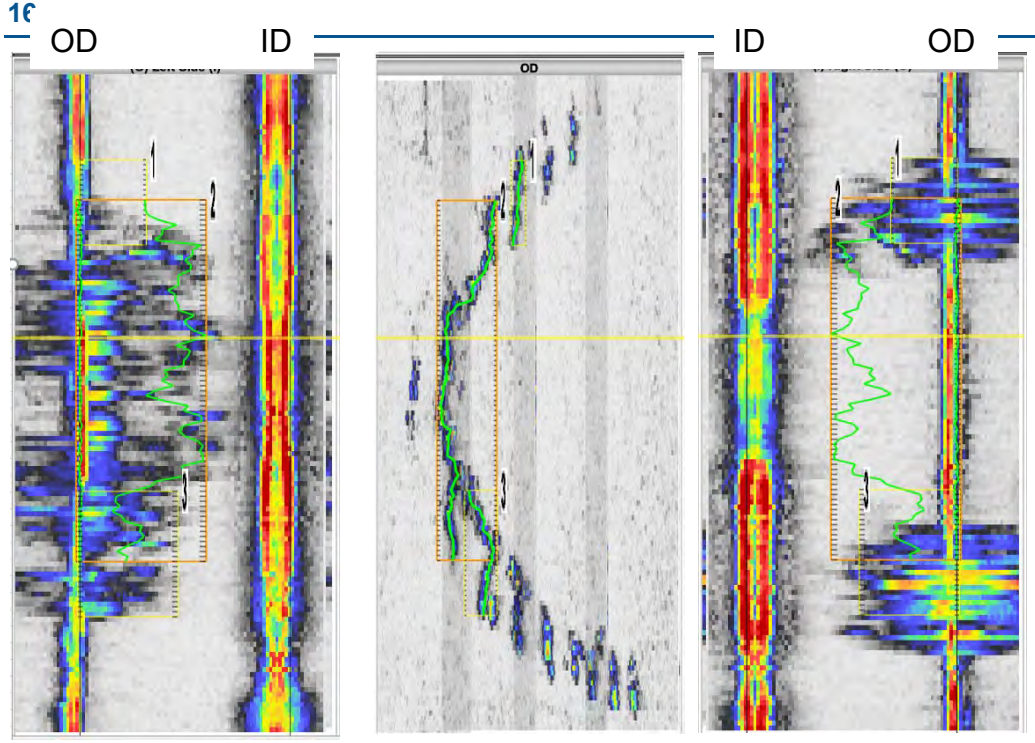
* Note: although figures show weld bumps this project is inspecting SCC in the pipe body

Update NDE-4-10 Year 2 2018 efforts

- **2.1 Field Trials**
  - Performed IWEX Scans at 3 field location (planned 2-3)
  - Scanned 20 joints/55 colonies (planned 15)
  - 3 joints saved for 2019 (looking for 4-5 joints) Still Need 1-2 more samples
  - 14 digs ongoing

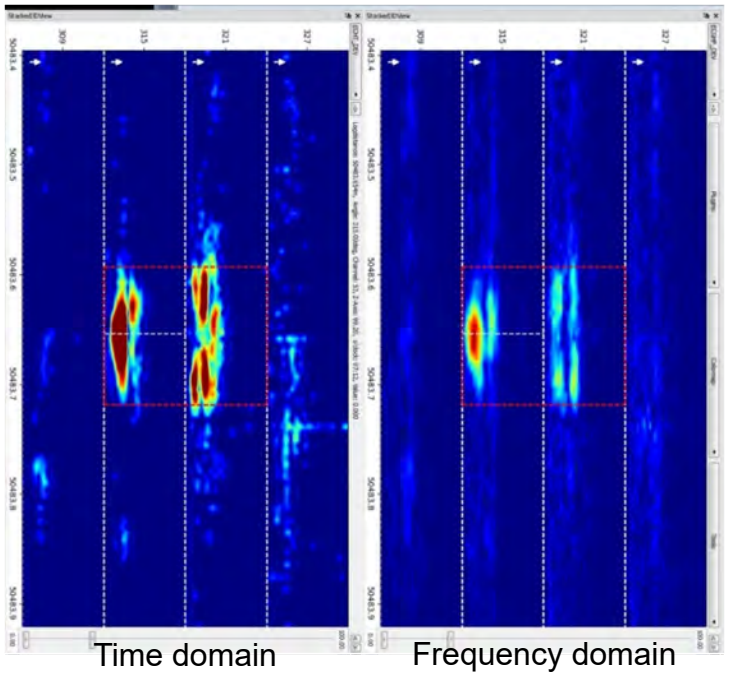
- **EMAT Comparison**
  - Just now beginning
  - 2.3 Process to compare IWEX/EMAT
    - *Pressure, length, depth*
  - 2.4 Perform Comparisons
  - 2.5 Evaluate effects of crack density/ morphology/ coating/ EMAT

Initial Comparison of IWEX & EMAT data



left side | OD surface view | right side

Rosen EMAT data



Time domain | Frequency domain

IWEX scans

Produces, a computed volumetric image of the crack colony

B-scans from left & right side of scan volume

Deepest portion of SCC colony in Left portion of scan data

EMAT data

Strip chart of reflections from 4channels of data

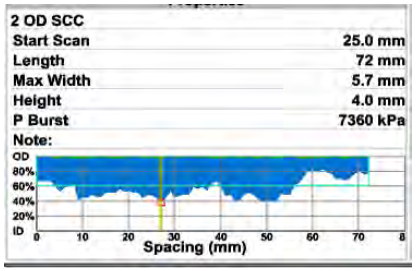
The signals show:

- one longer crack from one side
- two short cracks from the other side.

Development of ILI-NDT Comparison

- *Depth*
  - EMAT estimates depth of 55% wt
  - IWEX maximum height (depth) is 4.0mm (63% wt)
- *Length*
  - EMAT is estimated at 62mm
  - IWEX is 72mm
- *Due to the relatively short length of the flaw, only one depth value can be estimated from EMAT*
- *Only 2 parameter (length & depth) calculations are possible from EMAT data*
  - Effective area calculations of failure pressure is not possible from shorter flaws like this one.

Rosen EMAT



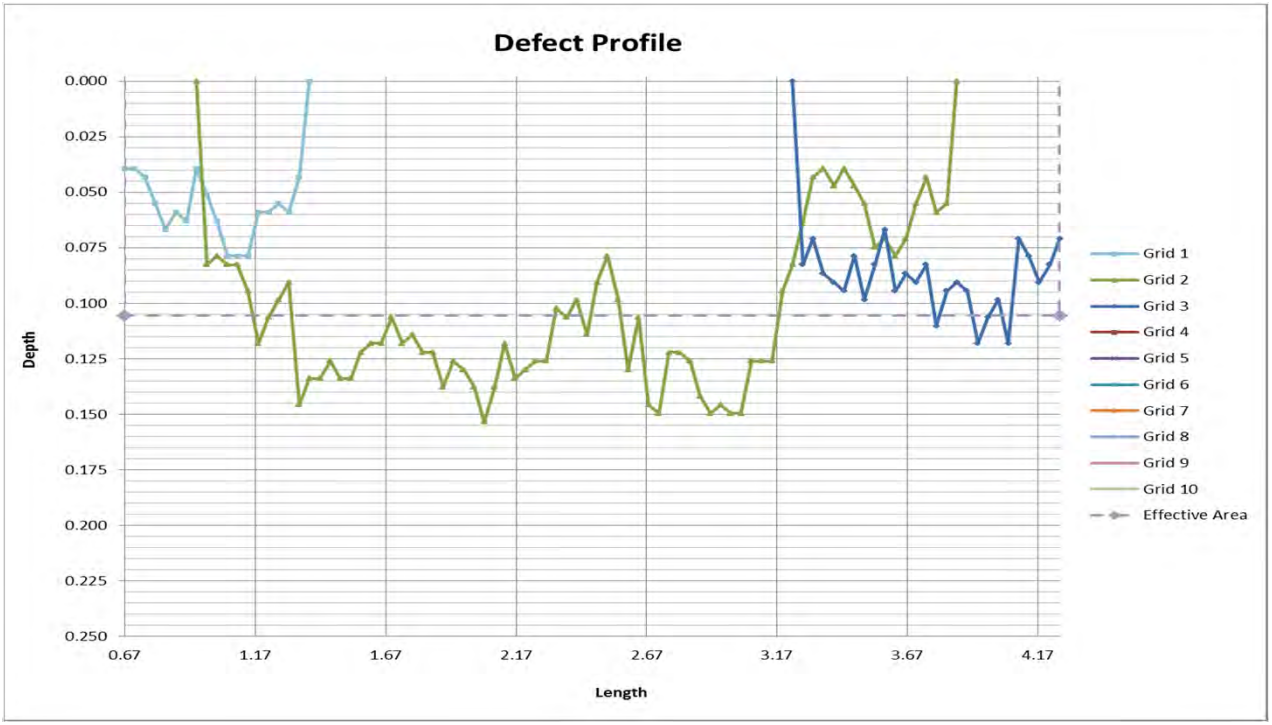
IWEX depth profile

Example 1 of P_{burst} Calculation

		Envelope Defect Profile	Row 1	Row 2	Row 3
Effective Area Method	Predicted Failure Pressure (Pf, psi)	990	1241	1042	1216
	Factor of Safety (P_f/MOP)	1.32	1.65	1.39	1.62

$P_f/MOP < 1.39$

Sample selected for year 3 burst tests

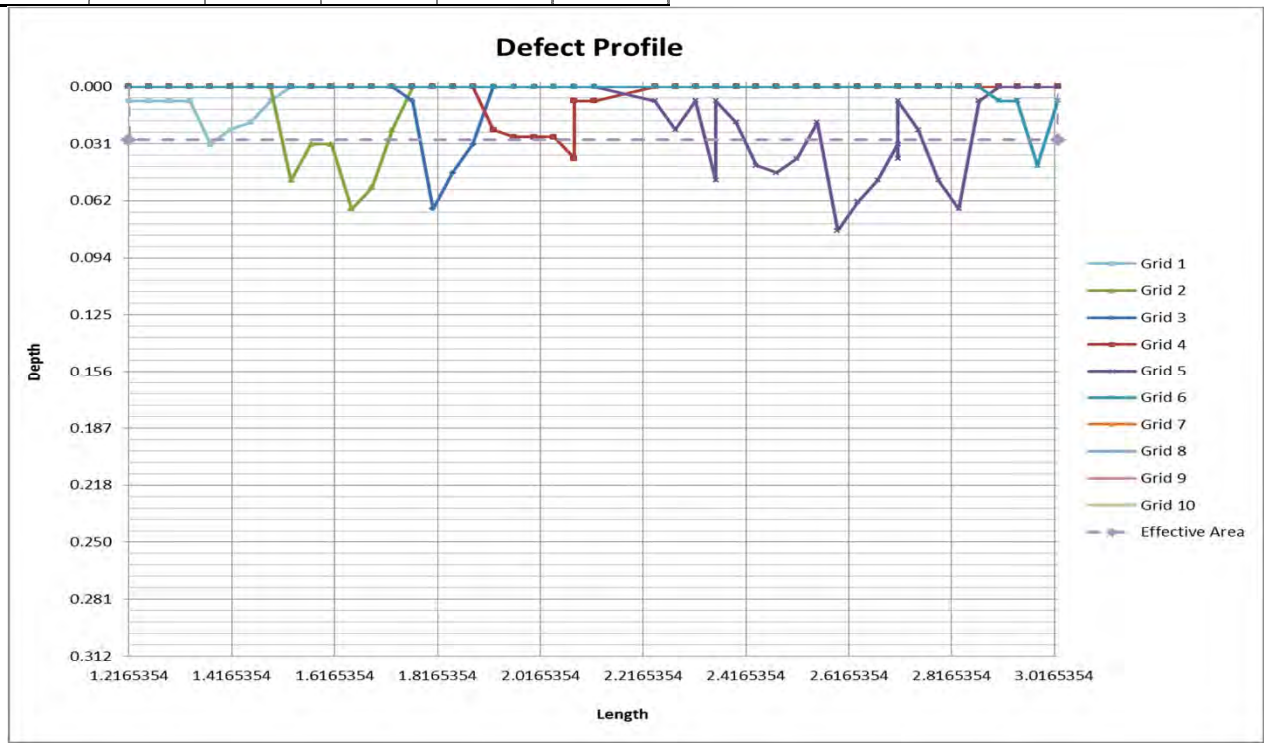


Example 2 of P_{burst} Calculation

		Envelope Defect Profile	4	6	7	9	11	13
Effective Area Method	Predicted Failure Pressure (Pf, psi)	1277	1289	1287	1288	1288	1284	1289
	Factor of Safety (P_f/MOP)	1.70	1.72	1.72	1.72	1.72	1.71	1.72

$P_f/MOP > 1.39$

Sample not selected for year 3 burst tests



Criteria for selecting Burst Sample

- **Looking for samples that will fail a Burst Test**
  - Selecting cracks in a colony that look like they will interact
  - Evaluating failure pressure using KAPA an effective area technique
  - Looking for calculated P_{fail} < 100% SMYS
- **Actual burst pressures and various failure pressure calculations will be compared in 2019.**

Summary and Conclusions

- **IWEX ultrasonic imaging is starting to allow for profiling of all cracks in a colony**
  - Profiling of cracks is similar to XCT profiles
  - Automated depth sizing is needed to profile all cracks on a routine basis
- **Procedures to compare IWEX crack profiles to EMAT data are being developed**
  - Should allow EMAT provider to better estimate sizing using ILI data
  - Will allow better quantification of ILI depth accuracy
    - *Determine ability of ILI to image individual cracks*
- **Year 3 will examine burst pressure predictions**
  - Should help determine procedures for examining burst pressure predictions
  - Should help improve determination of significant cracks
    - *Insignificant cracks will have little or no effect on burst pressure*

Pipeline Research Council International, Inc.

MAOP Verification of Facility Piping

Peter Veloo, Michael Rosenfeld, Troy Rovella

2019 PRCI Research Exchange Meeting

PRCI
LEADING PIPELINE RESEARCH

Exponent®

Kiefner
an Applus+ Company

PG&E
Pacific Gas and Electric Company®

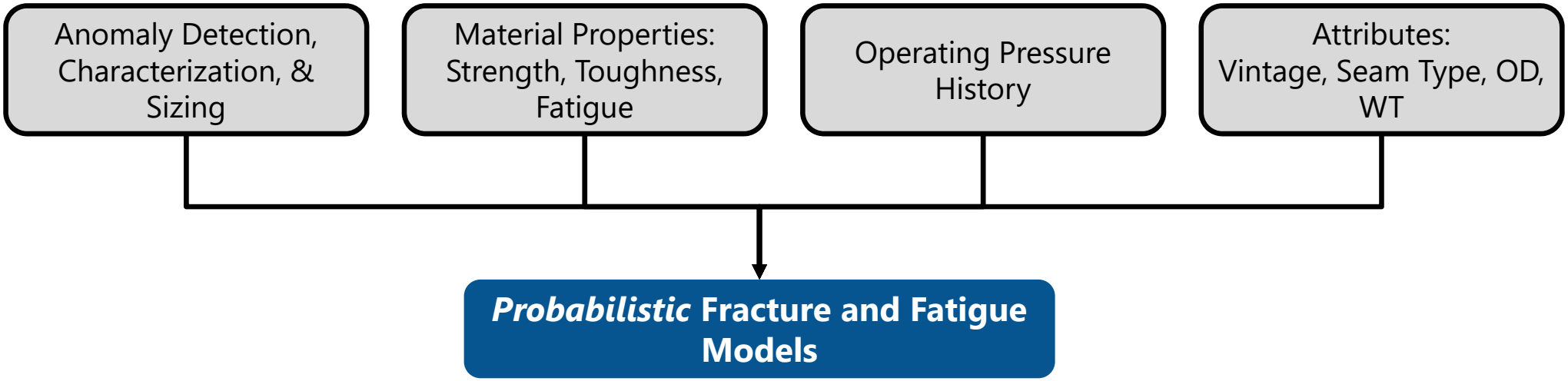
2016 Notice of Proposed Rulemaking

- **Pipeline and Hazardous Materials Association (PHMSA) NPRM §192.624 – Maximum Allowable Operating Pressure (MAOP) verification**
  - Grandfathered ('pre-code') pipe -§192.619(c)
  - Pipe without TVC records of a hydrostatic pressure test
- **NPRM §192.624 MAOP verification methodologies**
  - Replacement
  - De-rating
  - Pressure test
  - **Engineering Critical Assessment (ECA)**
  - **Alternative technologies**
- **NPRM §192.607 verification of pipeline materials**
  - Nondestructive examination (NDE) allowances
  - Establish populations

PG&E Gas Transmission Station Piping

- **Hydrostatic pressure testing or in-line inspection of facility pipe is more challenging compared to transmission line pipe.**
  - Program scope: 9 compressor stations, ~400 transmission regulating/metering stations, 3 terminals
    - *Average age of stations ~34 years old, Range of vintages from 1 to 87 years*
  - Replacement of an initial-life test cf. mid-life test
    - *Initial program focuses on **manufacturing and construction** flaws*

Engineering Critical Assessment



T. Anderson, Implementation of the MAT-8 Fracture Model into a Probabilistic Crack Management Framework, PRCI REX (2019)
P. Riccardella, D. Dedhia, S. Riccardella, T. Manning, ASME International Pipeline Conference (2018)
J. Ma, M. Rosenfeld, P. Veloo, T. Rovella, P. Martin, ASME International Pipeline Conference (2018)

Engineering Critical Assessment

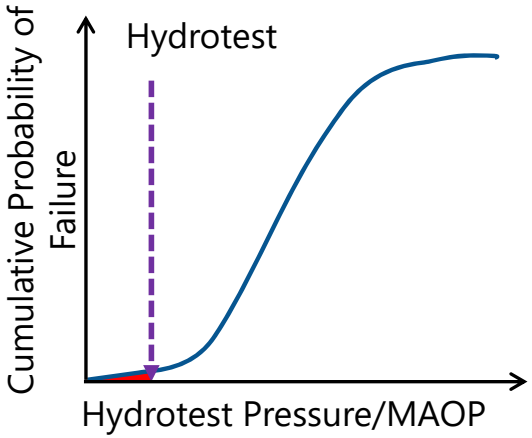
Anomaly Detection, Characterization, & Sizing

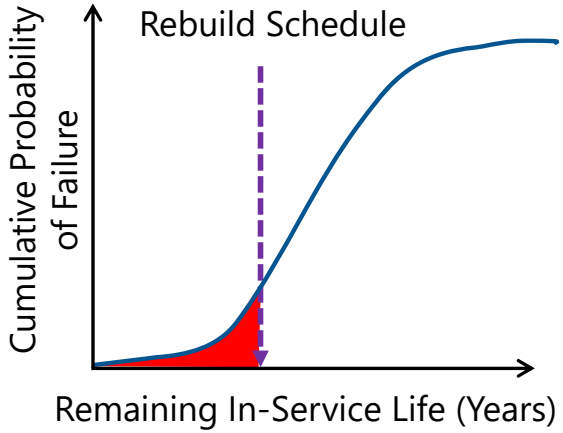
Material Properties: Strength, Toughness, Fatigue

Operating Pressure History

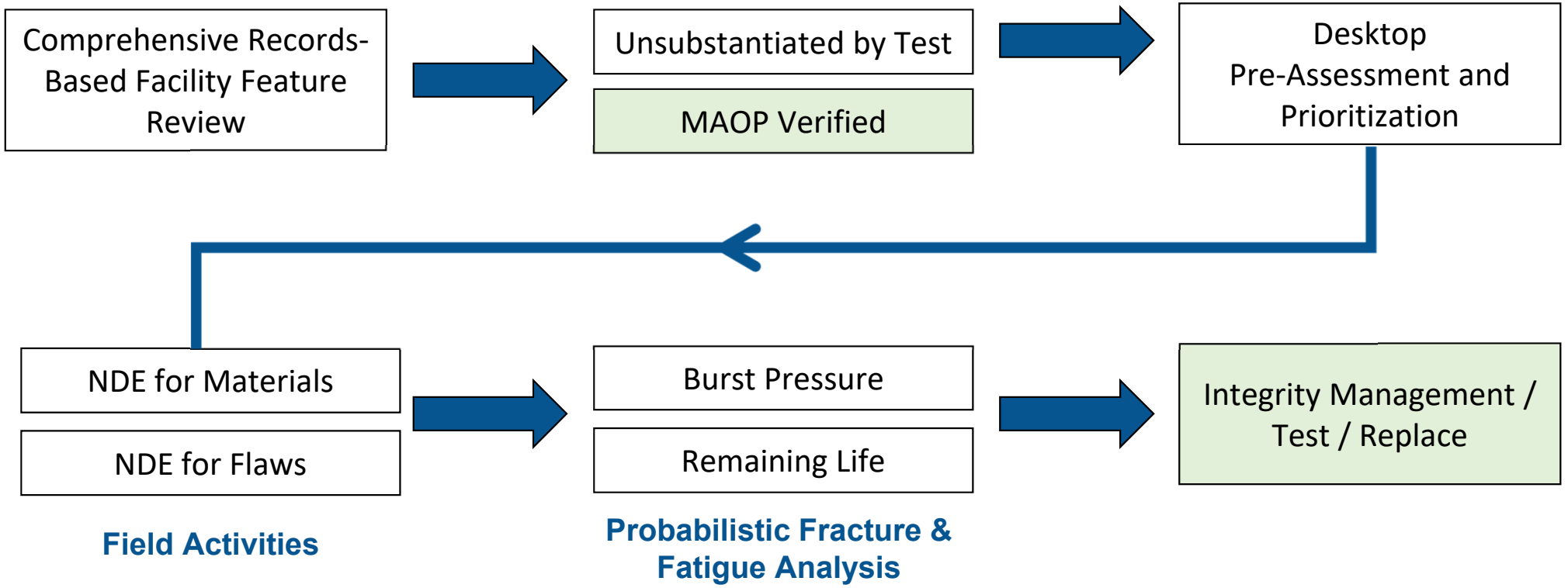
Specifications: Vintage, Seam Type, OD, WT

Probabilistic Fracture and Fatigue Models



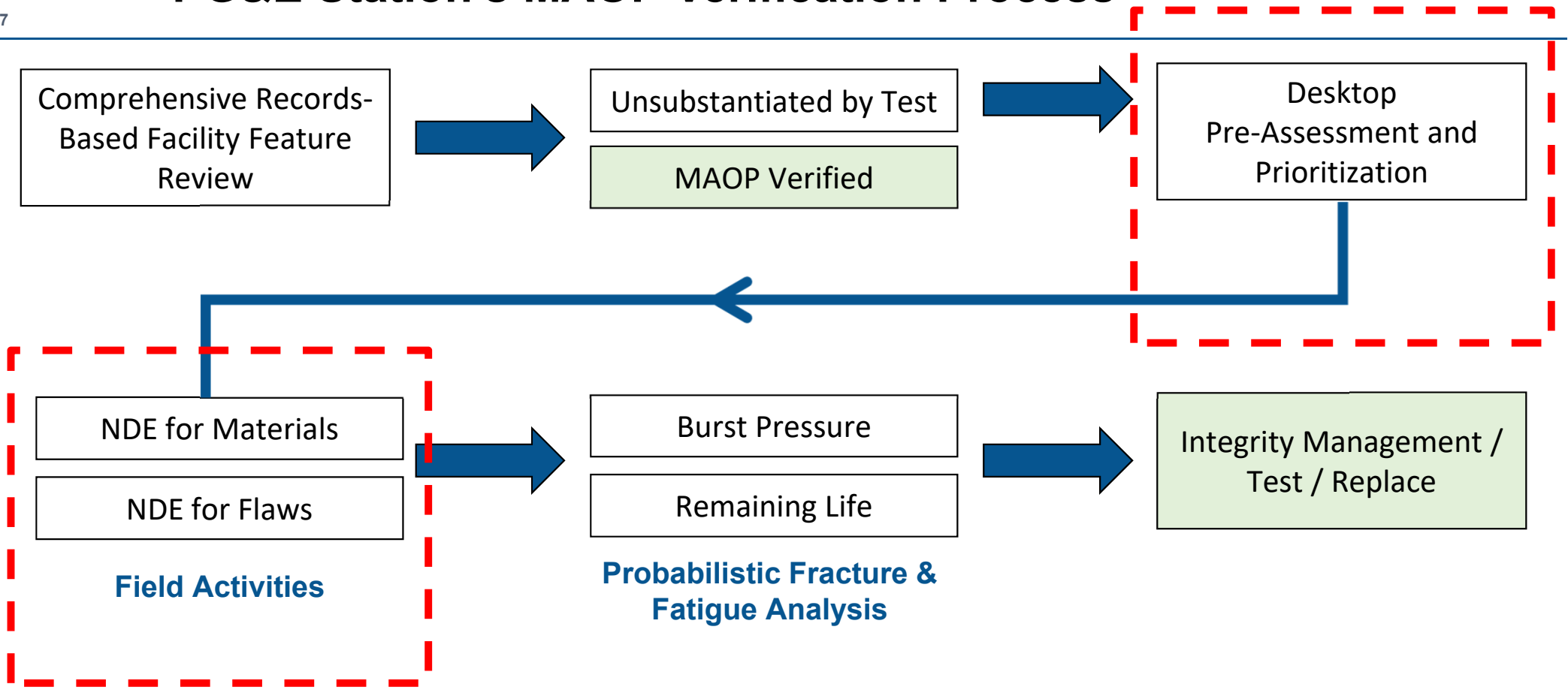


PG&E Station's MAOP Verification Process



J. Ma, M. Rosenfeld, P. Veloo, T. Rovella, P. Martin, ASME International Pipeline Conference doi:10.1115/IPC2018-78132 (2018)

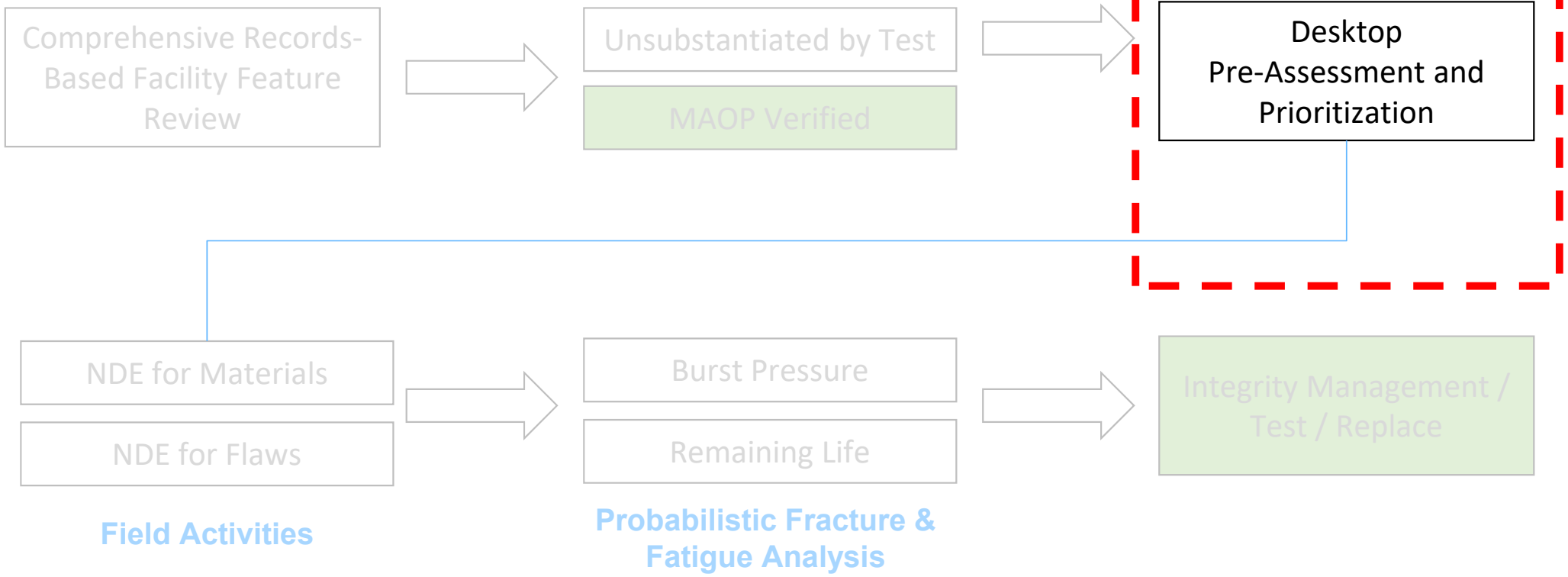
PG&E Station's MAOP Verification Process



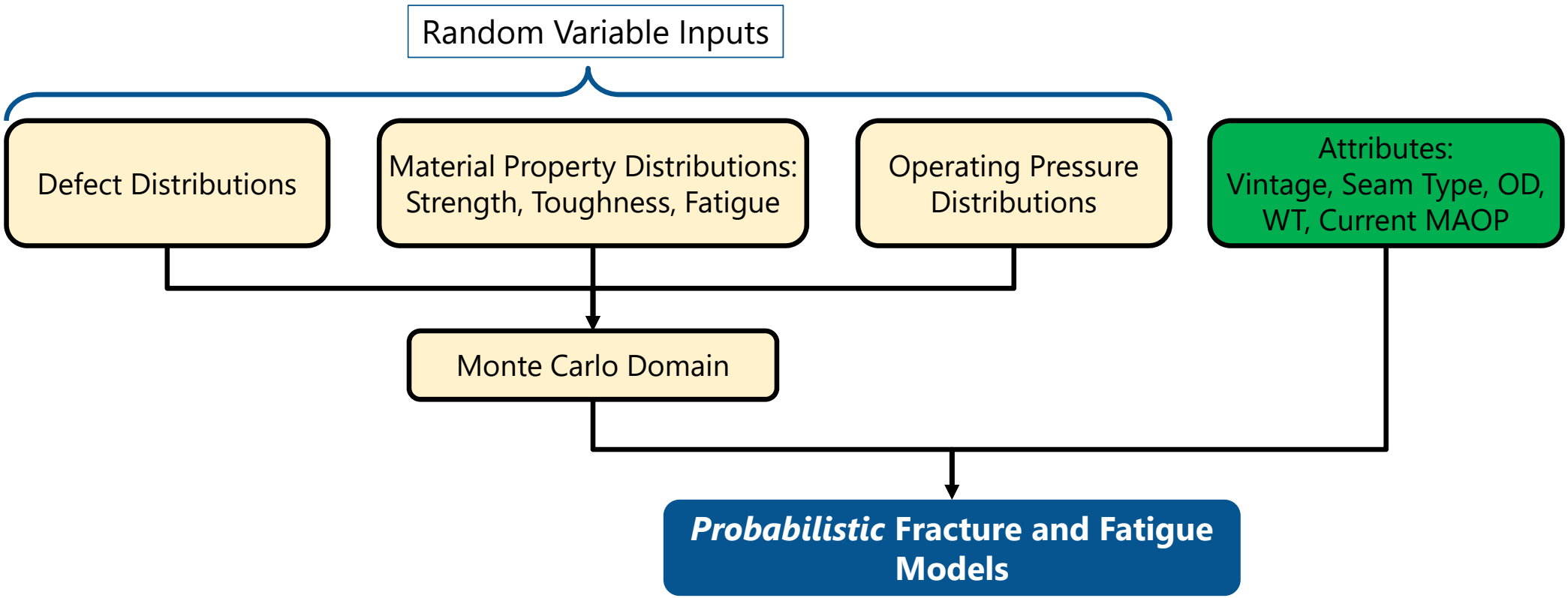
Motivations

- **Resource allocation for MAOP verification**
- **Applying shared ILI data to non-ILI facilities**
- **Rigorously establishing performance requirements of NDE**
  - Materials & flaws

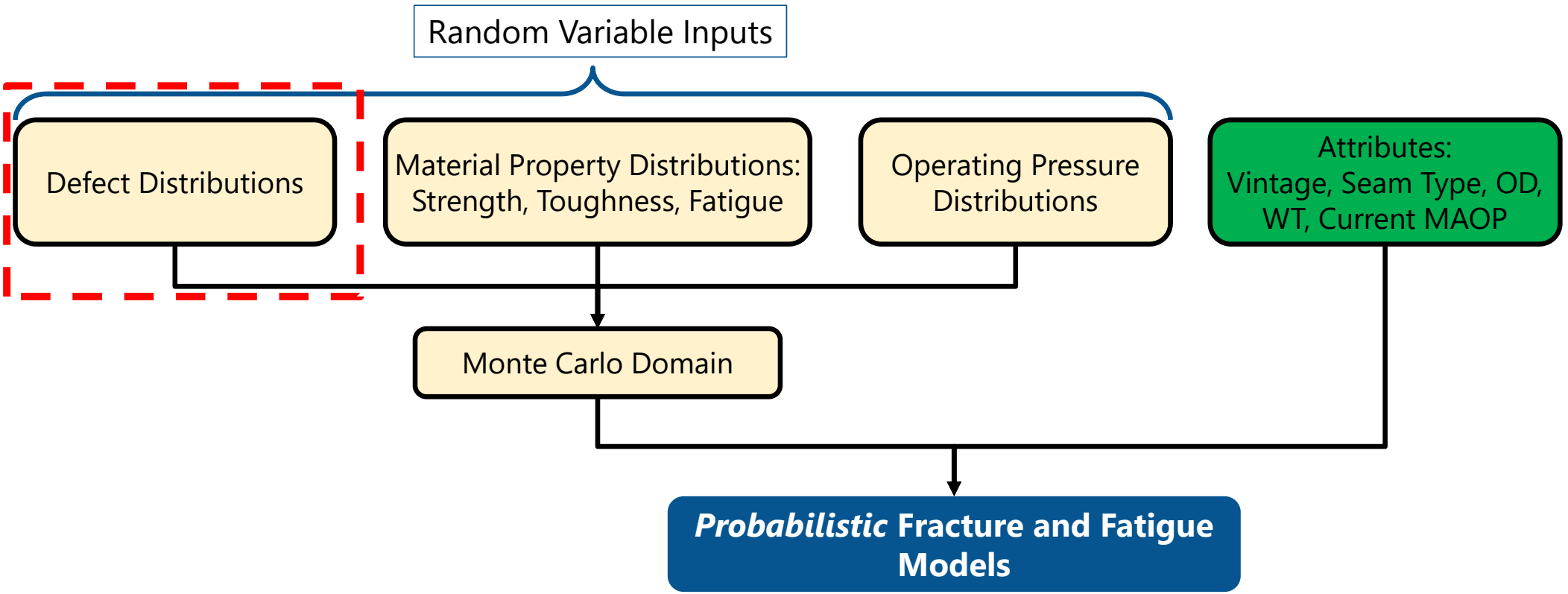
PG&E Station's MAOP Verification Process



Pre-Assessment and Prioritization (Pre-Field NDE)



Pre-Assessment and Prioritization (Pre-Field NDE)

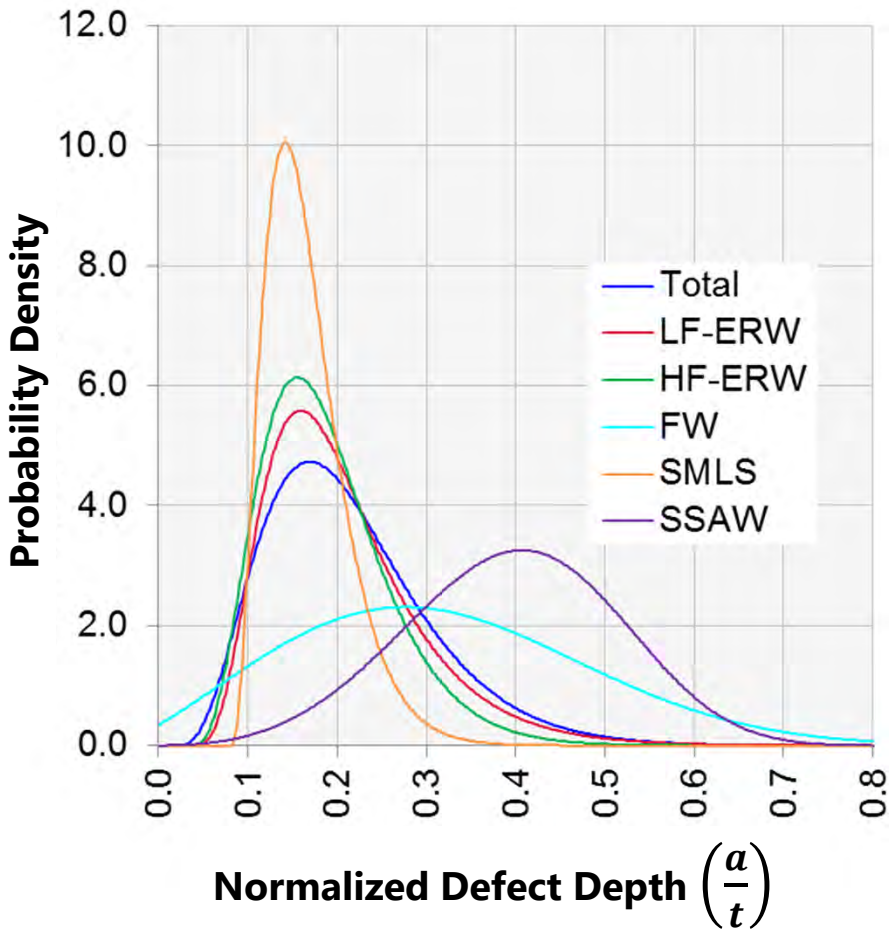


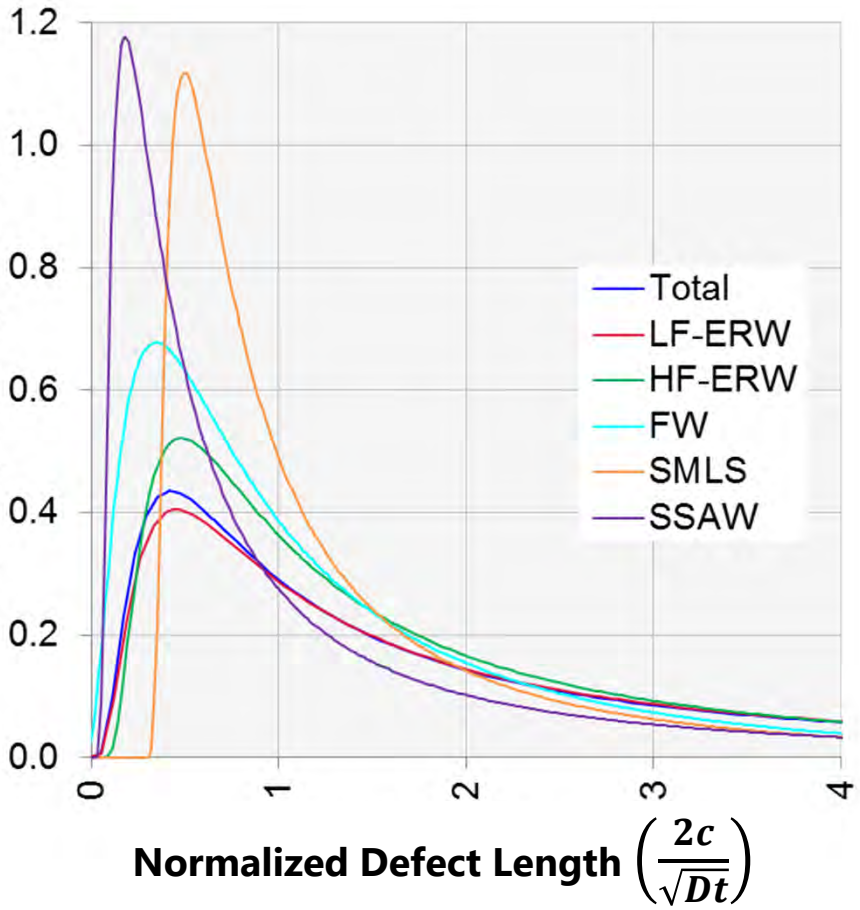
Defect In-Line Inspection Datasets

- **Defect size distributions based on > 10,000 miles identified in various operator's ILI and ITD programs**
  - LF ERW, HF ERW, FW, SSAW, SMLS
  - UTCD, EMAT, AFD, CMFL, KMAP, UT ITD
  - OD: 6.625 ~ 20 inches, WT: 0.157 ~ 0.5 inch
  - Grade: B ~ X65, Vintage: 1900 ~ 1999

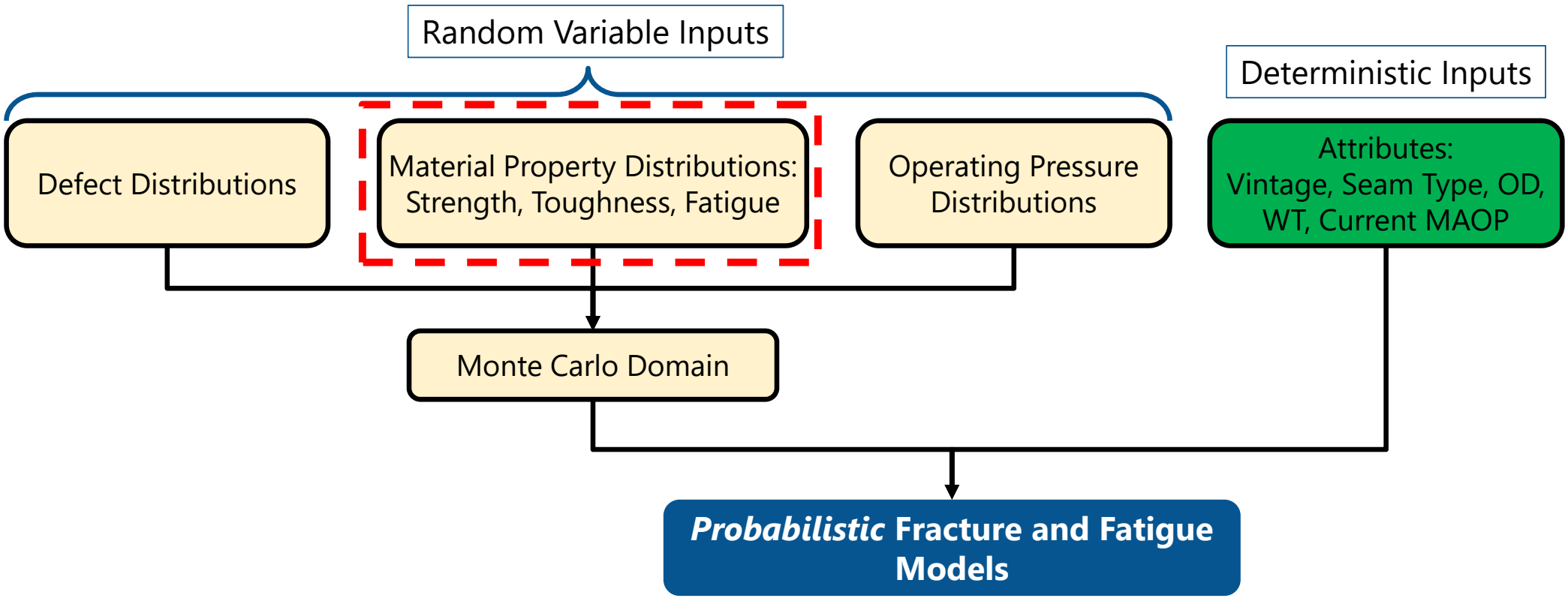
Seam Type	Count	Mileage	Density per Mile
LF/DC-ERW	9791	1248	7.85
HF-ERW	378	356	1.06
FW	858	562	1.53
SMLS	104	38	2.77
SSAW	371	127	2.93
Total	10558	2330	4.53

Defect Depth and Length Distributions



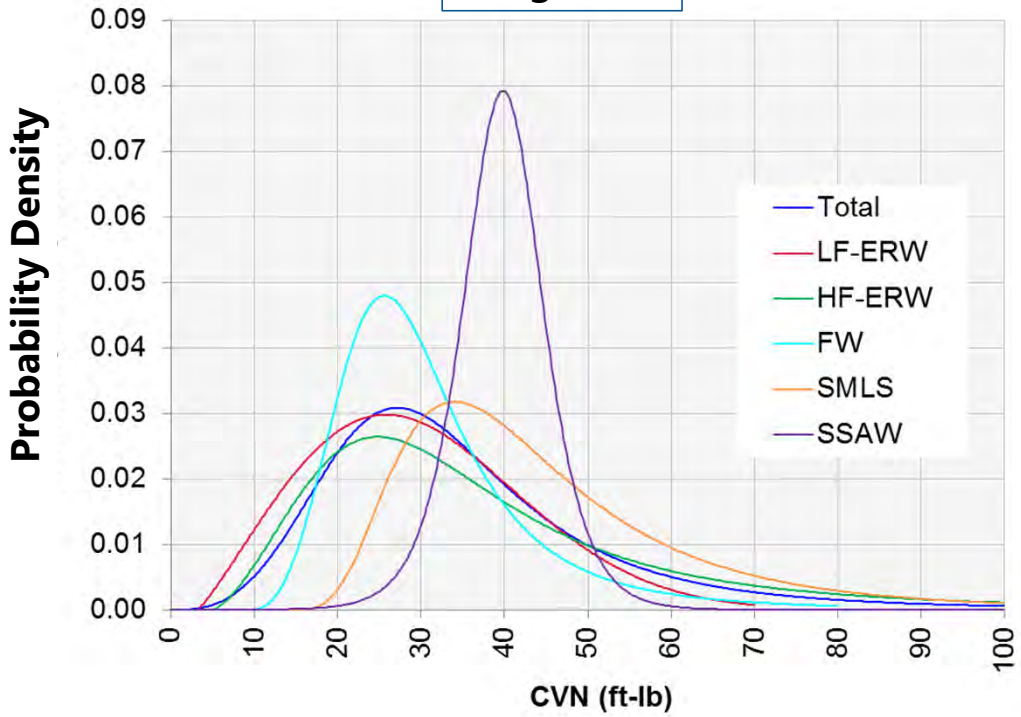


Pre-Assessment and Prioritization (Pre-Field NDE)

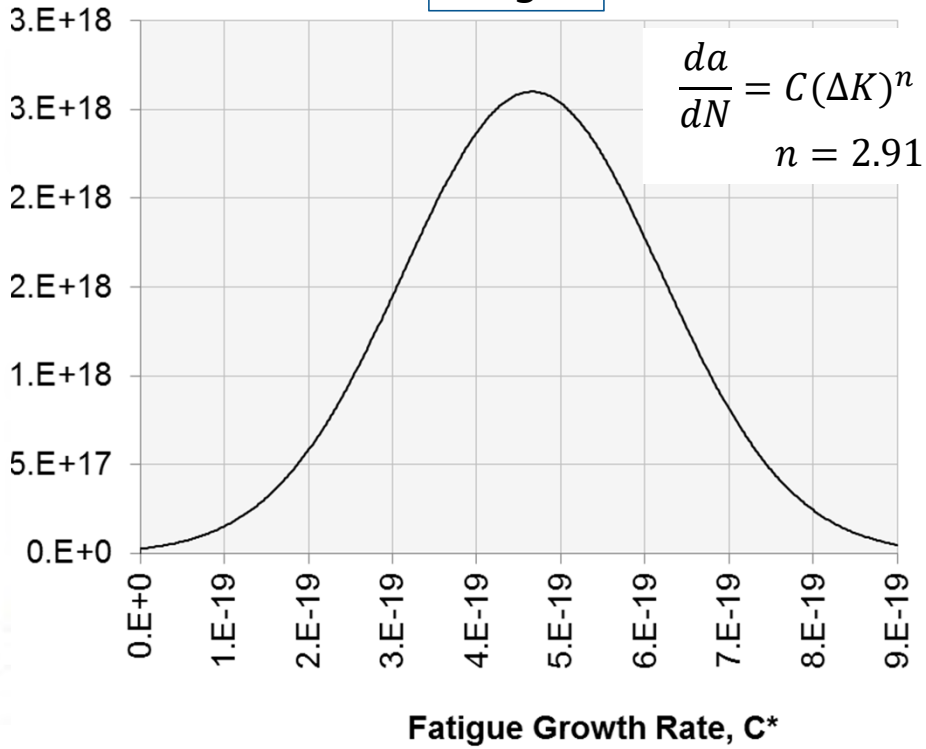


Material Toughness and Fatigue Growth Distributions

Toughness

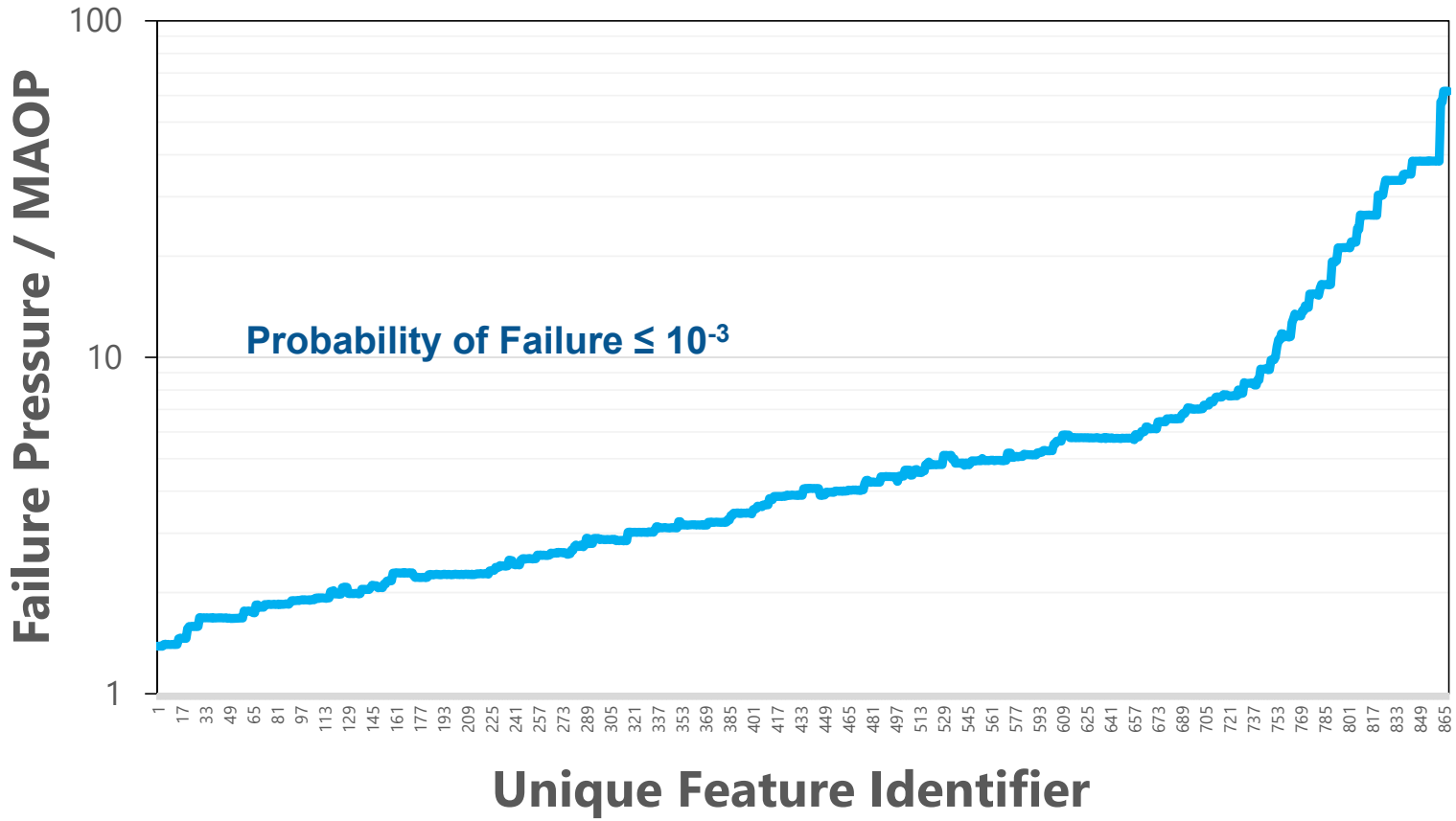


Fatigue



*PRCI SIA-1-1 Phase II, "Improved Methods for Estimating Fatigue Life of ERW Pipelines"

Pre-Assessments/Prioritization PG&E Facility Piping Rank

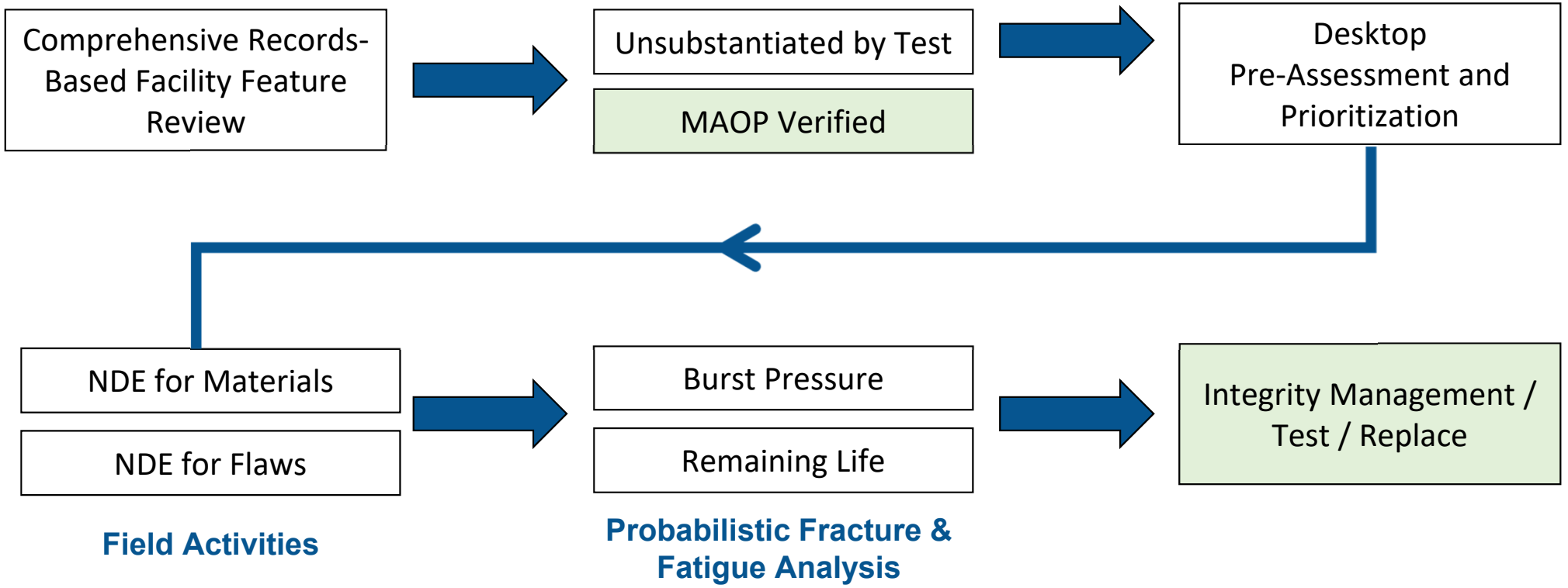


J. Ma, M. Rosenfeld, P. Veloo, T. Rovella, AGA Operations Conference (2018)

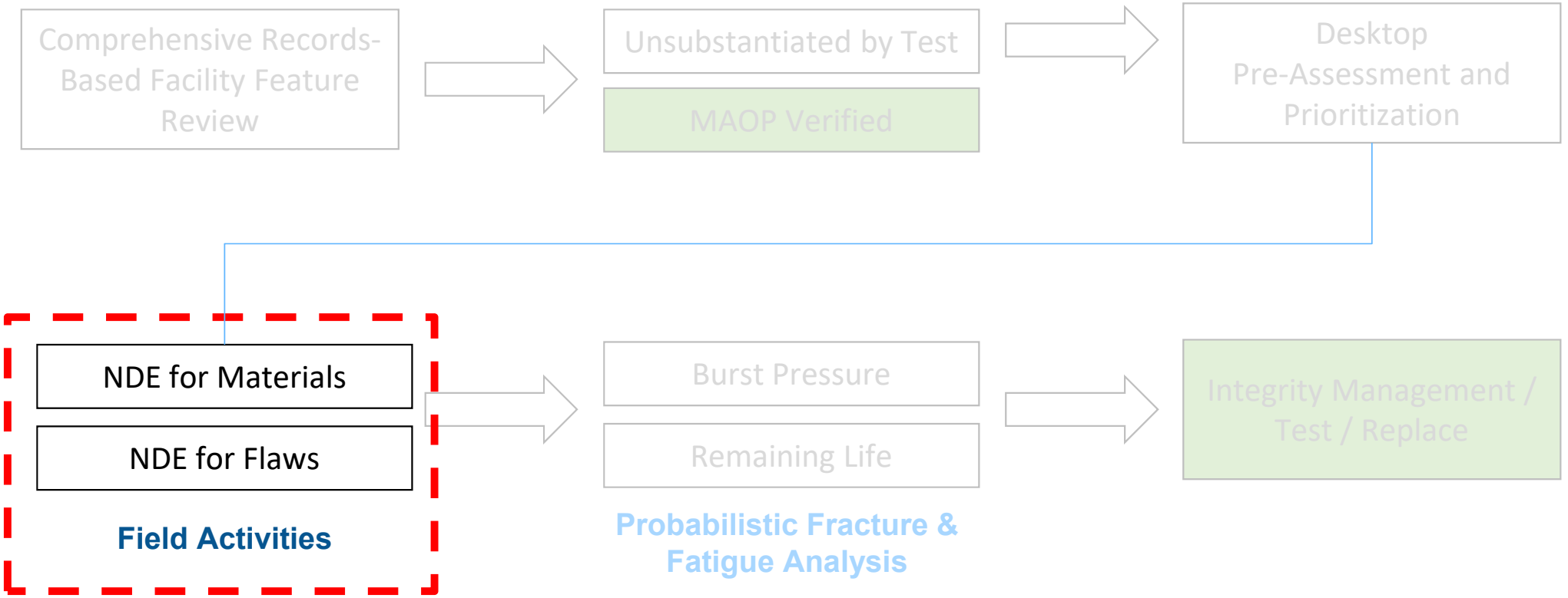
Pre-Assessment and Prioritization Data Needs and R&D

- **Vintage pipe body and long-seam crack and defect size data**
  - Validated in-line inspections results
  - In-ditch inspections data
- **Vintage pipe body, long-seam, and girth weld material properties lab data**
- **Datasets with high degree of dimensionality**
  - Vintage, nominal wall thickness, long-seam
- **Comprehensive sensitivity analysis**
  - Choice of distributions
  - Higher fidelity models
- **Improving computational efficiency and cloud-computing parallelization**
  - E.g., S. Wood, A. Garcia, Equivalent Load Fatigue, PPIM 2019
  - E.g., T. Anderson, J. Andrew, J. Moritz, PPIM 2018

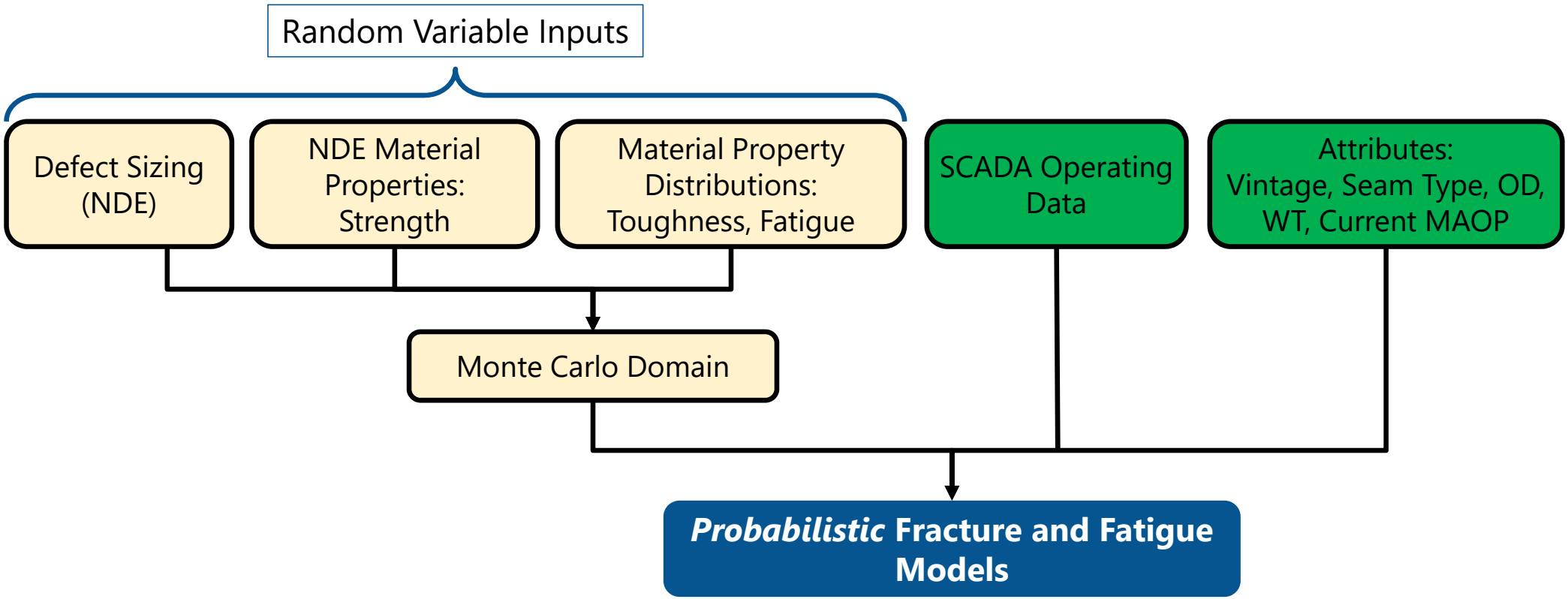
PG&E Station's MAOP Verification Process



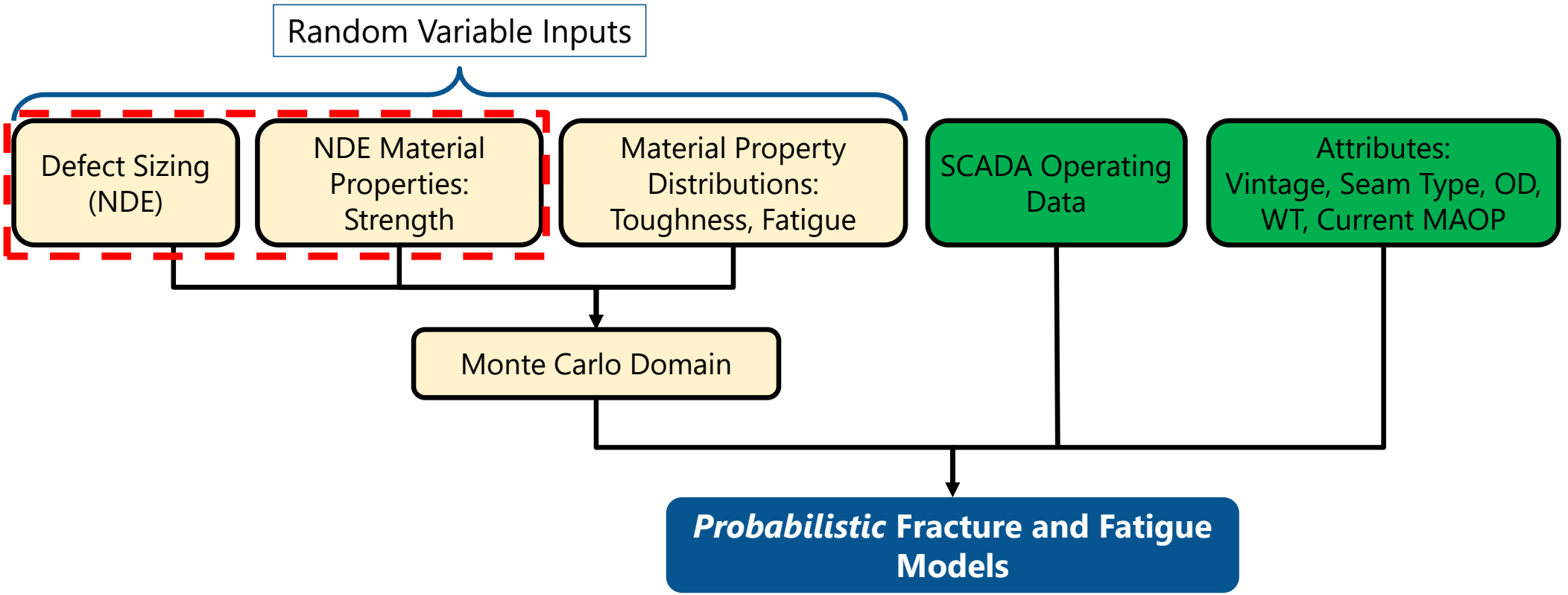
PG&E Station's MAOP Verification Process



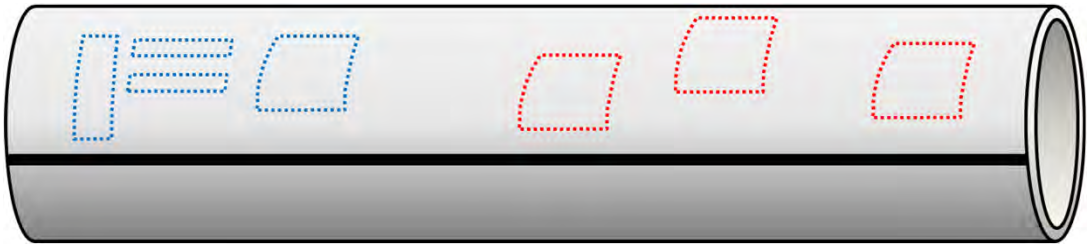
Post-Field Assessment

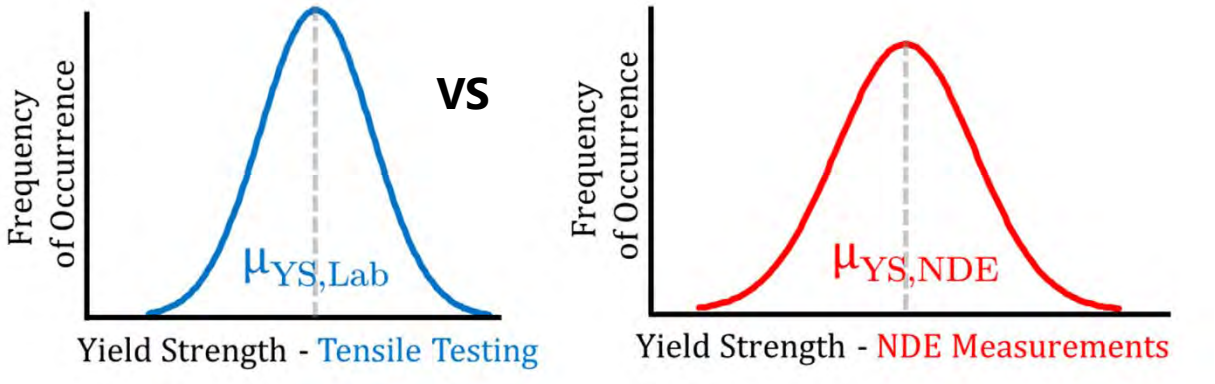


Post-Field Assessment



NDE Performance Assessment - Strength

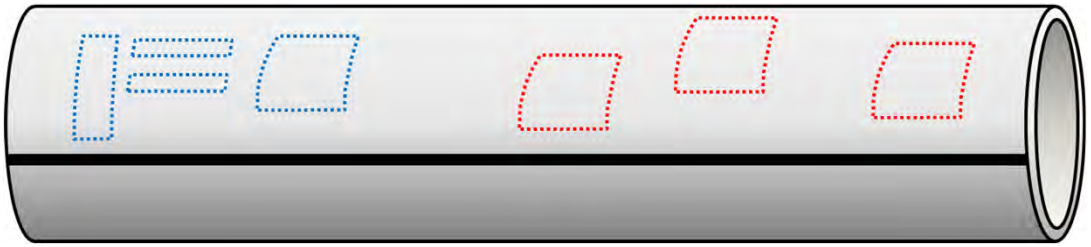


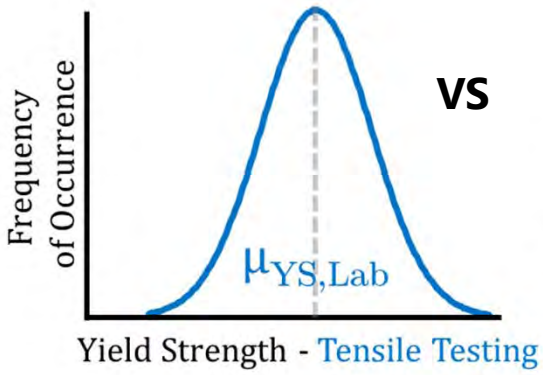


Summary	
No. of Pipe Samples	92
No. of Tests (IIT/Tensile)	2,451 / 376
Vintage	1934 – 2017
Grade	B to X70
Nominal OD (in)	4 ½ – 36

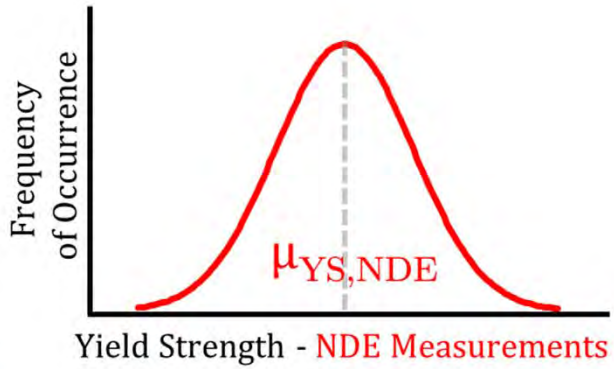
J. Kornuta, et al., ASME IPC (2018); J. Kornuta, et al., PPIM (2019)

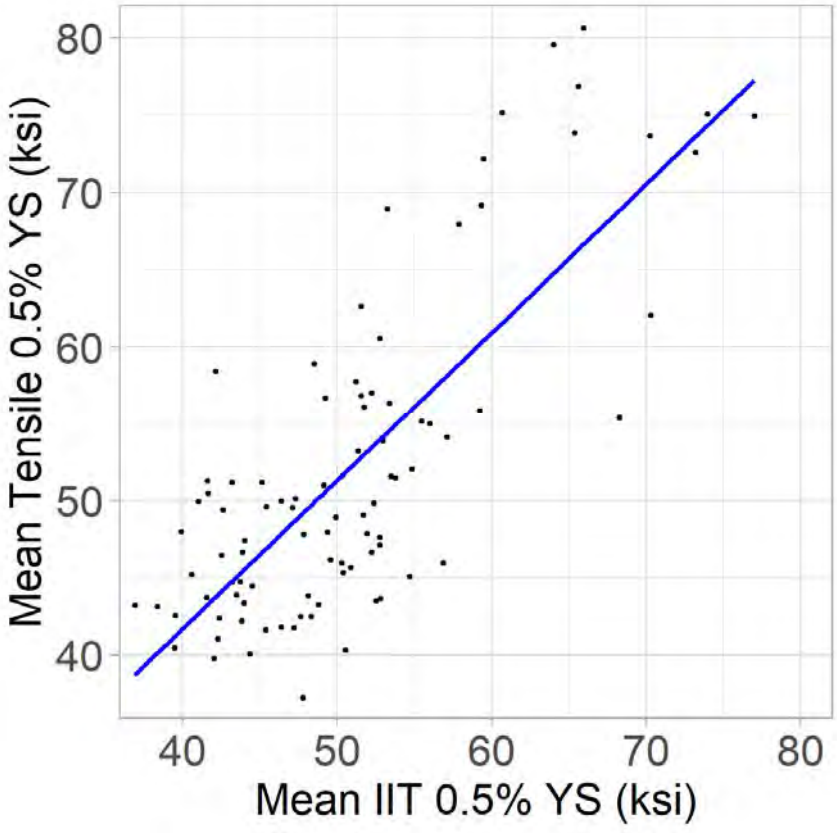
NDE Performance Assessment - Strength





VS





J. Kornuta, et al., ASME IPC (2018); J. Kornuta, et al., PPIM (2019)

NDE Performance Assessment – In-Ditch Flaw Sizing

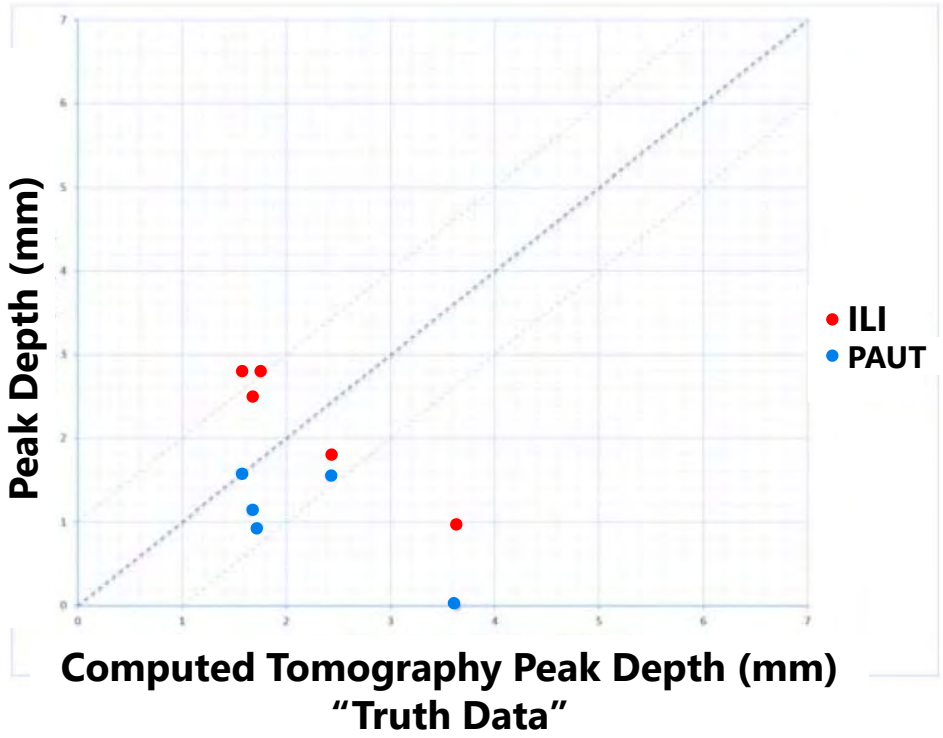


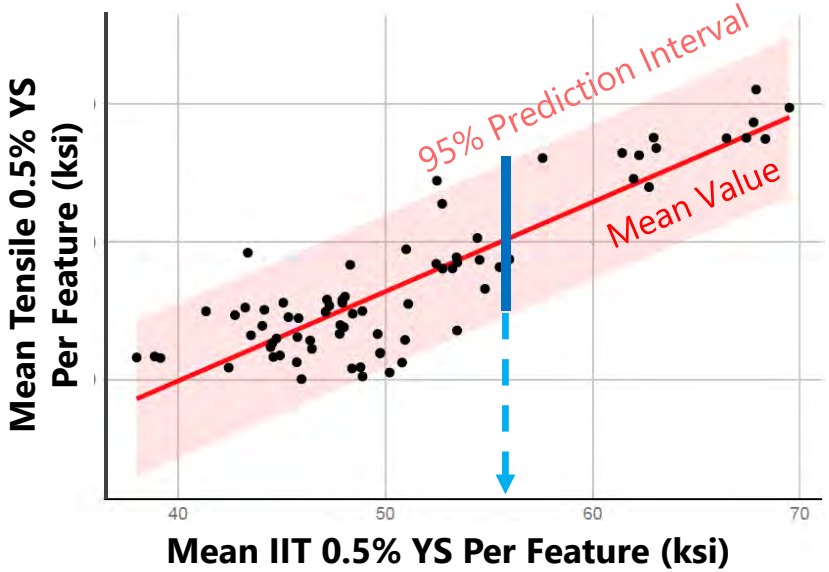
Figure 2. Prototype CT scanner for pipeline feature inspection (photograph courtesy of Inspection Associates, Cypress, TX; www.inspectionassoc.com).

M. Piazza, et al., ASME IPC (2018); M. Piazza, et al., PPIM (2019)

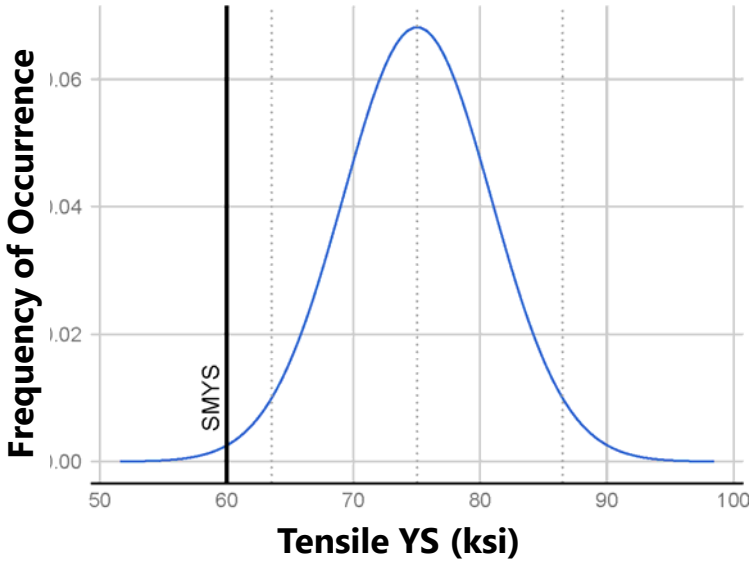
L. Torres, M. Fowler, J. Bergman, ASME IPC (2018)

NDE Performance as an Input to Probabilistic Calculations

Quantified NDE Performance (e.g., Tensile vs. IIT YS)



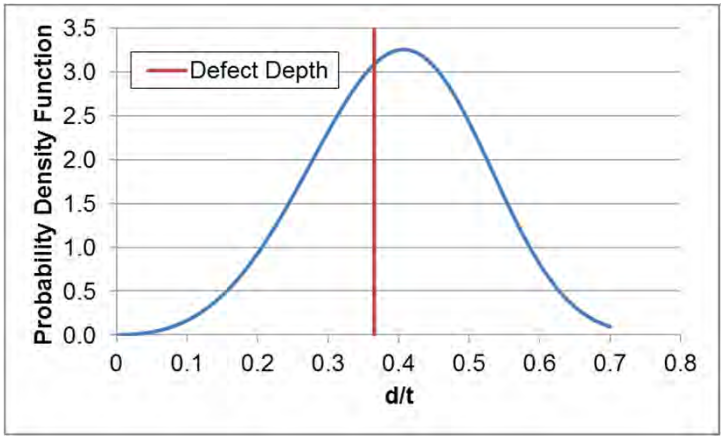
Probability Distribution Input for Fracture and Fatigue Calculations

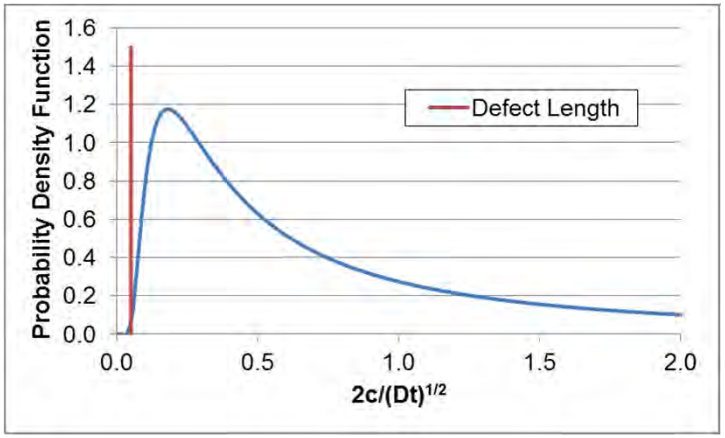


PG&E Pilot Implementation

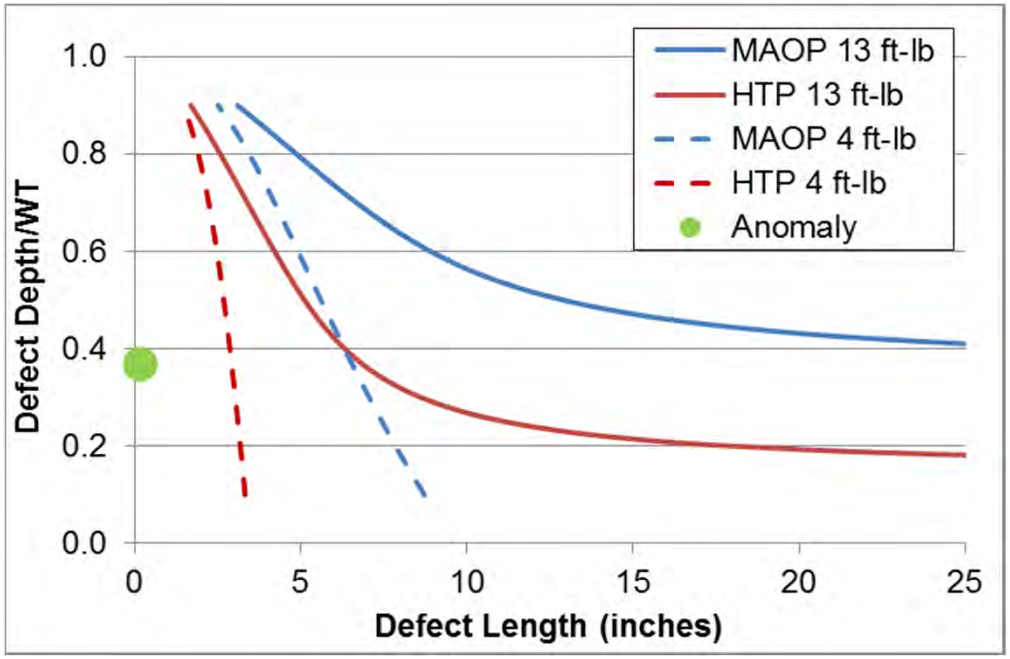
- **Currently in progress at nine PG&E stations**
- **NDE to determine material properties**
  - Composition, hardness, strength, microstructure, long seam
- **NDE to determine manufacturing and construction defects**
  - UT (PA, TOF-D, 0˚, auto), RT, MT

Pre- & Post-Field Assessments

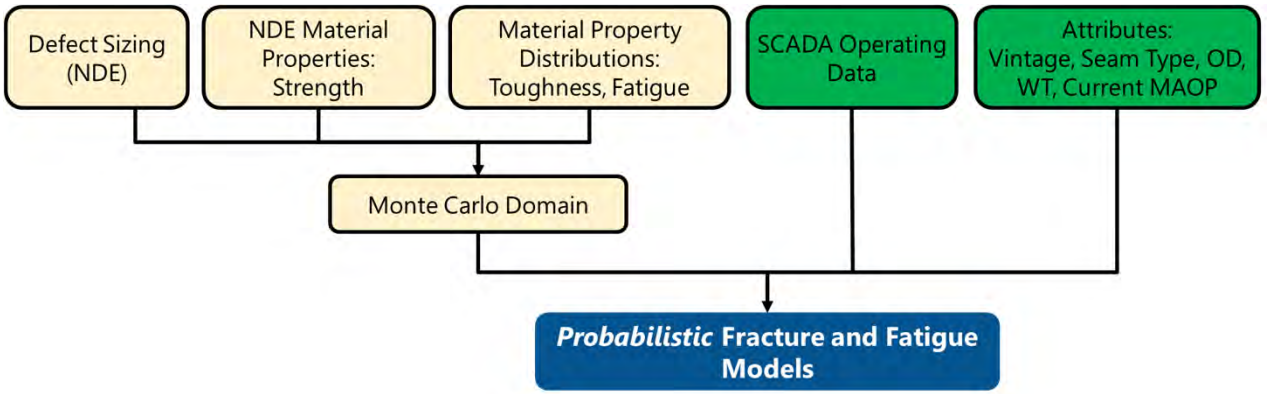


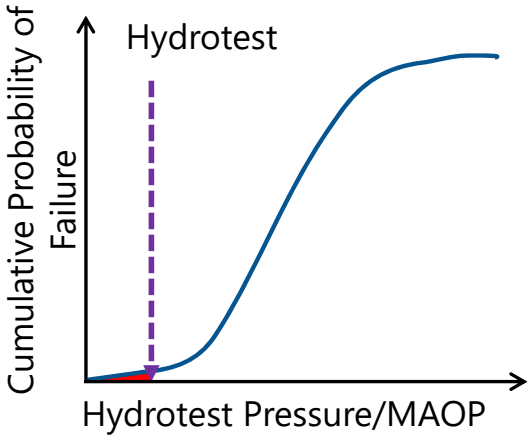


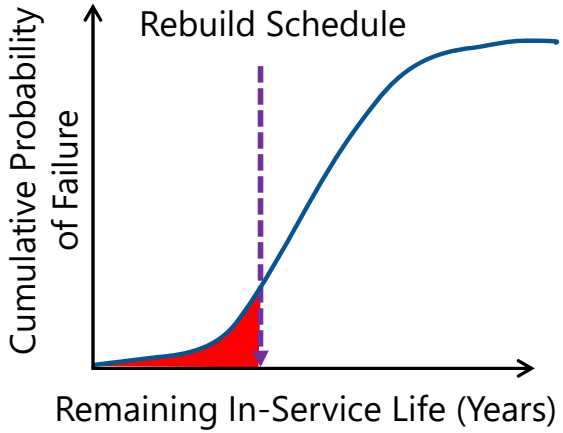
Analysis	POF (1.5xMAOP)	POF (10 Years)	POF (25 Years)	POF (50 Years)
Pre-NDE	3.63E-3	1.98E-5	3.89E-5	7.49E-5
Post-NDE	<1.00E-5	<1.00E-5	<1.00E-5	<1.00E-5



Establishing Accuracy Requirements – How Good is Good Enough?







ICP NDE Practical Examination Programs

Andri Orphanides – Credentialing Specialist
Manager, ICP
March, 2019

API Organization

- API writes the standards for O&G
  - API is about consensus building
- Certification Programs
  - Knowledge based 30 years
  - Practical exams in NDE space 16 years
- Infrastructure is in place

ICP UT Certification Offerings

- QUTE – Detection
- QUSE – Sizing
- QUPA – Phased Array

- QUSE PA – Crack Sizing
- QUTE TM – Thickness Measurement

QUTE – TM Thickness Measurement

- Multi stream programs
- Consensus and feedback
- Samples include flat plate, pipe, small bore pipe or fittings
- size of thickness range from 0.160 – 2.00 inches

Midstream Gap

- Pipeline operators working with API
- Identified goals:
  - Standardized competency of NDE Technicians (Training and Assessment)
  - Verification and assessment of in-line inspection (ILI) tool

Supporting Companies

- Colonial Pipeline
- Enbridge
- Explorer Pipeline
- ExxonMobil
- Phillips 66
- Plains All American
- Marathon Pipe Line
- Shell
- TransCanada
- TD Williamson Pipeline

Midstream Flow

- Utilize ICP platform
- Develop midstream-focused exams
- Long seam defect exam
  - Initial ERW focus
  - Potential expansions to DSAW and other seam types

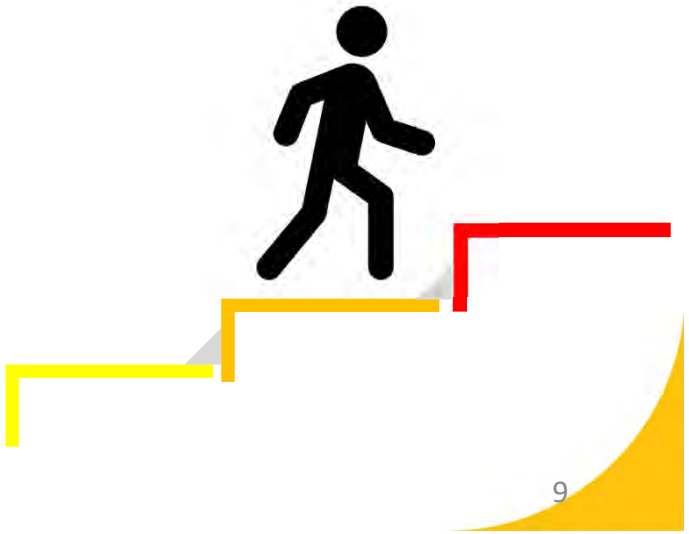
Outline of Certification

Measure technician competency in:

- ❑ Tool Calibration
- ❑ Detection of defects
- ❑ Identification of defects
- ❑ Sizing of defects

API Programs Moving Forward

- Expand program offerings
  - Enhance current
  - Expand and prioritize into streams
- API test centers
  - Identify expansion
  - Traveling exams
- Competency Gaps
  - Training
  - Job to Profession



ASNT's Industry Sector Qualification (ISQ) for the Oil & Gas Sector

ASNT...Creating a Safer World!™

The American Society for Nondestructive Testing (ASNT) has Developed a Performance Demonstration Program for the Oil & Gas Sector - ISI Performance Demonstration

ASNT's vision is for a single **NDE** performance demonstration program recognized and accepted by owner / operators in the Oil & Gas industry across the globe.

The purpose of this program:

- Standardize performance demonstration qualification testing of NDE technicians, to alleviate the burden of owner / operators from providing their own NDE performance demonstration program.
- Provide a program for owner / operators that do not have their own NDE program.
- To be an industry recognized program for the Oil & Gas sector while minimizing the impact of cost and over testing of NDT technicians.
- The program will strive to exceed the standards of all participating owner / operator representatives and to achieve the full support of industry.

For more information please contact ASNT ISC at 614.274.6003.

ASNT...Creating a Safer World!™

ASNT...Creating a Safer World!™

ISQ Program Development

- O&G Owner / Operator Steering committee
  - Sub-committee of the ASNT Certification Management Council
- Current Membership – Open to New Owner/Operator Members
  - Chevron
  - Shell
  - Marathon
  - BP
  - Valero
  - Flint Hills
  - ExxonMobil
  - Saudi Aramco
  - Phillips66
  - Colonial Pipeline
  - DuPont
  - EPRI – advisory member

ISQ Program

- Program Starting Methods & Dates
  - UT Thickness – April 1st
  - UTSW/PAUT/TOFD for ASME Weld Quality – Oct 1st
  - Others to come – Midstream & Upstream
- Deployment
  - ASNT AEC's (Authorized Examination Centers)
  - ASNT AEP's (Authorized Examination Proctors)
  - Exam Security Protocols
  - National & International Exams
  - Plans to Support the ACCP Certification Program

ASNT Commitment

- ASNT Executive Director
- Board of Directors
- ASNT ISC (International Services Center) Staff
  - Certification services
  - Financial & Development Support
    - Personnel Support $230,000
    - Legal, travel, and site set up of $102,500
    - Specimens and initial management $267,500
    - IT Systems $340,000
    - Total project financial commitment from ASNT to date $940,000 with NO return on investment expectation!

ISQ Management

- Computerized Systems Development
  - Online Application Process
    - Individual or Group Applications
    - Reviewed by ASNT ISC staff
  - Computerized Specimen Database
    - Computerized Examiner Support System
  - Computerized Data Entry & Grading
    - Only ASNT ISC staff will have answer keys and perform grading
    - No contractors or NDT Training companies will be allowed to grade exams or have answer keys
  - Online Searchable Database of Qualified Technicians

O&G ISQ Program

Questions?

Pipeline Research Council International, Inc.

PR-580-163710

Determining the Impact of Human Factors on the Performance of In-Service NDE: Through an Educational Lens

Jane Rau
JTrain, Inc.

PRCI 2019 Research Exchange Meeting
Houston, Texas
March 6, 2019

Learning Objectives

The learner will know and be able to:

- **Explain the importance of formative assessment**
- **Explain the difference between certification and qualification**
- **Describe recommended vs. mandated practices**

Project Objectives

- Identify approaches and methodologies currently used in transfer of knowledge in the pipeline industry.
- Determine ways to improve current practices utilizing research-based best practices in teaching and learning from academia.
- Done in parallel with hands-on performance demonstration of NDE testing (UT, MT) on samples with known damage.

Project Tasks

- Investigate background information on regulatory requirements and practices
- Survey owner/operators about the qualities of a “go to” NDE technician
- Review audit protocols for service providers and conduct audits
- Investigate current training documents and perform evaluation of materials

Project Tasks

- Assist in performing evaluations of vendors (from the audits) at the TDC and interview the same technicians
- Investigate Human and Organizational Factor (HOF) program development among pipeline operators
- Observe how trainers approach their target populations (UT/MT, Train the Trainer) and implement learning strategies

Research Results

Results described for each of the project tasks

NDE Standards

Six standards on NDE were reviewed:

- **One ISO**
- **Three ASNT**
- **One Canadian**
- **One British**

Owner/Operator Survey

- 24 individuals from 16 companies were surveyed
- 79% response rate
- 10 open-ended questions on survey
- Certification scheme mostly used was SNT-TC-1A
- Other schemes included PCN, CGSB, ASME V, API 1104, CWI, CSWIP, AINDT, CP 189
- “Experience” was the word most used to describe a “go to” NDE technician

Owner/Operator Survey

- **The qualities a "go-to" technician with limited experience possesses are:**
  - Willingness to learn
  - Highly motivated
  - Honest
  - Not afraid to ask questions when they don't understand
  - Adaptive
  - Eager to find opportunities to learn and broaden their knowledge

Owner/Operator Survey

Recommendations for NDE training and certification programs were:

- more hands-on real world sample training (not machined-flaws)
- more supervised field experience
- more on the job training

Owner/Operator Survey

This response summarized others' thoughts about working with NDE technicians:

- "I believe there is a definite issue with the current system in place for NDE Technician Certification and Training in the United States. The first part starts with the service providers. Due to the nature of SNT-TC-1A, these service providers can train and certify their own technicians as long as they meet the requirements specified by the recommended practice. The training requirements are very broad and not specific to what the technician will see in the field. The service providers need to create training programs specific to the field the technician will be sent to. If that were within a plant, vessel inspection, or pipeline anomaly inspections, the programs they develop need to be specific to the work performed and flaws they will encounter. The second part falls on the pipeline industry. Since this is a free market, the consumers of NDE can dictate the quality of NDE technicians. This will only be achievable if 1) the industry dictates or requires the above mentioned training and 2) the industry needs to have knowledge on how to identify good NDE."

Review of Protocols and Audit

- Four owner/operator protocols were reviewed to formulate questions germane to training and assessment for audits
- No protocols asked specifics about training as “education”
- Six global service providers were audited
- Three other service providers and a community college were asked the same questions as the audited companies

Audit Responses

- **Most followed SNT-TC-1A certification standards**
  - Other standards followed are CP-189, CP-105, and ASME
- **Two outsource training to other companies**
- **Eight train 3rd parties**

Audit Responses

- Definition of “certification:” passed all requirements and have appropriate documentation
- Definition of “qualified:” passed certification and performance exams
- Definition of “competence:” qualified and can perform the method successfully over a period of time

Audit Responses

- Class size ranged from one to 24
- NDE instructors are in-house SME's and Level III's (college instructors are industry SME's)
- Three companies have in-house "Train the Trainer" course for their instructors
- Three companies outsource "Train the Trainer" courses for their instructors

Audit Responses

- Four companies and college do not require “Train the Trainer” courses for their instructors
- All write their own curriculum and assessments
- Only one used short answer/essay assessments, nine used multiple choice questions
- No companies had anyone with an education background writing curriculum, assessments, or instructing
- All used only one instructor evaluating performance exams (inter-rater reliability)

Audit Responses

- **Eight use computer/web-based instruction**
- **None understood "formative assessment" (learning strategy"**
- **Obstacles found in training today's students:**
  - Language barriers
  - Immaturity
  - Poor math skills
  - Difficulty understanding vocabulary/terminology
  - Short attention spans

Review of Current Training Documents

- Reviewed four computer/web-based instruction sites
- Reviewed training materials from six companies that allowed perusal
- Reviewed training assessments from four companies that allowed perusal
- Not allowed to review any final qualification assessments

Evaluations of Vendors at TDC

Assist in performing evaluations of vendors at the TDC and interview technicians to find gaps in training and application

- Blind trials (UT/MT)
- Observed proctoring
- Interviewed eight technicians from seven companies
- Gave Learning Styles Inventory to each technician to determine strongest mode of learning: visual, auditory, kinesthetic

Investigate HOF

- **Discovered one owner/operator with HOF program**
- **Interview of HOF reliability engineer found:**
  - Human factors defined as environment, ergonomics
  - Programs are recommended, rarely mandated
  - Understanding, communication, and sharing are needed to make the programs successful
- **Industry HOF articles reviewed supported the operator's comments**

Observations of NDE Technician Training

- Observed five UT and five MT classes from global service providers and one community college
- “Powerpointless”
- Little or no student engagement
- Implemented learning strategies in one class…

Aha! Moment…

Observe Train the Trainer

- Difficult to find
- Located two owner/operators and four service providers with TTT courses
- Allowed to observe in one 40 hour TTT course and one day of another 40 hour course
- Reviewed the curriculum for two other courses
- Contained some learning strategies – not really understood by instructors

RCFA on NDE Tech Training

Failure: Not all NDE technicians are competent.

Analysis: Why aren't they competent?

Direct causes:

- **Ineffective instruction**
- **Ineffective curriculum/assessments**
- **Poorly prepared students**

RCFA on NDE Tech Training

Root causes:

- Instructors don't have knowledge of research-based learning strategies to implement. Train the Trainer courses don't model learning strategies.
- Curriculum and assessments are written by SME's, not assisted by educators who understand how to write aligned and effective curriculum and assessments.
- Many students are unprepared – have poor math skills, limited vocabulary, limited practical experience with tools of the trade (ruler)

RCFA – The Fix…

- **Require instructors (owner/operator and service providers) to take an effective 40 hour Train the Trainer course.**
- **Give pre-assessment to new NDE students to determine math and vocabulary levels and learning mode strengths**
- **Utilize educators who keep current with research-based learning strategies and best practices.**
  - Help write curriculum/assessments
  - Model learning strategies in Train the Trainer courses
  - Vet TTT classes for effectiveness

RFCA – The Fix…

Implement research-based learning strategies to improve transfer of knowledge:

- Essential question
- Aligned and relevant learning objectives
- Formative assessment
- Self-assessment
- Rubrics for assessment/self assessment
- Use of video to improve teacher effectiveness (video instructor teaching a class)
- Student seating for collaboration
- Learning style survey
- Questioning – wait time

RCFA – The Fix…

- Levels of questions
- Random selection
- Immediate and specific feedback
- Writing aligned and effective multiple choice questions
- Making connections to schema to generate learning and transfer
- Use of instructor/mentors who have successfully used learning strategies; coaching
- Backward design
- Flipped classroom
- Scaffolding
- Task analysis
- Mutual expectations/setting norms

RCFA – The Fix…

Computer/Web-Based training

- Utilize computer/web-based training with an instructor present to probe for learning using questioning techniques.

- Use with caution if used without instructor (story)

Recommendations

Standards

- **Work with SWOs for NDE standards to be written and adopted worldwide to…**
  - Create equity, and therefore continuity, in the education of NDE technicians

- **Establish an NDE qualification test to be written collaboratively and adopted by all owner/operators**

Recommendations

Audits

- Owner/operators should annually audit the service providers they use and include questions about training from an educational standpoint

HOF programs

- Owner/operators and service providers develop HOF program/position to include Human Factors from an educational viewpoint as well as environment, ergonomics, etc.

Interviews of NDE Technicians

- **Learning Styles Inventory**
  - All eight technicians were visual learners
  - NDE classes observed were mostly auditory/didactic; only visuals were PowerPoints, textbooks
- **Recommendations**
  - Have students fill out a learning styles inventory before the courses begin so the instructors can adjust delivery of instructional materials accordingly.

Interviews of NDE Technicians

- **Recommendations from interviews**
  - Create training programs specific to the field in which the technician will be working, rather than just the broad-based training specified by the recommended standards. (This was also suggested in the owner/operator survey.)
  - Utilize more hands-on training with real-life samples, not machined flaws.
  - Have more training on procedures, how to follow them, and the importance of following them.

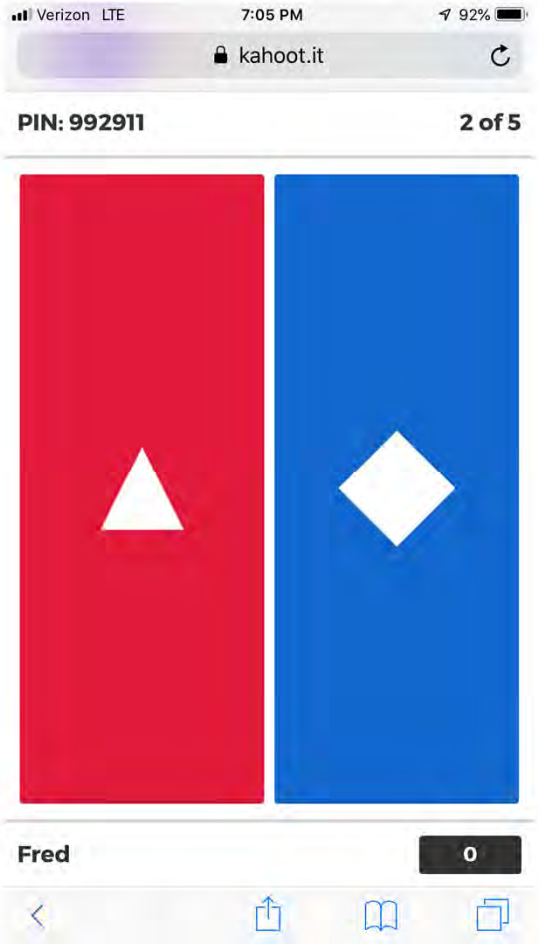
Interviews of NDE Technicians

- Present more training on client/technician communication and how to facilitate that communication.
- Develop a global database of mentor retirees to work with technicians in OJT.
- Require NDE instructors to periodically work in the field to have current experience on changes/applications.
- Require NDE instructors to take a vetted Train the Trainer course to improve their effectiveness in transferring knowledge.

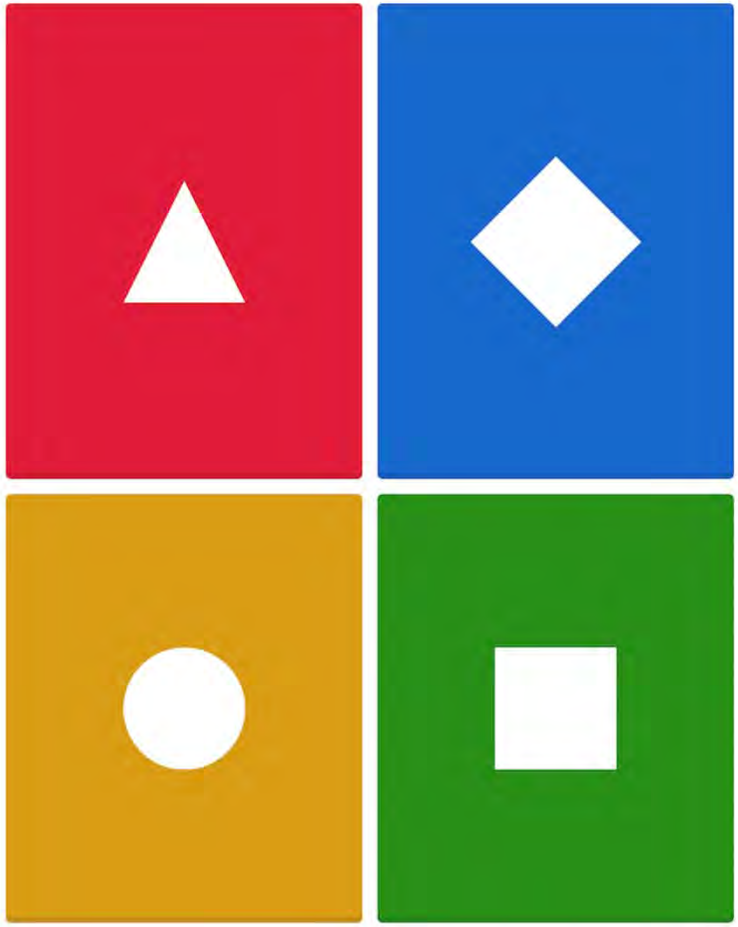
Formative Assessment

- Open the browser on your smartphone
- Type kahoot.it into the address bar
- Enter the code on the screen
- Enter your name or a nickname (appropriate please☺)

Kahoot



Kahoot



Pipeline Research Council International, Inc.

PRCI Project Code (DP-03-07)

Competency in the Pipeline Industry: An Industry Survey

Reena Sahney, P.Eng., M.Eng., MBA

JIVA CONSULTING | SCHOOL OF ENERGY

PRCI 2019 Research Exchange Meeting
Houston, Texas
March 6, 2019

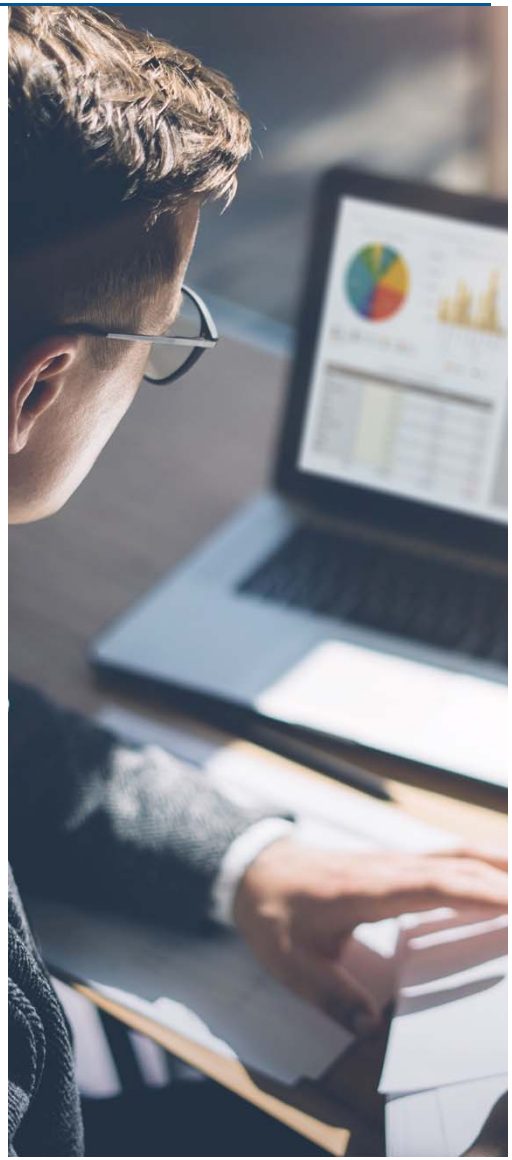
Agenda

1. **Executive summary: 10 min**
    1. Overview of the Initiative
    2. Nature of Survey Respondents
    3. Key Findings / Constraints to Analysis
    4. Summary Chart
    5. Other Observations

2. **Background: 5 min**
    1. Survey Framework
    2. Development of Survey Questions

3. **Summary of Findings: 10 min**
    1. Theoretical Knowledge
    2. Technical Skills
    3. Non-Technical Skills
    4. Experience
    5. Behavior

4. **Next Steps / Questions: 5 min**



Executive Summary

Overview of the Initiative

Purpose

- Understand baseline competency requirements for a number of areas within the pipeline industry (across pipeline lifecycle)
- Identify competency gaps within the industry

Approach

- Design and implement an online survey to be distributed to PRCI members (both operating and service companies)
- Analyze data and present findings to PRCI members

Outcome

- Findings can be used to mature industry-wide competency by developing a road map to close gaps

Executive Summary

Nature of Survey Respondents

Demographic Observations

> 85% work for an operating company

> 50% of respondents based in the United States

> 30% based in Canada

Oversight Role Observations

- Representation across pipeline lifecycle
- 54% oversee roles in Maintenance (including integrity)
- Respondents generally oversee 1-10 office-based individuals that have less than 6 years of experience

Executive Summary

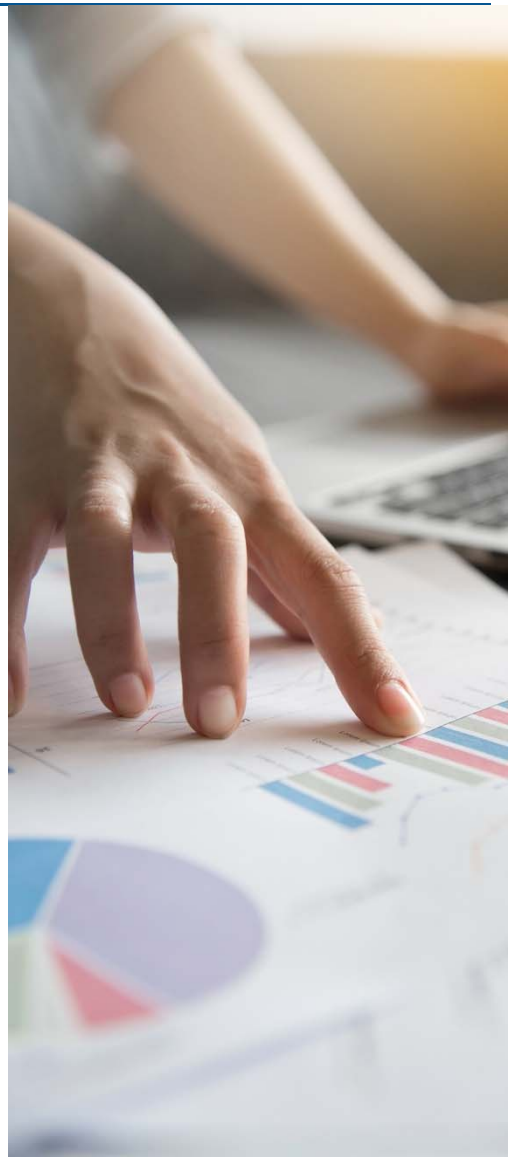
Key Findings

- Majority of respondents (71%) have a formal competency program
- Responses show that processes are highly subjective and lack repeatability, indicating lack of maturity (i.e., development) of components of competency throughout lifecycle of a role
    - E.g., reliance on hiring manager judgment or behavioral interviews versus standardized approach to assessing resumes and skills

Executive Summary

Constraints to Analysis

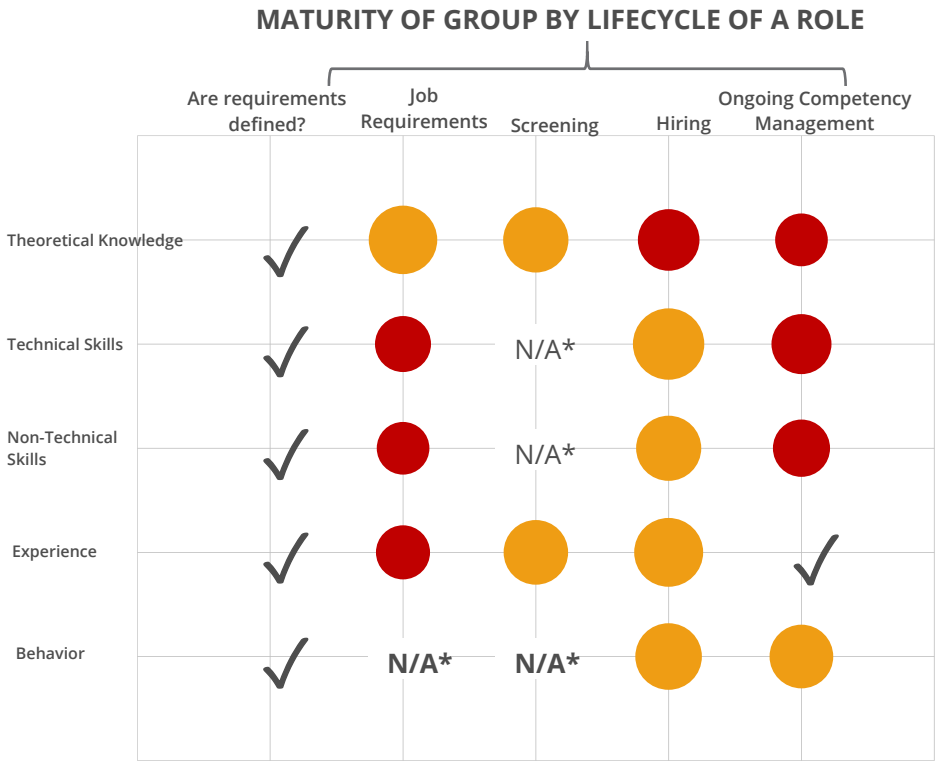
- While some limitations to the data exist, the survey sample size was sufficient to provide baseline insight into the industry
- Of 63 responses, 11 were from individuals not in an oversight role and 17 were partial survey responses
- Sampled data with these responses removed:
  - Results not materially skewed
  - Decision made to use full data set from SurveyMonkey for analysis



Executive Summary

Summary Chart

- While the majority of survey respondents (i.e., > 50%) define competency requirements in some form, there is an opportunity to increase maturity of approach



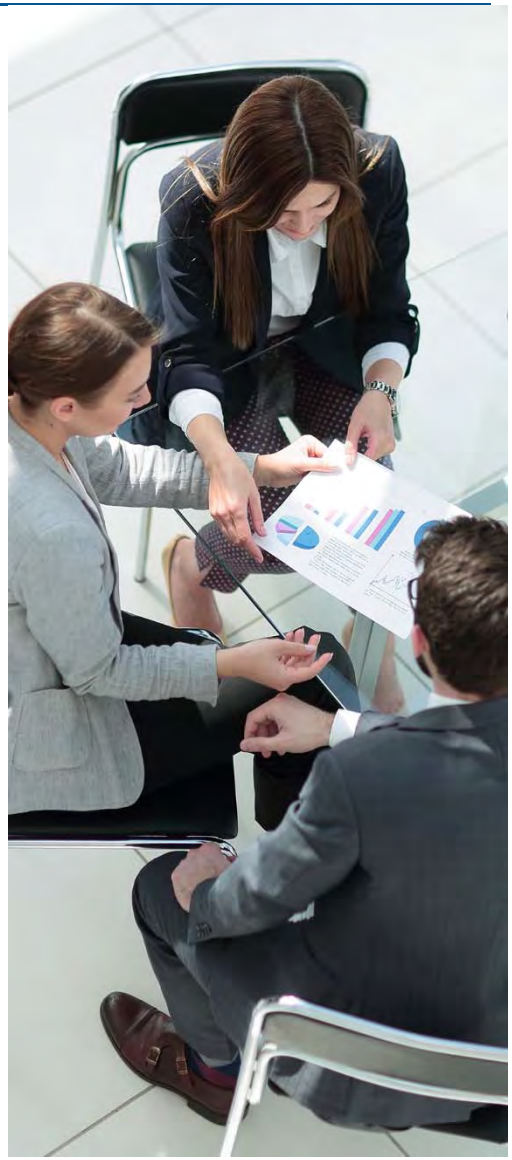
*N/A indicates areas where no survey questions were relevant

MATURITY OF GROUP BY LIFECYCLE OF A ROLE is measured by # of methods used in support of a particular component of competency (i.e., more methods used = greater maturity of competency program)

Executive Summary

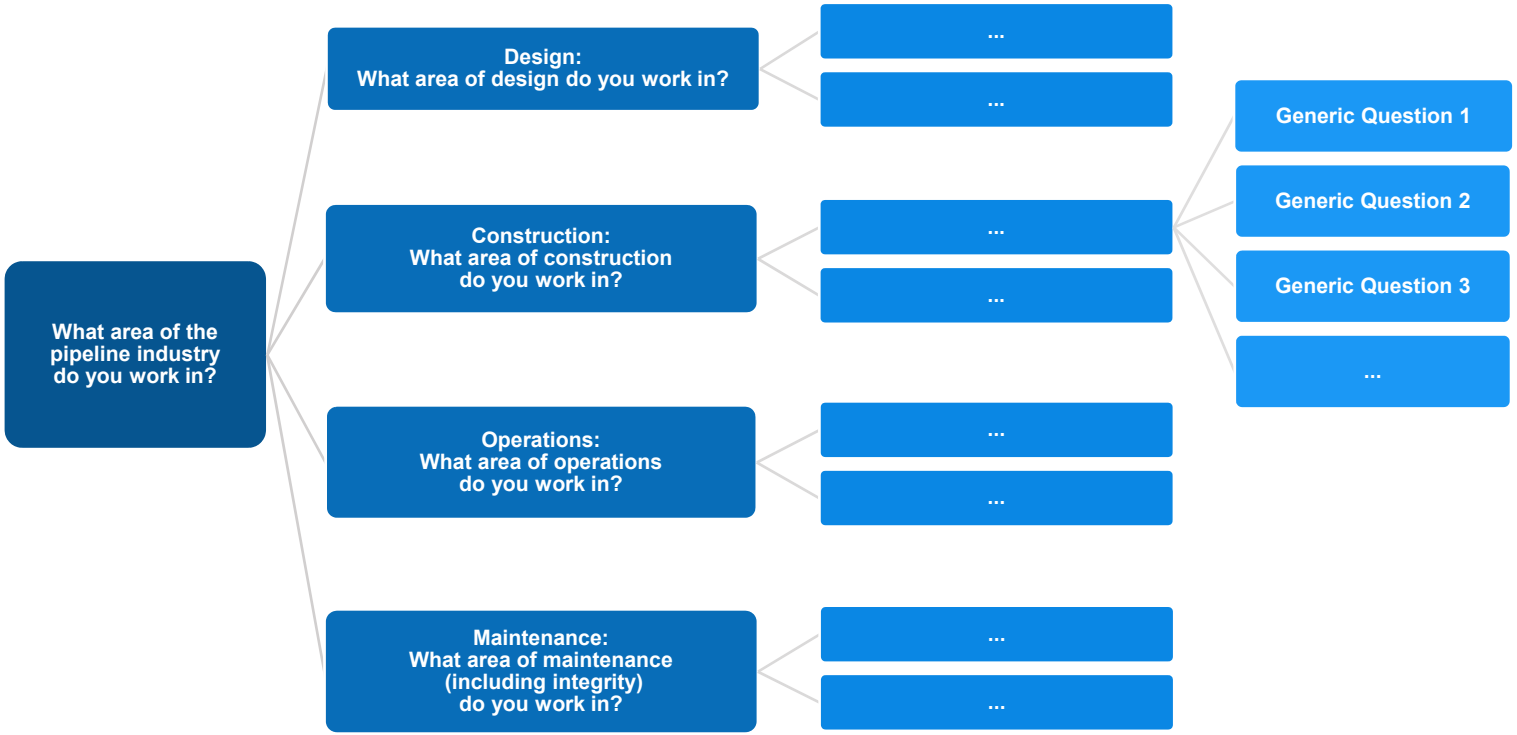
Other Observations

- Summary of responses to specific questions asked based on previous PRCI work team feedback:
- Majority of respondents consistently follow the defined competency requirements program
    - Note that ~5% of respondents chose not to answer this question
- Training on management systems is mandatory for half of survey respondents



Background

Survey Framework



Background

Development of Survey Questions

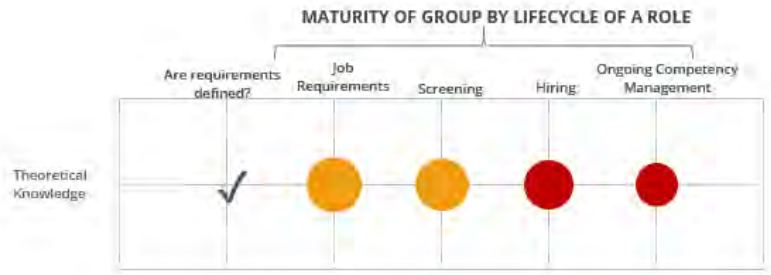
- Two concepts were used as the basis for developing the survey questions and structure as part of a consistent and systematic approach:
- Four components of competency
- Lifecycle of a role

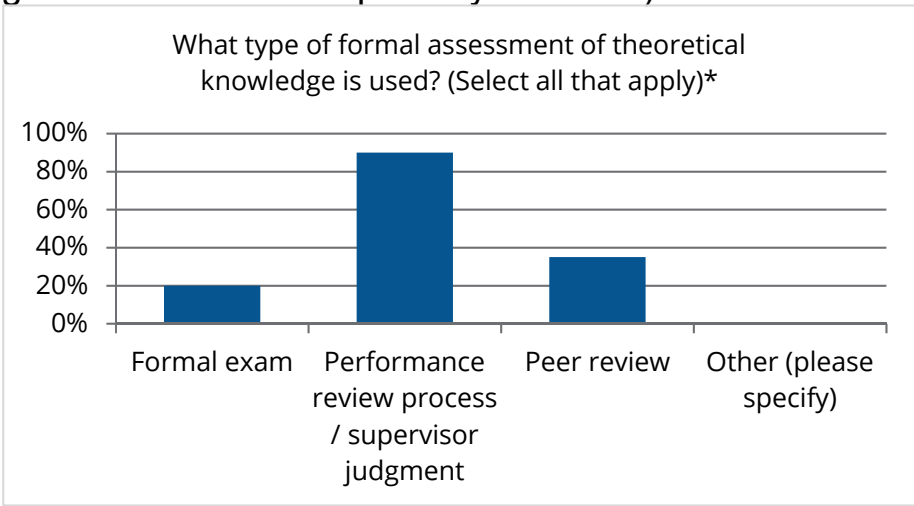
	Requirements Across Lifecycle of a Role			
Component of Competency	**Job Requirements**	**Screening**	**Hiring**	**Ongoing Competency Management**
Theoretical Knowledge	Generic Question 1	Generic Question 2	Generic Question 3	Etc.
Technical & Non-technical Skills	Etc.			
Experience				
Behavior				

Summary of Findings

Theoretical Knowledge

- In the early stages of the lifecycle of a role (i.e., job requirements and screening), theoretical knowledge is the most mature of the components of competency
- Most significant gap in maturity once employee has been hired
- Most notably, objective requirements are lacking for ongoing competency management
- Opportunity to standardize (e.g., define objective theoretical knowledge assessment methods as roles change using a standardized competency structure)

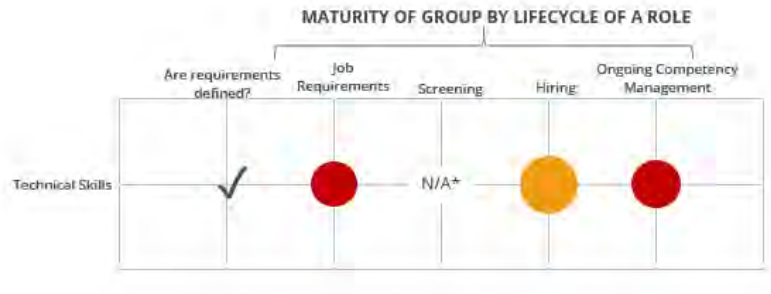


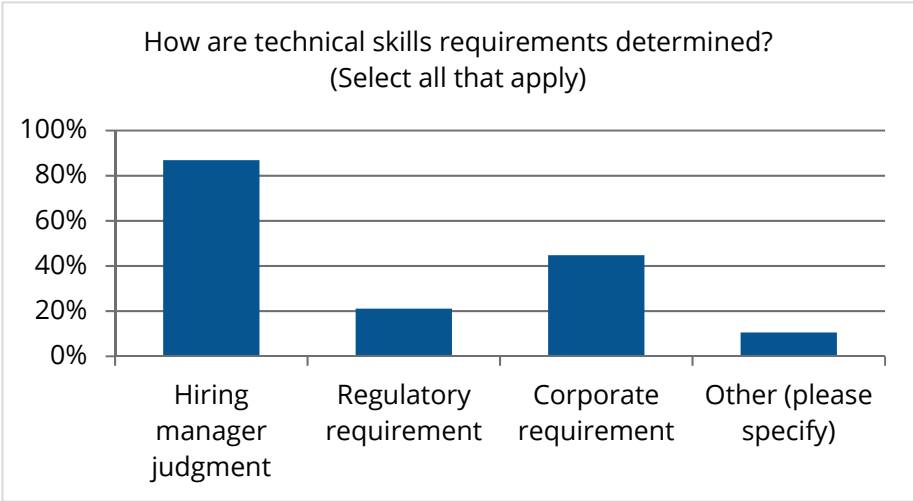


Summary of Findings

Technical Skills

- Competency requirements are slightly more mature for technical skills than for non-technical skills
- However, significant gaps exist in maturity throughout lifecycle of a role
- Most notably, where job requirements are defined, they tend to be subjective
- Opportunity to standardize (e.g., define objective job requirements and technical skills assessment methods using a standardized competency structure)

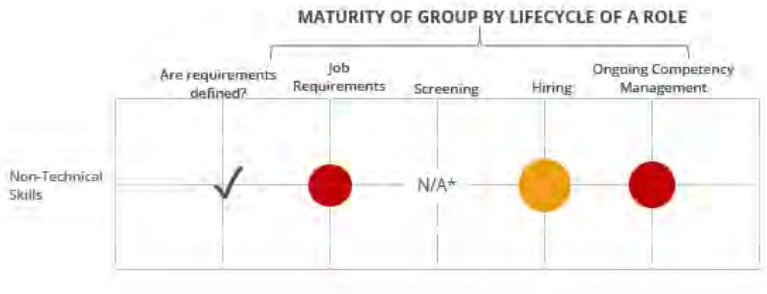


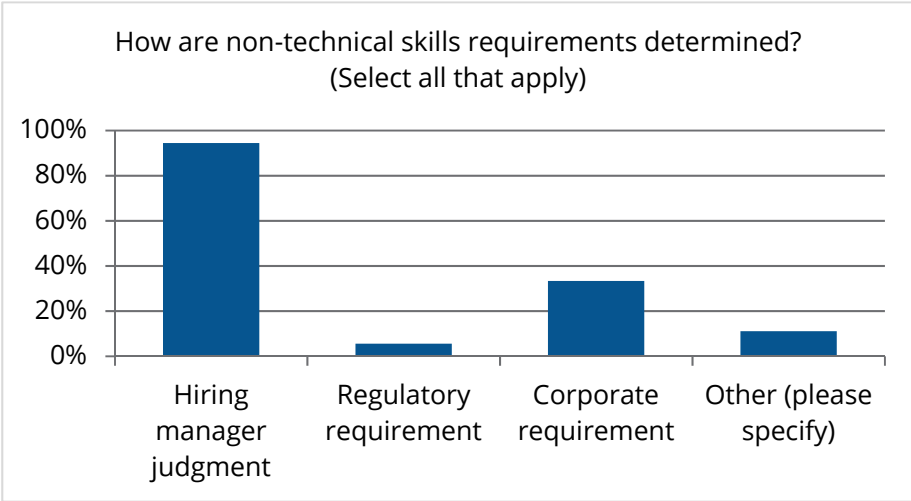


Summary of Findings

Non-technical Skills

- Non-technical skills is the least mature of the components of competency
- Similar to technical skills, significant gaps exist in maturity throughout lifecycle of a role
- Most notably, where job requirements are defined, they tend to be subjective
- Opportunity to standardize (e.g., define objective job requirements and non-technical skills assessment methods using a standardized competency structure)

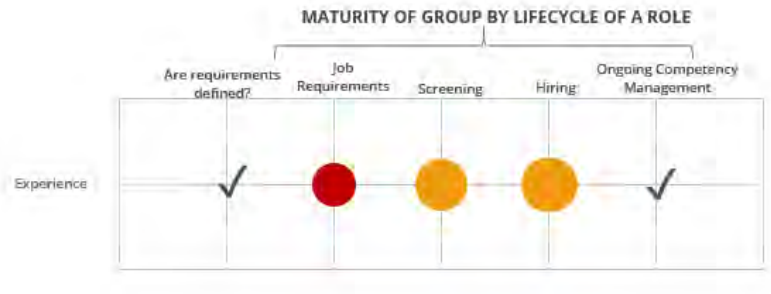


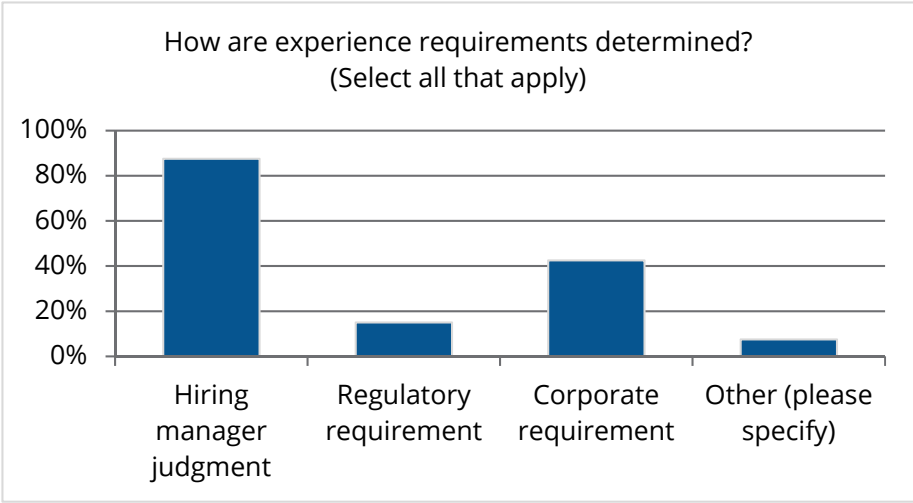


Summary of Findings

Experience

- In the intermediate stages of the lifecycle of a role, experience is the most consistently mature of the components of competency
- Most significant gap in maturity exists in job requirements
- Most notably, where job requirements are defined, they tend to be subjective
- Opportunity to standardize (e.g., define objective job requirements using a standardized competency structure)

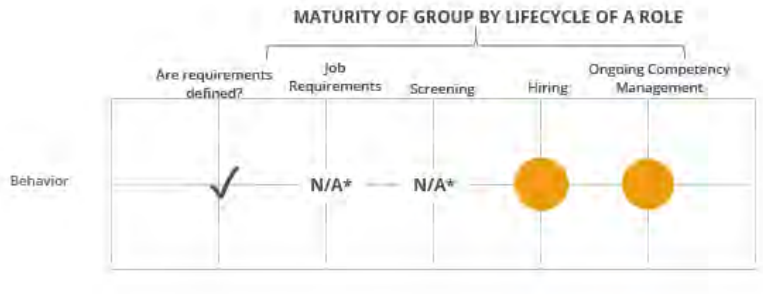


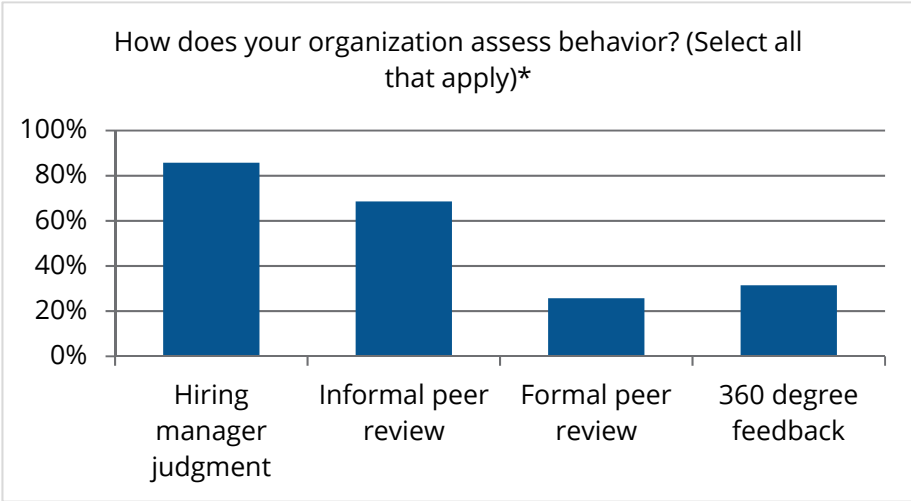


Summary of Findings

Behavior

- From the hiring process onwards, behavior is the most mature of the components of competency; however, gaps in maturity exist
- Most notably, objective requirements are lacking for ongoing competency management
- Opportunity to standardize (e.g., some respondents indicated use of “behavior tests” in the hiring process)





Next Steps

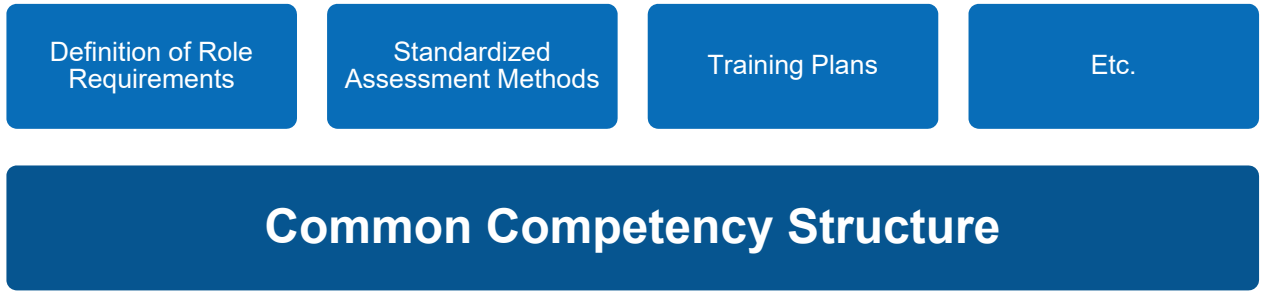
Summary of CEPA Effort

- Two parallel streams of work underway
- First stream of work involves development of a guidance document on competency management
- Second stream of work involves discussions with Australian Pipelines and Gas Association (APGA); goal is to determine if the existing APGA competency material can be leveraged for use in Canada
- Approach would allow significant time and cost reduction for member companies to adopt a formal competency-based approach that is already peer reviewed

Next Steps

Potential Extension of Work

- Gap identified in managing the ongoing competency of individuals indicates opportunity for a more systematic approach to competency management
- Formal industry centralized structure and approach (e.g., standard set of competencies across the pipeline lifecycle such as the effort currently underway through CEPA; adoption of common certifications such as NACE Level 1/2/3 Coating Inspector Program)
- Opportunity in other areas to mature approach to reduce subjectivity
- Development of individual tools and techniques to support competency management (e.g., standardized assessment methods)



Questions?

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Pipeline Research Council International, Inc.

PRCI Project Code (PR-680-183907)

Use of Aerial LiDAR Data Collection for Geohazard Assessment

Francois Rongere — PG&E
San Gunawardana — Enview
Aaron Rezendez — PG&E

PRCI 2019 Research Exchange Meeting
Houston, Texas
Date March 5, 2019

Objectives

- **LiDAR is extremely capable technology**
  - However, it is a complex topic and there are limited resources that are specific to pipelines on how to effectively deploy the technology
  - PG&E and Enview have learned lessons on how to operationalize LiDAR for gas transmission networks

- **Goal of this project are to:**
  - Share lessons on how to operationalize LiDAR for pipeline/ROW use cases
  - Discuss LiDAR considerations that are unique to pipeline geohazards
  - Provide lessons on how to balance data quality with cost-effectiveness

Work Performed

- **PG&E installed LiDAR sensor equipment on its patrol aircraft and collected high-res 2D and 3D data on its entire GT system**
  - 7,000 miles pipeline with a 2,000 ft wide swath
- **Enview used its geospatial AI platform to analyze the data for:**
  - Geohazards, class location, third-party activity & damage prevention
- **PG&E and Enview synthesized experiences to generate the final report which contains lessons learned**

Key Results

- **Operational lessons have shown that LiDAR can be used to support a variety of integrity and compliance activities:**
  - Geohazards
  - Depth of cover
  - Class location/HCA
  - ROW management and surveillance
  - Third-party damage monitoring
  - Pipeline markers

- **The key results of this work is a final report that contains a series of lessons-learned on operationalizing LiDAR**
  - A subset of these conclusions are presented in the following "Operationalizing" section

Sample Results – Imagery

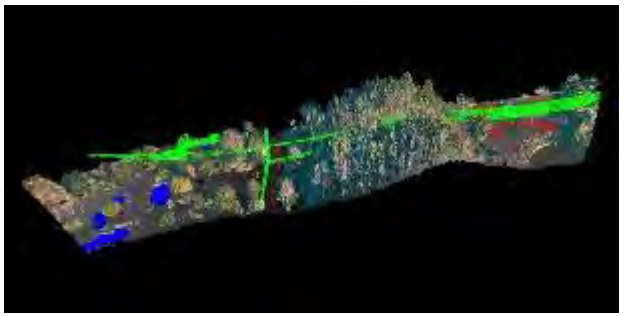
Map showing area of data collection by PG&E

Imagery from selected regions (clockwise from upper left: suburban, riverine, forested mountains, urban)

Sample Results – LiDAR Analytics

Raw LiDAR data for a mile of pipeline (35M points, 3 GB of data).

LiDAR data colorized with visual spectrum imagery.



The output of Enview's classification process to find ground, buildings, vegetation, power lines, and vehicles.

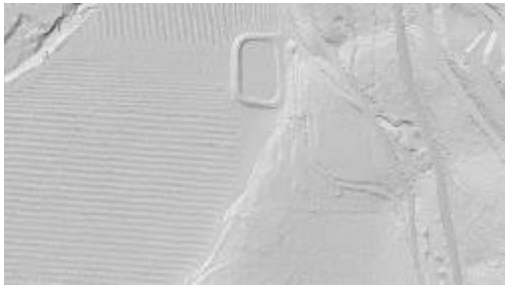
Sample Results - Topo Change

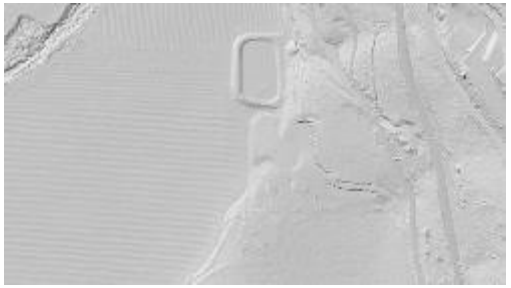
Topographic change measurement and detection (red is removed earth, blue is added earth)

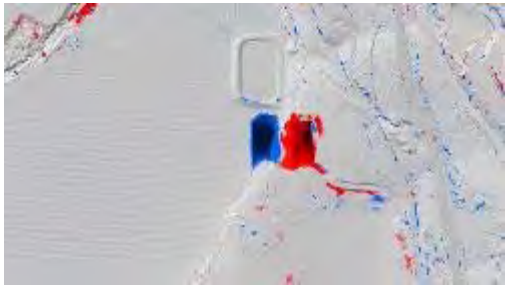
Before

After

Topo Change







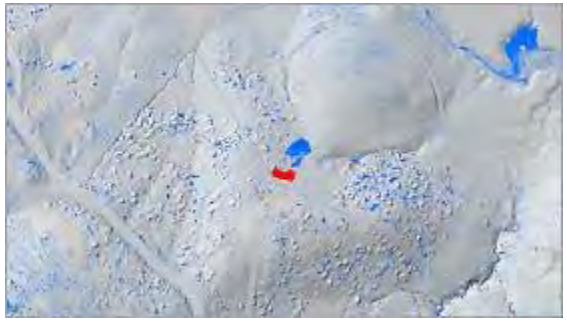
Sample Results - Landslides

Detection of a landslide near a pipe centerline
(red is the slide, and blue is the toe)

Before

After

Topo Change



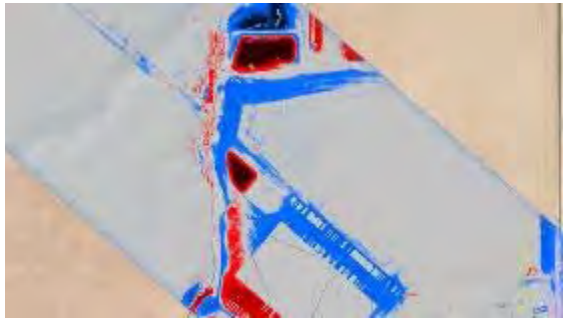
Sample Results - Erosion

Topo change detection shows loss of soil near the pipe centerline. This may be driven by changes in terrain and ground permeability.

Before

After

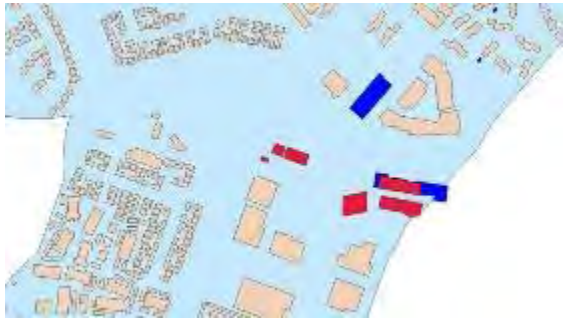
Topo Change



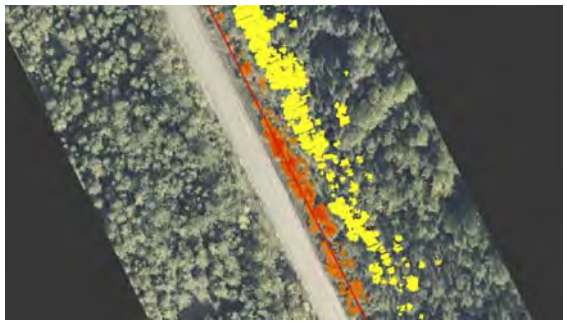
Sample Results - Other

PG&E and Enview are using the LiDAR datasets to support multiple additional pipeline/ROW use cases

HCA/Class Location



Veg Management



Pipeline Markers

Operationalization

- **Final Report**
  - Covers broad range of lessons learned
  - A selected subset of these learnings are included here

- **Selected Learnings**
  1. LiDAR Point Density
  2. LiDAR Spatial Distribution
  3. Orthoimagery
  4. Ground Control & Georegistration Accuracy
  5. Flight Planning
  6. Data Analytics
  7. Data Visualization
  8. Data Organization

Operationalization

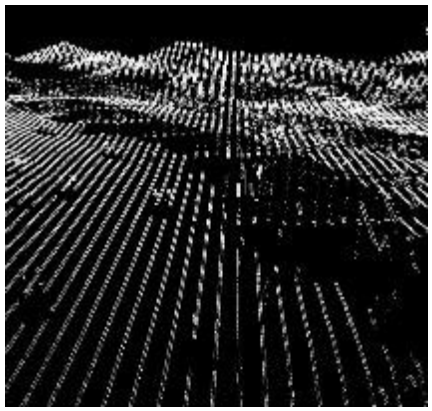
- **Data requirements - LiDAR**
  - Minimum Point Density

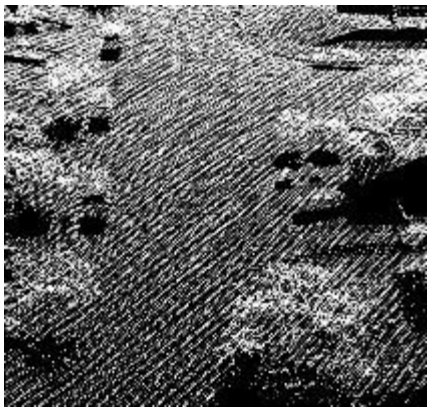
Point Density	Application Notes
<5	Too coarse
5-10	Wide area DEMs in non-vegetated areas
10-15	Suggested minimum for DEMs in non-vegetated areas
16	Recommended resolution for mixed-terrain and vegetation pipeline surveys. This is a cost-effective balance of high quality and efficiency of collection.
16-20	Suggested point density in areas of moderate vegetation density.
>20	Suggested for extremely thick canopy areas with high geohazard potential

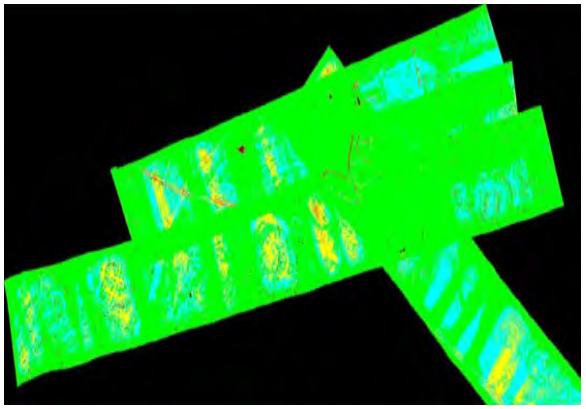
  - Considerations
    - *Average point density is not a useful measure (high density areas can offset unusably low density areas)*
    - *Instead, ask vendors to provide (1) a point density heatmap and (2) a report on how much area fell below the minimum point density spec*

Operationalization

- **Data requirements - LiDAR**
  - Spatial Distribution
    - It is possible to meet the data resolution spec while generating poor quality data
    - Operators should be mindful of even point spacing (see below left)







  - Considerations
    - *Operators should ask their vendors for data assessment products to aid in review and acceptance of data (see above right)*

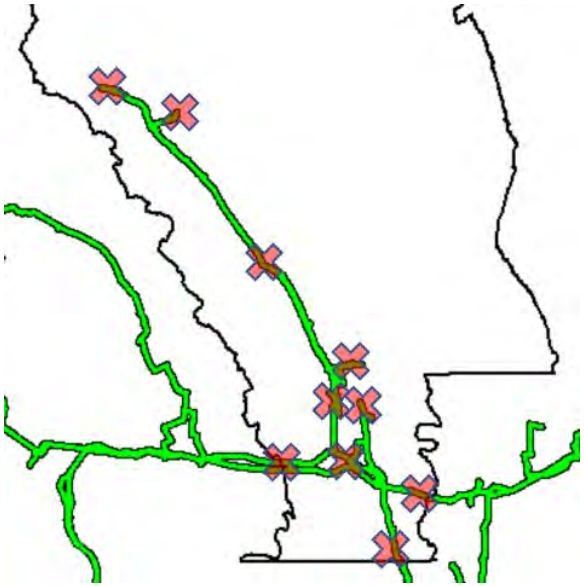
Operationalization

- **Data requirements - Imagery**
  - Orthoimagery
    - Most LiDAR flights are done at an altitude that supports 6” GSD imagery
    - Moving from 12” to 6” imagery has enabled teams to discern effects such as erosion without making field trips

  - Considerations
    - *Orthoimagery is very useful. However, care must be taken in specifying the level of QC required. Left unspecified, the default is a survey quality product that corrects non-functional (cosmetic) errors at greater expense/cost*

Operationalization

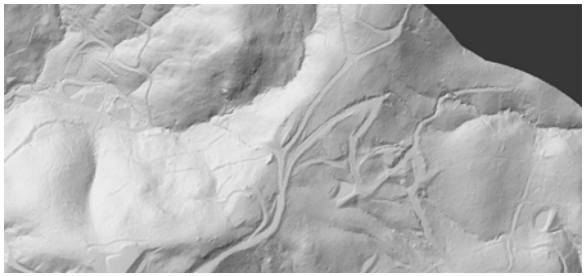
- **Ground Control & Georegistration Accuracy**
  - Employing disciplined ground control can give accuracies of ~3 cm



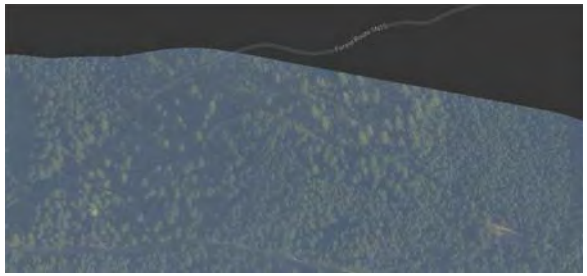
  - Considerations
    - *In a wide-area survey it is not unusual for the center of the AOI to have higher georegistration accuracy than the outer perimeter. This is not helpful for pipelines; need to specify a different control scheme (above)*

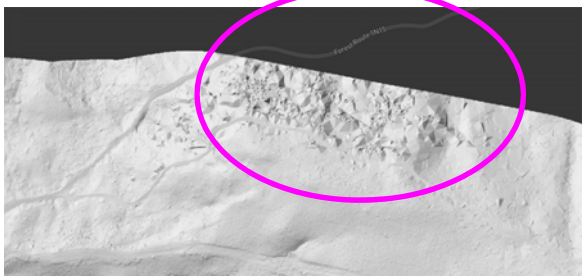
Operationalization

- **Flight Planning**
  - Upgrading to a larger sensor helps with efficiency (can cover a wide swath in a single pass)
  - However, a single pass flight plan has worse line-of-sight to ground than a multiple pass flight plan
  - May need to specify multiple lines in densely vegetated, hilly areas



Lower capability sensor: 2 passes. Good data.





Higher capability sensor: 1 pass. Note the scaling near thick vegetation

Operationalization

- **Data Analytics**
  - LiDAR analytics specifications originated from the electric transmission industry
  - The electric T&D spec is often over-specified for pipelines ops
  - Savings can be attained by limiting the point cloud labeling to those categories that are:
    - *Ground*
    - *Buildings*
    - *Vegetation*
    - *Other*
  - New computing technologies (e.g., 3D computer vision, deep learning, and cloud computing) can enable significant automation
    - *DEMs and hillshades for ~7,000 miles of pipe were generated in under 48 hours*

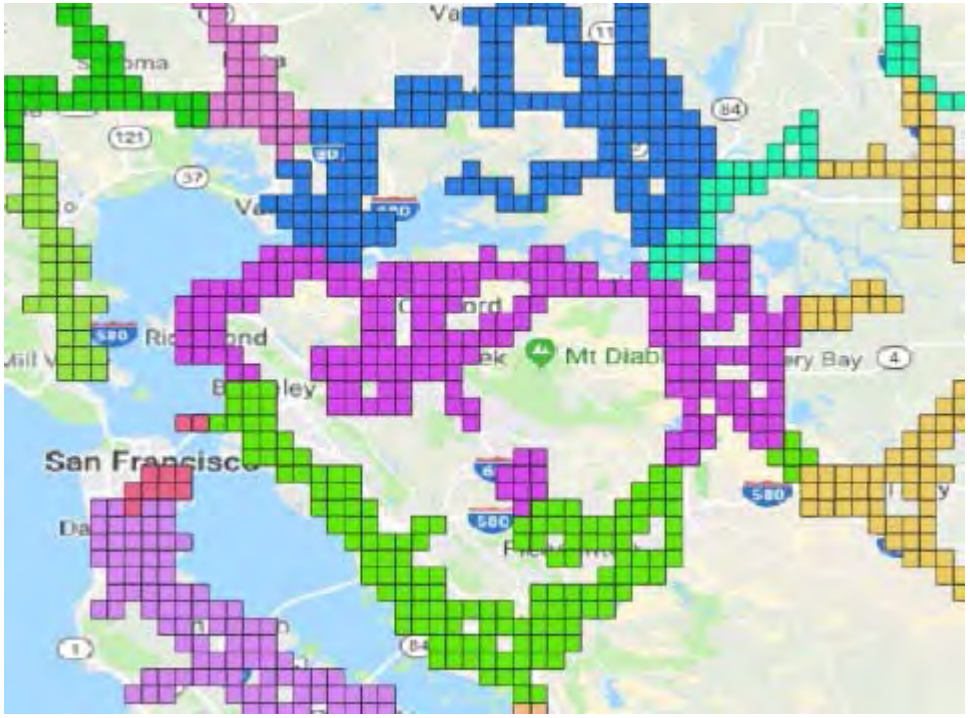
Operationalization

- **Data Visualization**
  - Data volume is large; must have good ways to see/access results
  - Must also support traditional GIS workflows (minimize change management)

Web dashboard used by Enview to inspect large LiDAR datasets.

Operationalization

- **Data Organization**
  - Data should be tiled in a consistent scheme that is searchable based on location (e.g., latitude and longitude)
  - Each deliverable should be delivered in the same consistent tiling scheme so that different data products can be easily overlaid

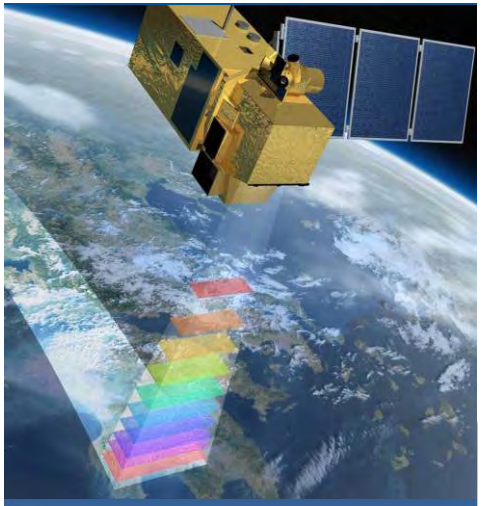


Tiling scheme use by PG&E and Enview. Different colors represent different counties.

Conclusion

- Discussed lessons learned on how to operationalize LiDAR
- Provided considerations that are unique to pipeline operators vs general-purpose surveys
- Shared learnings on how to balance data quality with cost-effectiveness

Thank you!

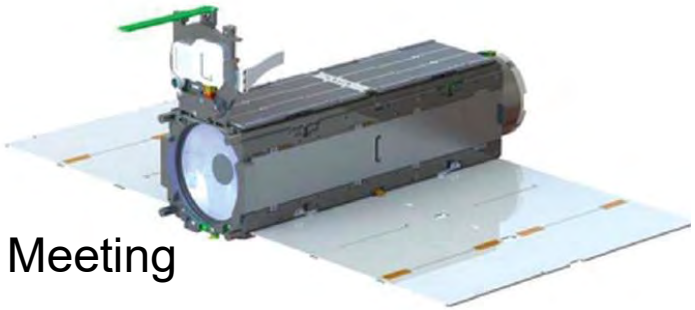


Pipeline Research Council International, Inc.

PRCI Project ROW 6-2

Evaluation of Current ROW Threat Monitoring, Application & Analysis Technology

Paul Adlakha
C-CORE



PRCI 2019 Research Exchange Meeting
Houston, Texas
March 5, 2019

Overview

- **Problem Statement**
  - To determine the capabilities of satellite technologies to strengthen and simplify the monitoring of threat & risks encountered by pipeline operators

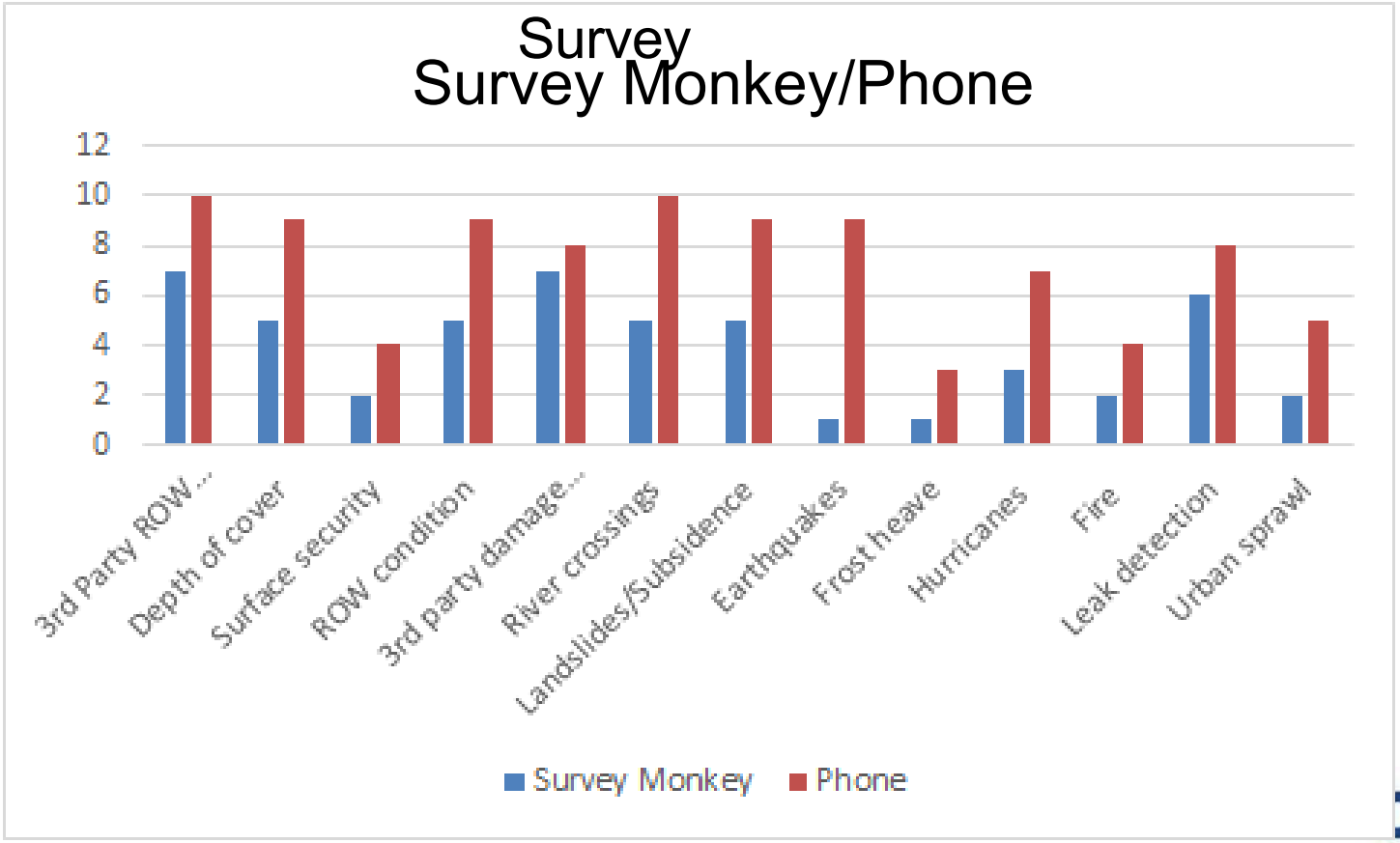
- **Objectives**
  - Clarity to satellite technology viability for threat reduction
  - Determine cost/benefit to address information requirements
  - Understand how operators would use data
  - Provide guidelines on monitoring evolution

Project Execution

- **Project tasks**
  - WP1000 Operator Inputs
  - WP2000 Monitoring Requirements
  - WP3000 Satellite Missions
  - WP4000 Satellite Missions vs Threats
  - WP5000 Gap Analysis
  - WP6000 Supplier Survey

WP 1000 Operator Inputs

- **22 responses: interviews and online**



WP 2000 Monitoring Requirements

- 3rd Party damage assessment
- 3rd party activity, RoW condition
- Landslides-creep-subsidence
- Leak detection
- River crossings
- Depth of cover

WP 2000 Monitoring Requirements

- **3rd Party damage assessment**
  - Event driven forensics
- **3rd party activity, RoW condition**
  - Digging, plowed areas, urban sprawl, feedlots, vegetation growth..
- **Landslides-creep-subsidence**
  - Ground movement, map of new slides
- **Leak detection**
  - Gas emissions, pools on surface
- **River crossings**
  - River bed scours, river bank erosion, water flows, debris
- **Depth of cover**
  - Loss of surface cover, exposed pipe

WP 2000 Monitoring Requirements

- **3rd Party damage assessment**
  - Event driven forensics
- **3rd party activity, RoW condition**
  - Digging, plowed areas, urban sprawl, feedlots,...
- **Landslides-creep-subsidence**
  - Ground movement, map of new slides

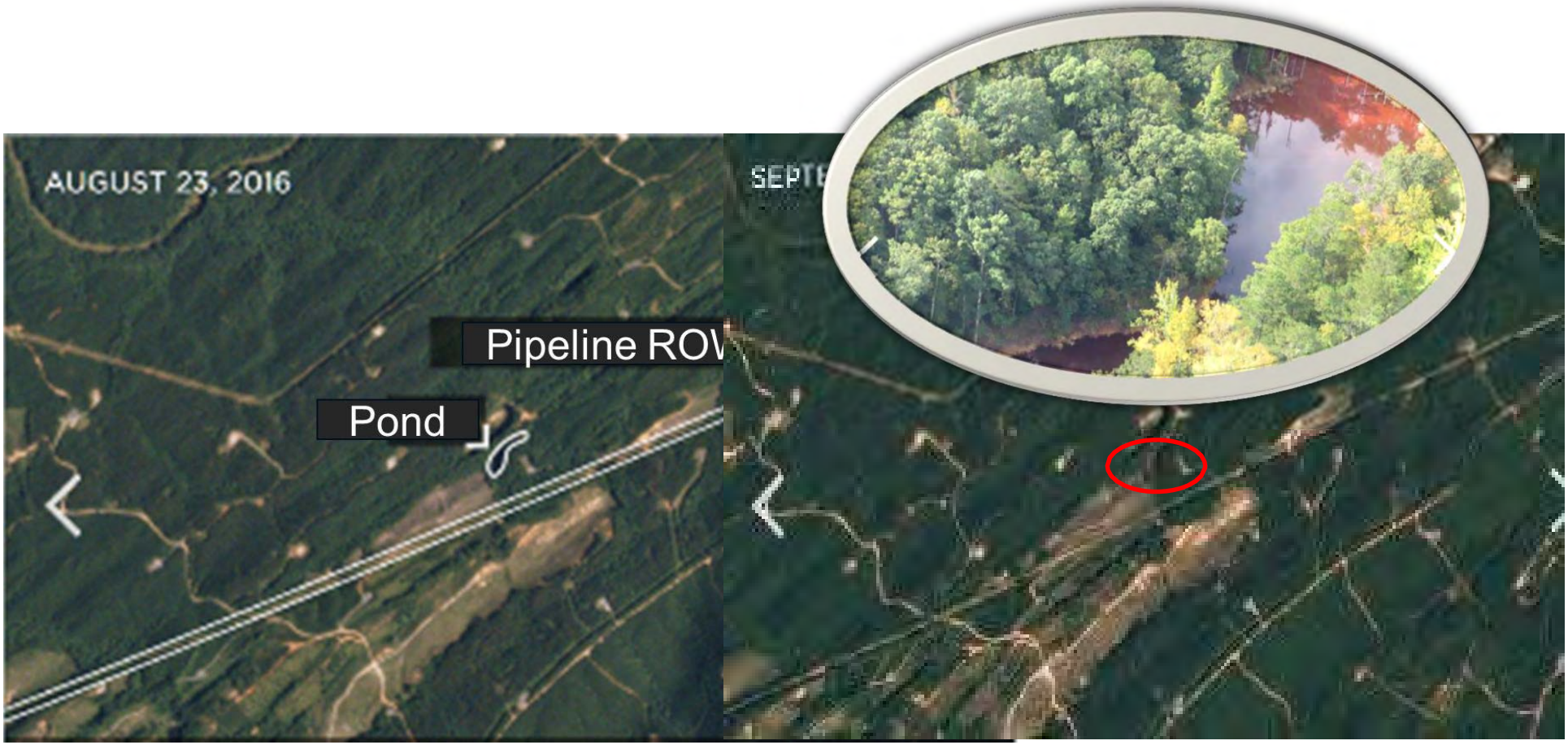
Directly detect

- Leak detection
  - Gas emissions, pools on surface
- River crossings
  - River bed scours, river bank erosion, water flows
- Depth of cover
  - Loss of surface cover, exposed pipe

Infer risk

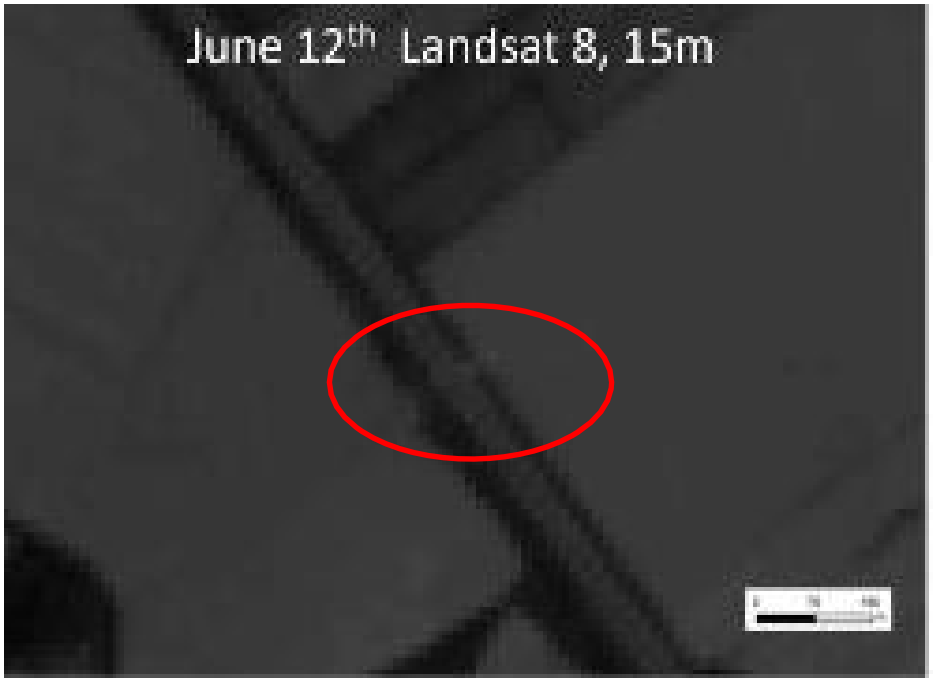
WP 2000 Monitoring Requirements

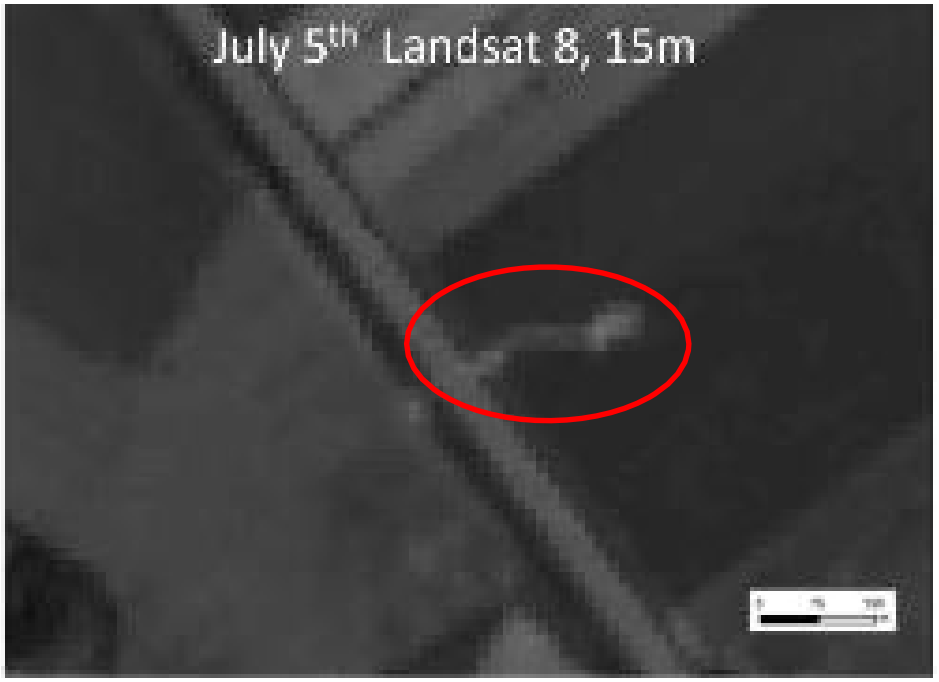
- **3rd Party damage assessment**
  - Event driven forensics



WP 2000 Monitoring Requirements

- **3rd party activity, RoW condition**
  - Digging, plowed areas, urban sprawl, feedlots, vegetation growth…
- Capability
  - Freely available data – medium resolution





WP 2000 Monitoring Requirements

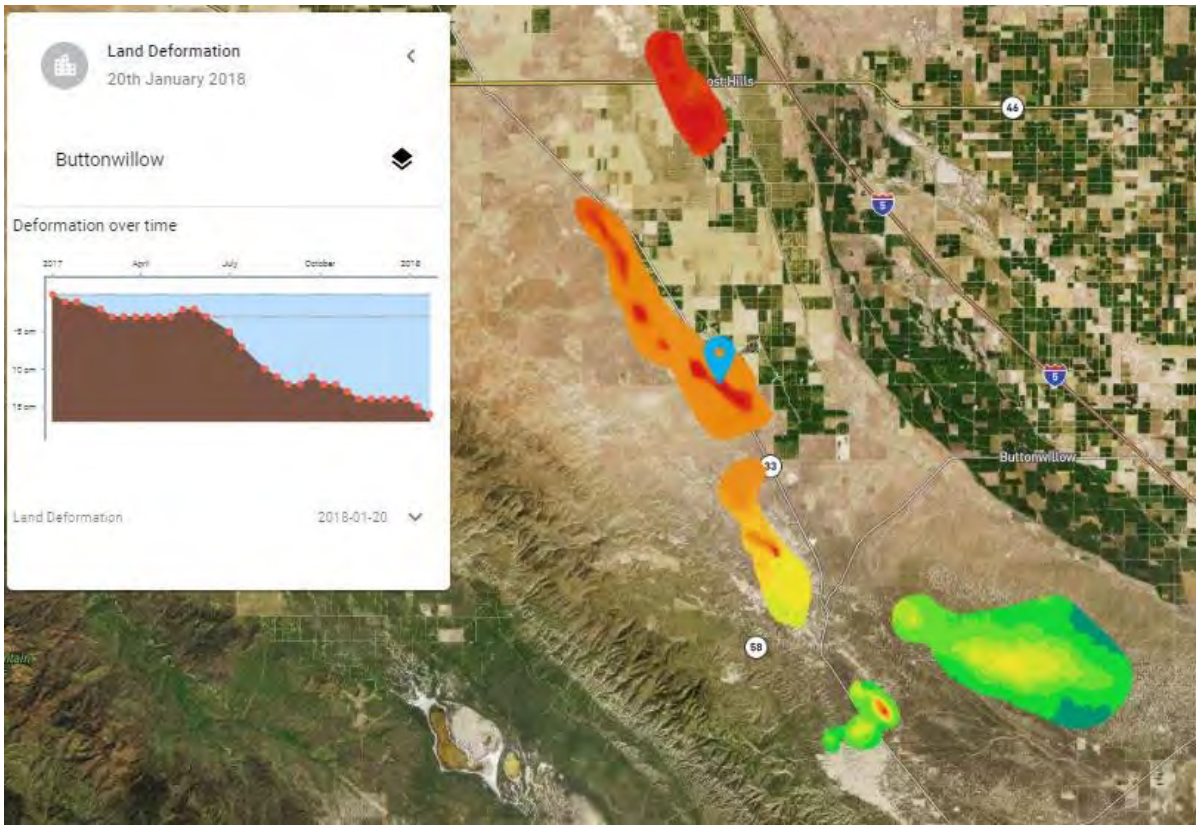
- **3rd party activity, RoW condition**
  - Digging, plowed areas, urban sprawl, feedlots, vegetation growth..
- Capability
  - Commercial data – high resolution

WP 2000 Monitoring Requirements

- **3rd party activity, RoW condition**
  - Digging, plowed areas, urban sprawl, feedlots, vegetation growth..
- Capability
  - Commercial data – very high resolution

WP 2000 Monitoring Requirements

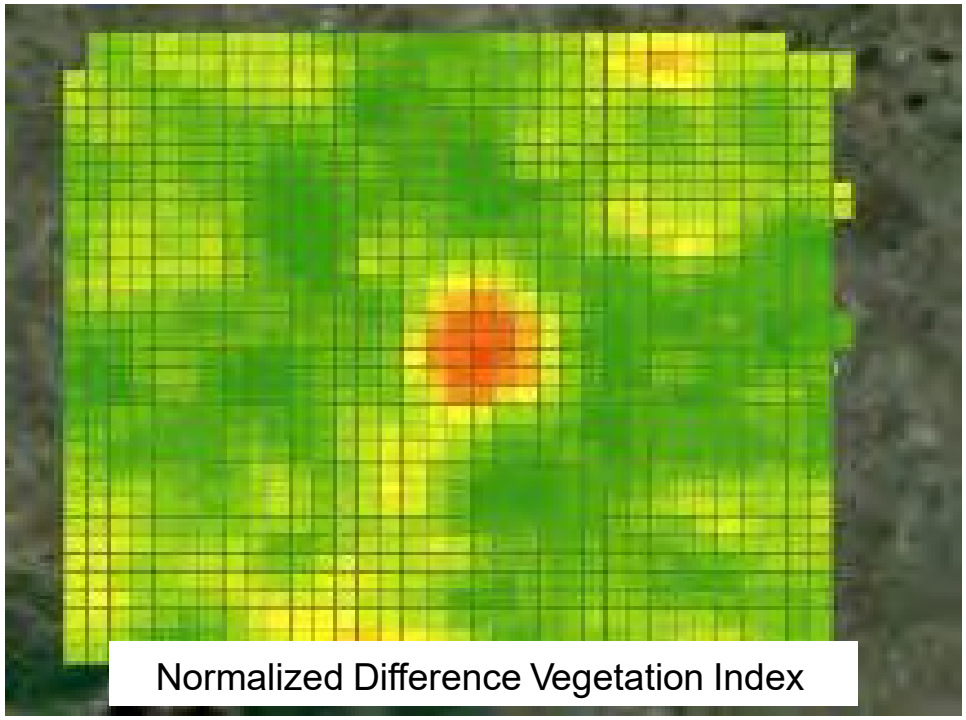
- **Landslides-creep-subsidence**
  - Ground movement



WP 2000 Monitoring Requirements

- **Leak detection**
  - Emissions, pools….

Infer leaks from Vegetation Stress



Normalized Difference Vegetation Index

WP 2000 Monitoring Requirements

- 3rd Party damage assessment
- 3rd party activity, RoW condition
- Landslides-creep-subsidence
- Leak detection
- River crossings
- Depth of cover

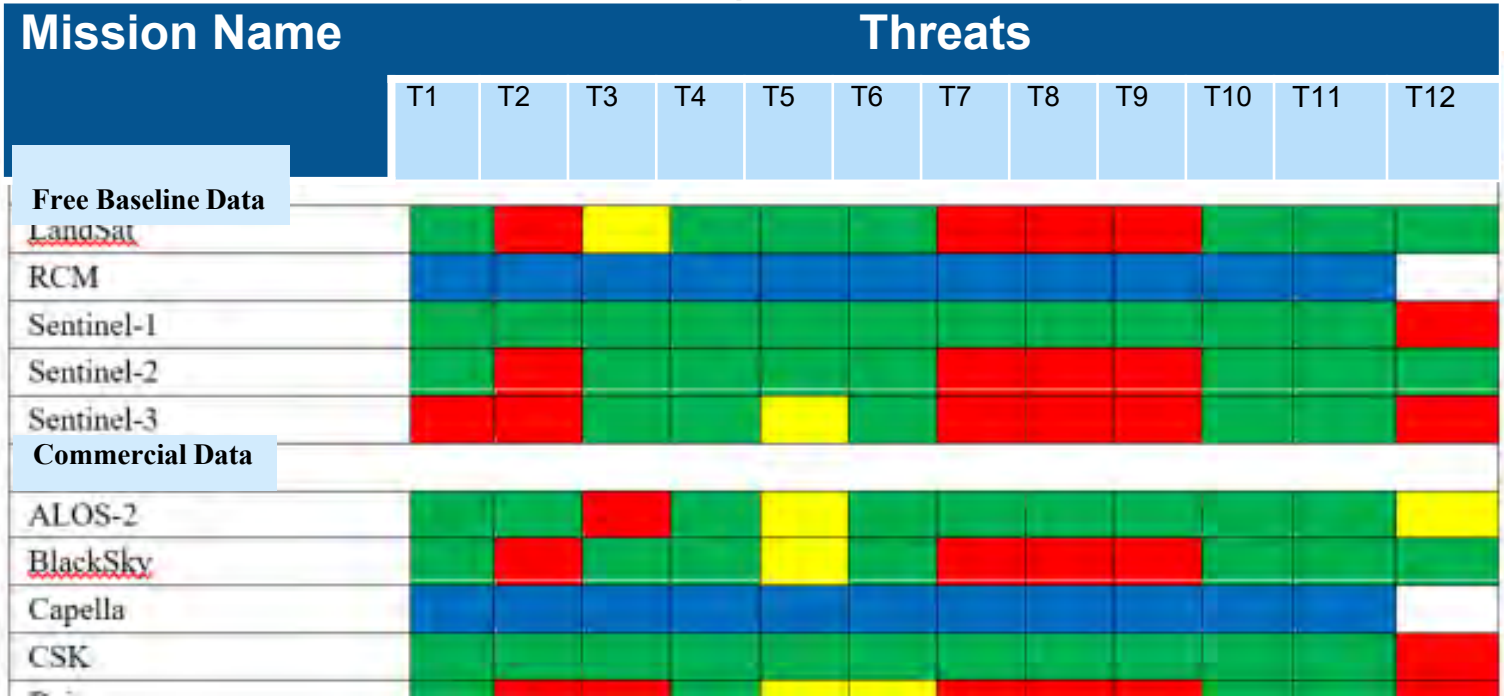
WP 2000 Monitoring Requirements

	High	Med	Low

SERVICE	PIPELINE		PIPELINE +	PIPELINE ++	
	Baseline Optical	Baseline Radar	Level 1	Level 2 Optical	Level 2 Radar
Satellites	Sentinel-2 Landsat 8	Sentinel-1	PlanetScope	DigitalGlobe Pleiades SkySat	RSAT2 TSX,CSK
Annual Price per 1000km [1]	$50k+	$25k+	$150k+	N/A-$250k+	$250k+
Threat/Product					
Damage assessment					
Damage assessment					
ROW Activity and Condition					
Contacts					
Ground preparation					
Digging/plowed areas					
ROW crossing					
Urban encroachment					
Tree type and growth					
Power line parallels					
Wetlands					

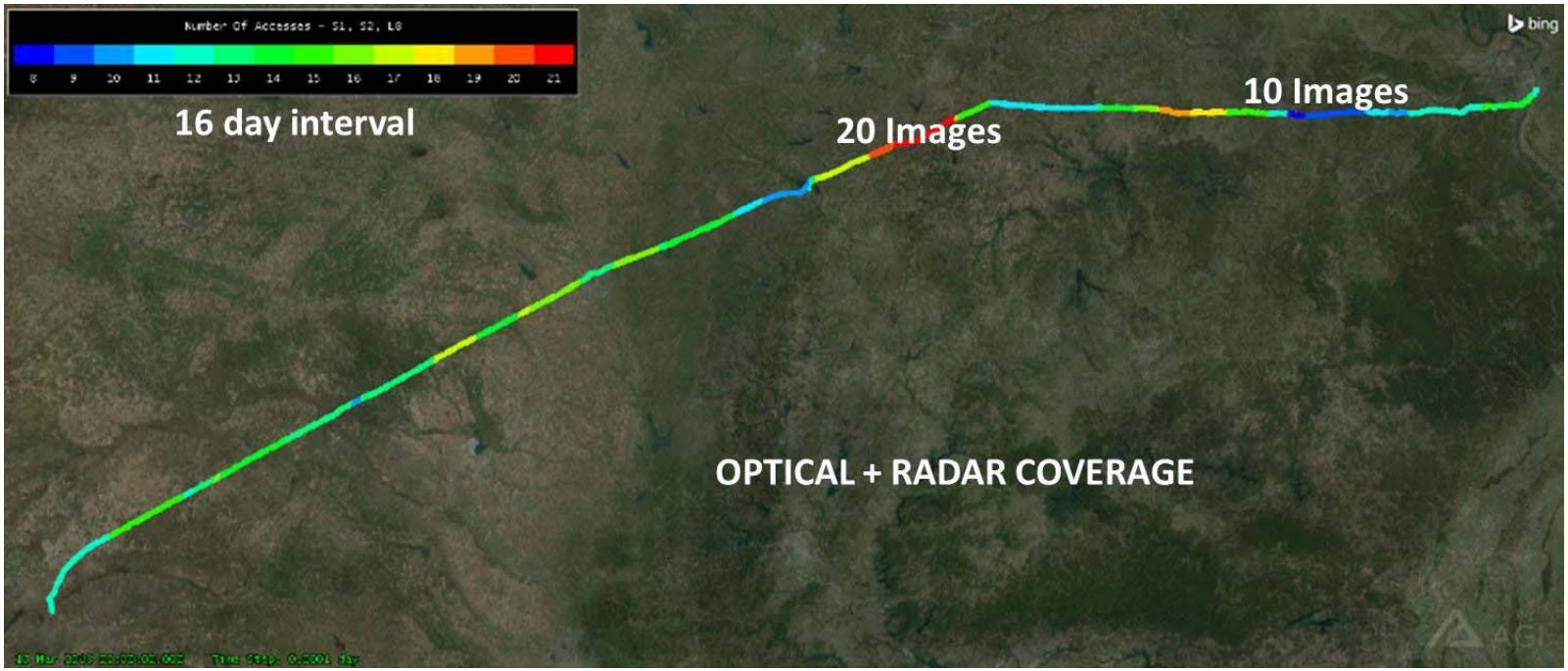
Project Execution

- **Project tasks**
  - WP3000 Satellite Missions
    - *Reviewed 29 missions*
  - WP4000 Satellite Missions vs Threats
    - *Overview of mission capabilities to address threats*



Project Execution

- **Project tasks**
  - WP5000 Gap Analysis



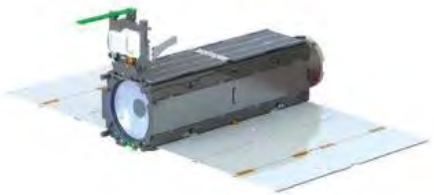
  - WP6000 Supplier Survey

Results

- **Industry advances**
  - Data policy
  - Innovative missions

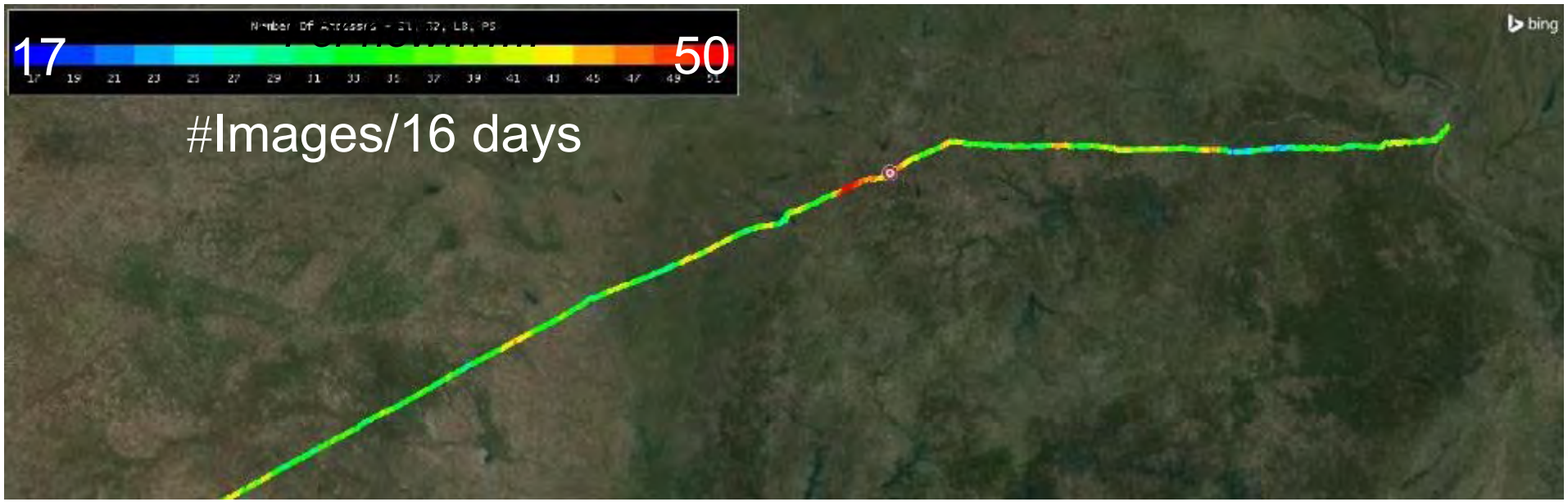
  - Entire ROW at weekly revisit or better
    - *ESA: free and open Sentinel data*

  - Entire ROW at daily revisit or better
    - *PlanetScope constellation in place*



Results

- **The potential to address threats**
  - Direct vs indirect threats. Scale of threats (size and revisit)
    - *Direct:* *Surface clearing, ground movement…*
    - *Indirect:* *Leaks, changes in depth of cover…….*
- **Role of satellite monitoring**
  - Monitoring vs Surveillance



Results

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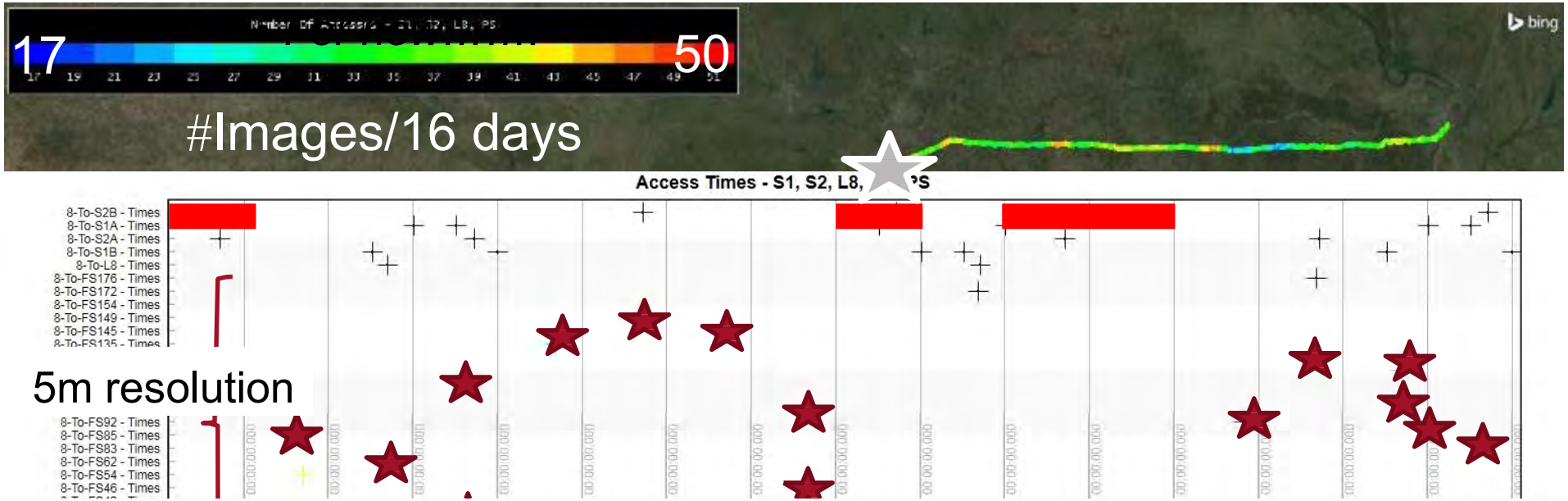
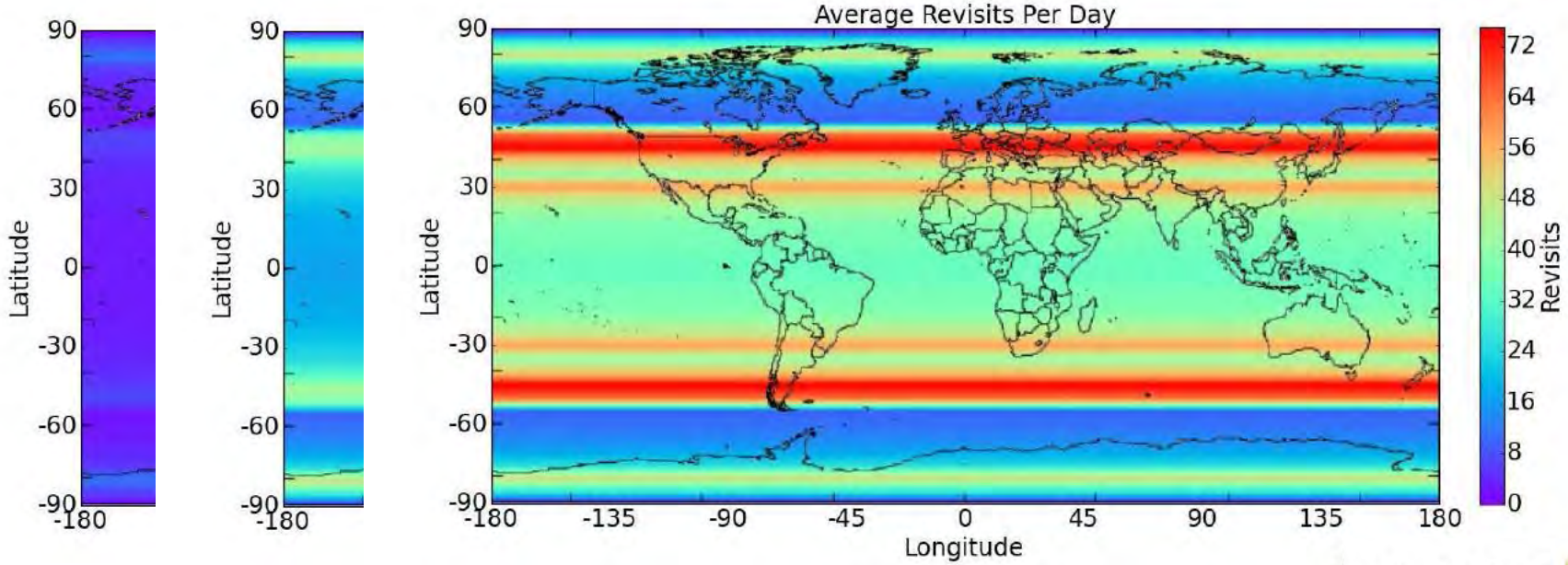


Results

- **Role of satellite monitoring**
  - Monitoring vs Surveillance
    - *In the future…….*



BLACK SKY
YOUR WORLD NOW

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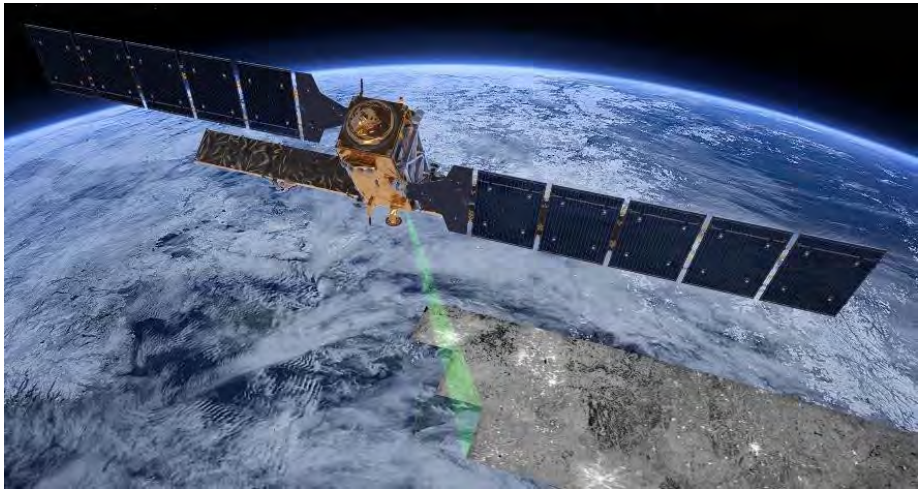
Results

- **Limitations**
  - Optical: clouds, night time, smoke, tree canopy

Results

- **Limitations**
  - Radar: North South slopes and movements



Recommendations

- **Monitoring vs surveillance role**
- **Focus on direct threats for main cost/benefit**
- **Use satellites to cue aerial (or field) patrols**
- **Analyze archive prior to monitoring program start**
  - Landsat 8 Feb 2013
  - Sentinel 2A June 2015
  - Sentinel 2B March 2017
  - PlanetScope Feb 2017 (constellation completed)

Recommendations

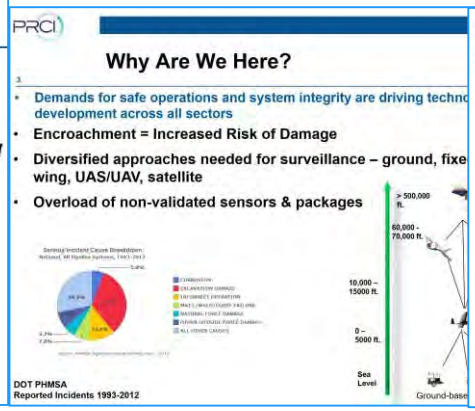
- Analyze archive for incident investigations
- Avoid reliance on measurements for North South movements
- Use very high resolution data for localized areas

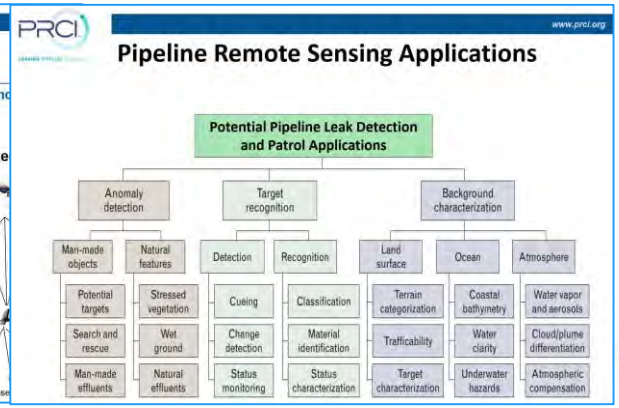
Recommendations

- **Next steps**
  - Implement baseline program on entire ROW
  - Integrate analysis into operations
  - Implement a satellite industry scan program

planet. urthecast Capella Space ICEYE SATELLOGIC BLACKSKY YOUR WORLD NOW

  - Provide outreach briefings



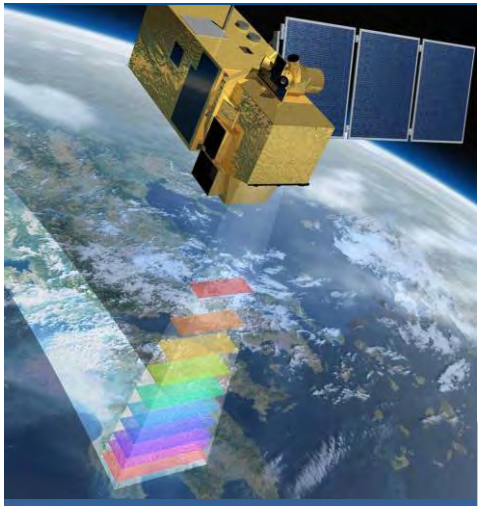


c-core

Recommendations

- **Next steps**
  - Develop threat control site inventory
    - *Long term site activity with field feedback*
  - Develop operator control site collaboration
    - *Scheduled operator maintenance activities*
      - Varying sites with similar activities and field feedback
    - *Develops calibrated test data set for analytics*
  - Initiate study on north-south slopes or north-south movements

- **https://www.youtube.com/watch?v=IKNAY5ELUZY**

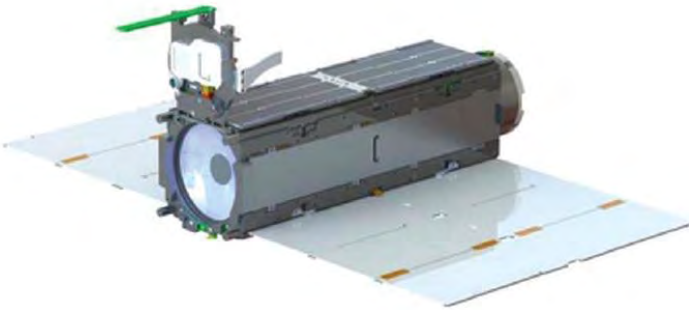


Pipeline Research Council International, Inc.

Evaluation of Current ROW Threat Monitoring, Application & Analysis Technology

THANK YOU

Paul Adlakha
C-CORE
Paul.Adlakha@c-core.ca



Pipeline Research Council International, Inc.

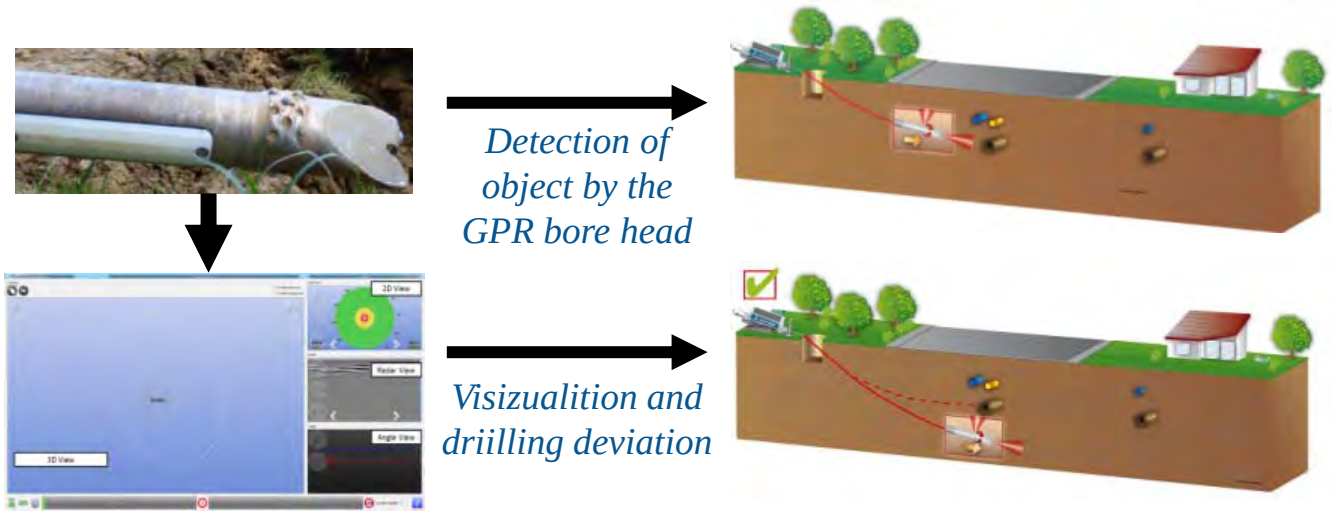
Obstacle Detecting Technology for Horizontal Drilling

Presenter Name
Carine Lacroix

PRCI 2019 Research Exchange Meeting
Houston, Texas
Date March 5 - 6, 2019

Introduction : What is Orfeus ?

ORFEUS : Operational Radar For Every drill string Under the Street



Introduction : Orfeus Project

- **Movie**

An International Project

	Partner	Country	Role
	Osys Technology limited	UK	Coordinator / Electronics
	Wellington Associates	UK	Innovation advisory
	IDS	Italy	GPR design and manufacturing
	Tracto Technik (TT)	Germany	Manufacturer of horizontal drilling machine
	RICE	France	Referrer / End User
	Exergia	Greece	Communication
	Vilkograd	Slovenia	Civil engineering company
	Euram Ltd	UK	Budget Management
	Dublin city	Ireland	Referrer / End User
	J&P Geo	France	Consultant
	Florence Engineering	Italy	Tilt sensor design
	Gas Technology Institute	US	Coordinator / Demonstration US
	OTD	US	Funder for US site demo
	PG&E Company	US	Referrer / End User

Orfeus System

- **Orfeus system is made with:**
  - Bore head
  - Radar antenna
  - Electronics housing
  - Angular position sensors and signal transmission
- **And:**
  - Software for signal and GPR treatment

Orfeus Radar Software

3D view

Angular speed

2D,view

Radar view

Angular position

Test Trials

- **Test sites**
  - Lennestadt 27/04/15
  - Stuttgart 06/05/15
  - Saint-Denis (Paris) 16/06/15
  - Livermore 20/05/17

- **Different drilling conditions:**
  - Rotation velocity: 30 rpm and 60 rpm
  - Movement velocity: from 1 cm/s to 5 cm/s

- **Objective**
  - Analysis of some case of interest in terms of target visibility. Both real-time and post-processed data are shown were studied

Focus on La Courneuve Test Site

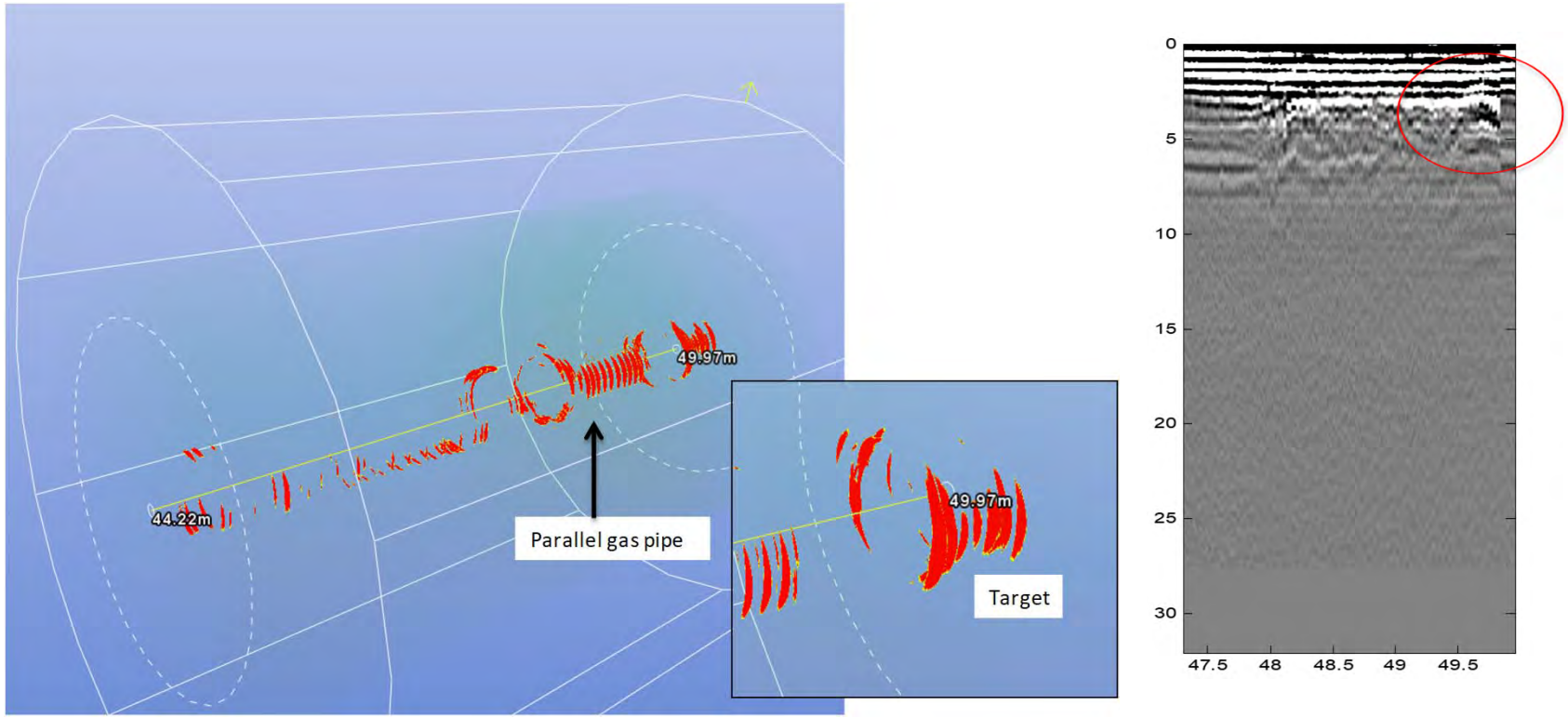
❑ Overview of test sites:

- Location : Place Georges Braque, La Courneuve, 93120
- Pipe laid : Water pipe PE 125 mm OD
- Drilling length : Average of 75 m
- Depth: Between 1.20 and 1.60 m
- Difficulties: Lot of buried networks

Results and Outcome

Detection by ORFEUS of object on cartography ...or not

Radar data from la Courneuve, test site, section d 44m to 50m of the drilling :



PGE Demonstration – Livermore, CA

- **Objective:** To demonstrate the capabilities of the pre-commercial ORFEUS obstacle detection system for HDD.
  - Identify any shortcomings to setup potential future research projects to assist in bringing the product to market

- Demonstration held at PGE training facility in Livermore, CA on 4/25/17

PGE Test Site (obstacles buried)

Orfeus - Survey_2016.11.01_012
3D view
Enable data view
Enable targets view
35.69m
35.43m
Disk View
Radar
Angle
94.1 /s

Conclusions and Perspectives

- **After 6 test sites ,validation of :**
  - Detection capacity and reliability of GPR in different kind of soil
  - Communication part
  - Performances of modified drill rod in bentonite
  - Robustness (chocks and vibrations)
  - Feedback of operators

- **ORFEUS system needs identified :**
  - Improvement of antenna position, to better detect obstacles in front of the antenna
  - Detection of obstacles when not rotating
  - Raise up detection length (≈50cm)
  - Optimization of warning system

Industrialization of the Orfeus System

- **Funding from US, European & Brazilian DSO and PHMSA in order to reach industrialization within 2 years**
- **This project seeks to improve the ORFEUS obstacle detection technology by:**
  - Making improvements to the bore head radar
  - Software enhancements to improve the user interface
  - Improvements in the communications to the drill head enabling the lengthening of the total drill length
  - Performing system validations and market launch preparations
  - Conducting operational field tests.

Pipeline Research Council International, Inc.

Remote Monitoring of Geohazards for 300 Kilometers of Pipeline and Right-of-Way Protection in Permafrost, Snow and Vegetation Using Radar Satellite Interferometry (InSAR)

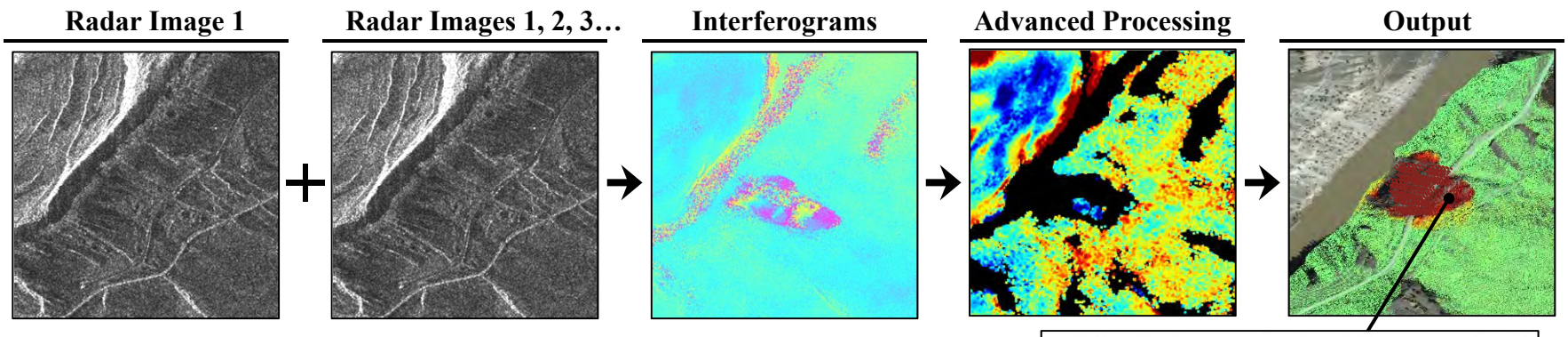
Chris O'Neill
Enbridge

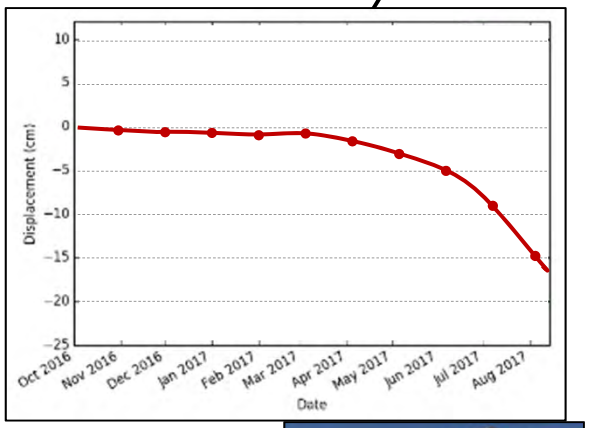
Kris Covey
3vGeomatics

Masuo Takahashi
JAXA

PRCI 2019 Research Exchange Meeting
Houston, Texas
Date March 5, 2019

InSAR Uses Radar Satellite Images Taken Over Time To Precisely Measure Ground Displacement





Area of Coverage: 70km x 70km

Resolution: 10 meters

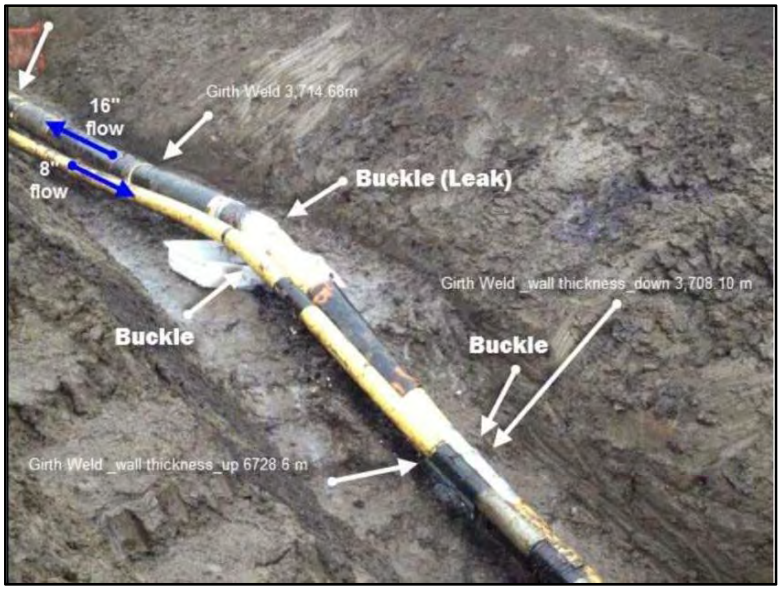
Precision / Detection Limit: Centimeters of motion

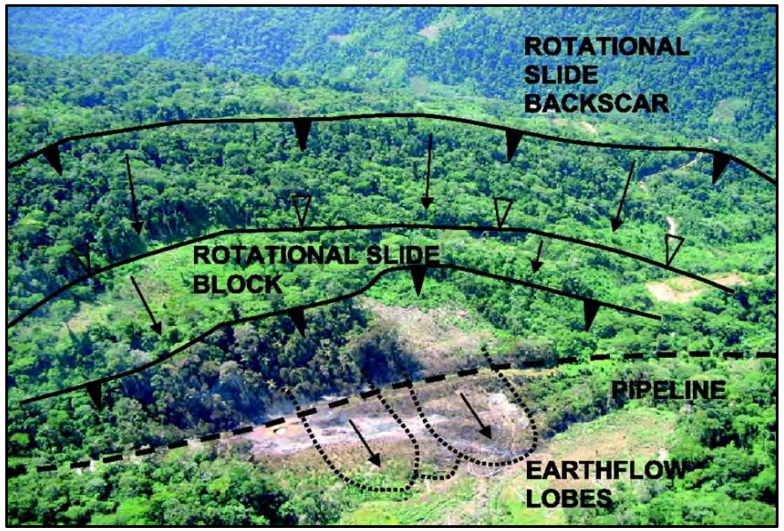
Measurement Frequency: Every 14 days

On-site Requirements: Remote sensing, no site visit required

Pipeline Applications for InSAR

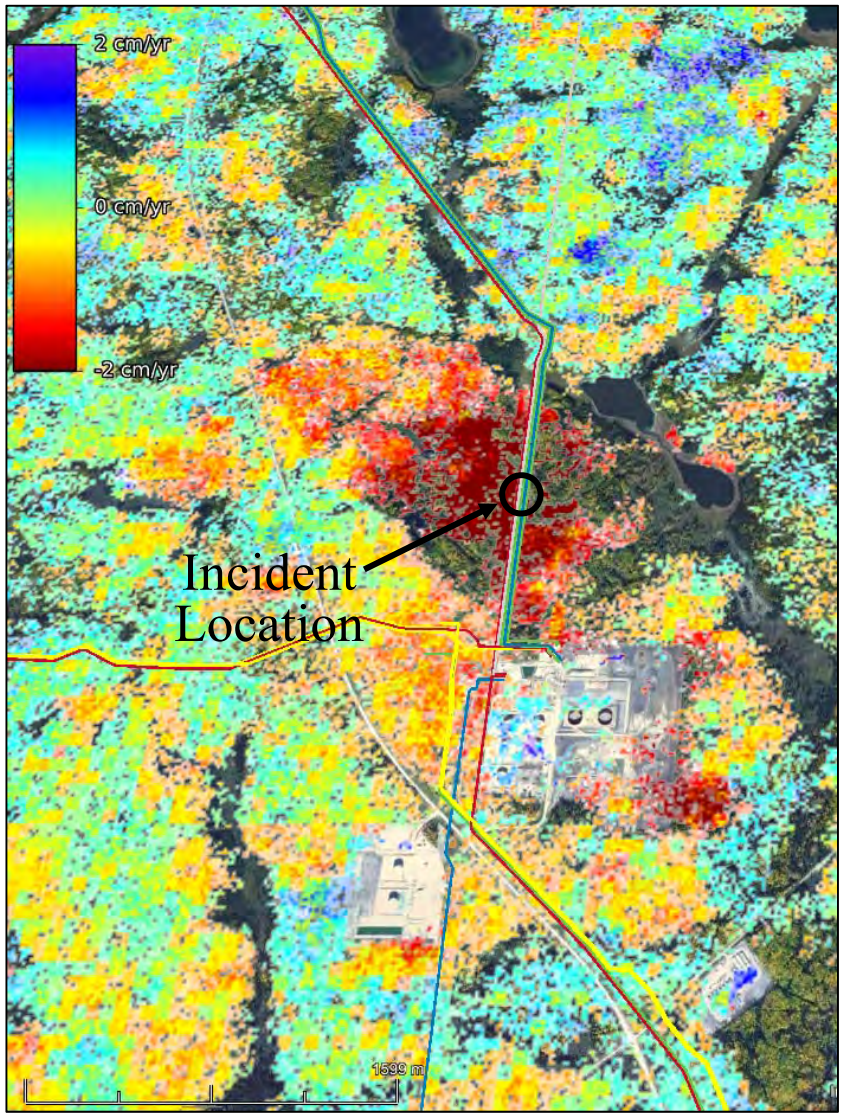
- Identifying landslides and other areas of displacement along pipeline networks
- Incorporating displacement monitoring into pipeline right of way maintenance and inspection programs
- Identifying critical locations for targeted use of ground-based instruments
- Using InSAR to verify and align ground movement with other data sources
- Improving effectiveness of landslide mitigation practices
- Routing of new pipeline construction





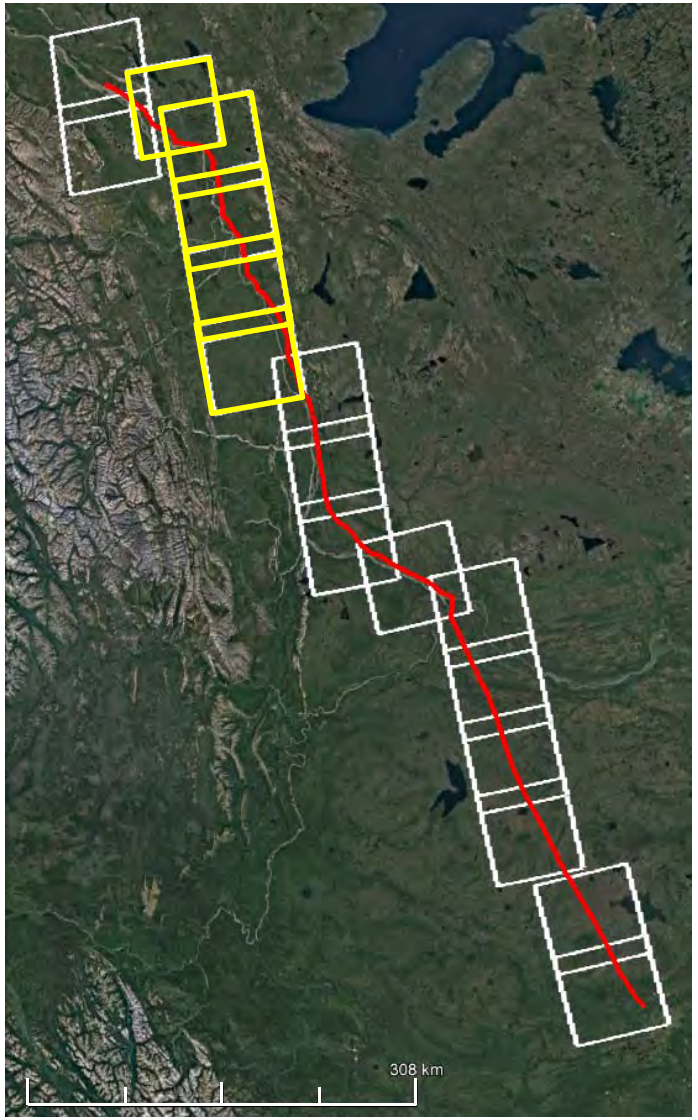
Recall: Historic InSAR Data Identified Slope Movement Prior to Business Interruption

- InSAR analysis conducted in 2018 of ALOS-1 images acquired from 2007 – 2011
- Analysis identified slope movement of up to 10cm/yr across area 250 acres in size
- Business interruption occurred due to landslide in June 2013
- Results presented by Stantec and Enbridge at IPC Calgary (Sept 2019)



Phase II Project Overview: Monitoring 300+ km of a Remote Pipeline for a Major Operator

- 800+ km pipeline in northern Canada containing permafrost, snow, and vegetation
- Right of way has history of slope instability, leading to pipeline being taken out of service in 2015
- 3vG tasked ALOS-2 to acquire five footprints from April – October 2018 (300+ km total)
  - 70 x 70 km each, 10m resolution
  - Images acquired every 14 days



JAXA's Radar Satellite Missions

Masuo TAKAHASHI, Shinichi SOBUE

takahashi.masuo@jaxa.jp

Satellite Applications and Operations Center
Japan Aerospace Exploration Agency

March 5, 2019

Continuous Observations by ALOS Series

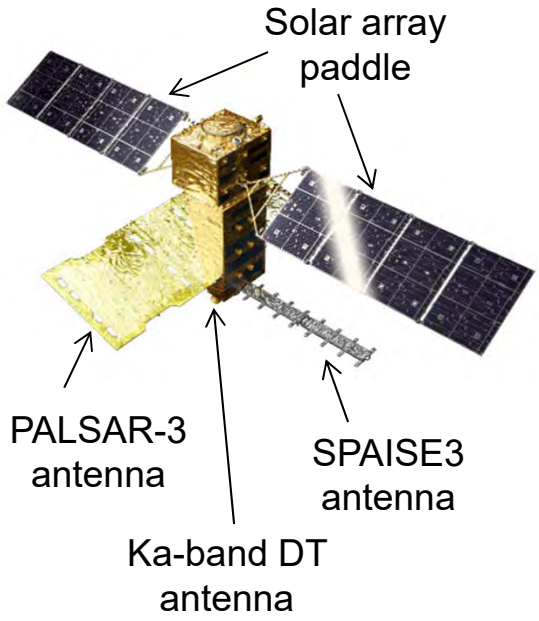
- ✓Assurance of safety and security of citizens, *i.e.* disasters monitoring and management, land deformation monitoring, national developing management, foods and natural resources, environmental issues in global etc.
- ✓Enhancement of commercial use of Earth observation data, *i.e.* National Spatial Data infrastructure (NSDI) and new applications.

Advanced Land Observing Satellite-2 (ALOS-2)

Launch Date	May 24, 2014
Life time	5 years (target: 7 years)
Application	Disaster, Land, Agriculture, Natural Resources, Sea Ice & Maritime Safety
Resolution & Image Size	• ScanSAR: 100m res., 350km / 490km swath • Stripmap: 3 to 10m res., 50 to 70 km swath • Spotlight: 1×3m res., 25km swath
Orbit	Sun-synchronous orbit Altitude: 628km Revisit: 14 days Orbit control: ≦+/-500m
Band (Wavelength)	L-band (23.5 cm) Long wavelength penetrates through vegetation
InSAR Precision	2 – 3 cm

Advanced Land Observing Satellite-4 (ALOS-4)

Launch Date	**JFY 2020** by H-3 launch vehicle
Life time	7 years
Application	Disaster, Land, Agriculture, Natural Resources, Sea Ice & Maritime Safety
Resolution & Image Size	• ScanSAR: 25m res., 700km swath • Stripmap: 3m to 10m res., 100 - 200km swath • Spotlight: 1m × 3m res., 35km swath
Orbit	Sun-synchronous sub-recurrent orbit Altitude: 628 km Revisit time: 14 day **(Same orbit as ALOS-2)**
Band (Wavelength)	L-band (23.5 cm) Long wavelength penetrates through vegetation
InSAR Precision	2 – 3 cm



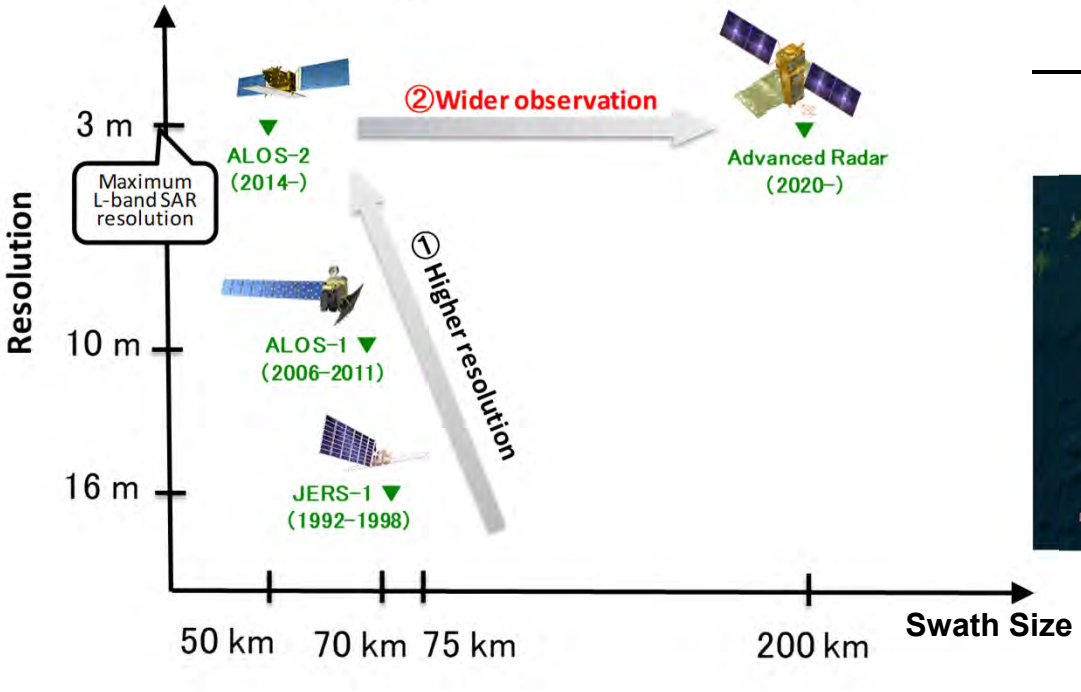
Future Application Realized by ALOS-4

More frequent observation

- ✓ Detection of early indication of crustal changes and ground deformation (volcanos, land subsidence and land slide)
- ✓ Infrastructure Displacement Monitoring for avoiding missed abnormal changes and more effective civil engineering infrastructure management)

Mutual interference with ALOS-2

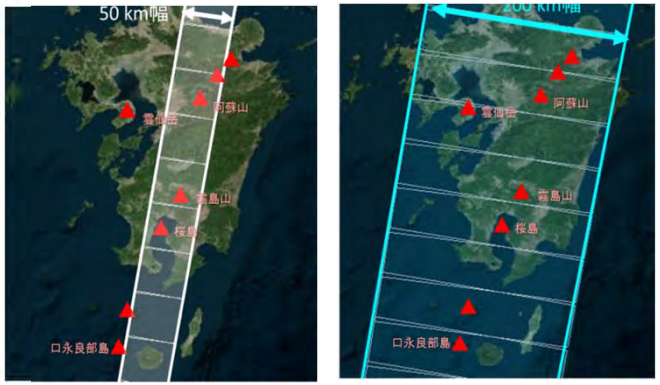
- ✓ Understanding long-term crustal changes and ground deformation



3 meter resolution

50 km swath (ALOS-2)

200 km swath (ALOS-4)



Overview InSAR Results of Pipeline ROW

- 5 ALOS-2 stacks (300+ km), 10m resolution; 12 images per stack, April to October 2018

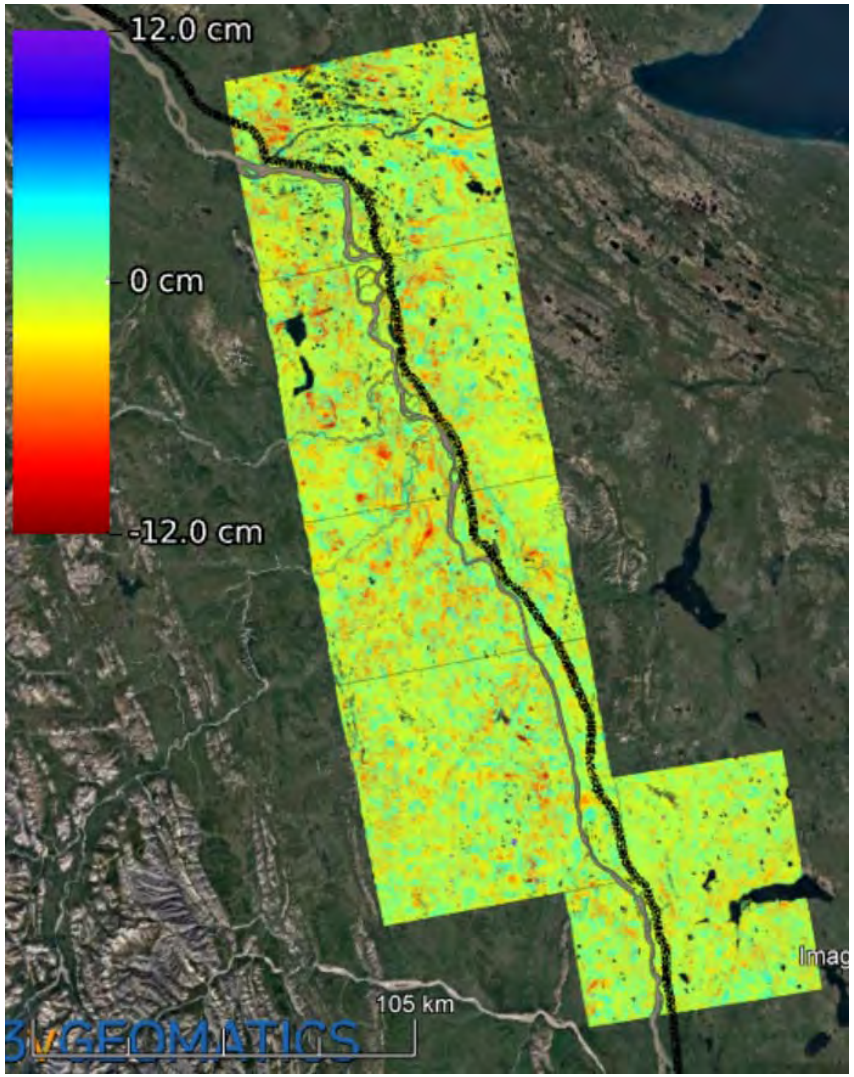
✓ Data coverage with ALOS-2 is essentially 100%!

✓ Over 9.2M data points generated with 3km swath over ROW

✓ Displacement noise floor *currently* at 10cm per year

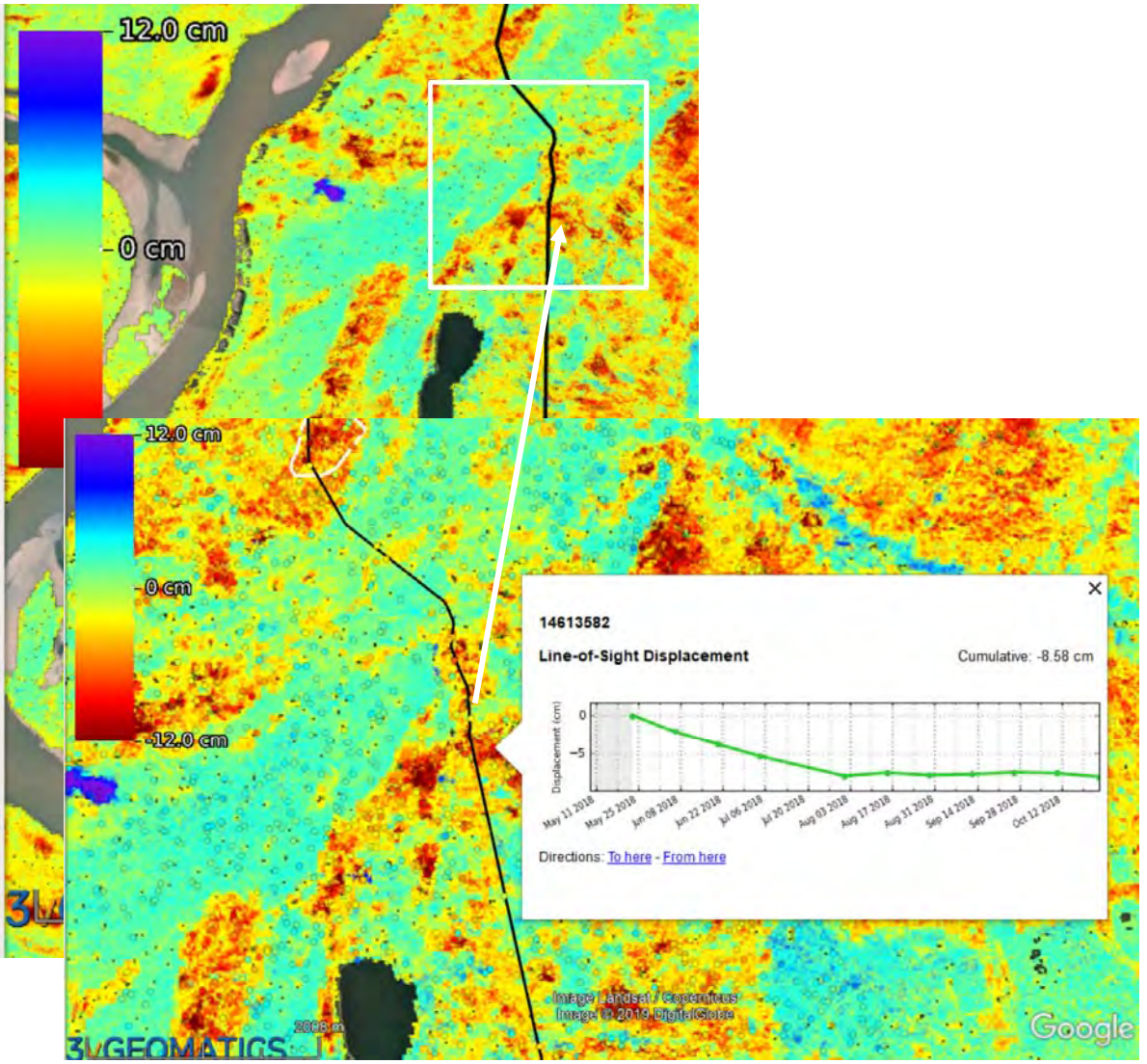
✓ Minimum detectable displacement area with 10m resolution is ~10,000 square meters (2.5 acres)

  - ALOS-2 with 3m resolution... 900 sqm. (0.22 acres)



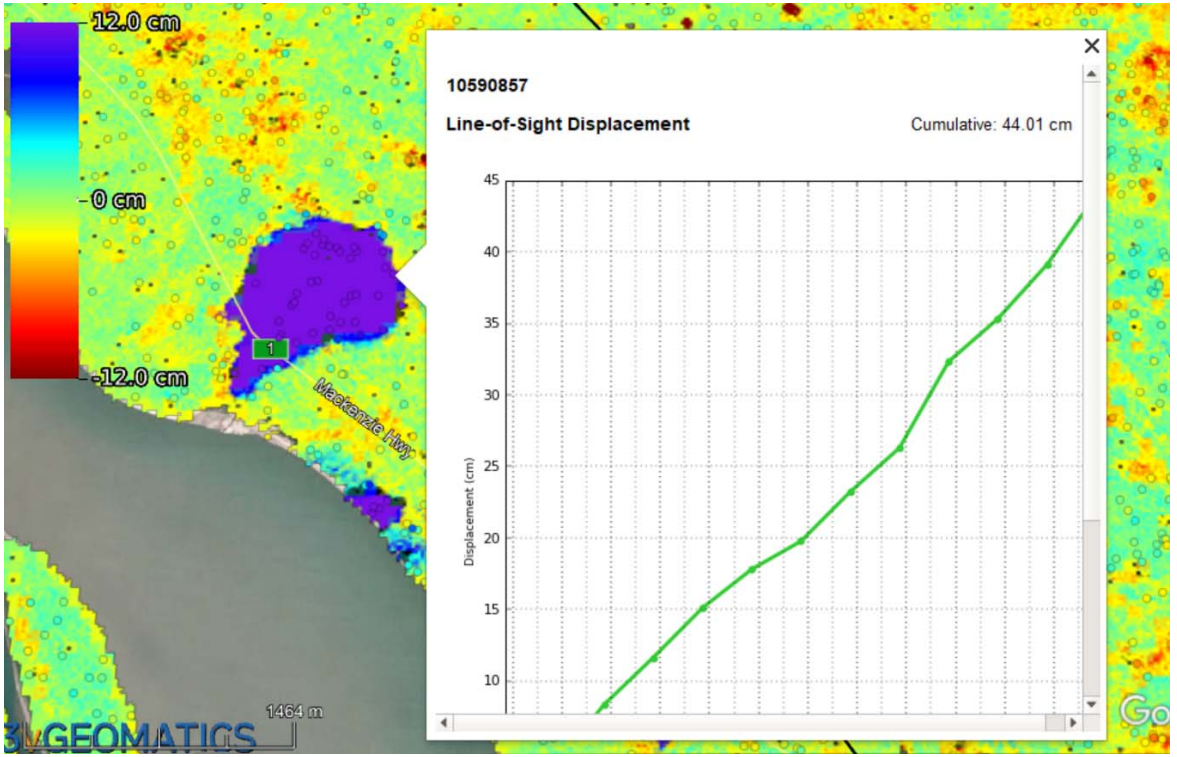
Detailed InSAR Results: Identification of Permafrost Boundary Locations

- InSAR results showed numerous large movement areas consistent with permafrost thaw
- 10cm subsidence measured over 3 months (May – July), then stable to October
- Pipeline is subject to ‘wrinkling’ (local buckling of walls) at permafrost boundaries



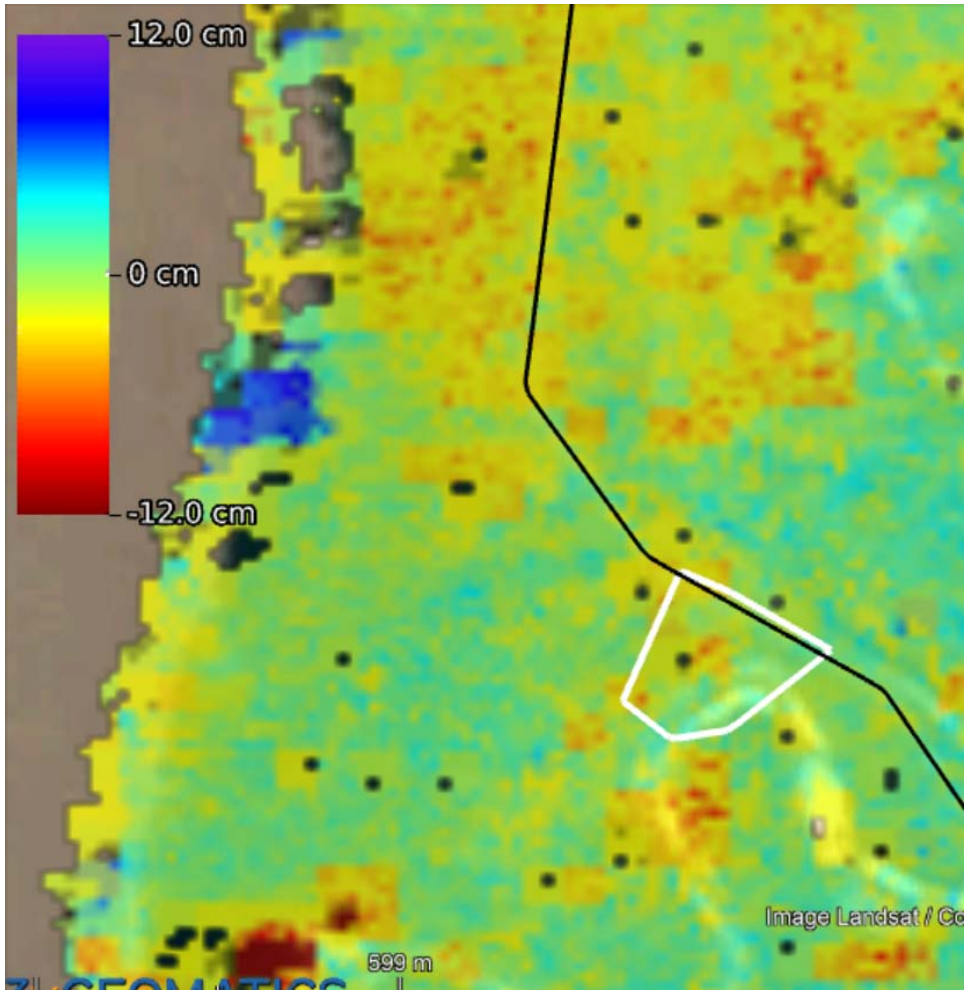
Detailed InSAR Results: Landslide Detection

- Large landslide (179 acres) detected downhill from ROW, impacting access highway, sliding at over 1.5 meters per year.
- No major landslides were identified that represent significant risks to the pipeline



Detailed InSAR Results: Missed Geohazard

- InSAR results did not show smaller-scale (e.g., 100 ft wide) geohazard activity that was identified by the operator
- 10 meter resolution of the satellite images is too coarse to detect movement areas this small.
- Erosion based processes are also difficult to detect via InSAR because the ground targets disappear over time.
- Imaging geometry: the satellite is sensitive to motion along the “line-of-sight” direction. Any displacement perpendicular to this direction will not be captured (i.e., north-south motion)

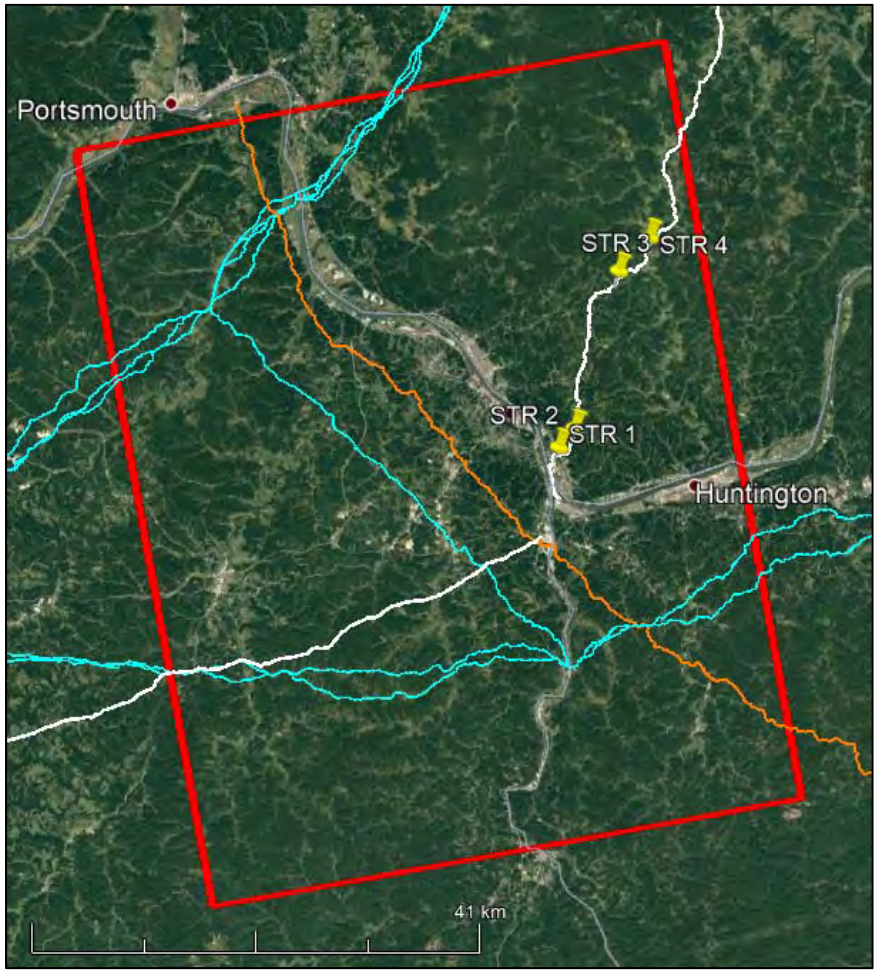


Conclusion

- Contemporary InSAR monitoring of 300km of pipeline ROW in remote northern Canada with permafrost, snow, and vegetation
- Achieved essentially 100% data coverage
- Two of the three key geohazards of concern were addressed:
  - ✓ *Permafrost thaw which can wrinkle the pipe*
  - ✓ *Large landslides (or lack thereof) that can completely rupture the pipe*
  - ✘ *Smaller-scale, erosional based displacement areas that can expose the pipe*
- Going forward, 3vG can use 3 meter resolution ALOS-2 images on all new projects to detect smaller-scale motion (0.25 acres)

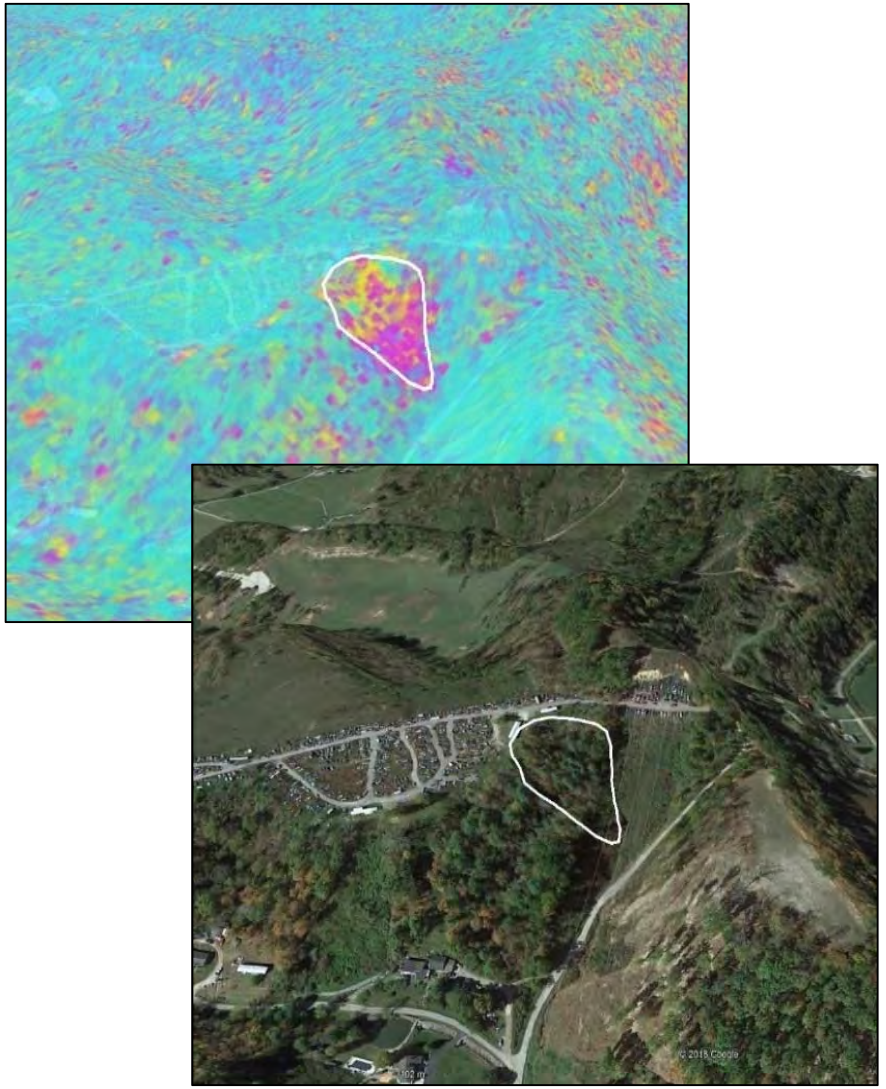
Additional Update: PRCI Project in Appalachia Mountains (GHZ-2-03)

- 3vG also engaged in PRCI project with Marathon as lead sponsor
  - Location: Kentucky (Appalachia Mountains)
  - Deliverable: InSAR analysis of 3 meter resolution ALOS-2 images acquired from March – November 2019
- Note: 3vG tasked ALOS-2 to acquire 4 images from July – October 2018 to get a head start on image collection



Additional Update: PRCI Project in Appalachia Mountains (GHZ-2-03)

- Preliminary interferogram
  - Excellent data coverage
  - Small landslide detected along transmission ROW, approximately 6300 sqm (1.5 acres)
- Full Results to be delivered at end of 2019



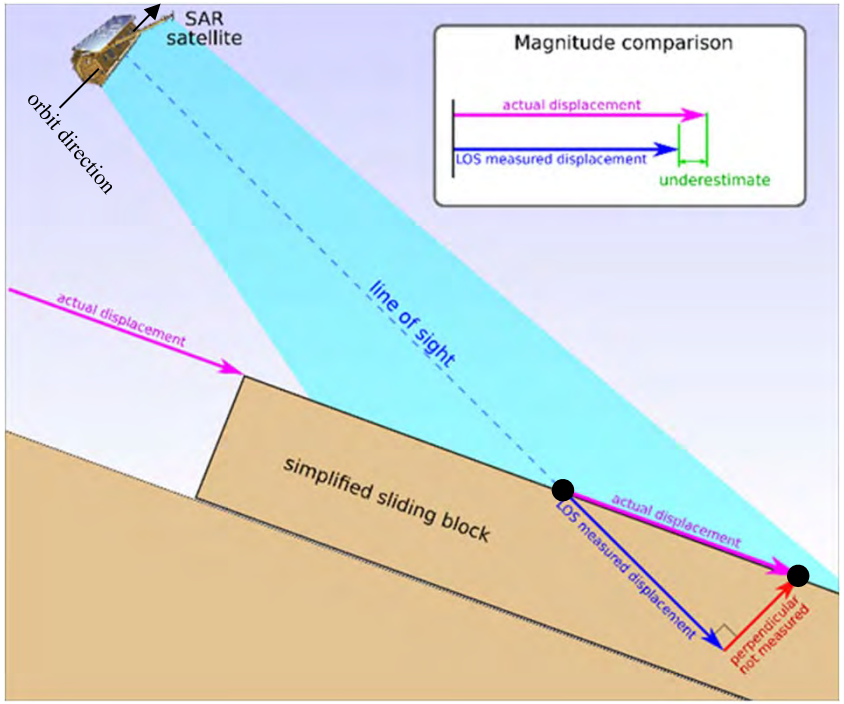
Recommended Approach

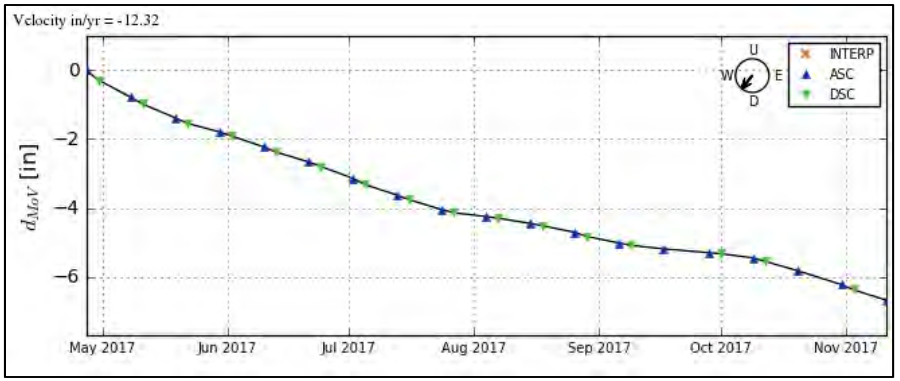
- All ROWs with high geohazard risk should be monitored using InSAR
- Phased implementation approach with ALOS-2:
  - *5 images – data coverage analysis*
  - *10 images – average displacement rate*
  - *15 images – full InSAR results with time series charts*
- Carry into ongoing monitoring program with quarterly updates
- Option to include displacement reports after each new satellite image acquisition (4cm precision)
- Carry into continued ongoing monitoring with ALOS-4 in 2021

APPENDIX

InSAR From One Satellite Look Direction Produces 1D Measurements

- 1D measurements are in the line-of-sight (LOS) direction
- The actual displacement direction is typically a component of the LOS, thus the measured displacement will be an *underestimate* of the actual displacement
- Measurements can be easily translated to a known direction, e.g., down a slope or vertical sinking
- Measurements generated from 2 satellite look directions (Ascending and Descending) produce 2D measurements; the direction of displacement can then be calculated in terms of east-west, up-down





Pipeline Research Council International, Inc.

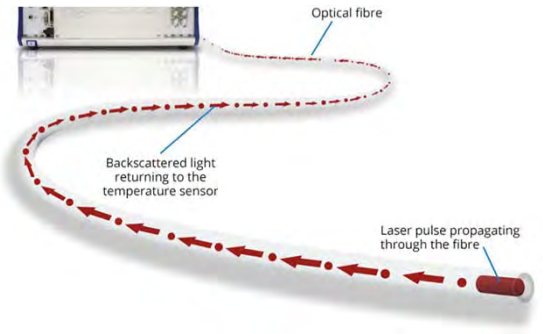
Application of Machine Learning to Improve Leak Detection Capabilities of Distributed Temperature Sensing (DTS) Systems

Maria Araujo, Manager R&D
Southwest Research Institute

PRCI 2019 Research Exchange Meeting
Houston, Texas
March 5, 2019

Pipeline Leaks: Still a Challenge

- **Detecting leaks from liquid pipelines continues to pose a significant challenge for pipeline operations**
  - Small leaks are of particular concern
- **Distributed Temperature Sensing (DTS) systems are commonly used for continuous pipeline monitoring**



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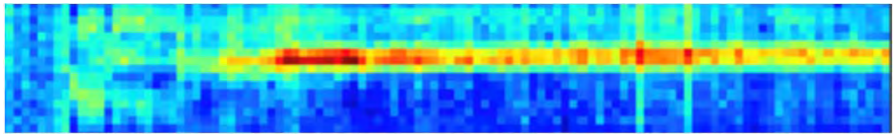
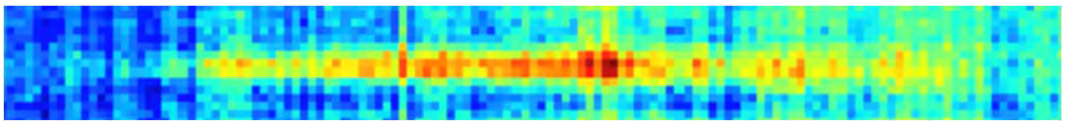
DTS Overview

- **DTS leverages unexpected deviations in temperature at different locations**
  - Indicative of various physical changes in the environment
  - Contact with a hydrocarbon due to a pipeline leak
- **Temperature variations stemming from leaks may not be significantly greater than signal noise floor**
- **System must be configured to detect small leaks while rejecting non-leak temperature anomalies**



Leak Event

Non-Leak Event



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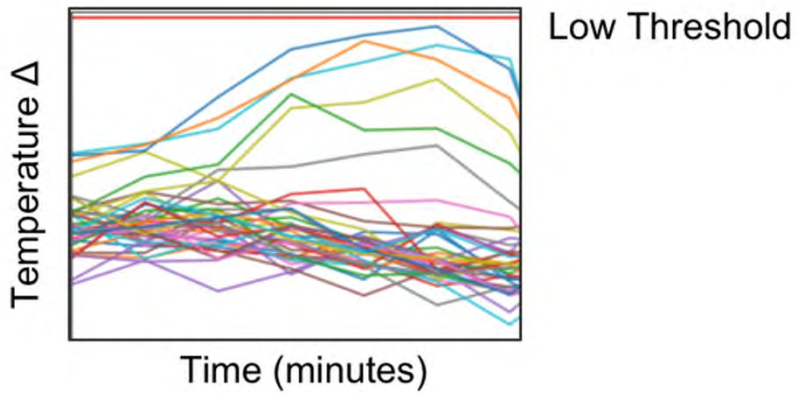
DTS Operation

- **Systems must be tuned on a per-segment basis**
  - Requires significant time and resources and must be repeated periodically
- **Many factors influence frequency and intensity of backscattered signals**
- **Current approach is to use a variety of averaging and differencing calculations**

Certain Leaks are Hard to Find

- Many leaks produce a very small temperature gradient
- Slow leaks can be filtered out by data pre-processing
- Tuning threshold to low – high false alarm rates
- Tuning threshold to high – leaks are missed



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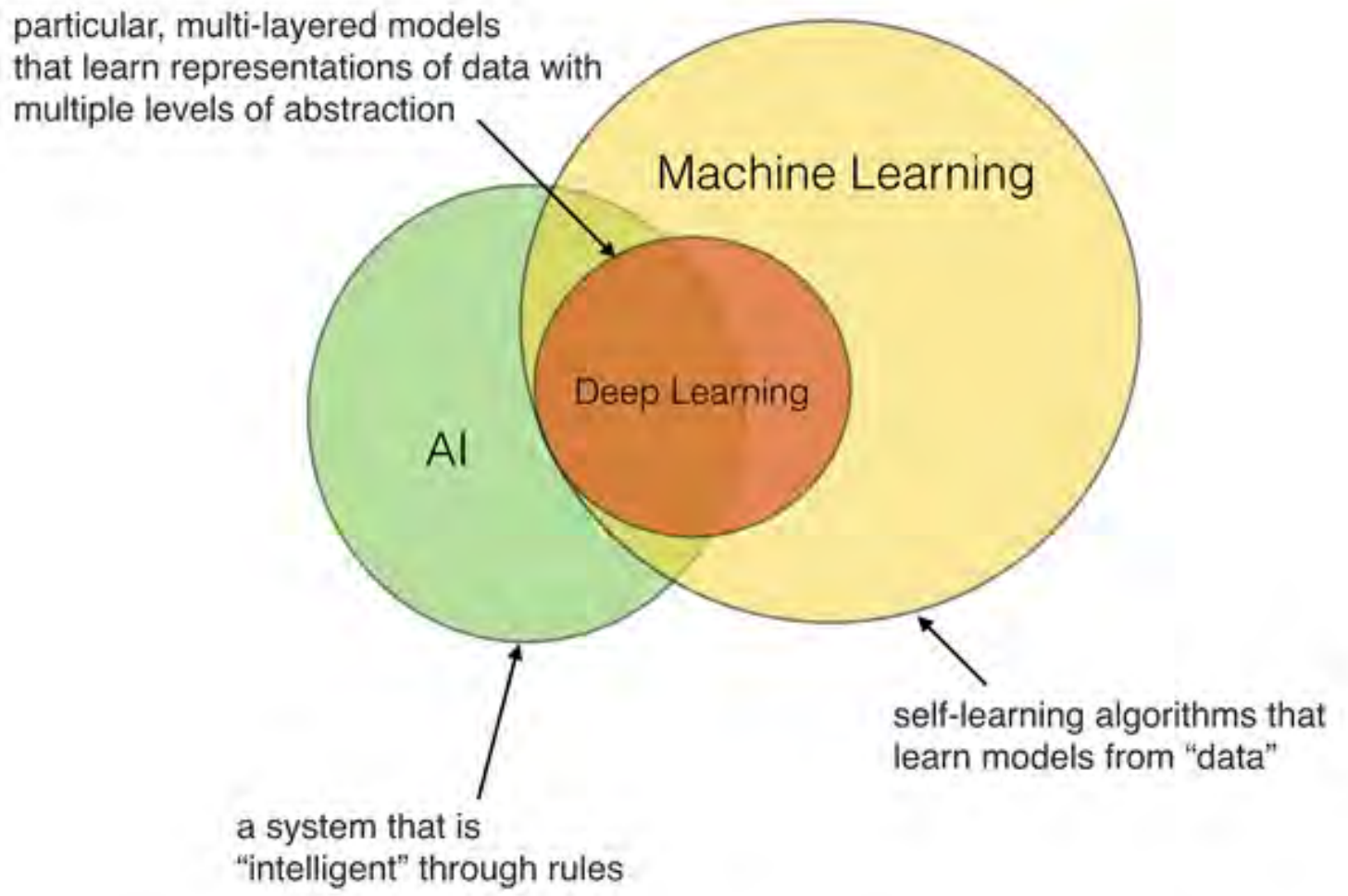
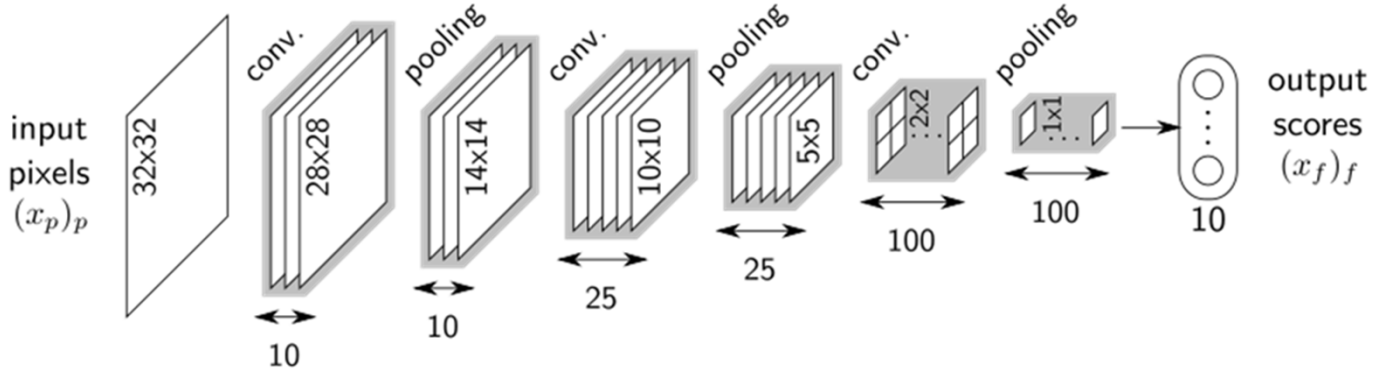
Machine Learning



Identifying the Hard to Find Leaks

- **Several machine learning and deep learning techniques were investigated**
- **Machine Learning approaches**
  - K-Nearest Neighbors
  - Support Vector Machines
  - other statistical machine learning classifiers.
- **Deep Learning approaches**
  - Long Short-Term Memory (LSTM)
  - Convolutional Neural Networks (CNN) (Figure)



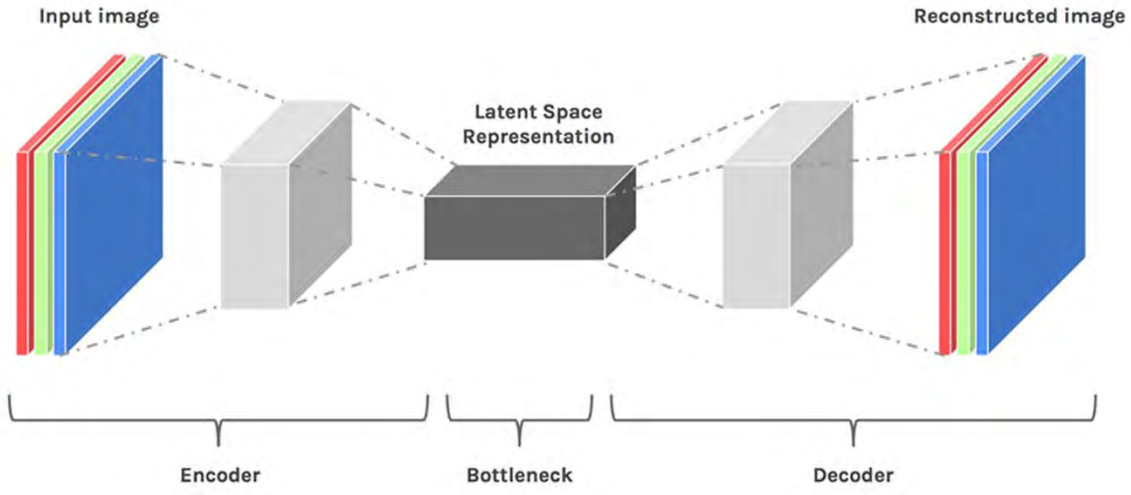
Supervised versus Unsupervised

- **Many ML algorithms are classification techniques**
  - These techniques require a significant amount of data representative of every class
- **Many techniques require that each instance of a class be represented approximately equally to prevent 'overfitting'**
- **The given dataset contained 0.00001% leak samples to non-leak sample data**

ML Model

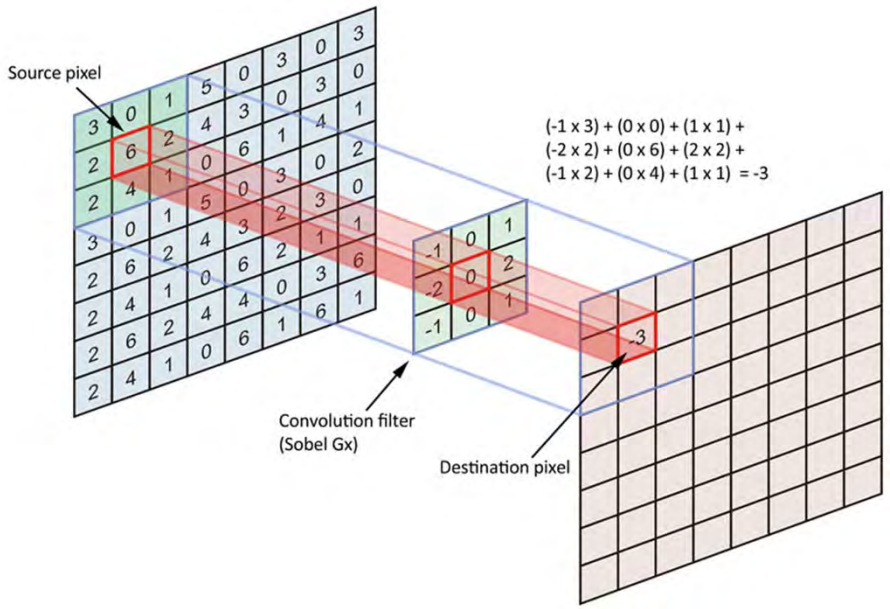
- We chose to evaluate the leak events as an anomaly problem rather then a classification problem

- Deep convolutional undercomplete autoencoder model



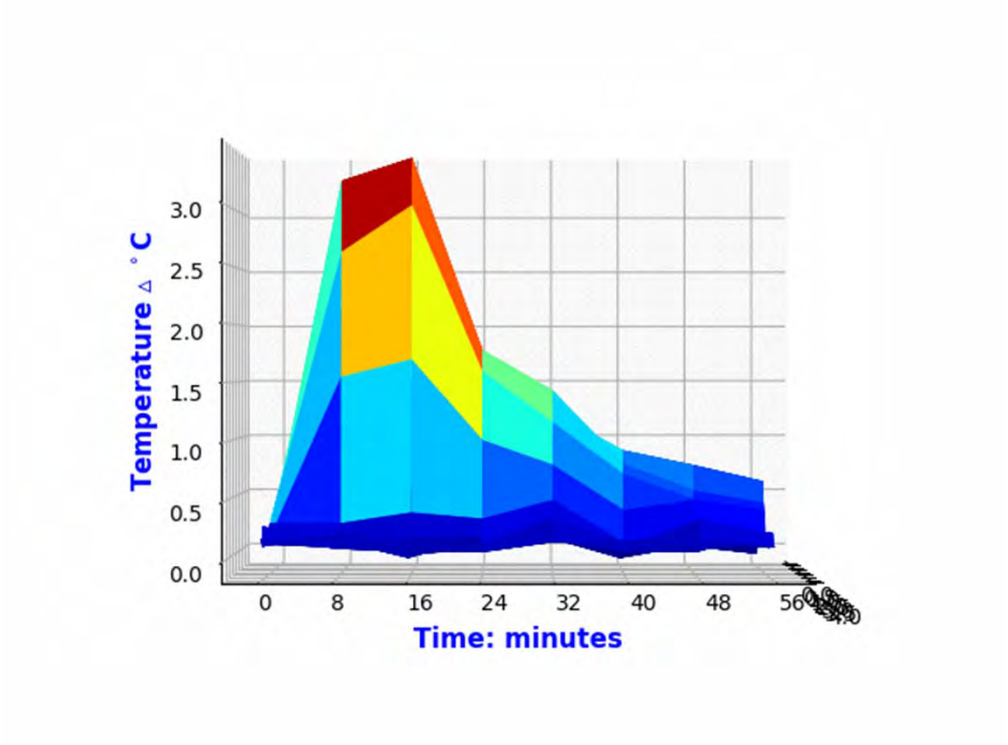
Convolutional Process

- **Incorporates both temporal and spatial information**
- **Reduces the dimensionality of the signal, while learning the best fundamental encoding of the data**
  - This is technique is similar to Principal Component Analysis (PCA) but the encoding transformation is non-linear in nature



Data Curation

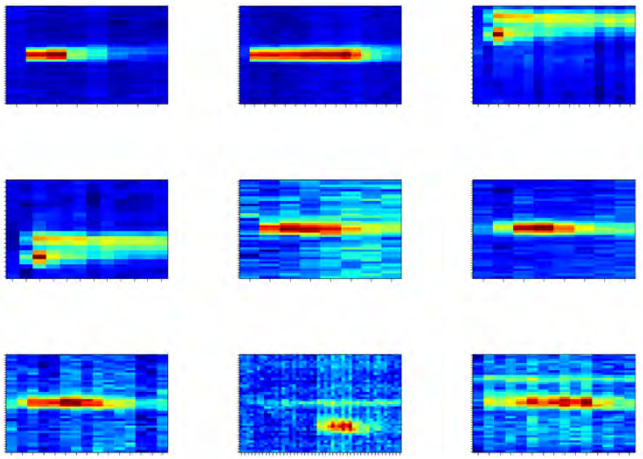
- 2-dimensional (2D) temperature over time data to 3-dimensional (3D) temperature over time over distance data represented as an image



Data Sets

- **The datasets contained 9 leak events**
- **The data was separated into 3 sets**
  - Training
  - Testing
  - Validation (completely separate dataset)

TEST #	DATE	TIME	LOCATION [M]	STANDARD DTS DETECTED?
1	Day 1	8:18	19080.9	Yes
2	Day 1	16:17	19077.9	NO
3	Day 1	16:17	19076	NO
4	Day 2	11:10	12454.4	NO
5	Day 2	12:15	12454.4	Yes
6	Day 2	13:49	12454.4	Yes
7	Day 3	8:16	12454.4	Yes
8	Day 3	10:52	12454.4	NO
9	Day 3	11:24	12454.4	NO



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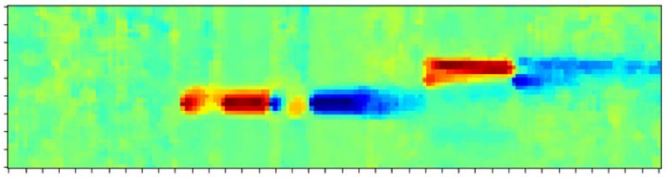
Training the Model

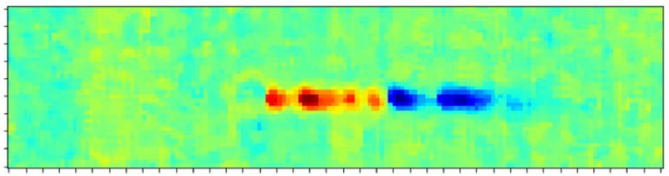
- **Training set contained no leak events**
- **A convolutional undercomplete autoencoder was trained on 3D Time x Distance windows**
  - Model was trained to recreate the input
- **This allowed to learn the fundamental representation**
  - Pattern of life
- **Test Metrics**
  - If reconstruction error (mean absolute error) between input and output is high then it is anomalous

Testing the Model

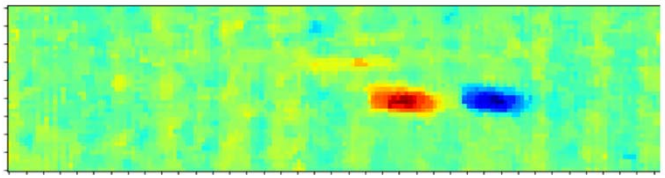
LEAK TIME/ LOCATION	STANDARD DTS TRESHOLD HIGH DETECTED: Y/N	STANDARD DTS THRESHOLD LOW DETECTED: Y/N	SWRI ALGORITHM DETECTED: Y/N
Day 1 - 8:18 19080.9 m	Yes	Yes	Yes
Day 1 - 16:17 19077.9 m	Yes	Yes	Yes
Day 1 - 16:17 19077.9 m	Yes	Yes	Yes
Day 2 - 11:10 12454.4 m	No	No	Yes
Day 2 - 12:15 12454.4 m	No	Yes	Yes
Day 2 - 13:49 12454.4 m	No	Yes	Yes
Day 3 - 8:16 12454.4 m	No	No	No
Day 3 - 10:52 12454.4 m	No	No	No
Day 3 - 11:24 12454.4 m	No	No	Yes
# of False Positives	0	4937	1



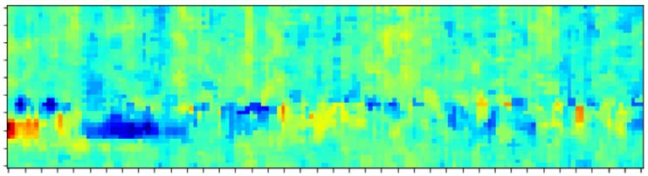
Leak 1,2 and 3 at 19088m



Leak 4,5 and 6 at 12454m



Leak 9 at 12454m



False Positive

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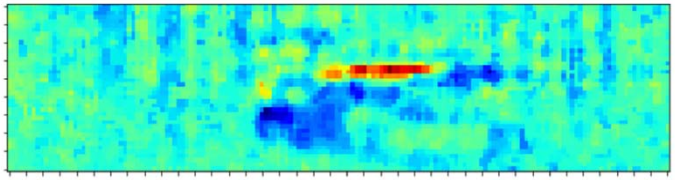
Validating the Model

- **Set never before seen by Model**
  - 10 Days of Data

LEAK LOCATION	STANDARD DTS TRESHOLD HIGH DETECTED: Y/N	STANDARD DTS THRESHOLD LOW DETECTED: Y/N	SWRI ALGORITHM DETECTED: Y/N
# of False Positives	2	1527	0
2 leaks at 19077 m	No	No	Yes



Leaks at 19077m

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Conclusion and Next Steps

- **Results presented are proof-of-concept**
  - They give an indication of the types of improvements that can be achieved
  - Actual improvements can be considerably greater once we consider realistic datasets
- **Algorithm training was performed using data that did not include leaks**
  - On a full-scale development effort, we would include leaks in the training dataset, which would open the possibility to use additional methods

ML Can Find the Hard to Find Leaks

- **Improvements to existing DTS algorithms by the introduction of ML techniques can quite significantly improve system performance**
- **A full scale development effort could provide**
  - Improved sensitivity – ability to detected leaks that go undetected today
  - Ability to lower false alarm rates
- **This technique can also be applied to significantly boost the leak detection performance of :**
  - Computational Pipeline Monitoring (CPM)
  - Distributed Acoustic Sensing (DAS)

Other Applications

- Intrusion Detection (DAS)
- Fault Monitoring
- Fire Detection
- Power Line Monitoring
- Seismic Shifting

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Questions?

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Pipeline Research Council International, Inc.

SmartBall technology : An innovative multi-sensor tool for long inspections of oil and gas pipelines

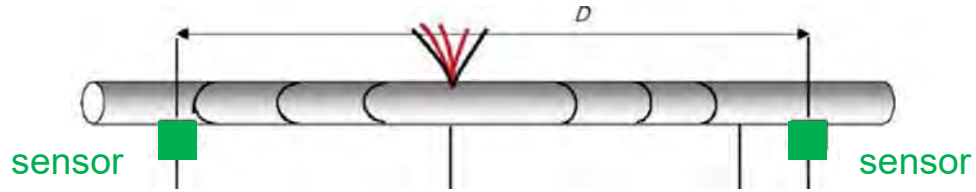
Carine LACROIX, Emilie DRUAIS
GRTgaz RICE

PRCI 2019 Research Exchange Meeting
Houston, Texas
Date March 5 - 6, 2019

Introduction

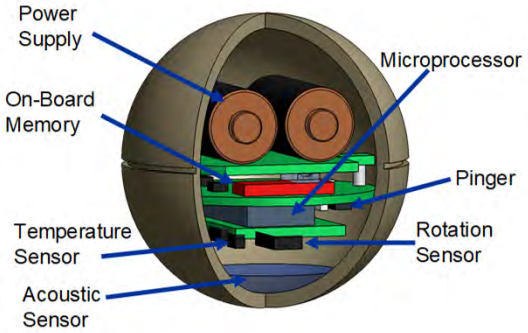
- **Operational need :** detect gas leakage of unpiggable pipelines

  - Permanently settled acoustic sensors : performances depend on the distances between two sensors, the size of leakage, ambiant noise, ..



  - Cable based technologies : cost, retrofitting, ..

  - Smartball : multi-sensor platform (acoustic, temperature, pressure, ..)



Free swimming acoustic sensors : close to leaks

➡ technology selected for lab test

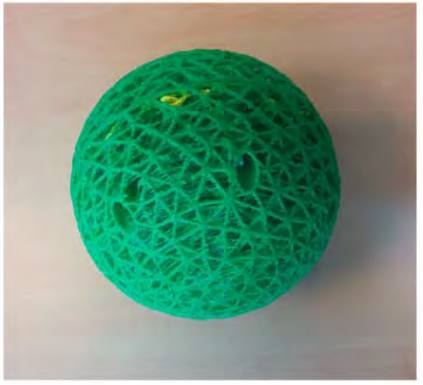
Smartball : presentation

- Free swimming sensor from PURETECH
- Used for water or oil leakage detection of pipelines : ~15 000 miles oil & gas pipeline already inspected)
- Cost ? 70 k€ for 100 km (to be confirmed by PureTech)
- DN 150 mm minimum

SmartBall

Metallic ball with embedded sensors

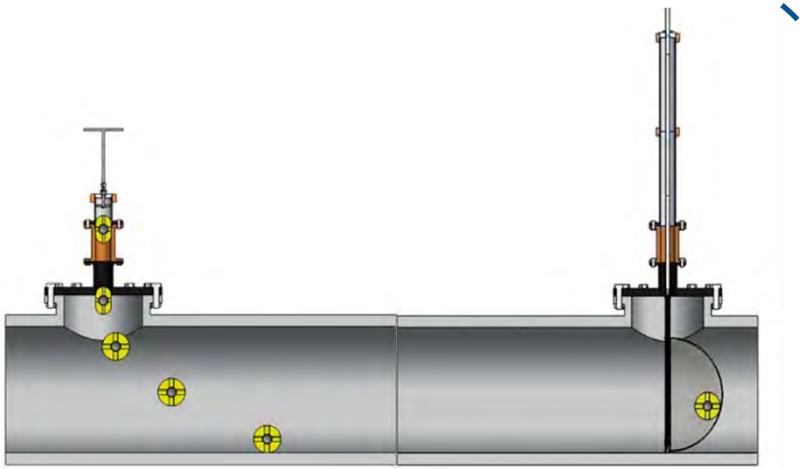
3D printed polyurethane coating



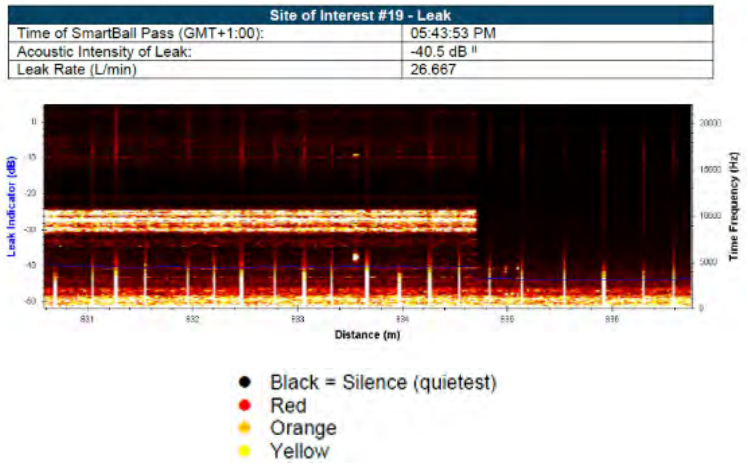
SmartBall ready to be inserted in pipelines

Smartball : presentation

- **Pipeline inspection :**



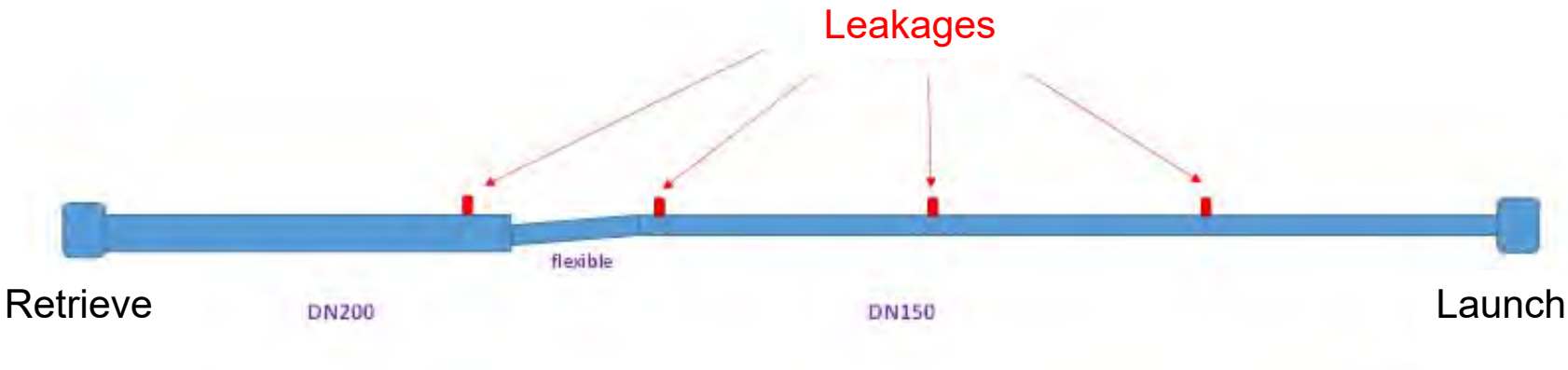
- Launched & retrieved from pig traps
- GPS tracking (1 to 2 km at the surface along the pipe)
- ~0,5 - 1 m accuracy and autonomy of 8 h of inspection/day



- Acoustic measurement during inspection
- Data analysis after inspection (no real time monitoring)

Lab tests done by GRTgaz & PURETECH

- **GRTgaz Lab facilities :**
  - Smartball : fixed position => phase 1 : static test
  - Smartball rolling inside the pipeline => phase 2 : dynamic test



Lab tests done by GRTgaz & PURETECH

- **GRTgaz Lab facilities : phase 1 - static test**
  - Flow variation : 0,5 L/h à 10 000 L/h
  - Pressure variation : 4, 8, 16 bar
  - Distances leakage-sensor :
    - *SmartBall right under the leak : leakage a*
    - *30 cm to the leak : leakage b*

Phase 1 : Static tests

- **Results : phase 1 - static tests**

<table>
<tr><th colspan="4">Right under the leak</th></tr>
<tr><th>Leakage flow Qv (L/h)</th><th>P = 4 bar</th><th>P = 8 bar</th><th>P = 16 bar</th></tr>
<tr><td>0,5</td><td rowspan="4">No</td><td rowspan="4">No</td><td>No</td></tr>
<tr><td>42 < Qv < 68</td><td rowspan="9">Yes
(Threshold : 110)</td></tr>
<tr><td>110 < Qv < 137</td></tr>
<tr><td>156 < Qv < 206</td></tr>
<tr><td>340 < Qv < 488</td><td rowspan="7">Yes
(Threshold : 450)</td><td rowspan="7">Yes
(Threshold : 488)</td></tr>
<tr><td>610 < Qv < 660</td></tr>
<tr><td>970 < Qv < 1100</td></tr>
<tr><td>1580 < Qv < 1800</td></tr>
<tr><td>4500 < Qv < 4960</td></tr>
<tr><td>9420 < Qv < 9750</td></tr>
</table>

Phase 1 : Static tests

- **Results : phase 1 - static tests**

  - SmartBall : leakage a (right under the leak)

	Leakage flow Qv (L/h)	Leakage flow Qv (Nm^3/h)	Estimated hole diameter (mm)
P = 4 bar	450	2,07	0,8
P = 8 bar	488	4,04	0,8
P = 16 bar	110	1,72	0,4

P ↗ better detection

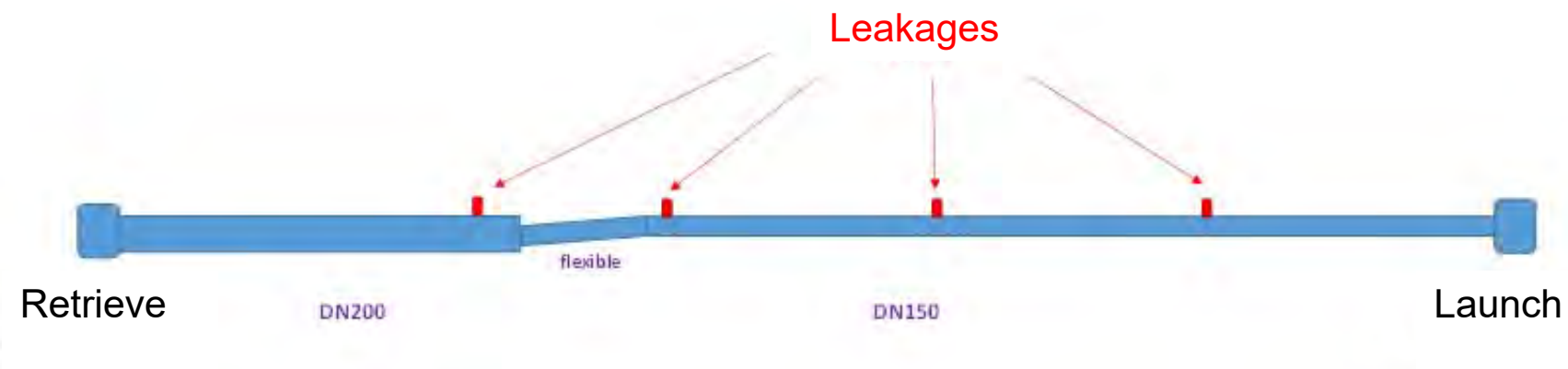
  - SmartBall : leakage b (30 cm)

	Leakage flow Qv (L/h)	Leakage flow Qv (Nm^3/h)	Estimated hole diameter (mm)
P = 4 bar	670	3,08	1
P = 8 bar	495	4,09	0,8
P = 16 bar	250	3,91	0,6

☞Small sizes leak detected (<1 mm), even at low pressure for leakage a & b

Phase 2 : Dynamic tests

- **Smartball is rolling along the pipe : 17 m of bend test**
  - o 4 simulated leakages
  - o Obstacles (flexible with slight angle tilt, penetrating welds, flange, ..)
  - o Diameter variation : DN150 to DN200

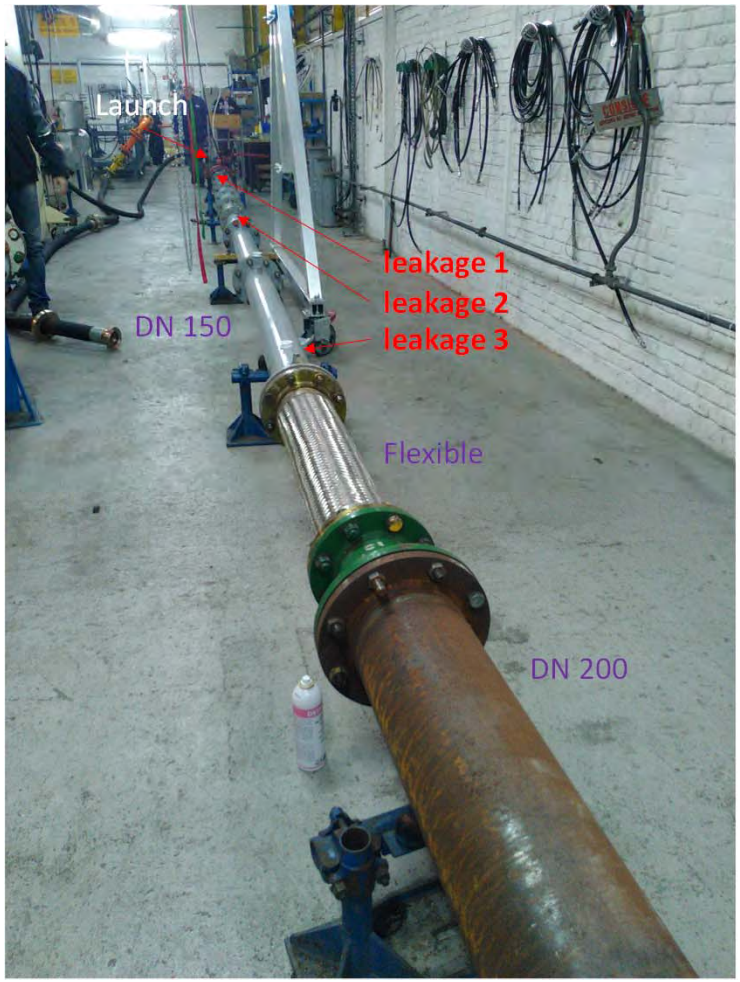


Phase 2 : Dynamic tests

- **Bend test :**

Phase 2 : Dynamic tests

- **Bend test :**



Phase 2 : Dynamic tests

- **Results :**
  - SmartBall rolling not disrupted by :
    - Diameter change (DN 200 – DN 150)
    - Presence of penetrated welds
    - Presence of flexible
  - Gas flow regulation with a laminating valve : generated noise higher than acoustic signal from simulated leakages

    ➡ Evaluation of gas leakage detection performances in dynamic condition : not possible
  - The minimum gas flow that allows Smartball rolling is 5 to 6 m/s, (pigs used ~ 1-2 m/s).

2018 : Conclusions

- Static tests : Small sizes leak detected (<1 mm), even at low pressure
- Dynamic tests :
  - 5 to 6 m/s to roll,
  - rolling not disrupted by the simulated (small) obstacles,
  - generated noise covered the acoustic signal of leaks.

Perspectives for gas leakage detection

- 2019 - Lab test
  - Static : increase the pressure (> 40 bar) to be more representative of the transmission operating pressure
  - Dynamic : repeat the test with different configuration (to low the generated noise)

- 2019 - Live inspection : insert the SmartBall in GRTgaz network in live conditions to determine
  - Launch and retrieve real drawbacks
  - Difficulties not predicted
  - ..

Perspective : Smartball as a vector ?

- GRTgaz is currently looking for industrial collaborations to :
  - optimize gas inspection based on SmartBall : as example no real-time monitoring, no ATEX, ..
  - develop the idea of using SmartBall as a vector for :
    - the georeferencement of networks ➡ integration of high resolution sensors for precise mapping of gas networks
    - T or P measurements, ..

Pipeline Research Council International, Inc.

Autonomous Aerial Detection of Liquid Hydrocarbon Leaks in Water Bodies

Maria Araujo, Manager R&D
Southwest Research Institute

PRCI 2019 Research Exchange Meeting
Houston, Texas
March 5, 2019

Technical Background

- **Leaks from liquid hydrocarbon pipelines are frequent occurrences**
- **Navigable waterways and ecologically-sensitive surface water zones are regulated, high-consequence areas**
  - Small leaks from these pipelines are difficult to detect and can have significant environmental impacts
- **Another need is post-flooding surveys**
  - e.g., leaks from facilities after Hurricane Harvey

Recent Major Spills in Water

SwRI
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Peripheral Solutions

Ophir Corporation's duoThane™ System

Light-Induced Fluorescence LiDAR

SMART LEAK DETECTION (SLED) FOR WATER BODIES

(SLED/Water)

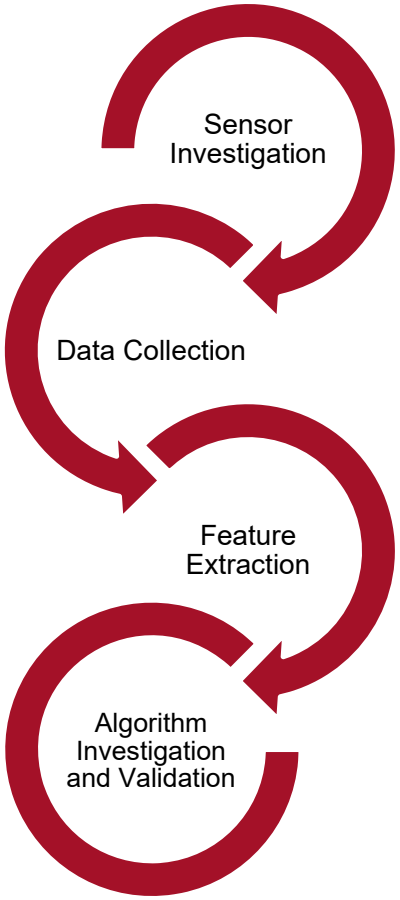
Research Project Objectives

1. **Investigate what types of sensors and different combinations of sensor inputs provide the best indication of oil slicks on water surfaces,**
2. **Investigate adequate techniques to identify unique "fingerprints" of crude oil slicks based on different combinations of sensor data**
    1. Under different lighting and weather conditions, in order to significantly reduce false positive rates.
3. **Assess whether the technique can be successfully implemented on a moving platform (e.g. UAV). If not, assess limitations and potential improvements that can be made so that the technique can be used on a moving platform.**

Technical Approach

Technical Approach

- Sensor Investigation
- Data Collection
- Feature Extraction and Evaluation
- Algorithm Investigation, Validation, and Refinement



Sensor Investigation

- **Using commercial-off-the-shelf cameras:**
  - FLIR A65 – long-wave infrared (LWIR) thermal camera
  - IDS UI-5240SE – visible light camera

Camera	Spectral Range	# Channels	Resolution	Lens/FOV
FLIR A65 Thermal camera	7.5µm–13µm	1	640 x 512	25mm/ 25° (H) x 20° (V)
IDS UI-5240SE CMOS	0.4µm-0.9µm	3	1280 x 1024 Binned to 640 x 512	25mm/ 25° (H) x 20° (V)

Sensor Investigation (Cont'd)

- Same cameras used for SLED

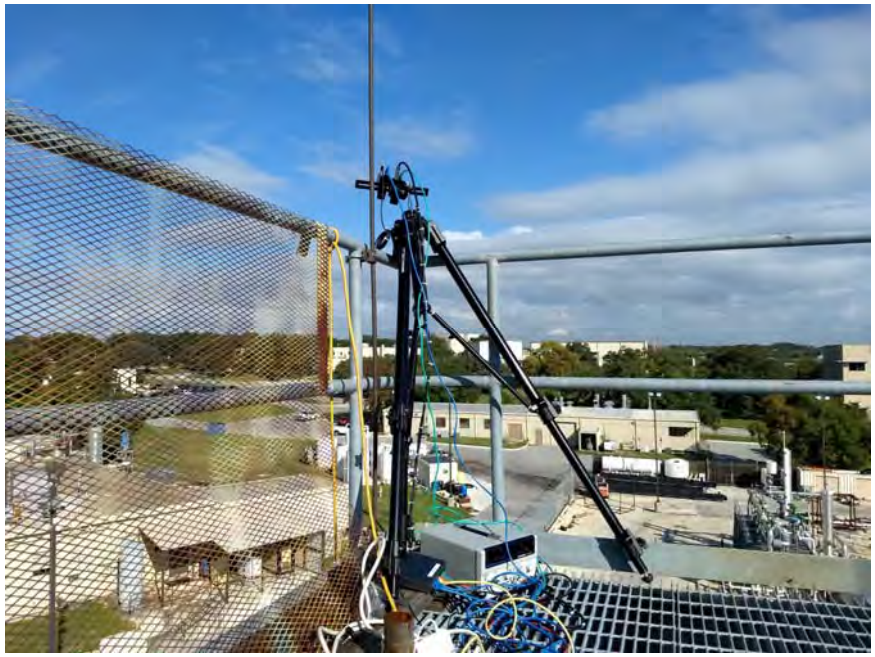
Data Collection

- **Imaging both stagnant and moving pools of water from various distances**
- **Dynamic set of conditions:**
  - (1) image registration
  - (2) discontinuities in the oil surface area
- **Iterations will be used to adjust data collection matrix**

Data Collection Matrix

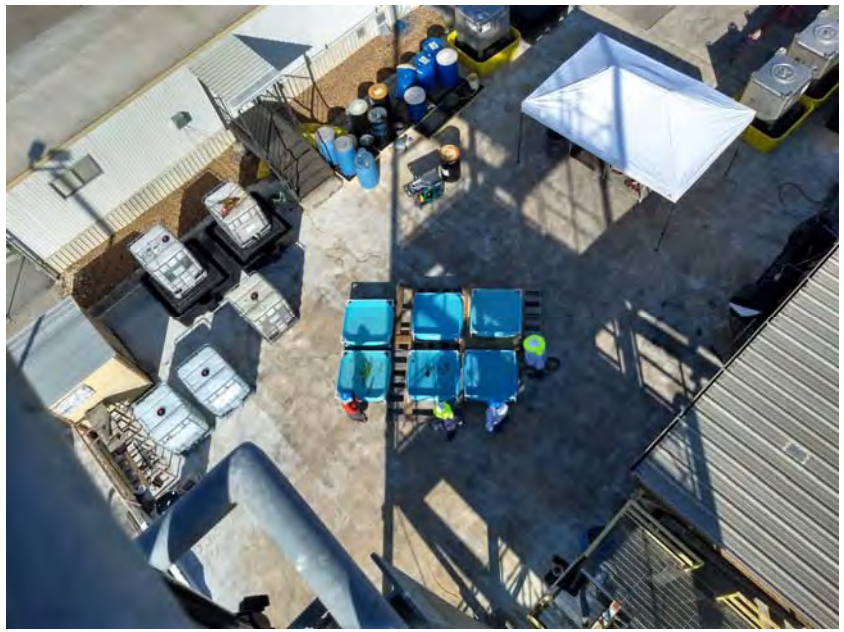
Parameter	Values
Relevant Fluids	Water only Crude oil on water Crude oil only Other substance on water
Water conditions	Stagnant (e.g. typical of marshes) Ripples (of varying degrees, typical of river movement) Slow moving (typical of lakes)
Oil appearance	Uniform Disperse Discontinuous
Camera conditions	Stationary Panning Vibrating (e.g. simulating aircraft mounting vibration)
Water depth	<1” 1”-6” >6”
Bottom of water	Dark Light
Angle of view	Steep Shallow
Lighting	Bright Cloudy Discontinuous
Distance (camera to leak)	10 ft, 100 ft, 300 ft, 500 ft

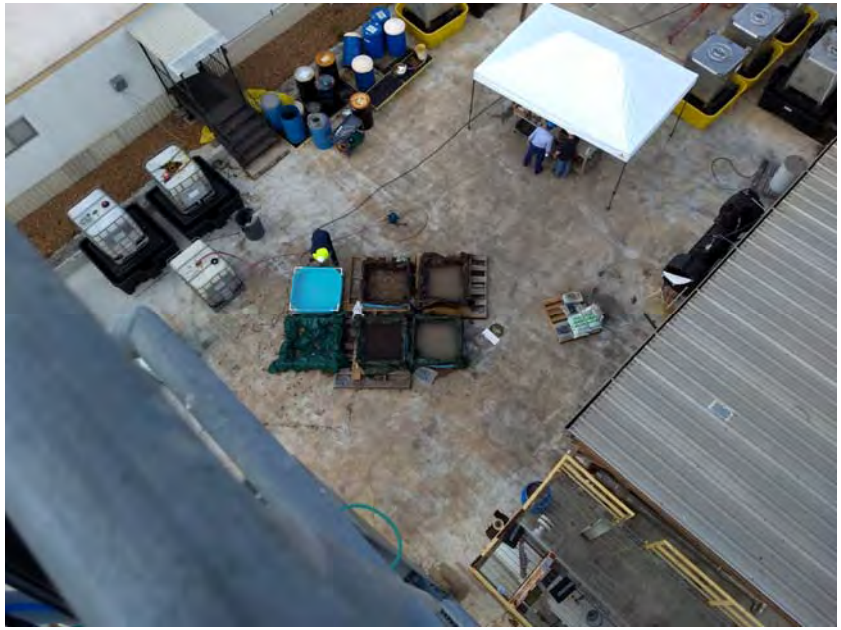
Initial Data Collection



SwRI
SOUTHWEST RESEARCH INSTITUTE

Initial Data Collection





Initial Data Collection

SwRI
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Feature Extraction and Evaluation

- Visible imagery will be used in conjunction with thermal
- Thermal signature will not be the only feature present in the data, the dispersion patterns that oil makes in the water will be a key factor in detection and false positive rejection

Algorithm Investigation, Validation, and Refinement

- SLED uses powerful ML and CNN techniques for multi-spectral feature learning and classification to image and video data streams

- The SLED and SLED/M leak detection projects both successfully utilized fully CNNs for segmentation (a subset of CNNs) to classify and localize hazardous substances within video imagery in real-time

Algorithm Investigation, Validation, and Refinement

- Sensors placed at various distances and angles-of-view to provide a comprehensive suite of data for analysis and algorithm validation and refinement
- Care taken to simulate a surface turbulence as close to a typical river crossing as possible

Algorithm Investigation, Validation, and Refinement

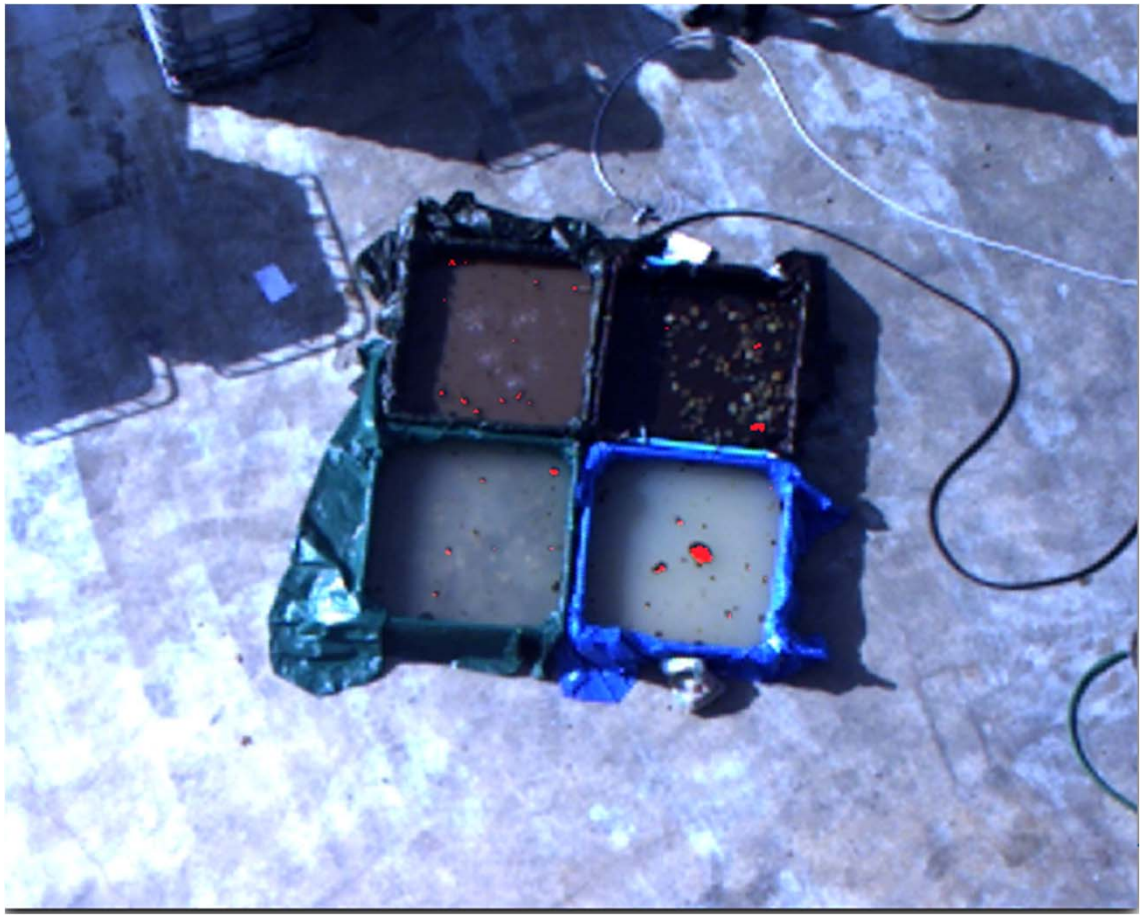
- **The algorithm will be validated using holdout sets of recorded data which were not previously used during training**
- **The results will be evaluated based on detection rates and false positive rates**
  - Accuracy of oil slick detection will be based on the following:

- *Precision* = $\frac{t_p}{t_p+f_p}$
- *Recall* = $\frac{t_p}{t_p+f_n}$
- *Accuracy* = $\frac{t_p+t_n}{t_p+t_n+f_p+f_n}$
- *Intersection over Union* = $\frac{Area\ of\ Overlap}{Area\ of\ Union}$
  - Metric for accuracy of segmentation labels

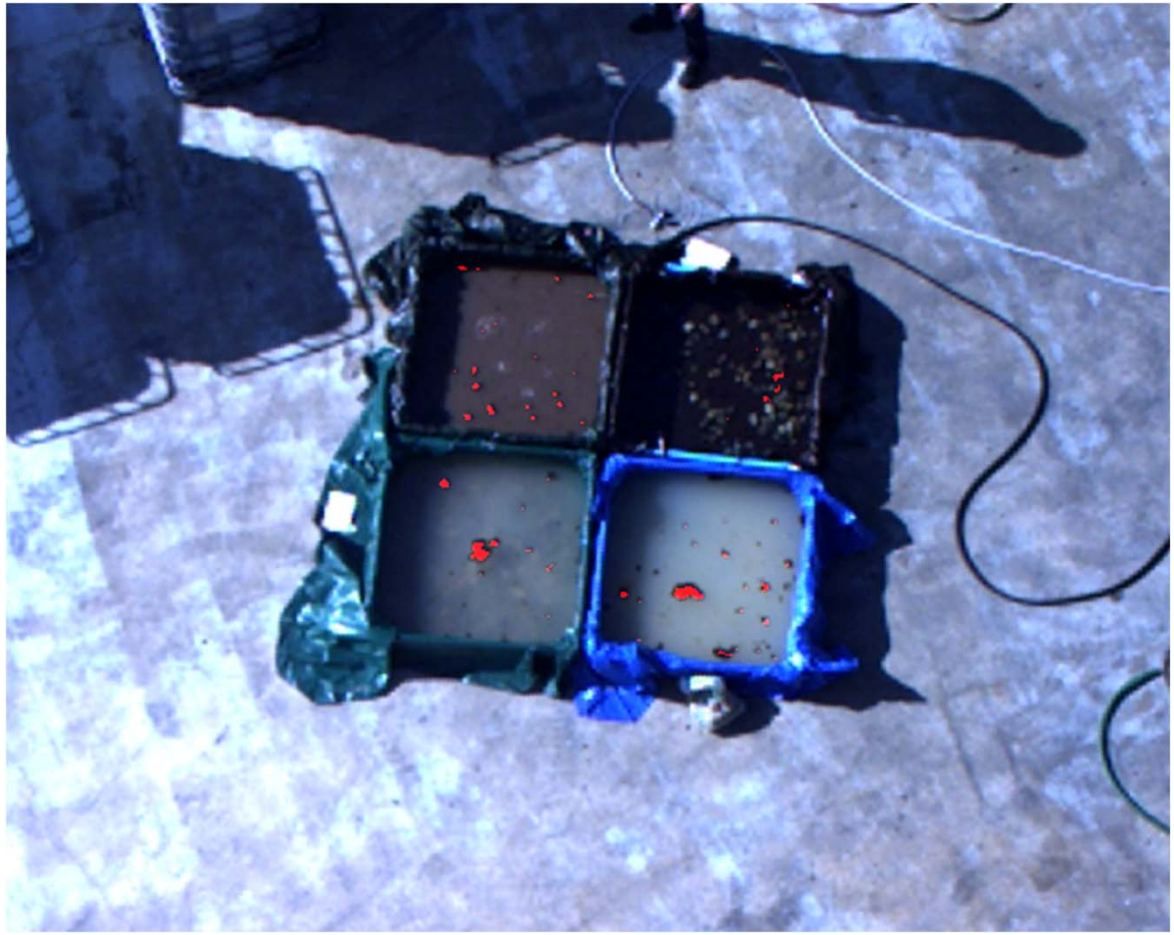
$$t_p = true\ positive$$
$$t_n = true\ negative$$
$$f_p = false\ positive$$
$$f_n = false\ negative$$

Initial Results

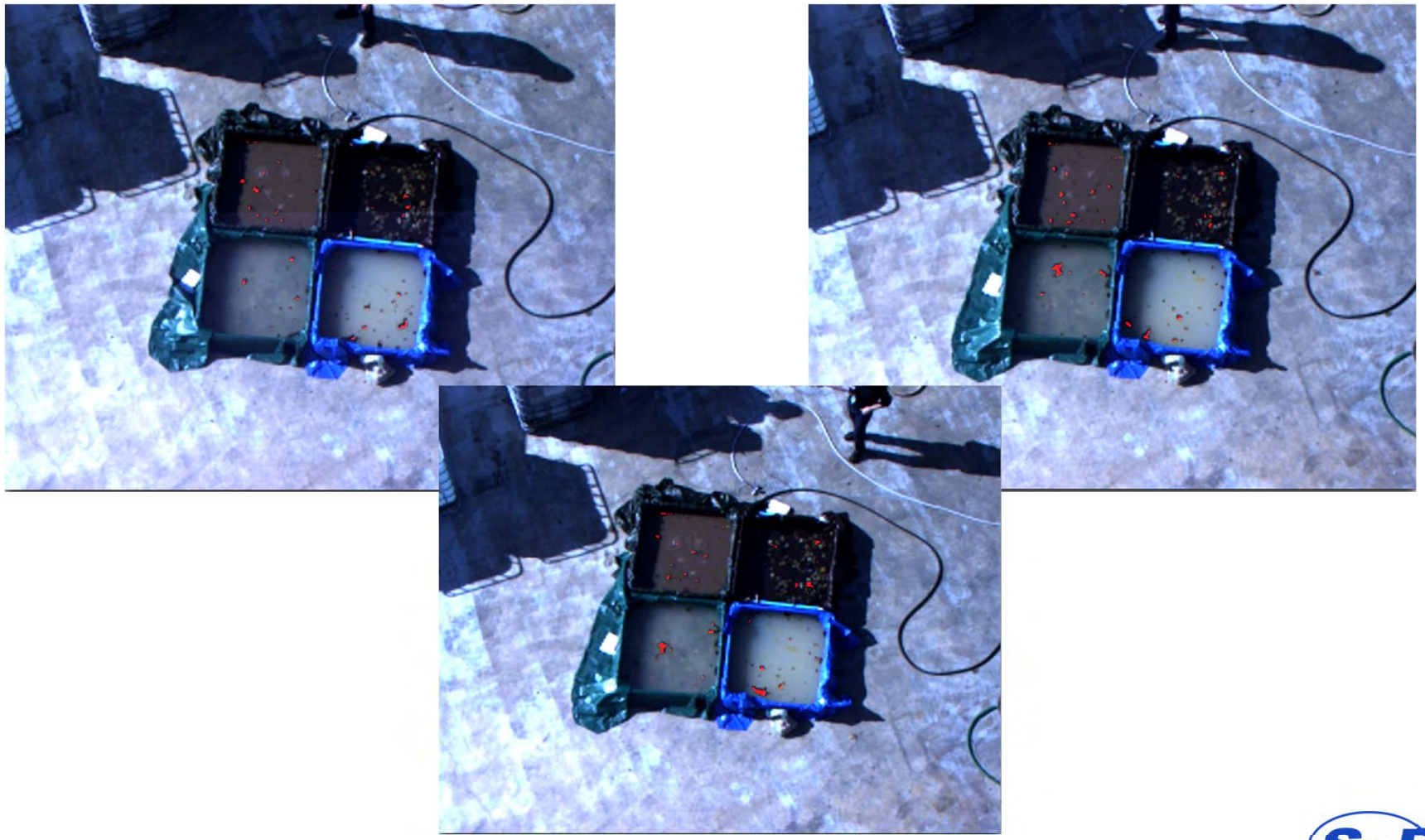
Different Substrates



Oil on Water



Oil on Water



Conclusion and Next Steps

- **There is a key need for real-time ability to determine if hydrocarbon product is floating on water surface**
  - Numerous pipelines run in marshy areas and detection/locating of leaks is an industry gap
- **Leaks from liquid hydrocarbon pipelines are frequent occurrences**
- **Navigable waterways and ecologically-sensitive surface water zones are regulated, high-consequence areas**
  - Small leaks from these pipelines are difficult to detect and can have significant environmental impacts
- **Another need is post-flooding surveys**
  - e.g., leaks from facilities after Hurricane Harvey
- **Ongoing development of SLED/Water seeks to develop a prototype technology to inspect water bodies aerially (e.g. drone) and provide real-time alerts if contamination is detected**

Questions?

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Pipeline Research Council International, Inc.

PRCI Mechanical Damage Program

Full-Scale Testing to Develop a Pipeline Leak Rate Estimation Tool

Mark Piazza
Colonial Pipeline Company

PRCI 2019 Research Exchange Meeting
Houston, Texas
Date March 5 - 6, 2019

Overview and Outline

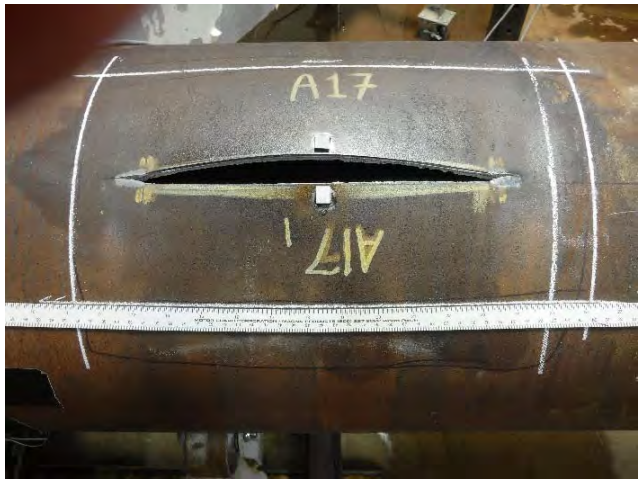
- Introduction
- Leak Rate Estimation
- Experimental Program
- Comparison to Modelling Techniques
- Sample Application
- General Observations

Introduction

- **Pipelines have a "license to operate" under a regulatory regime and focus of public demands for:**
  - maintaining system integrity
  - protecting public safety, and
  - protecting the environment
- **Integrity management programs are established to ensure demands and requirements are met**
  - IM programs are based, in part, on risk analysis and risk management concepts
  - quantitative risk management employs engineering tools

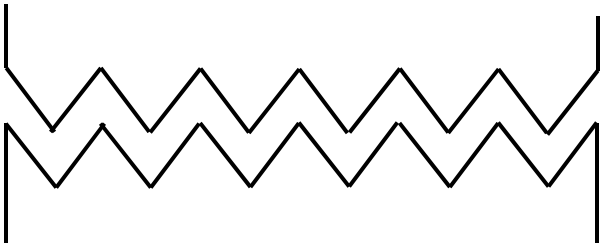
Leak Rate Estimation

- **Fracture mechanics considers crack mouth opening to infer potential for fracture**
- **In this application we use the crack mouth opening displacement to estimate the size to of the pipe wall opening**
  - Annex F of BS 7910 - Fracture mechanics provides CMOD or opening area estimate
  - Annex K of API 579 - describes ID and OD CMOD recognizing the effect of pipe bulging



Leak Rate Estimation

- **The leak rate through a small opening can be estimated as an orifice flow where the leak rate is a function of the**
  - Pressure differential across the pipe wall
  - Opening area
  - Fluid properties
- **More detailed leak rate estimation techniques consider**
  - Elongated path over textured fracture surface
  - Viscosity resistance to flow
  - Inertial losses due to flow direction changes
  - This technique requires calibration but is a more mechanistically direct approach



Experimental Program

- The theoretical estimates of the leakage rate show increasing leak rates with increasing pressure
- The initial thinking was that the theoretical models would provide “conservative”, upper bound leak rate estimates
- A testing program was developed to measure leakage rates at various crack sizes and internal pressures to compare with the theoretical value
- The goal of the experimental program was to develop an estimate of the total leak volume that could be derived from crack features

Experimental Program

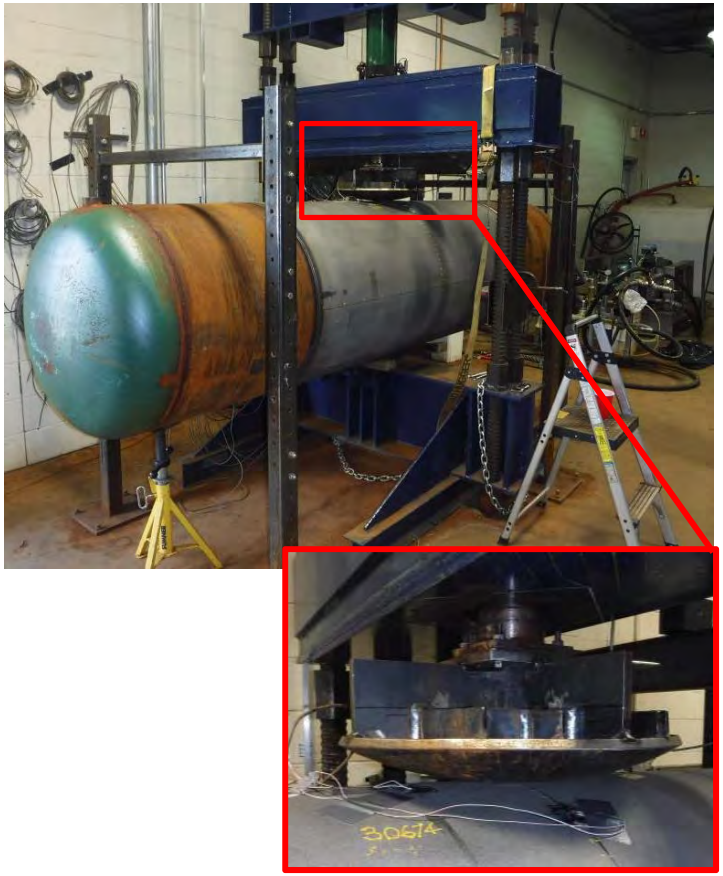
- **A test procedure was developed to consider a dent feature similar to one of interest**
  - 1.3% pipe OD . . . 10mm / 0.39 in. deep . . . (shallow dent)
  - 32 inch (813 mm) dia X-52 pipe with 0.281 inch (7.1 mm) wall
- **The BMT full scale test facility was used to create the dent, generate a fatigue crack and measure leak rates**

Experimental Program

The test procedure included:

1. Create dent to focus the pipe wall stress fluctuations at a specified location
2. Dent shape and restraint define the crack location, initiation surface and orientation
3. Cycle internal pressure to promote fatigue crack initiation and through wall growth

MD-4 Program protocols applied



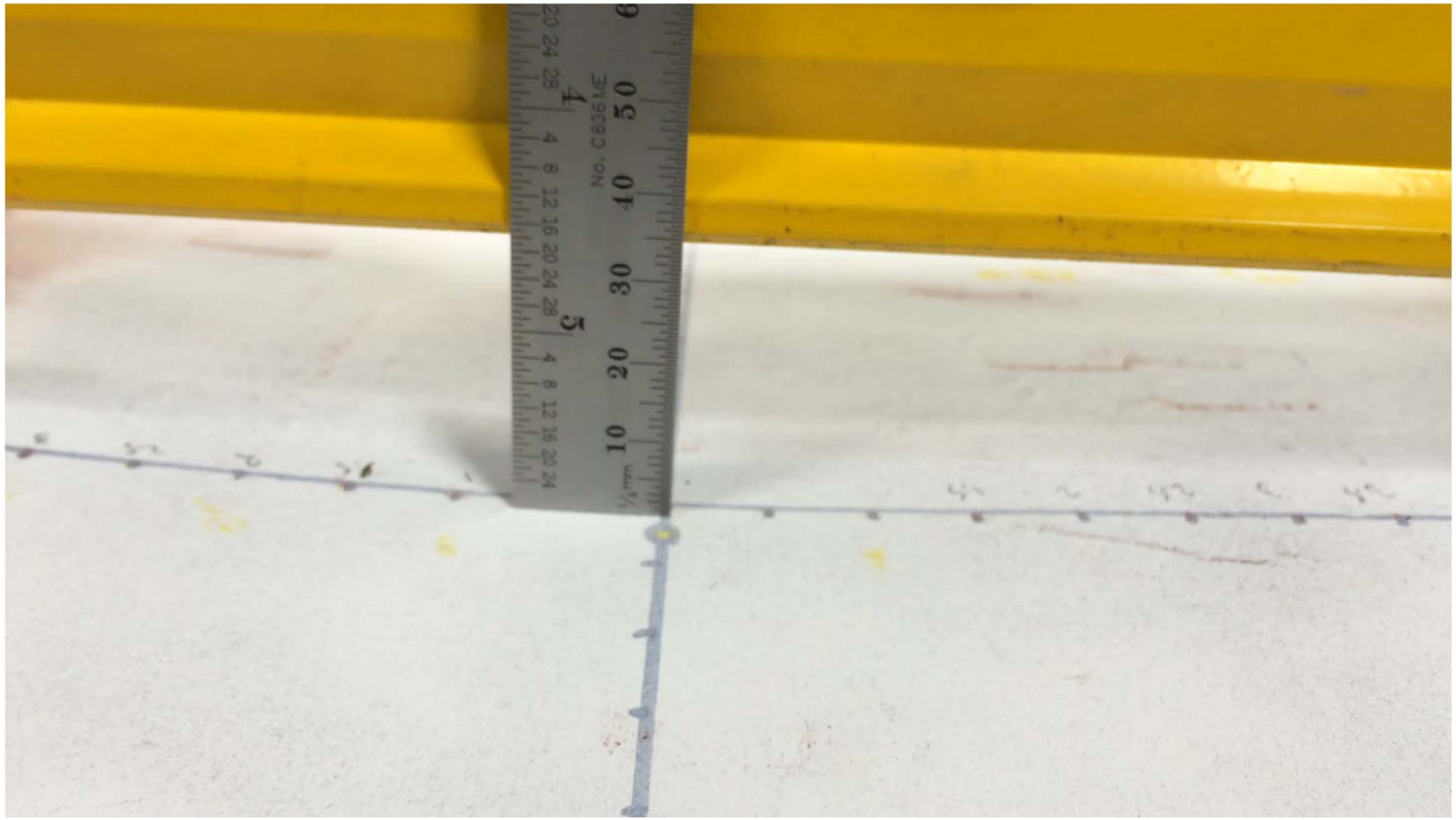
Experimental Program

Dent Creation:

- Pipe OD=32” ; Pipe WT=0.281”
- Indentation Depth = 10% OD (3.2”)
- Indentation pressure = 0 psi
- P_{max} = 70% P_{SMYS} = (639 psi)
- Residual depth at zero pressure after P_{max} = 1.23% OD (0.39”)
- Cyclic Pressure = 10% to 60% P_{SMYS} = (91 to 548 psi)

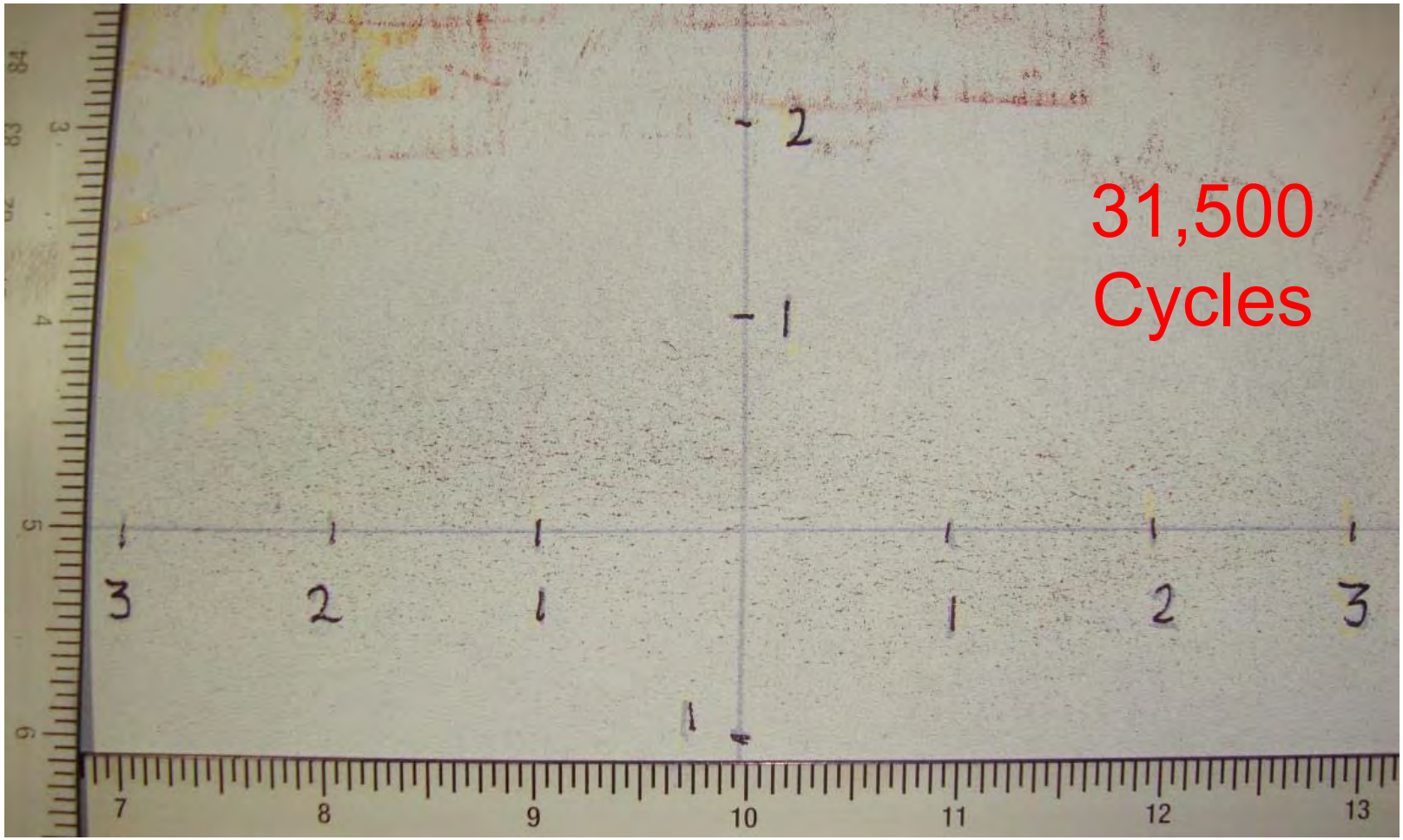
Experimental Program

90 to 600 psi pressure fluctuation



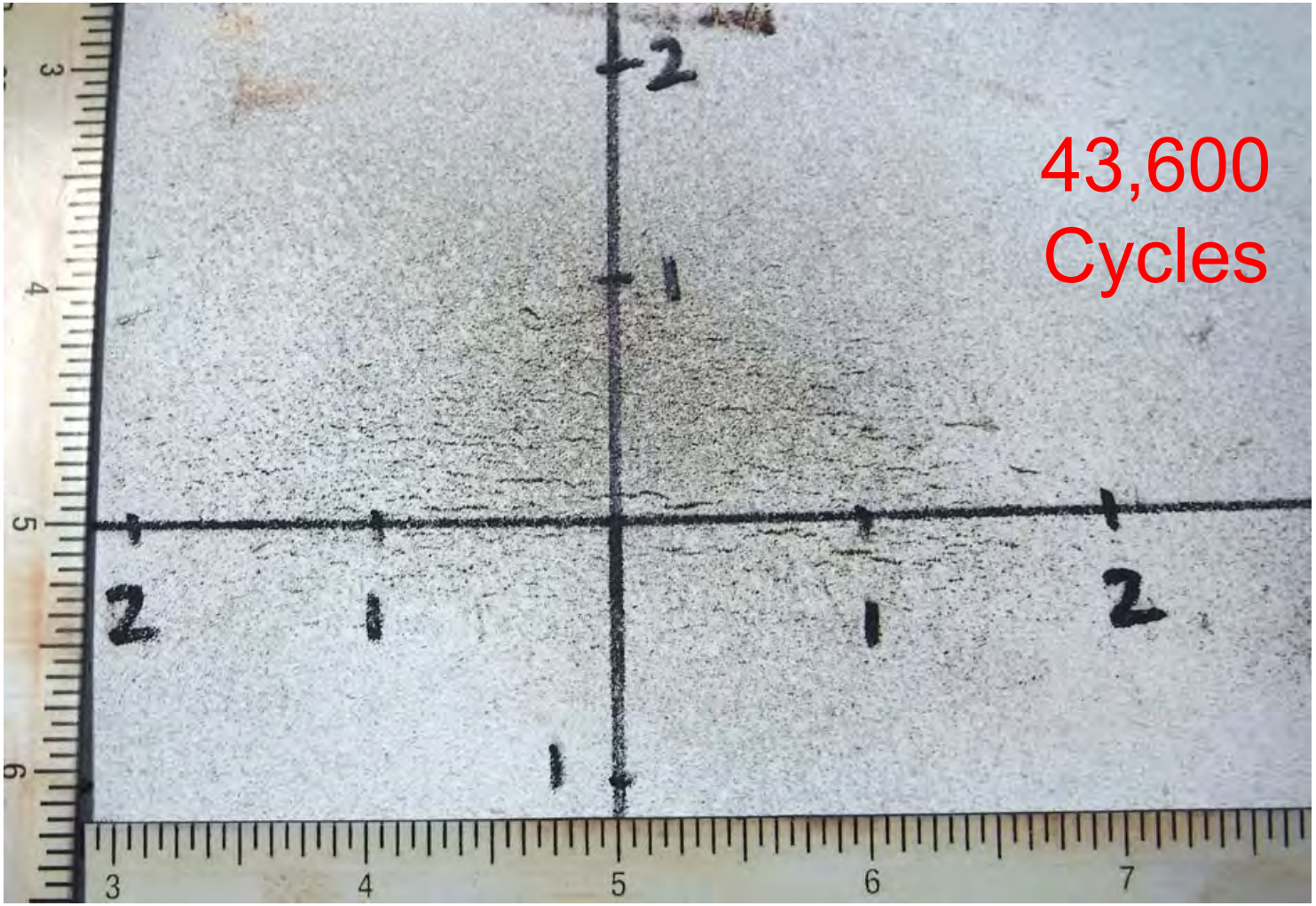
Experimental Program

- **Cycle Internal Pressure to Create Fatigue Cracks**



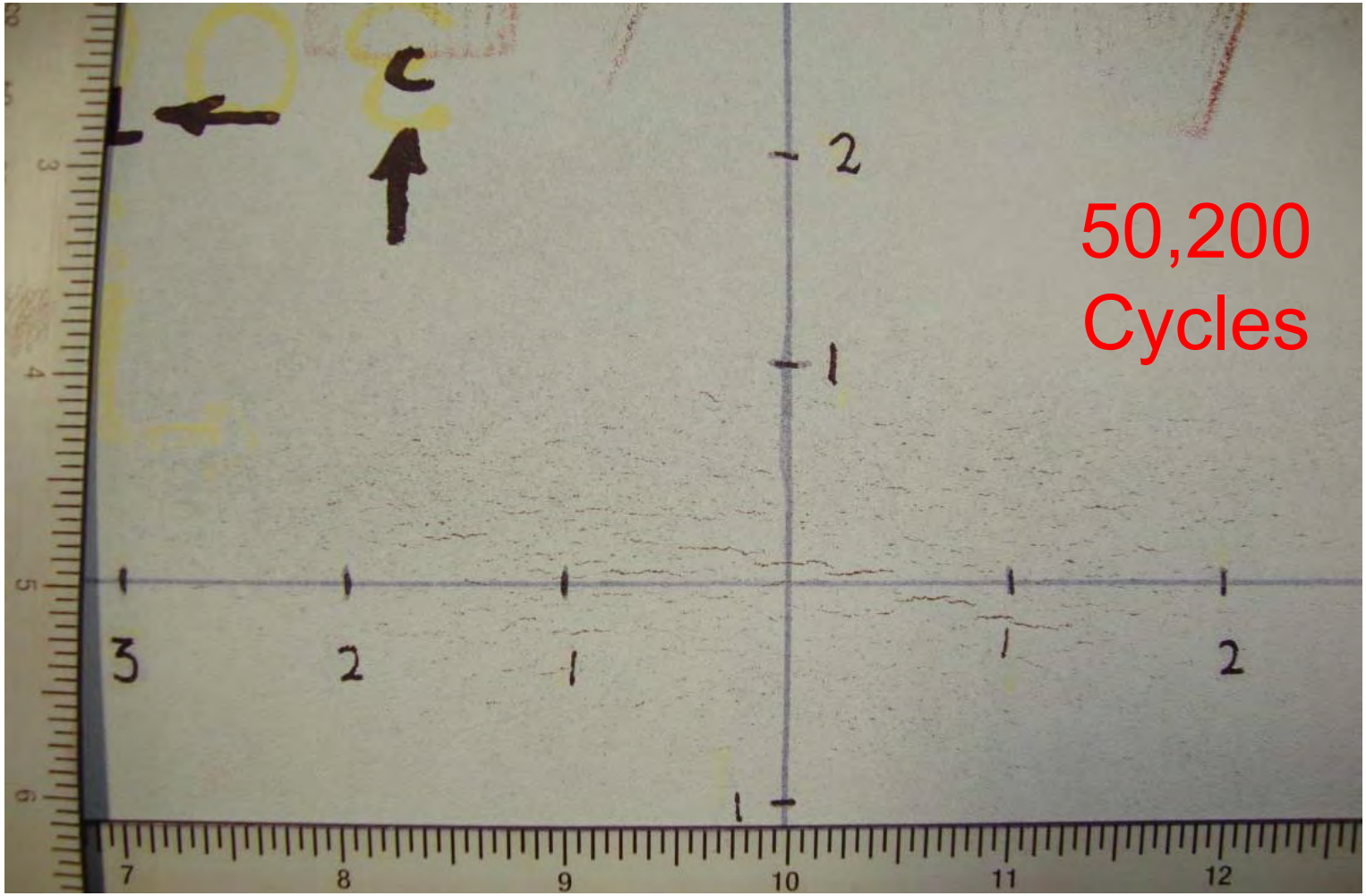
Experimental Program

- Cycle Internal Pressure to Create Fatigue Cracks



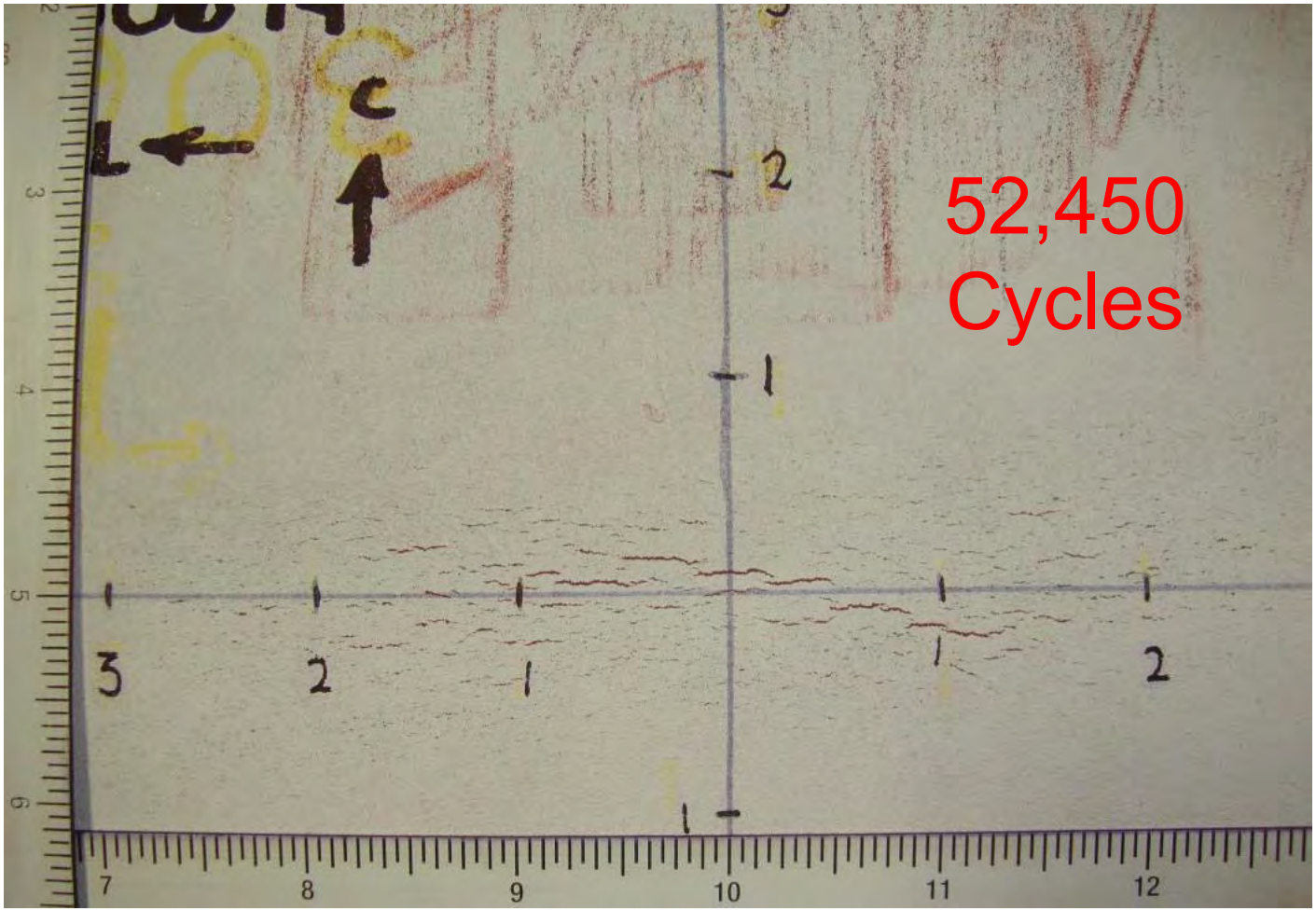
Experimental Program

- Cycle Internal Pressure to Create Fatigue Cracks



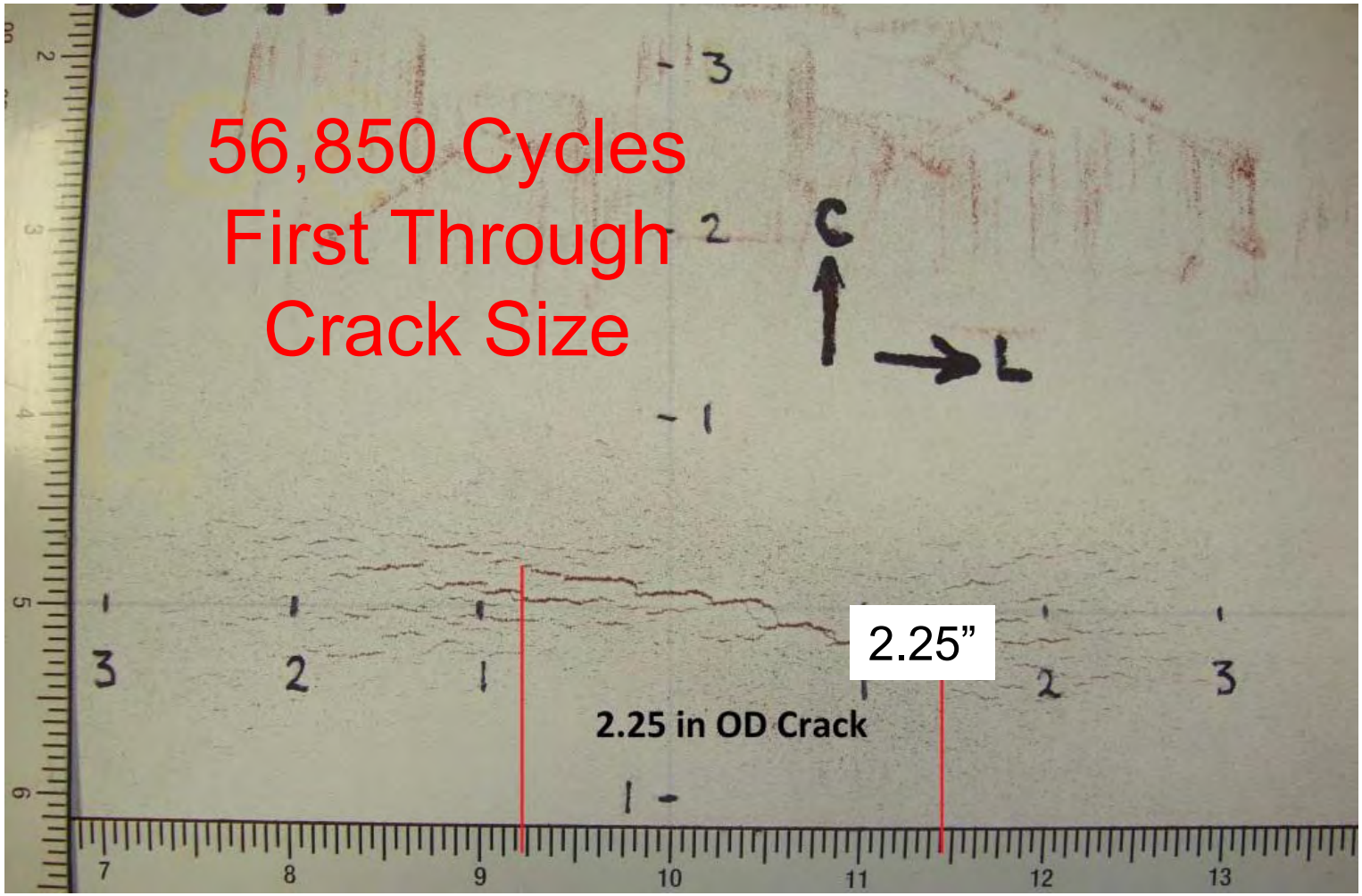
Experimental Program

- Cycle Internal Pressure to Create Fatigue Cracks



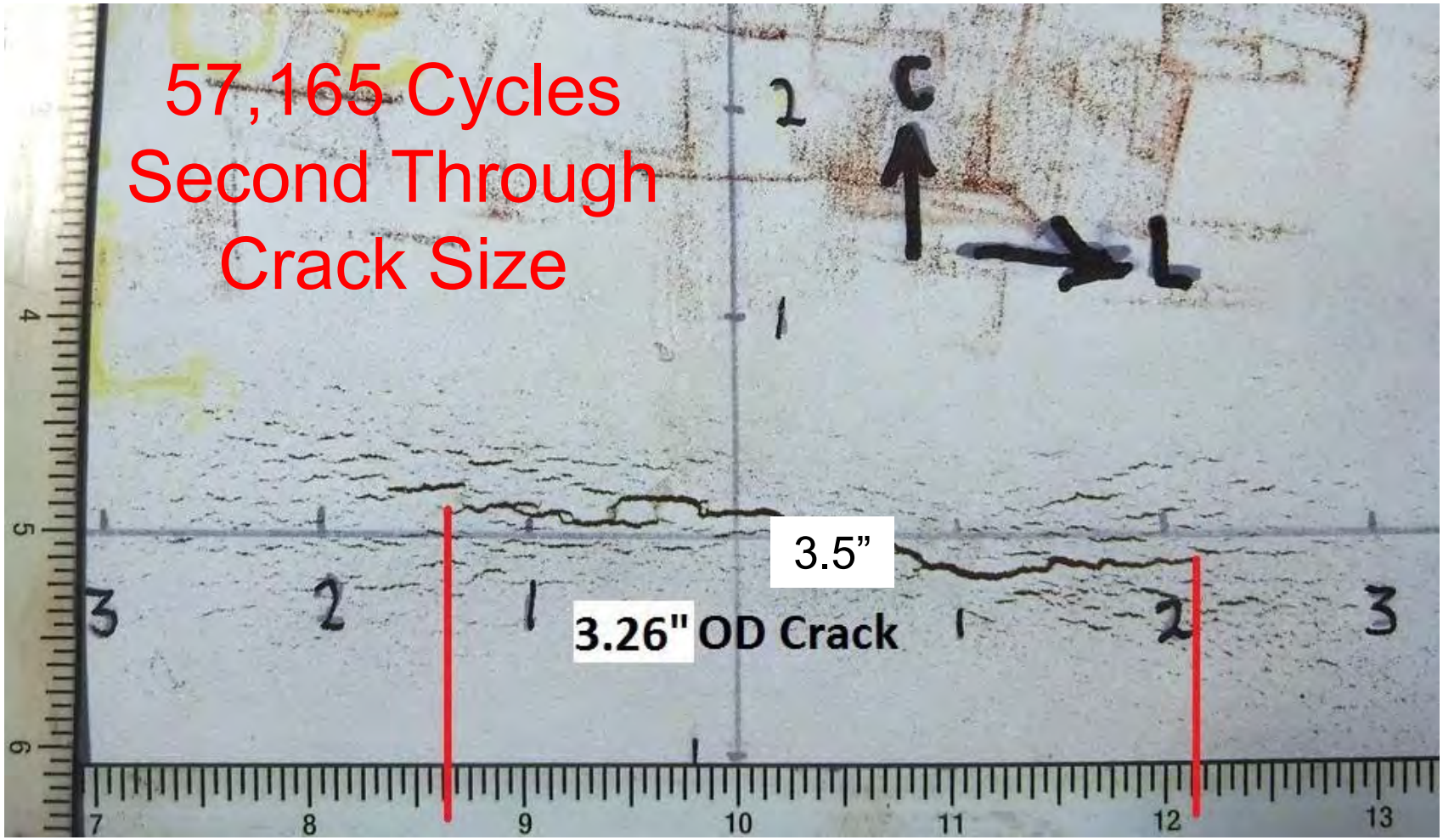
Experimental Program

- **Cycle Internal Pressure to Create Fatigue Cracks**



Experimental Program

- **Cycle Internal Pressure to Create Fatigue Cracks**



Experimental Program

- **Measured Crack Sizes**

Crack	Outside Surface Length	Inside Surface Length
1	2.25 inch (57 mm)	1.6 inch (41 mm)[+]
2	3.5 inch (89 mm)	2.80 inch (71 mm)

[+] Estimated based on ultrasonic measurements and the aspect ratio and through wall crack angles of similar experimentally observed cracks

Experimental Program

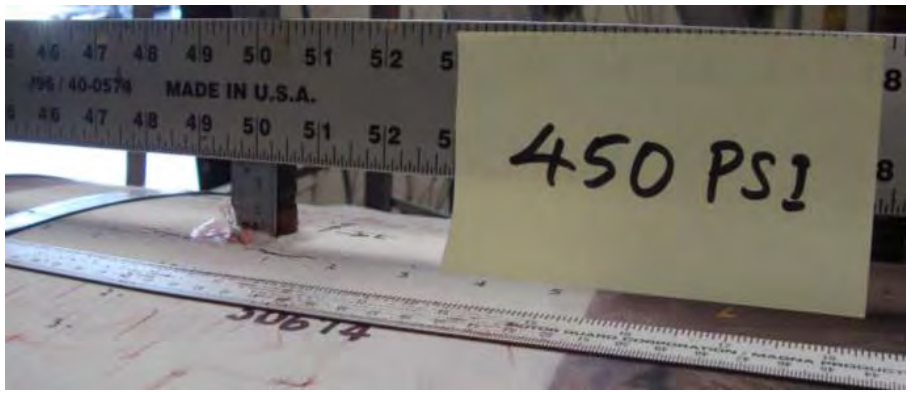
The leak rate test at the through wall crack includes:

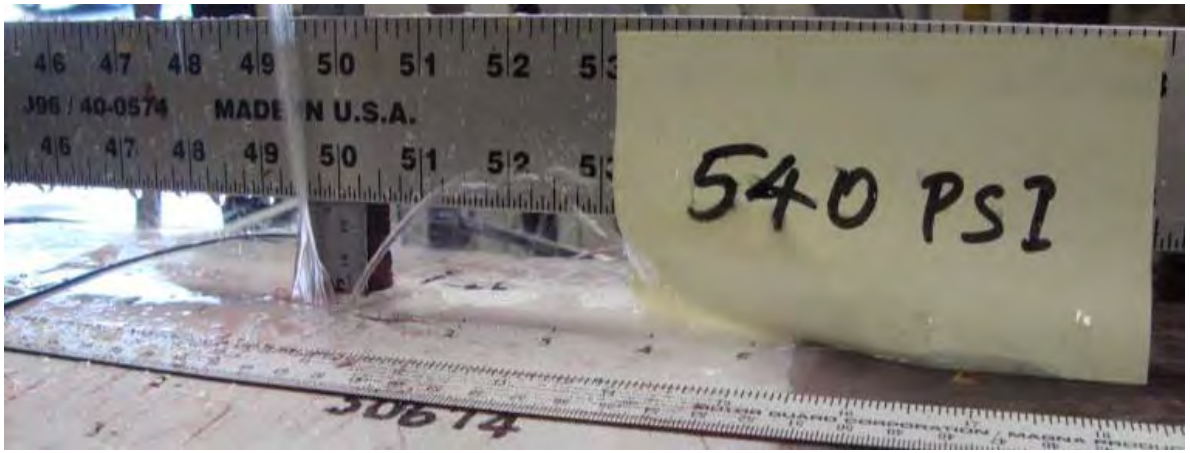
- MPI outside diameter surface crack length measurement
- Hold the internal pressure at a desired value
  - *90, 160, 180, 240, 270, 360, 450, 540 psi*
  - *0.62, 1.1, 1.24, 1.65, 1.86, 2.48, 3.10, 3.72 MPa*
- Capturing the water exiting the pipe over a time period
- Weigh the captured water (subtracting container)
- Divide water mass by density and leak time to estimate leak rate
- Increase the pipe internal water pressure and repeat

- **Cycle internal pressure to grow crack length and repeat**

Experimental Program

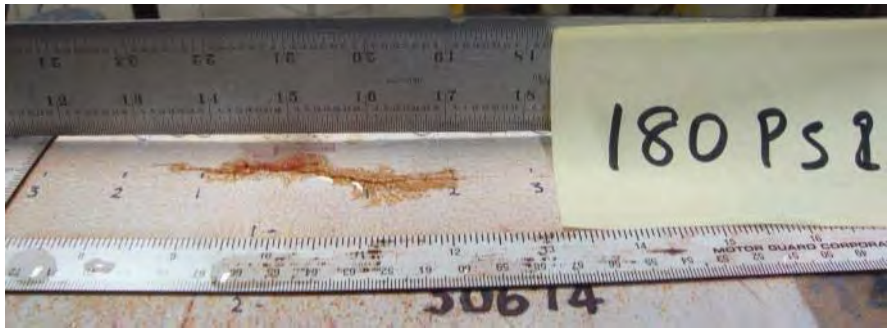
- **2.25” Crack Leak Rate (90, 160, 180, 240, 270, 360,450, 540 psi)**

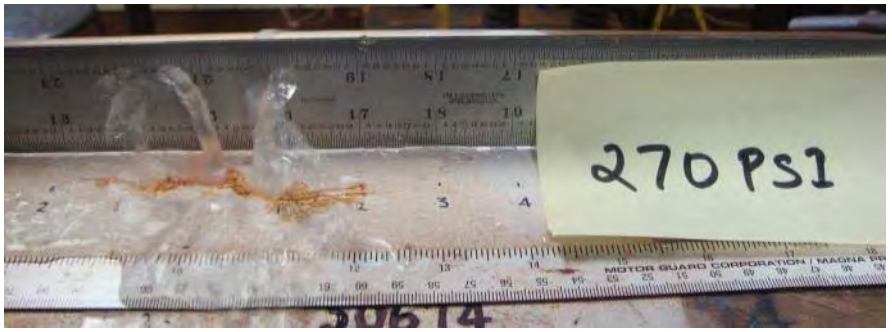


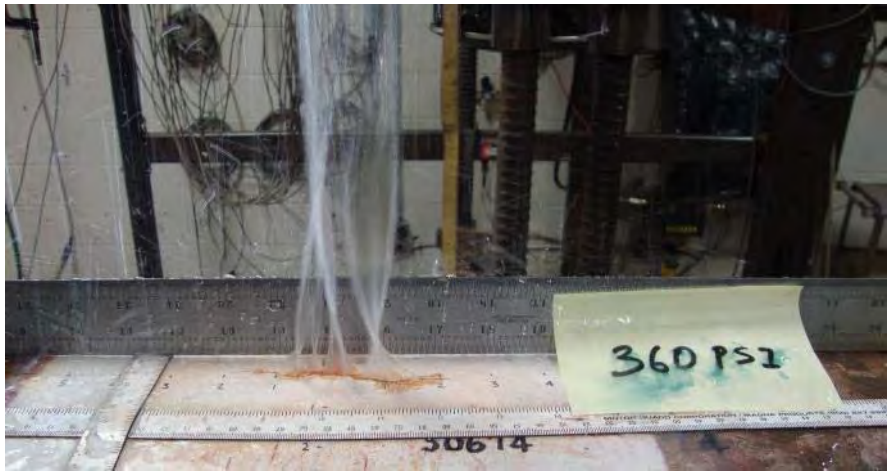


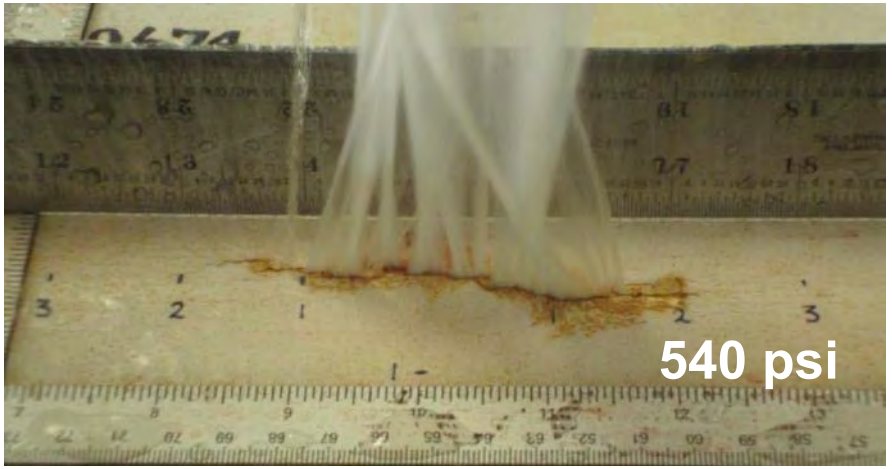
Experimental Program

- **3.5” Crack Leak Rate (90, 160, 180, 240, 270, 360, 450, 540 psi)**



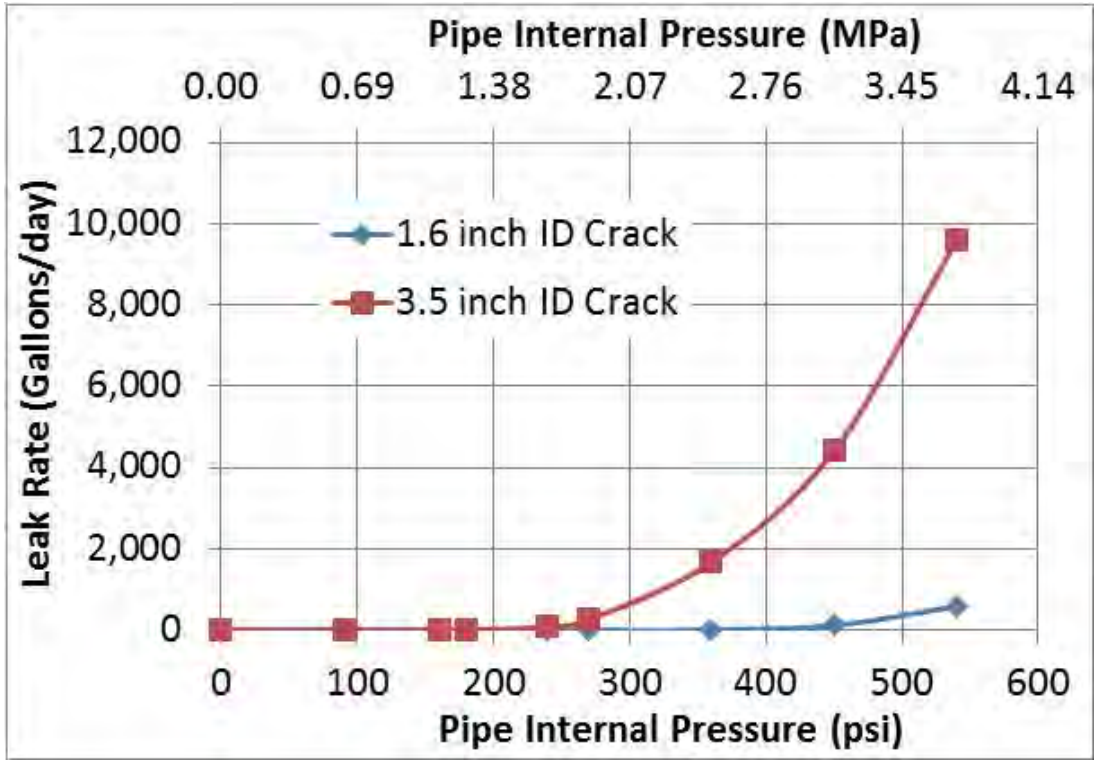






Experimental Program

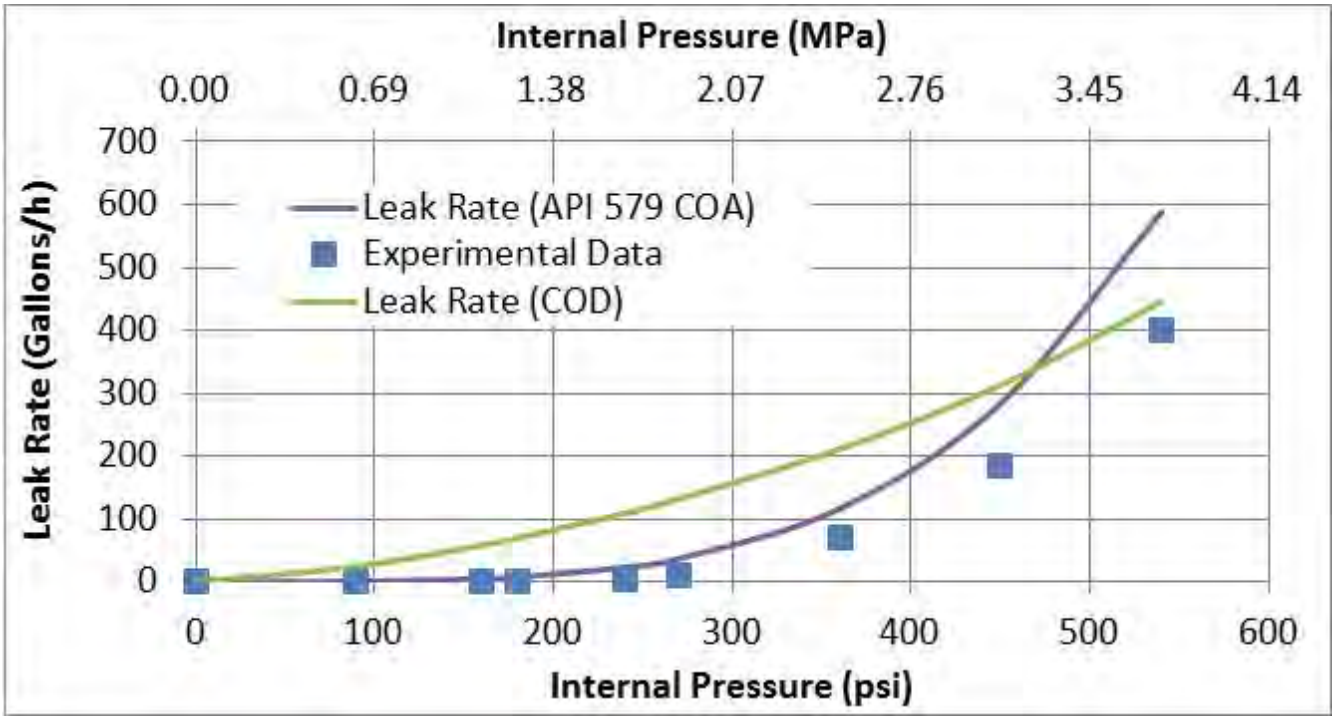
- **Leak Rate Summary**



Crack Length	No Leak Pressure
2.25 in (57 mm)	360 psi (2.48 MPa)
3.5 in (89 mm)	180 psi (1.24 MPa)

Compare of Models with Experiment

- **Models Reasonably Overpredict Leak Rates**

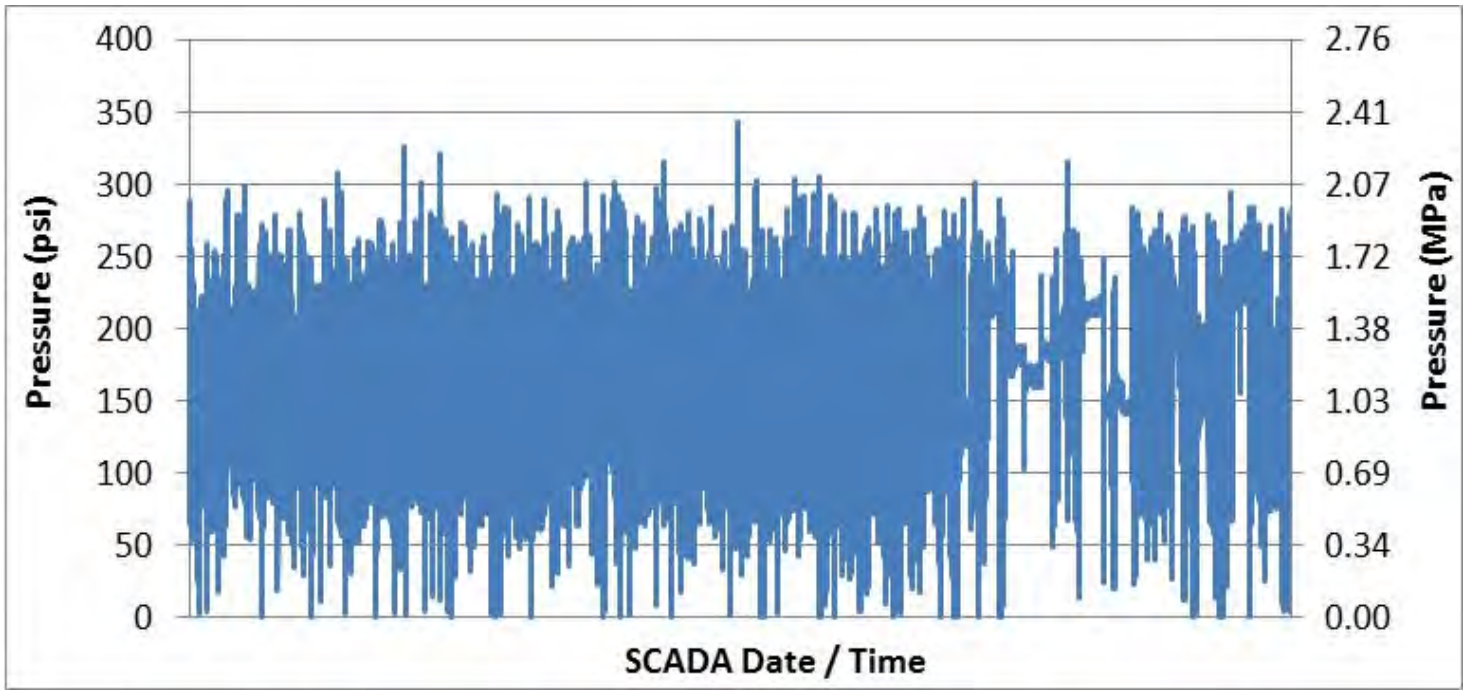


Sample Application

- **Estimate leak volume from a crack in a dent based on known operating conditions**
- **Consider time between initiation of a leak, detection and taking mitigating actions:**
  - pressure reduction to reduce the leak rate or stop leakage;
  - shutting down the line to reduce or eliminate further leakage, or
  - repair of the through wall crack with pipe replacement or sleeving.
- **Detection can include**
  - PPA/MBLPC (Pressure Point Analysis/Mass Balance Line Pack Compensation)
  - Acoustic tools that detect leak signatures

Sample Application

- **SCADA Defines Time at Each Pressure (Specifically No Leak Pressures)**

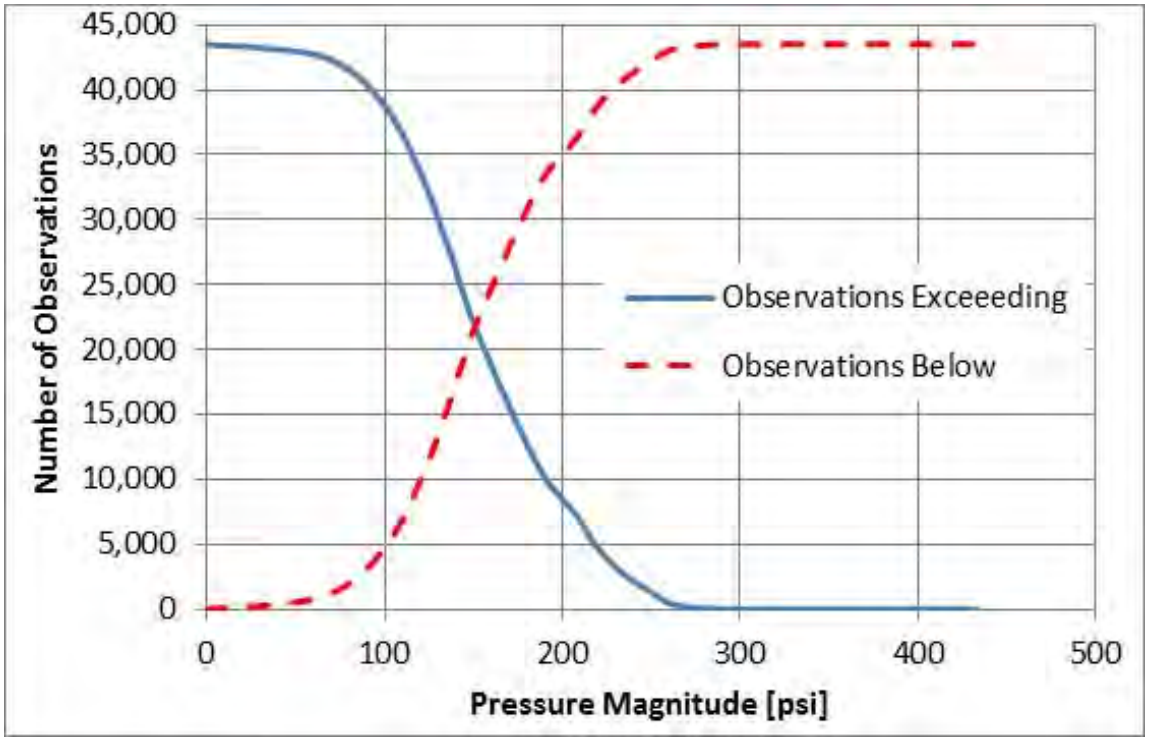


13 months of SCADA data considered Interpolated to feature site

Sample Application

- **SCADA Defines Time at Each Pressure (Specifically No Leak Pressure < 200psi)**

≈ 75% of observations below leak threshold



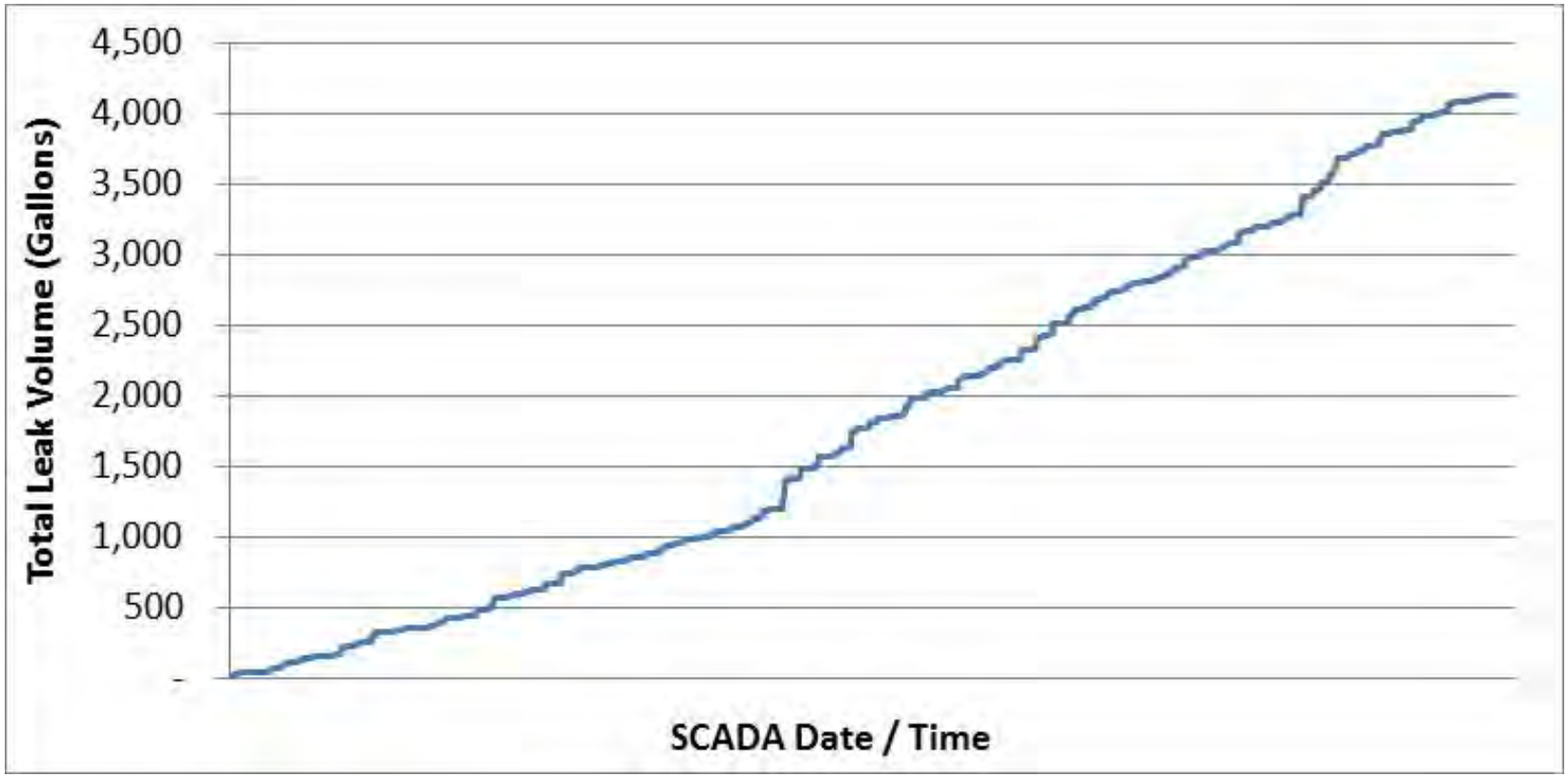
Sample Application

- Reduce SCADA data to peak & valley pts
- Define Time at Each Pressure & Leak Rate

		Total Leak Volume (Sept 2014 - Oct 2015) =					5,648.53	Gal
						Interval	Cumulative	
		Time	Time	Average	Average	Leak	Leak	
Date Time	Pressure	Interval	Interval	Pressure	Leak Rate	Vol	Vol	
	[psi]		[s]	[psi]	[gal/d]	[gal]	[gal]	
01/09/2014 0:00	195	0:54:00	3240.00	198	1.17	0.04	0.04	
01/09/2014 0:54	200	0:06:00	360.00	200	1.55	0.01	0.05	
01/09/2014 1:00	200	1:00:00	3600.00	202	1.93	0.08	0.13	
01/09/2014 2:00	203	0:01:00	60.00	196	1.08	0.00	0.13	
01/09/2014 2:01	189	0:00:00	0.00	186	2.30	0.00	0.13	
01/09/2014 2:01	183	0:00:00	0.00	181	3.52	0.00	0.13	
01/09/2014 2:01	178	0:01:00	60.00	176	4.30	0.00	0.13	

Sample Application

- For interval calculate leak volume & sum



Conclusions from Research

- **Experimental data provides means of validating or calibrating theoretical leak rate estimation techniques**
- **Estimated leak rates appear conservative (over predictions) for the conditions considered**
- **Additional validation for a greater range of pipe and crack sizes**
- **Can be used to support consequence assessment**
  - Provided realistic estimate of total leak volume

Thank you for your Attention

- Questions?

Pipeline Research Council International, Inc.

Visualizing buried networks in Augmented Reality – RA CANA

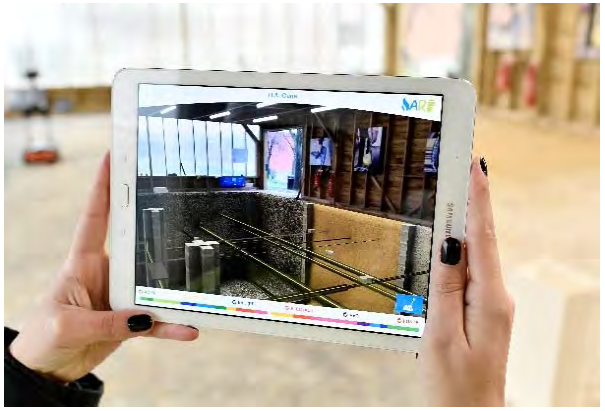
Carine Lacroix
GRTgaz RICE

PRCI 2019 Research Exchange Meeting
Houston, Texas
Date March 5 - 6, 2019

Introduction

- **Description of the project RA CANA objectives :**
  - to visualize in Augmented Reality
  - the underground
  - in the most simple and efficient way
  - thanks to a digital application

- **In order to**
  - to reduce the damages to the structure
  - by helping the operator to interpret the underground



Tasks taken

- **Using a test area dedicated to the works on detection / localization of underground utilities**
  - In 200 m2 area
  - buried pipelines of different material (steel, poly-ethylene, iron cast, PVC)
  - service lines, electrical cables, markers, marker tapes, PE slabs
  - at different depths
  - Recovered by different types of soil
  - Urban area simulated (the half of the area recovered by asphal)
- **Geopositioning (XYZ positions) of each buried items with a precision of 3 cm maximum.**
- **Modeling data**
  - made in FBX format thanks to a CAD software.
- **Indoor localization (“Match Moving” Methodology)**
- **Realistic rendering**

Research Results and outcome

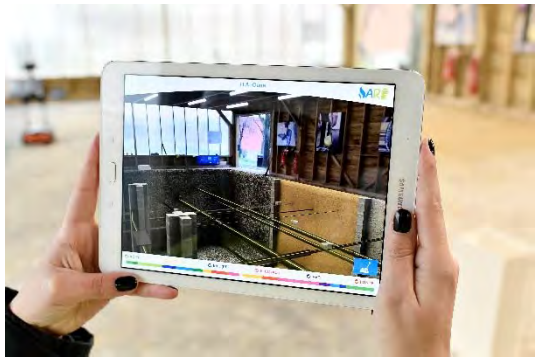
- **Data Geolocalization is one of the essential step :**
  - The data positioning mode and accuracy must be in accordance to the augmented reality application's use cases
  - Because critical parameter for utilities mapping
  - Indoor localization
  - GPS system cannot be used because the test facility is covered
  - Match Mooving Methodology
    - *Markers were installed on the four walls of the facility*

Research Results and outcome

- **Rendering was made in a realistic way:**
  - Physical laws defined in order to make the 3D scene more realistic
  - For underground utilities mapping, the key element : the distinction between different networks.
  - Distribution pipelines were represented as a black cylinder with yellows stripes
  - Separation walls modeled and textured too, in order to give the user the illusion of depth

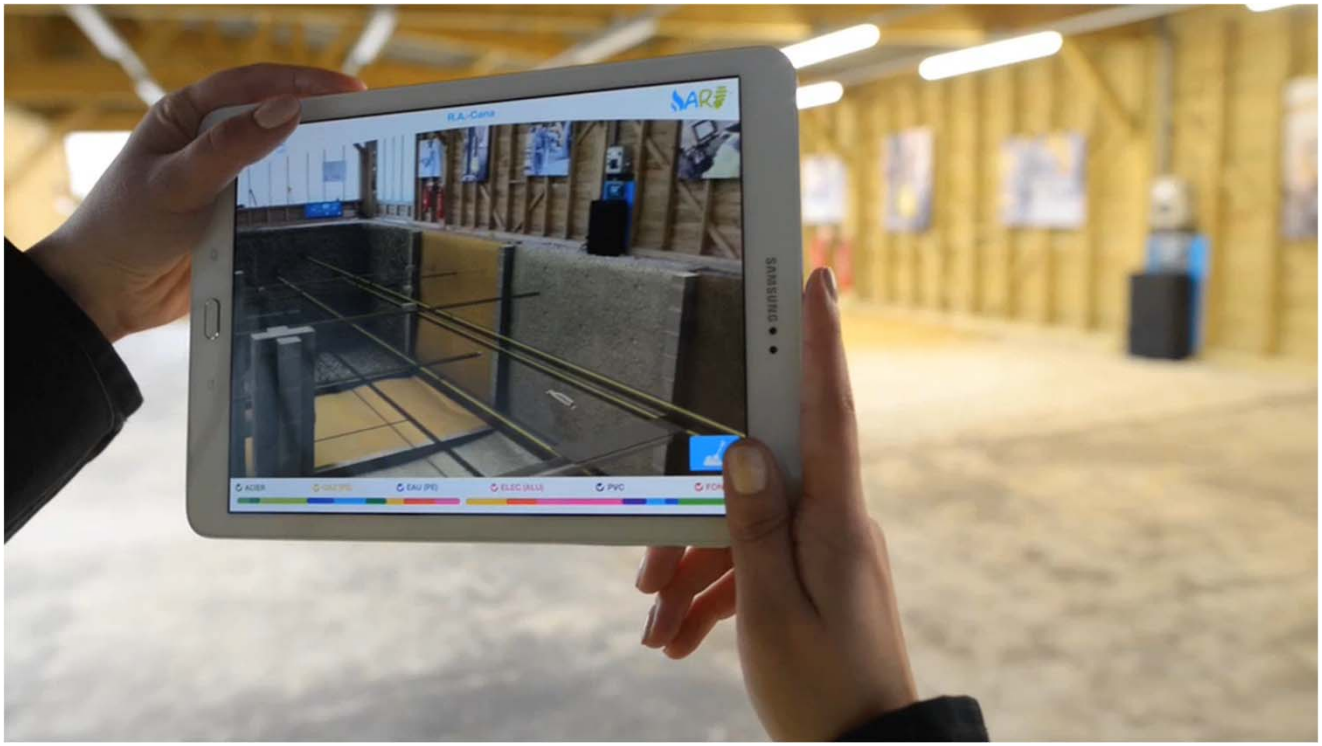
Research Results and outcome

- **Two modes were tested:**
  - an application on Samsung S2 tab

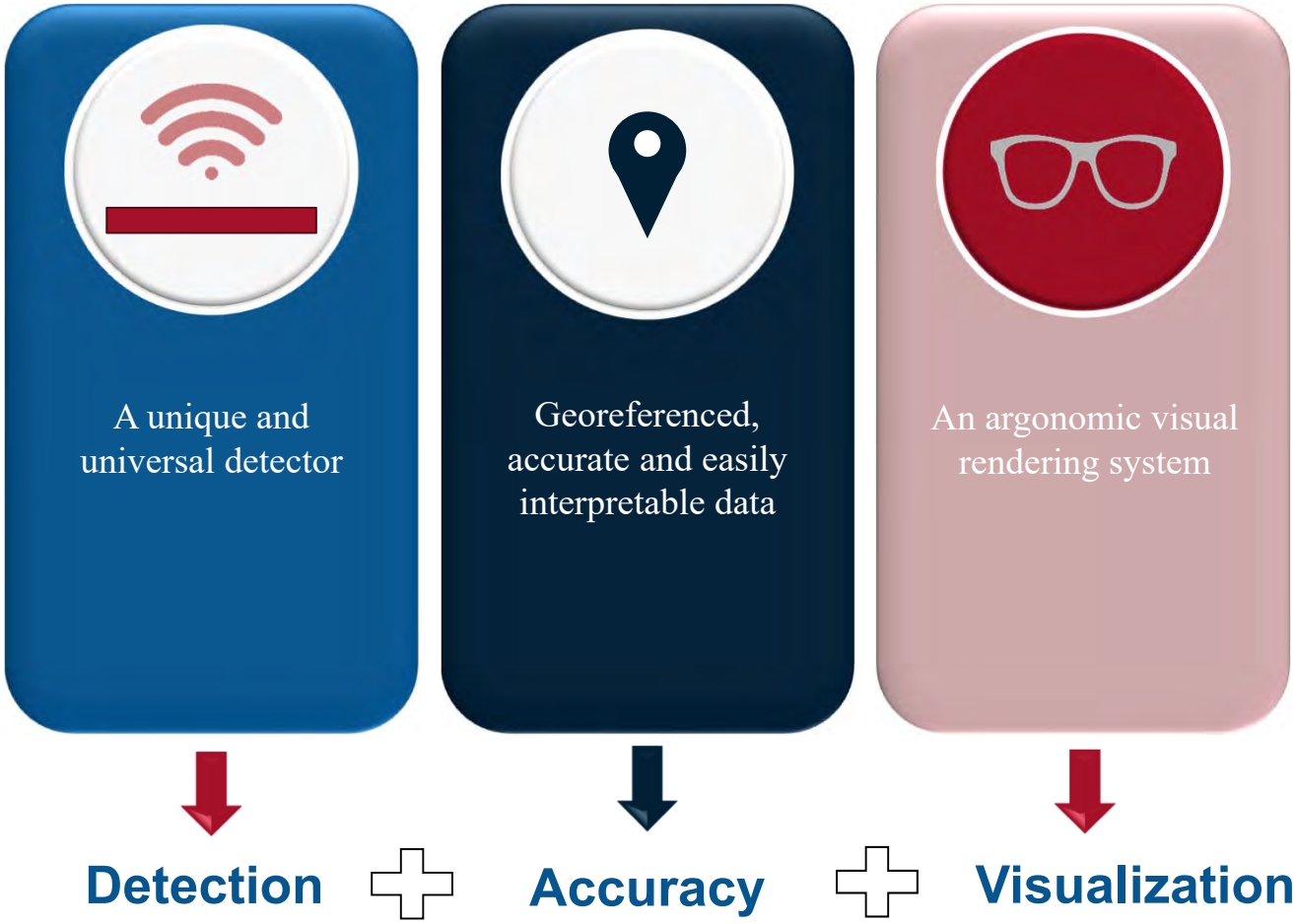


  - and an application on MS Hololens

The following…



Three major steps



How?

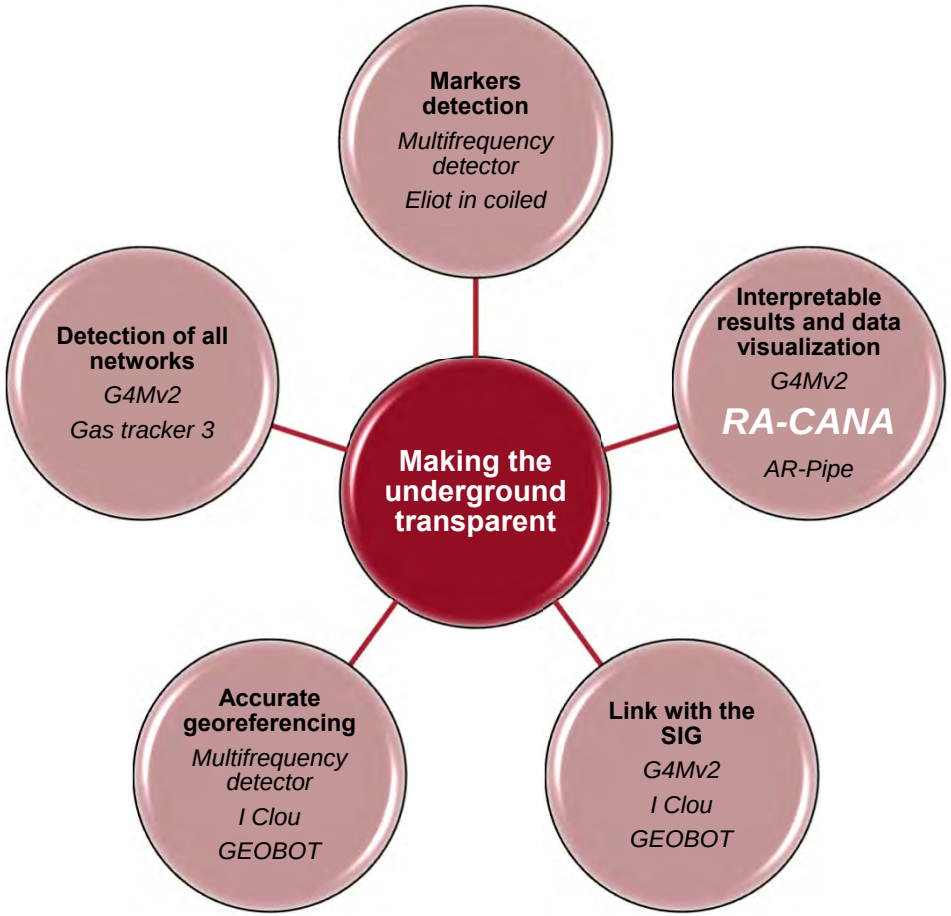
Universal and single detector

Communicating markers and pipes

Field location
Projection of GIS data

Data vizualisation

Our R&D projects are related to expected functionalities



Conclusions

- **Third-party interferences is one of major issues of underground utilities operators**
- **Operators can continue together :**
  - on improving detection/mapping tools and exploring **AR technology** through different use cases and applications
  - On improving each step of the data processing and display to switch from a lab application **to a real site**

  - On making the **underground transparent**

Enhanced Girth Weld Performance for Grade X70 Pipelines

Presented by:
Robin Gordon, Pat Vieth, Yong-Yi Wang,
Bill Bruce & Daniel Guzman

PRCI Research Exchange
Houston
March 5 – 6, 2019

MICROALLOYING Dynamic Risk CRES DNV·GL iti INTERNATIONAL

Overall JIP Objectives

- Determine the circumstances of recent girth weld failures in Grade X70 pipelines.
- Develop guidelines to enhance the performance of girth welds in X70 pipelines. The guidelines will cover both:
  - Linepipe
  - Girth Welding

JIP Workscope & Current Status

- JIP launched in March 2017 and initiated in June 2017.
- The JIP will be broken down into the following 3 Phases:
  - Phase 1 – Review of Recent Failures & Development of Preliminary Guidelines based on Current Knowledge
  - Phase 2 – Experimental Test Program and Supplementary Finite Element Analysis
  - Report – Develop Best Practice Guidelines and Performance Requirements
- The JIP has currently 23 Sponsors
  - Pipeline Operators, Line Pipe Manufacturers, Steel Producers

JIP Project Team

Technical Team

- Robin Gordon
- Yong-Yi Wang
- Bill Bruce
- Patrick Vieth
- Daniel Guzman

Technical Advisors

- Malcolm Gray
- Phillip Kirkwood

Advisory

- Stephen Rapp (Chair)
- David Johnson
- David Warman
- David Horsley

JIP Sponsors

- American Steel Pipe
- Australian Pipeline Auth.
- Arcelor Mittal
- Berg
- Borusan Mannesmann
- Boardwalk
- Cheniere
- Dura Bond
- Enbridge
- Energy Transfer
- Enterprise
- Evraz
- Jindal
- JSW Steel
- Kinder Morgan
- Pacific Gas & Electric (PG&E)
- POSCO
- SSAB
- Stupp
- TransCanada
- Welspun
- Williams

Project Status

- Phase 1 has been completed.
- Phase 2 will be complete by end of March 2019.
- Phase 3 will be complete by end of May 2019

JIP Workscope : Phase 1 (6 Tasks)

Task	Description
1	Review of recent pipeline failures
2	Review of Grade X70 pipe manufacturing methods.
3	Review of Metallurgical Work on HAZ Softening.
4	Review of Under-matching / HAZ Softening
5	Development of Preliminary Guidelines
6	Development of Phase 2 Workplan

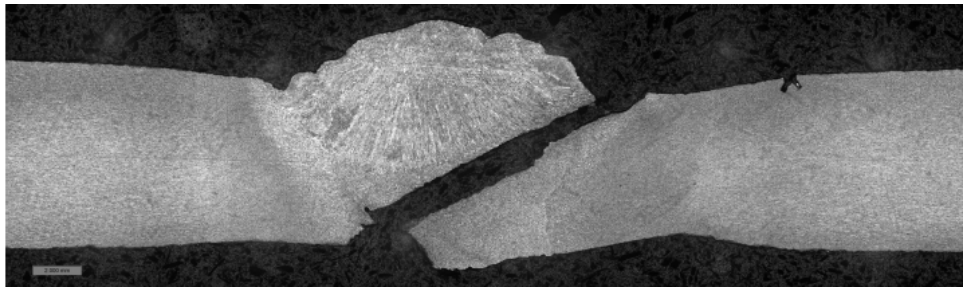
Review of recent pipeline failures

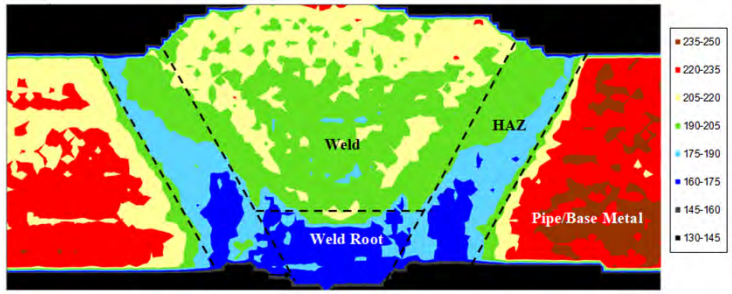
- Five (5) failures were reviewed.
  - Four (4) in-service failures
  - One (1) hydrostatic failures (leak)
- All Failures occurred in SMAW or SMAW / FCAW girth welds.
- Several steels exhibited low Pcm values

Incident	Pipe Grade	Diameter (inch)	Wall (inch)	Pipe Manufacture	Pipe Pcm	Girth Weld
1	X70	20	0.312	ERW	0.131	SMAW (E6010 / E8010)
2	X70 / X80	30	0.486	SAWH	0.185	SMAW E6010 + FCAW (*)
3	X52	12.75	0.250	ERW	0.124	SMAW
4	X70	30	0.430	SAWH	0.156	SMAW (E6010 / E8010)
5	X70	30	0.515	SAWH	0.169	SMAW (E6010 / E8010)

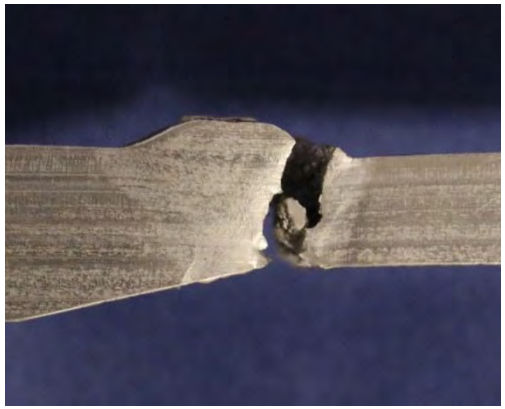
Typical Girth Weld Failures

Incident 1
Grade X70 ERW

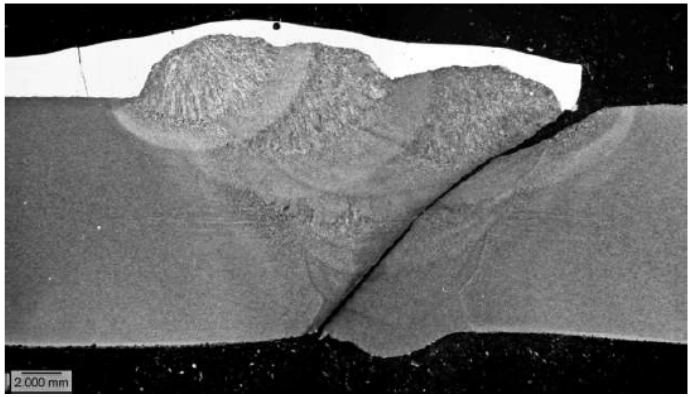




Incident 2
Wall thickness transition



Incident 4
Grade X70 SAWH



Review of Recent Pipeline Failures

- Failures occurred during original construction hydrostatic test or within a few years of entering service.
- Post Failures Investigations included:
  - Visual examination of failed girth welds
  - Metallurgical investigation: Existence of flaws
  - Pipe properties, mechanicals and composition
  - Cross-weld tensile tests and hardness tests

Review of Recent Pipeline Failures

- Girth welds did not contain weld defects
- Girth weld high-low misalignment was not a contributing factor
- Pipe strength met minimum API 5L requirements
- Cross-weld tensile tests met API 1104 requirements
- Pipes and welds (including inspection) were code-compliant

Review of Recent Pipeline Failures

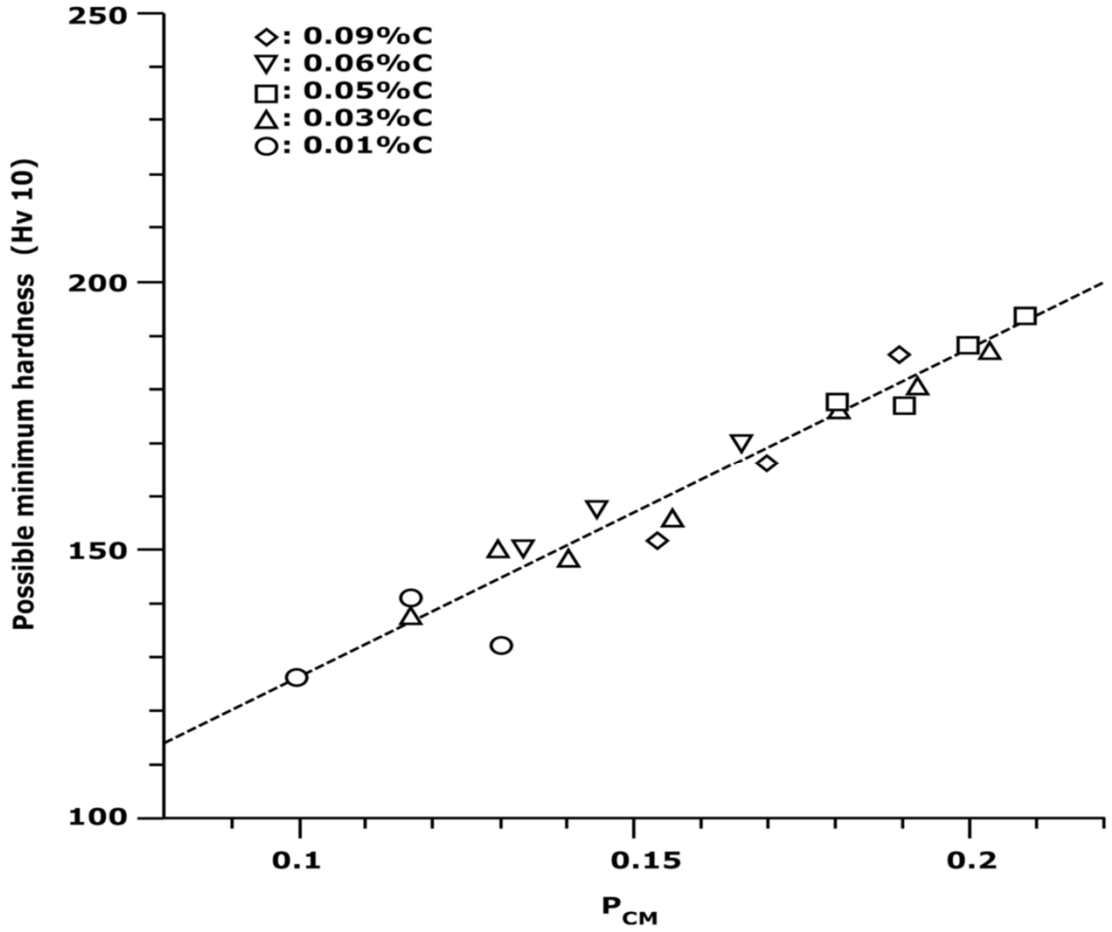
- Tensile overload failures occurred at low nominal strain in Grade X70 girth welds made with SMAW and SMAW / FCAW procedures.
- The major factors included;
  - Girth weld under-matching accentuated by the use of lower strength consumables in the weld root.
  - Heat-affected zone (HAZ) softening.
  - The bevel geometry of manual welding processes that favor tensile failure through plastic straining along 45-degree shear planes.

Review of Grade X70 Pipe Manufacturing

- There is no universal alloying or rolling philosophy for API 5L Grade X70 linepipe.
- Almost all modern X70 linepipe is produced from TMCP Steel.
  - Carbon content has reduced to improve weldability, Charpy Toughness, Fracture Control etc.
  - High water cooling rates have been adopted by some mills to reduce alloy costs resulting in lean steels that derive a large proportion of their strength from TMCP.
  - Concern that low carbon steels with lean microalloying may be particularly susceptible to HAZ softening.

Review of Grade X70 Pipe Manufacturing

- **HAZ Softening vs Pcm**



A correlation between Pcm and HAZ Softening is being evaluated in Phase 2 of the JIP.

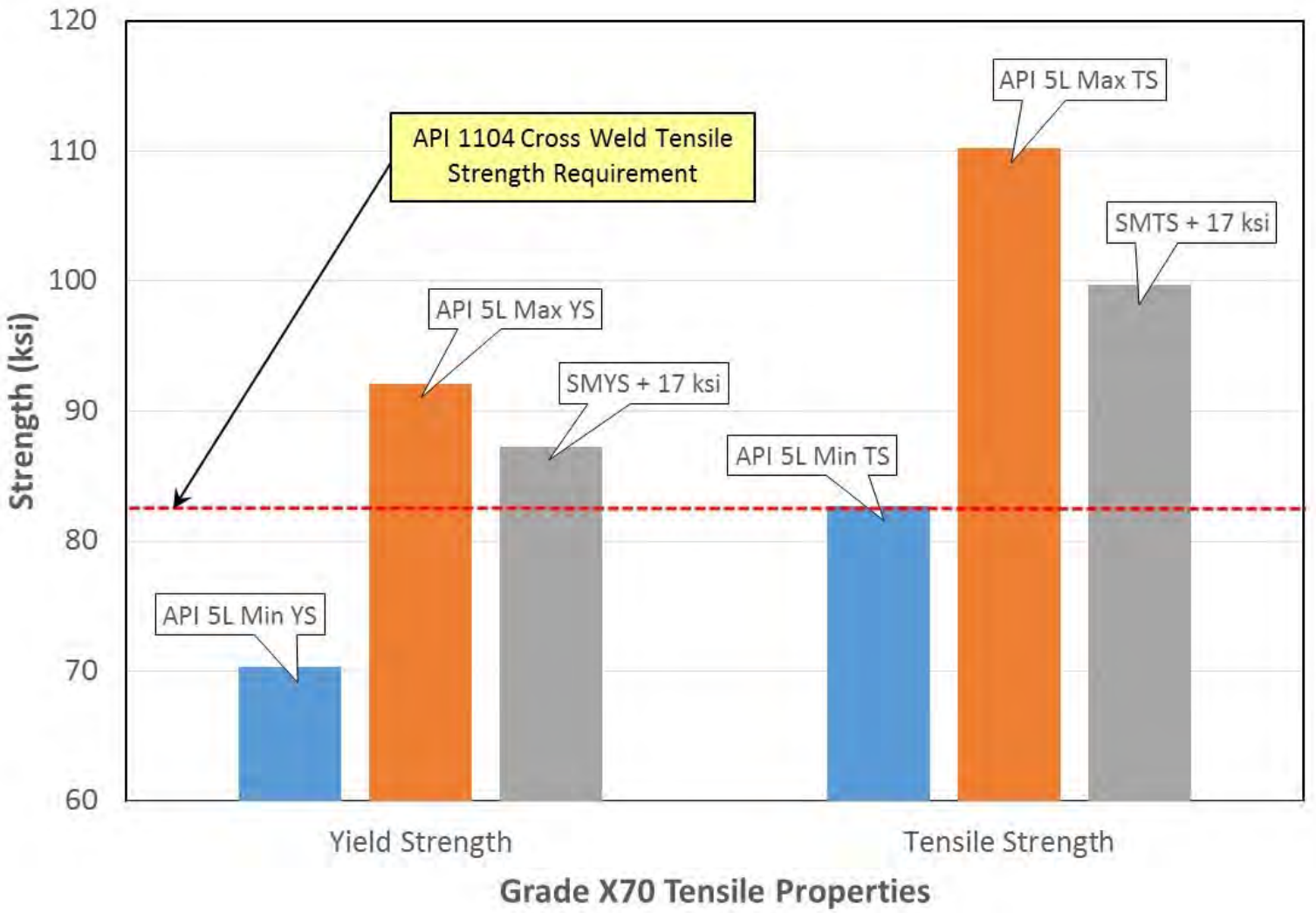
Role of Girth Weld Overmatching

- No significant change in SMAW welding consumables for the past 25+ years.
- Increased use of pre-heat for cellulosic stick welding in the past 10+ years thereby reducing weld cooling rates
- Although API 1104 requires that cross weld tensile tests are performed during WPQ, it is important to note that API 1104 does not require girth weld overmatching.
- Two cross weld tensile specimen geometries included in API 1104:
  - Conventional cross weld (weld cap and root not machined off)
  - Reduced Section Tensile (weld cap and root machined off)

API 1104

- Main Body
  - *If the specimen breaks in the weld or fusion zone and the observed strength is greater than or equal to the SMTS of the pipe material and meets the soundness requirements of 5.6.3.3, the weld shall be accepted as meeting the requirements.*
- Annex A
  - *If the specimen breaks at a strength equal to or greater than the SMTS of the pipe, the result is acceptable and no further testing is required. Although tensile specimen failure in the weld is acceptable, provided the strength requirement is met, gross weld strength under-matching should be avoided*

API 1104 : Girth Weld Overmatching



Phase 1 : Preliminary Recommendations

Linepipe Specification Requirements - Pcm

- Develop guardrails to limit chemical composition / TMCP rolling practice
- Mitigate excessive HAZ Softening

Linepipe Tensile Specification Requirements

- Specify longitudinal tensile tests for new linepipe orders
- Recommend limits placed on the max longitudinal YS and TS (Common requirement for offshore pipelines)
- Recommend longitudinal tensile tests be performed throughout pipe production at the same frequency as transverse tensile tests.
- Revisit role of flattened strap tensile test methods and 100% mill hydrostatic requirements

Phase 1 : Preliminary Recommendations

Girth Weld Performance Requirements

- Main goal : Avoid gross weld strength under-matching. Girth welds should overmatch pipe longitudinal properties.
- It is perhaps too early to state that low strain girth weld failures are limited to SMAW or FCAW girth welds but it is clear that SMAW and FCAW girth welds are more susceptible to low strain failures, particularly in thin wall pipes where:
  - The use of a lower strength weld consumable for the root pass results in a large proportion of the overall weld thickness comprised of lower strength weld metal.
  - The HAZ width is a significant proportion of the pipe wall thickness.
  - The weld geometry favors failure through a 45 degree shear plane
- Given the above, SMAW and SMAW/FCAW girth welds in thin wall X70 pipe require special consideration.

Phase 1 : Preliminary Recommendations

Welding Alternatives to traditional E6010/E8010 cellulosic girth welds to ensure overmatching

- Higher strength root pass (e.g., E8010),
- Combination procedures (cellulosic-coated SMAW electrodes for the root and hot passes and a hydrogen controlled welding process for fill and cap passes).
  - Gas-shielded flux-cored arc welding (FCAW-G)
  - SMAW low-hydrogen (e.g., E9045) vertical down.
- FCAW can be deployed using mechanized welding equipment or can be used in a semi-automatic (hand held) manner. Self shielded FCAW should be avoided.

JIP : Phase 2 Workscope (6 Tasks)

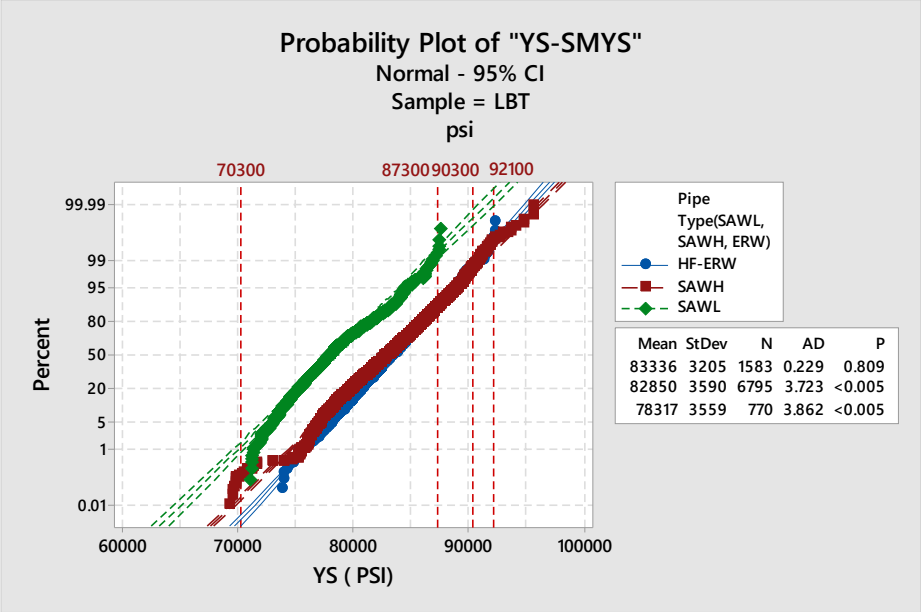
Task	Description
1	API 5L Grade X70 Pipe Property Database
2	Girth Weld Procedure Qualification Database
3	Tensile Strain Capacity Analysis
4	HAZ Softening Trials
5	Girth Weld Tests
6	Alternative Welding Options

X70 Database

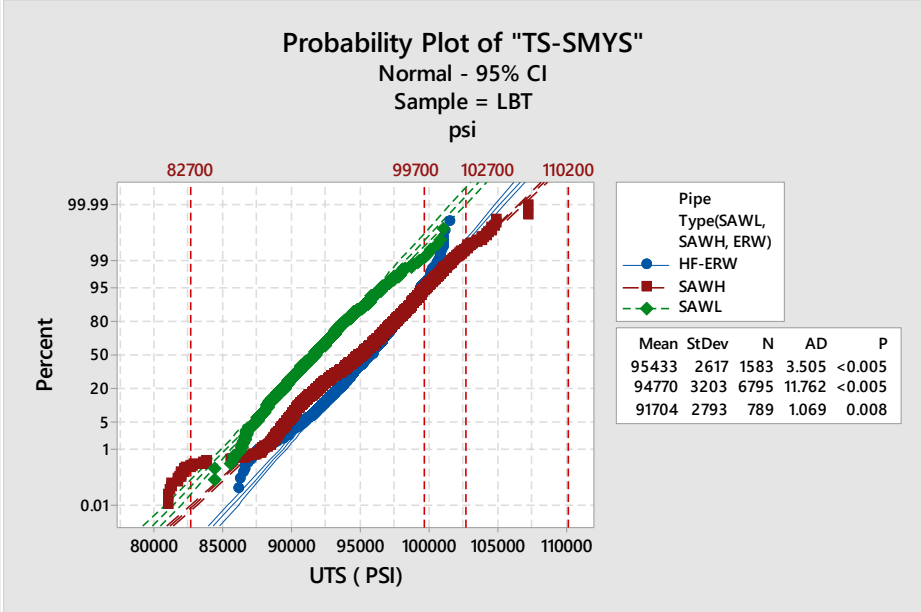
- Number of Pipe mills: 8 (American, Berg, Borusan, Durabond, EVRAZ, Jindal, Stupp, Welspun)
- Number of Plate Mills Suppliers: 3 (AM-NS, BAO,POSCO)
- Number of Coil Producers: 4 (AM-NS, AM-Bremen, US-Steel, TISCO)
- Pipe Fabrication Records :
  - SAWL : 3, 404
  - SAWH : 15,400
  - HF-ERW : 9,767
- Total Number of samples: 28,571
- Pipe Range Outer Diameters: From 20-Inch to 46 Inch
- Pipe Wall thickness: From 0.3-Inch up to 1.8-Inch

X70 Longitudinal Pipe Properties

YS-L



TS-L



- Cumulative Probability Distributions are parallel,
- Average YS-L for SAWH & ERW X70 Pipe is 5 ksi higher than SAWL.
- Approximately 0.5% of SAWH X70 pipe exceeds the PSL2 YS-T requirements.

Tensile Strain Capacity Analysis

Objectives

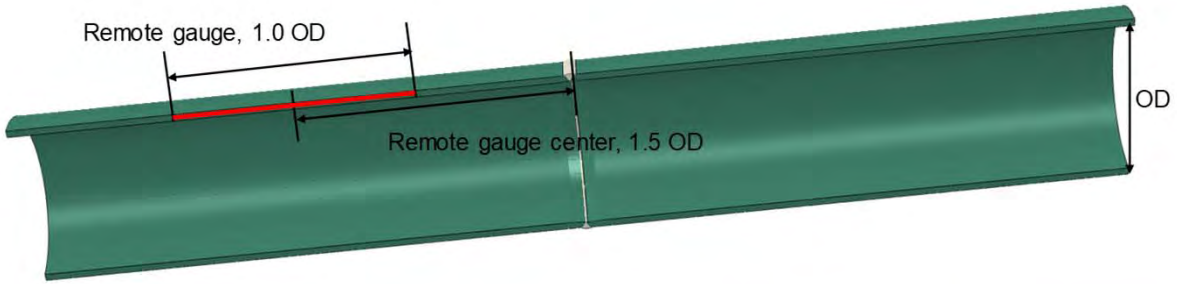
- Perform FEA of manual pipeline girth welds to determine the structural significance of girth weld under/overmatching in combination with HAZ softening.
- Identify options to mitigate low nominal strain failures in manual girth welds.
- *The work is co-funded by this JIP and PRCI*
  - *JIP funding: manual welds without wide cap*
  - *PRCI funding: manual welds with wide cap*

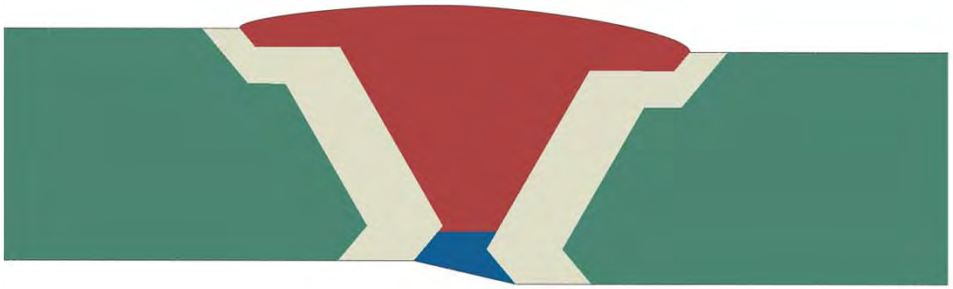
Tensile Strain Capacity Analysis

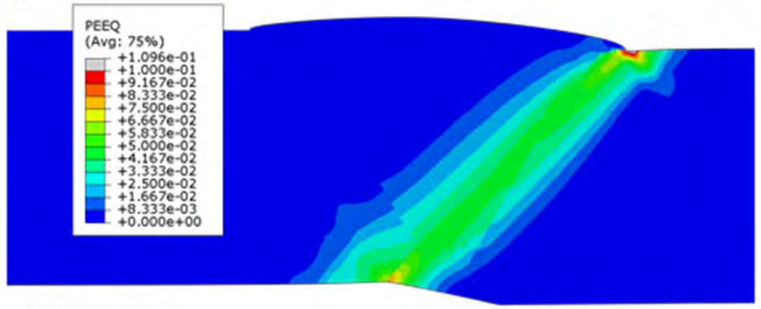
Scope and parameters examined

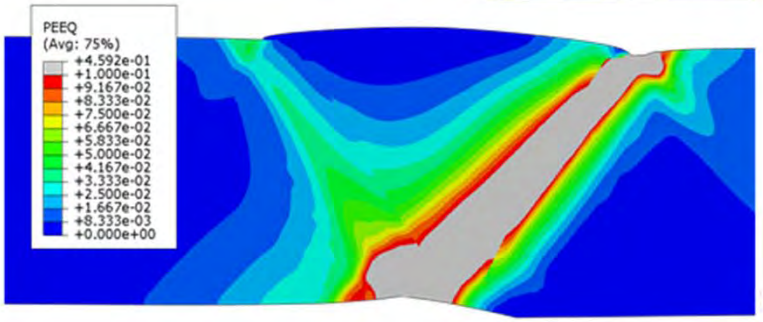
Parameter	Range/Values	Number of Cases
Pipe wall thickness	Thin and medium (3/8" and 5/8", 9.525 & 15.875 mm)	2
Pipe strength & strain hardening	Low, middle and high	9
Weld root consumable	E6010 and E8010	2
Fill/cap consumable	E8010	1
HAZ softening level	10% and 20%	2
HAZ width	2.5 mm and 4.5 mm	2
Bevel geometry	Standard	1
Cap reinforcement - width	2.8, 6.4, 9.0 and 12.0 mm beyond the original bevel	4
Cap reinforcement - height	0.8, 1.6, 2.1 and 3.0 mm	4
High-low misalignment	1/16"	1

Tensile Strain Capacity Analysis









TSC Analysis - Main Conclusions

The following parameters (in order) impact the TSC of Normal Welds (i.e., girth welds without extra cap reinforcement)

1) Weld strength mismatch
2) HAZ (level of softening and width)
3) Weld root strength

- The lower parameters become more important if the higher-order parameters don't dominate.
- Impact of pipe strength (6010 / 8010 SMAW)
  - Upper Bound Tensile Properties: TSC is limited due to under-matched girth welds).
  - Lower Bound Tensile Properties : TSC acceptable.
  - Average Properties: TSC is generally OK but can be marginal as girth weld under-matching becomes more significant.

TSC Analysis - Main Conclusions

- Extra weld cap can be an effective approach to improve girth weld tensile strain capacity
- Appropriate cap dimensions are affected by the level of weld strength undermatching and HAZ softening.
  - If the undermatching and HAZ softening are moderate, extra cap width is effective.
  - If the undermatching/HAZ softening level is high, both width and height are needed to compensate for the low strength in the weld area.
  - If HAZ softening level is very high and the width is wide, cap reinforcement may not be sufficient.

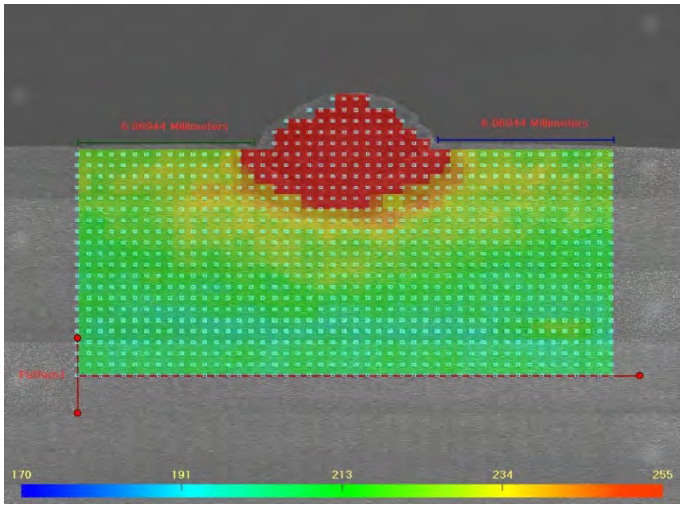
Girth Weld Test Program

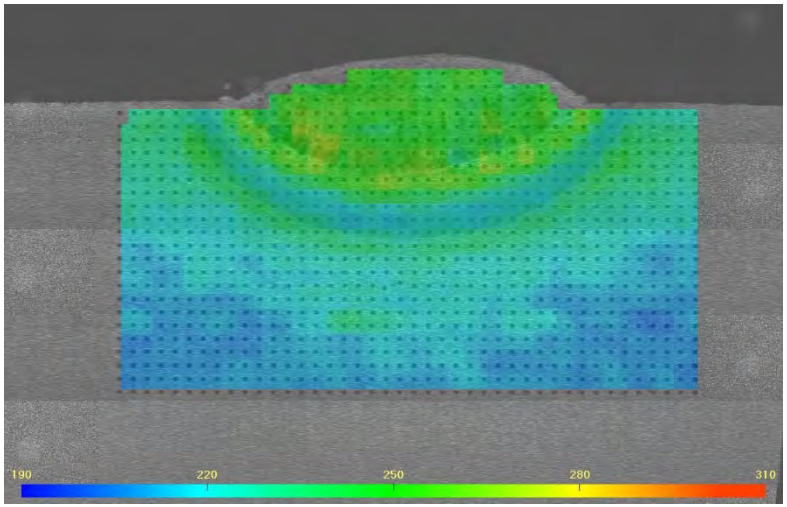
- Perform tests to fully characterize the pipe and girth weld properties of the girth weld failures reported in Phase 1 of the JIP.
- Perform tests on additional X70 girth weld samples provided by Operators to assess:
  - Girth weld / HAZ hardness distributions
  - Girth weld HAZ softening
  - Girth weld strength (over-matching vs under matching)
- Test Program includes 11 Grade X70 girth welds
  - Chemical Analysis
  - Hardness Surveys
  - Cross Weld Tensile Tests (with and without cap/root)
  - PHMSA All Weld Metal Tensile Tests

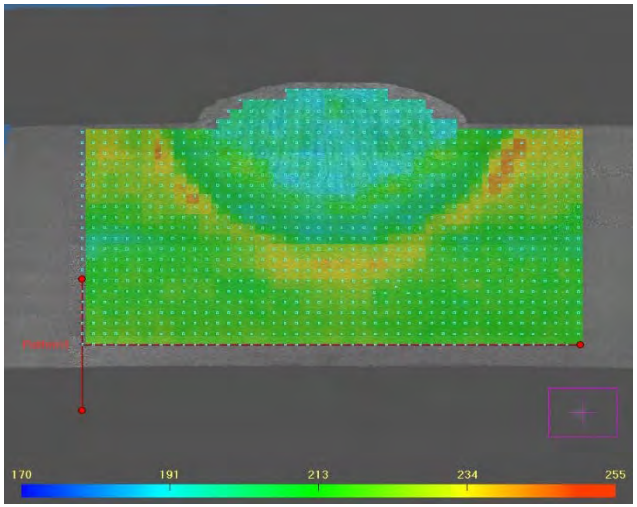
HAZ Softening Trials

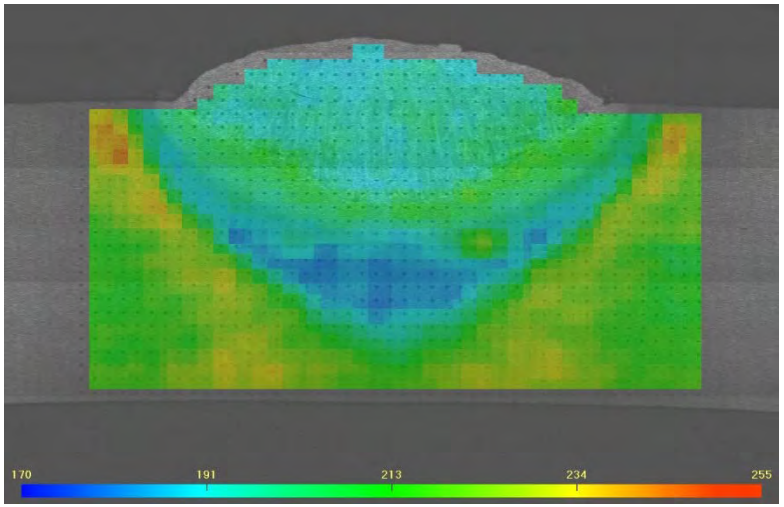
- Perform Bead on Pipe tests to evaluate HAZ softening.
- Determine HAZ softening susceptibility of Grade X70 pipe and determine if can be correlated with pipe chemistry / Pcm etc.
- Develop recommendations on chemical composition limits for X70 pipe to mitigate HAZ softening, e.g., minimum Pcm value.
- Eight Grade X70 pipe materials that cover the popular Alloy Designs with Pcm values ranging from 0.10 to 0.20.
- BOP Tests will also be performed to evaluate effect of Pre-Heat

BOP Tests (0.5, 1.0, 2.0 & 3.0 kJ/mm)









Alternative Welding Options

Objectives

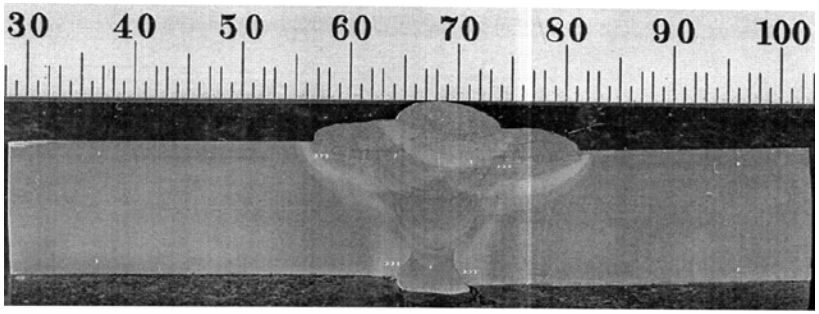
- Evaluate alternative manual welding options for X70 pipelines to the standard SMAW 6010 root pass and 8010 fill and cap pass procedure.
- Review the results of welding trials performed by operators to assess alternative manual welding procedures for X70 pipelines.

Preliminary Results of Review

- Review technical information and the results of welding trials performed by operators identified E8010 for root pass welding and low-hydrogen vertical down (EXX45) for fill and cap pass welding as the most promising alternatives.

Experimental Program

- Experimental portion of this task includes:
  - Welds made with E8010 for all passes (including root) and wide, tall cap pass
    - Wide to provide protection for softened HAZs
    - Tall to compensate for undermatching strength weld metal



  - Welds made with E9045 for fill and cap passes
    - With both E6010 and E8010 root passes
    - Determine if the use of E9045 for the fills and cap would preclude the need for a wide, tall cap

JIP Schedule

- Testing and data analysis completed by end of April 2019
- Draft Final Report completed by end of May 2019.
- Expectation is that the JIP final results will be published as open literature.

Pipeline Research Council International, Inc.

PRCI Project Code (SIA-1-4)

Mechanical Properties of Vintage Girth Welds and Their Implications on Performance

Dan Jia (presenter) and Yong-Yi Wang
Center for Reliable Energy Systems

PRCI 2019 Research Exchange Meeting
Houston, Texas
March 5-6, 2019

Overview

- Background and Incentive
- Objective
- Generic Test Program
- Overview of Tested Girth Welds
- Principle Outcome
- Use of Outcome

Background and Incentive

- **Vintage Girth Welds**
  - Large portion of transmission pipelines (>75% mileage pre-1970)
  - Many constructed without 100% NDE
  - May have low toughness compared to modern girth welds
  - Undetected girth weld flaws may be present in vintage pipelines
- **Project Incentive**
  - Enabling FFS assessment → economic benefits + ensuring safety
  - FFS assessment requires
    - *Material property data*
      - Limited vintage girth weld material property data currently available
    - *Flaw characteristics*
    - *Applied stress/strain*

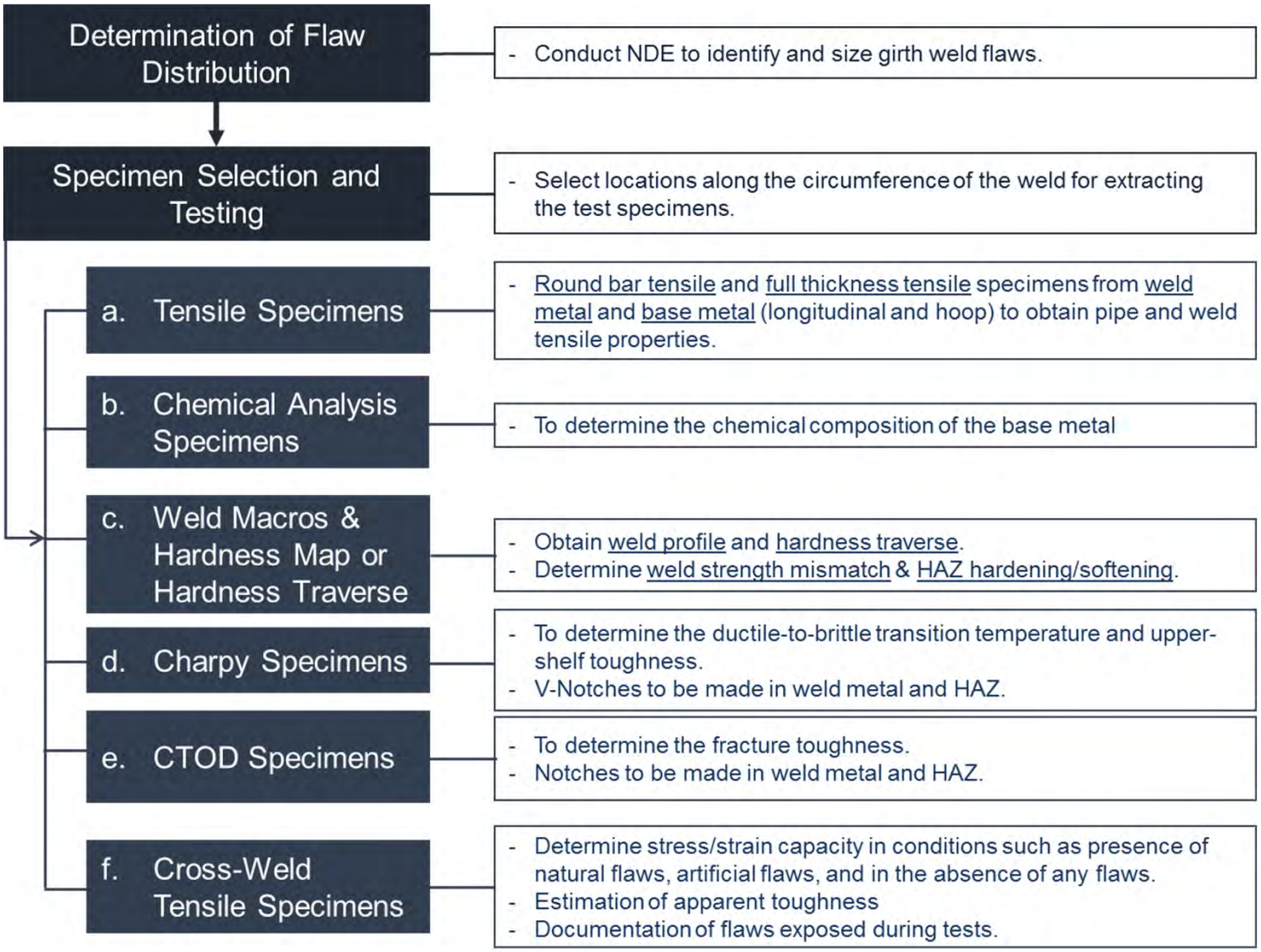
Objective

- **Overall Project Objective**
  - Generation of material property inputs required for performing accurate structural integrity assessment of vintage girth welds
  - Reporting characteristics of weld flaws identified by NDE
  - Evaluation of NDE techniques

SIA-1-4 Phase and Funding Year (FY)	Current Status	Girth Welds	Number of Girth Welds
Phase 1, FY 2014	Work completed; draft final report submitted	1960s SMAW	4
Phase 2, FY 2015		1940s SMAW	3
Phase 3, FY 2016		1950s SMAW	2
Phase 4, FY 2017	Work ongoing	Thin wall SMAW and Oxy-acetylene welds	6
		1950s SMAW (Weld 43)*	1

*For Weld 43, the reported flaws by NDE were summarized in the Phase 1-3 report. Mechanical testing will be covered in Phase 4.

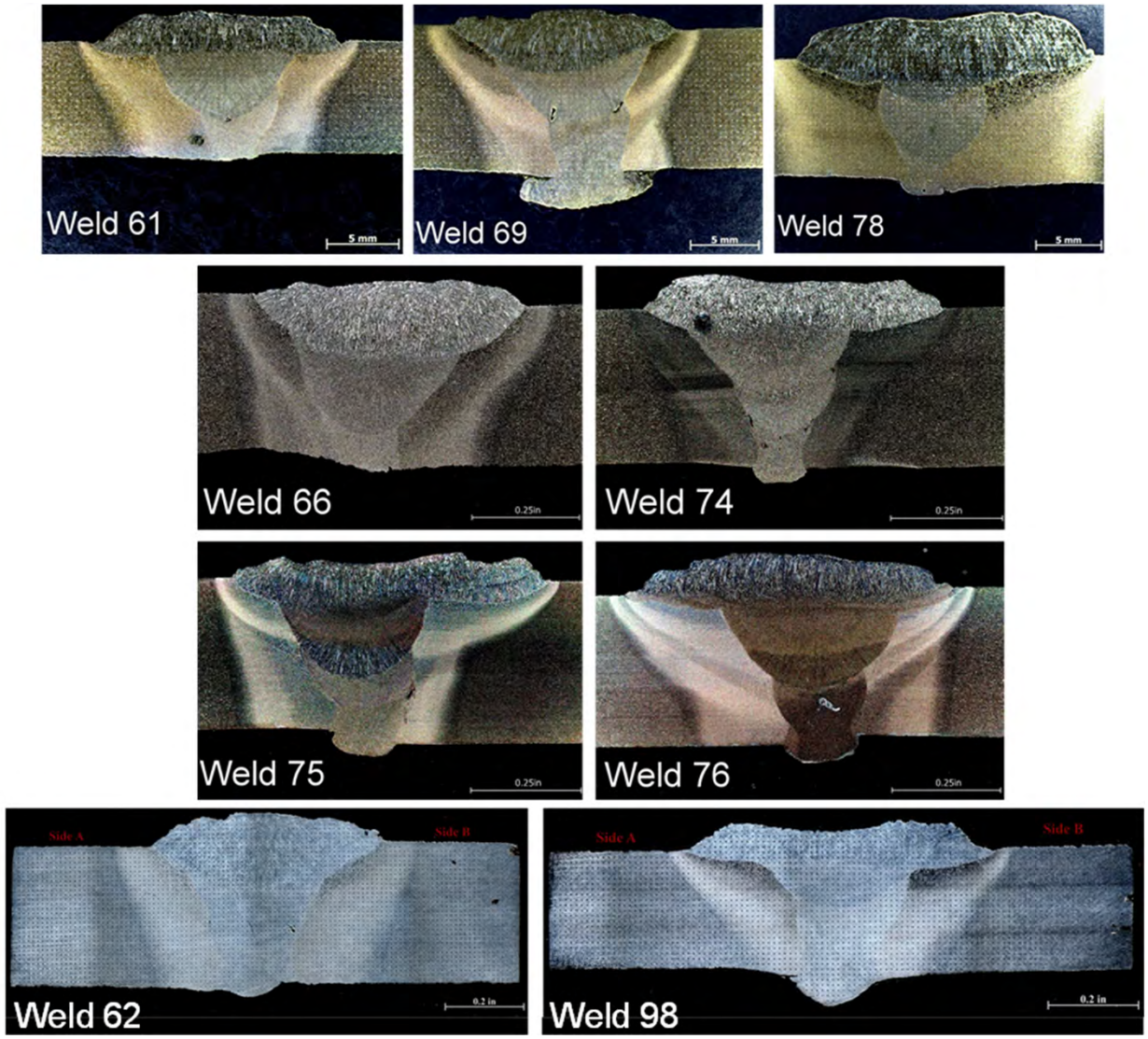
Generic Test Program



Summary of Girth Welds (Phases 1 to 3)

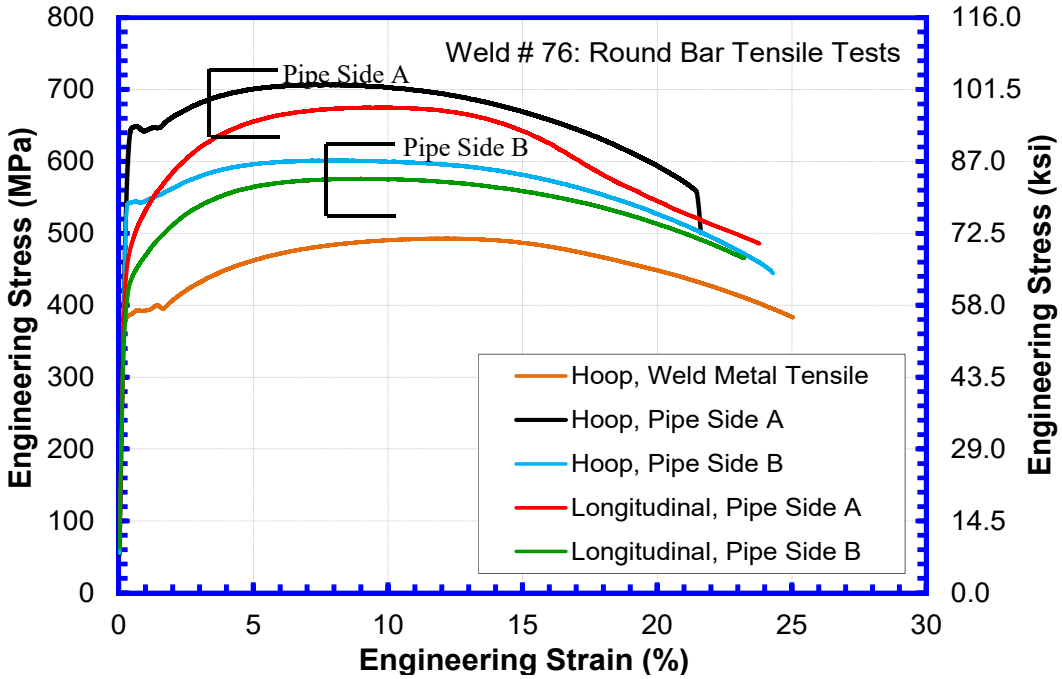
Girth Weld Number	OD	WT	Year of Construction	Pipe Grade	Seam Type
	in	in			
61	20	0.313	1943	B	ERW
69	24	0.375	1943	X37	Seamless
78	24	0.375	1943	X37	Seamless
98	26	0.281	1949	X52	Flash Weld
66	30	0.375	1955	X52	DSAW
62	30	0.375	1957	X52	EFW
74	36	0.375	1964	X52	SAWL
75	36	0.375	1964	X52	SAWL
76	36	0.375	1964	X52	SAWL

Girth Weld Macros



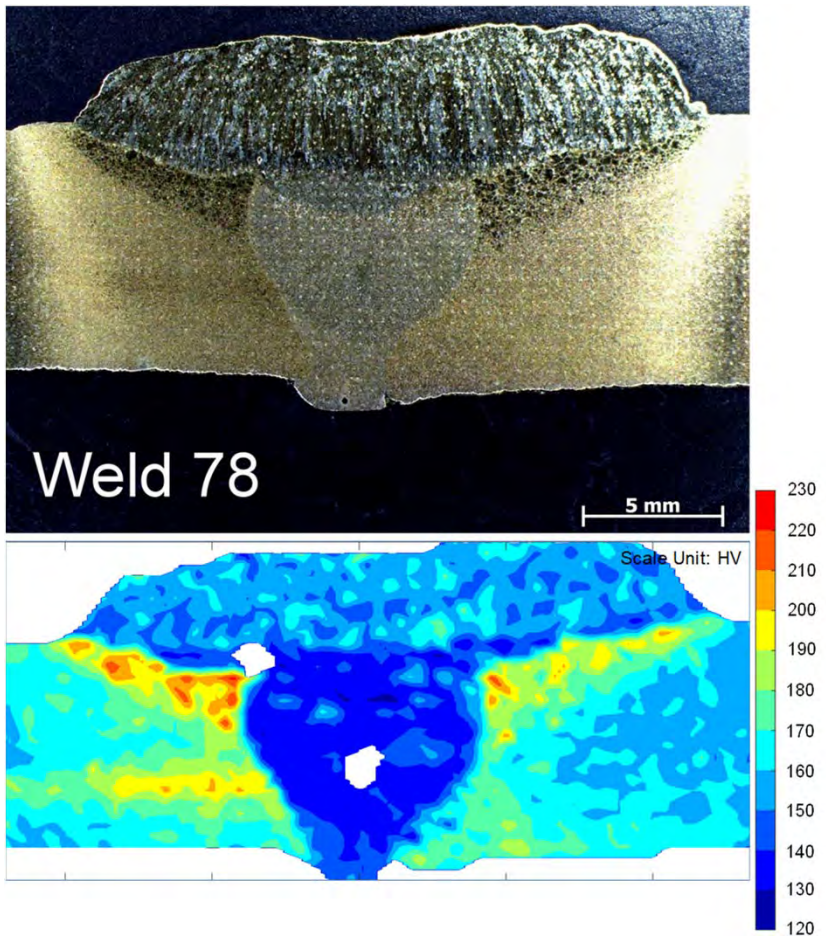
Principal Outcome

- **Pipe properties**
  - Hoop & longitudinal
  - Actual vs. SMYS
  - Anisotropy
  - Difference between one side vs. the other side



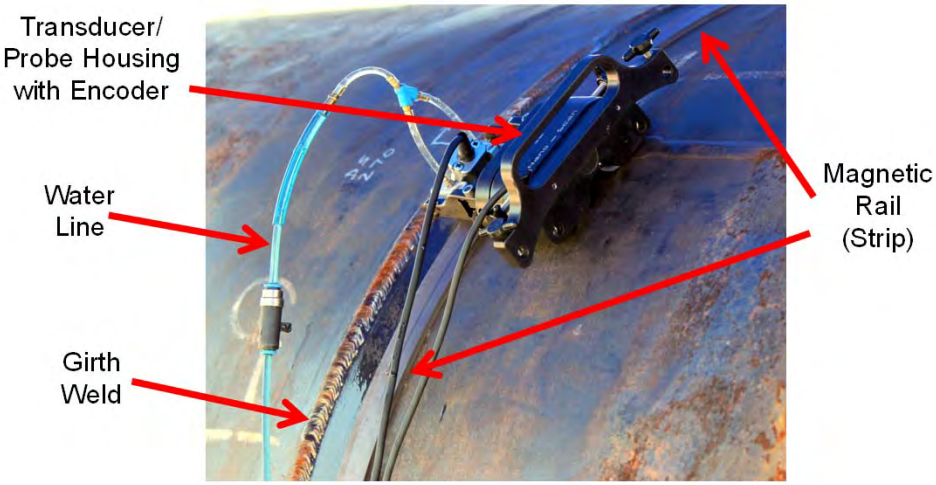
Principal Outcome (cont.)

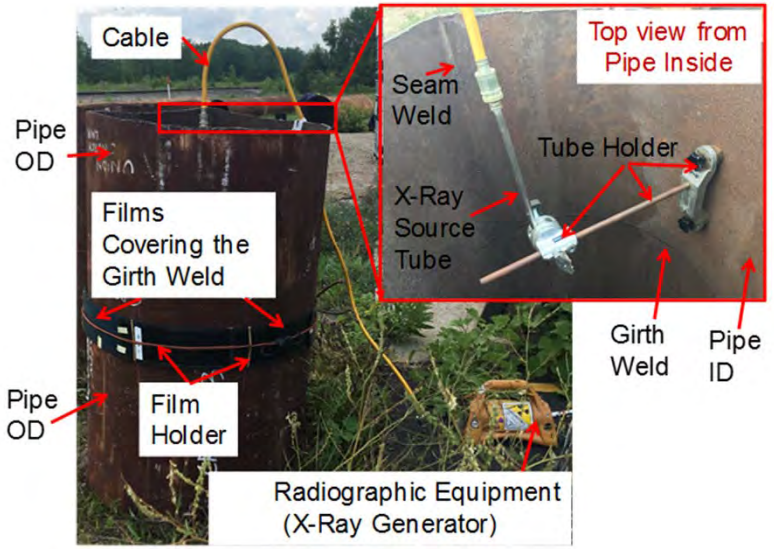
- **Girth weld properties**
  - Weld profile
  - Strength of deposited weld metal → weld strength mismatch
  - HAZ hardness
  - Charpy
    - *Deposited weld metal*
    - *HAZ*



Principal Outcome (cont.)

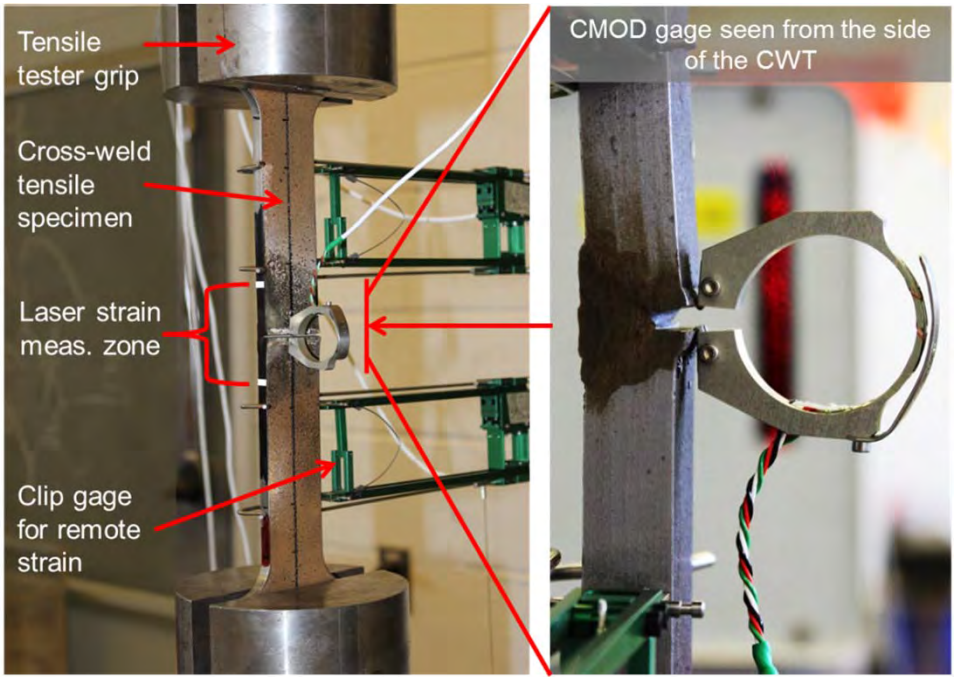
- **Girth weld flaws**
  - More volumetric and planar flows
  - Flaws of various heights and length were found.
    - *In most cases, flaws were of one weld bead height. Some had greater height*
    - *In most cases, length were less than 2-4 inches*
- **NDT Verification**
  - X-ray vs. UT
  - Both misses large flaws

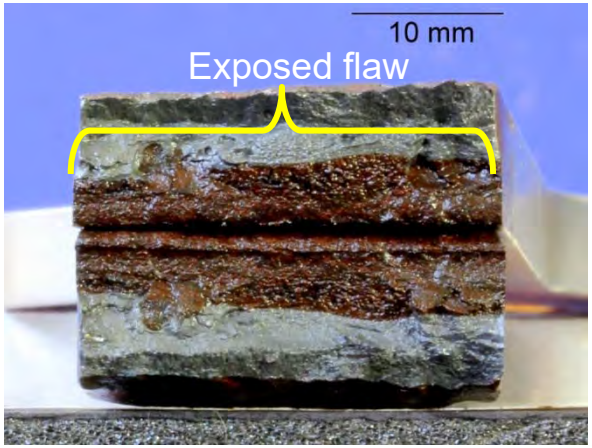


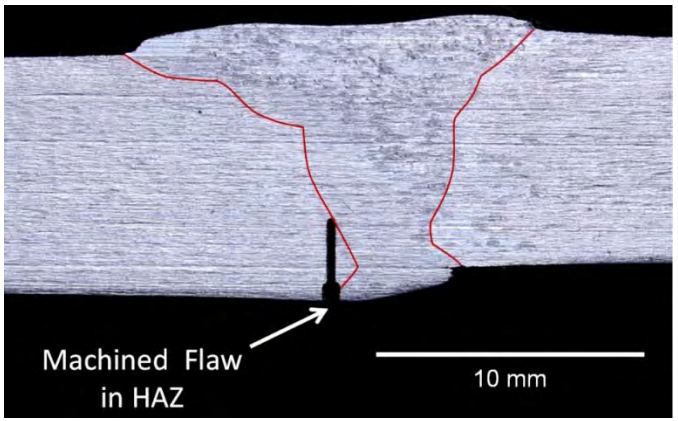


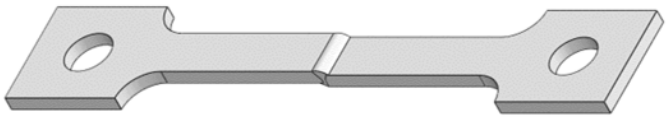
Principal Outcome (cont.)

- **Apparent CTOD toughness, for input in tensile strain capacity assessment**









Principal Outcome (cont.)

- **Girth weld performance**
  - Overall vintage SMAW performed well, despite having flaws
    - *Cap reinforcement*
    - *No HAZ softening*
    - *Low level of weld strength undermatching*

How will Operators Use the Deliverables?

- **To predict vintage girth weld performance**
  - SIA-1-4
    - *Material properties (pipe + girth weld)*
    - *Girth weld flaw characteristics*
  - SIA-1-7
    - *Assessment procedures*
    - *A software/tool*
- **To develop alternative X-ray criteria using fitness for service principles**
  - SIA-1-4
    - *Girth weld flaw characteristics*

- **Thank you**

Pipeline Research Council International, Inc.

Fracture Resistance Testing of Dissimilar Girth Welds Using SE(T) Specimens

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PRCI 2019 Research Exchange Meeting
Houston, Texas
Date March 5 - 6, 2019

Overview and Project Description

Further developments and validation of a fracture resistance test procedure using SE(T) specimen geometries which is applicable to evaluate the ductile tearing properties for (dissimilar & undermatch) girth welds of typical C-Mn pipes internally clad with nickel-chromium corrosion resistant alloys (Inconel 625 CRA Alloy) and subsequent use in engineering critical assessment (ECA) procedures by Petrobras in offshore & subsea pipes

Main Activities

- Production of dissimilar girth weld and extraction of several weld centerline SE(T) fracture specimens
- Further development of in-house computer code (FRACTUS2D) to determine *J* and CTOD resistance curves implementing new set of compliance solutions and η-factors
- 3-D finite element analysis of weld centerline SE(T) fracture specimens taking into account the effects of weld groove and clad layer on compliance solutions and η-factors
- Fracture resistance testing in terms of *J* and CTOD resistance curves, including crack growth measurements
- Comparison of different CTOD evaluation procedures, including DCG and DIC technique
- Planning of further work on fracture testing of nickel-chromium girth welds

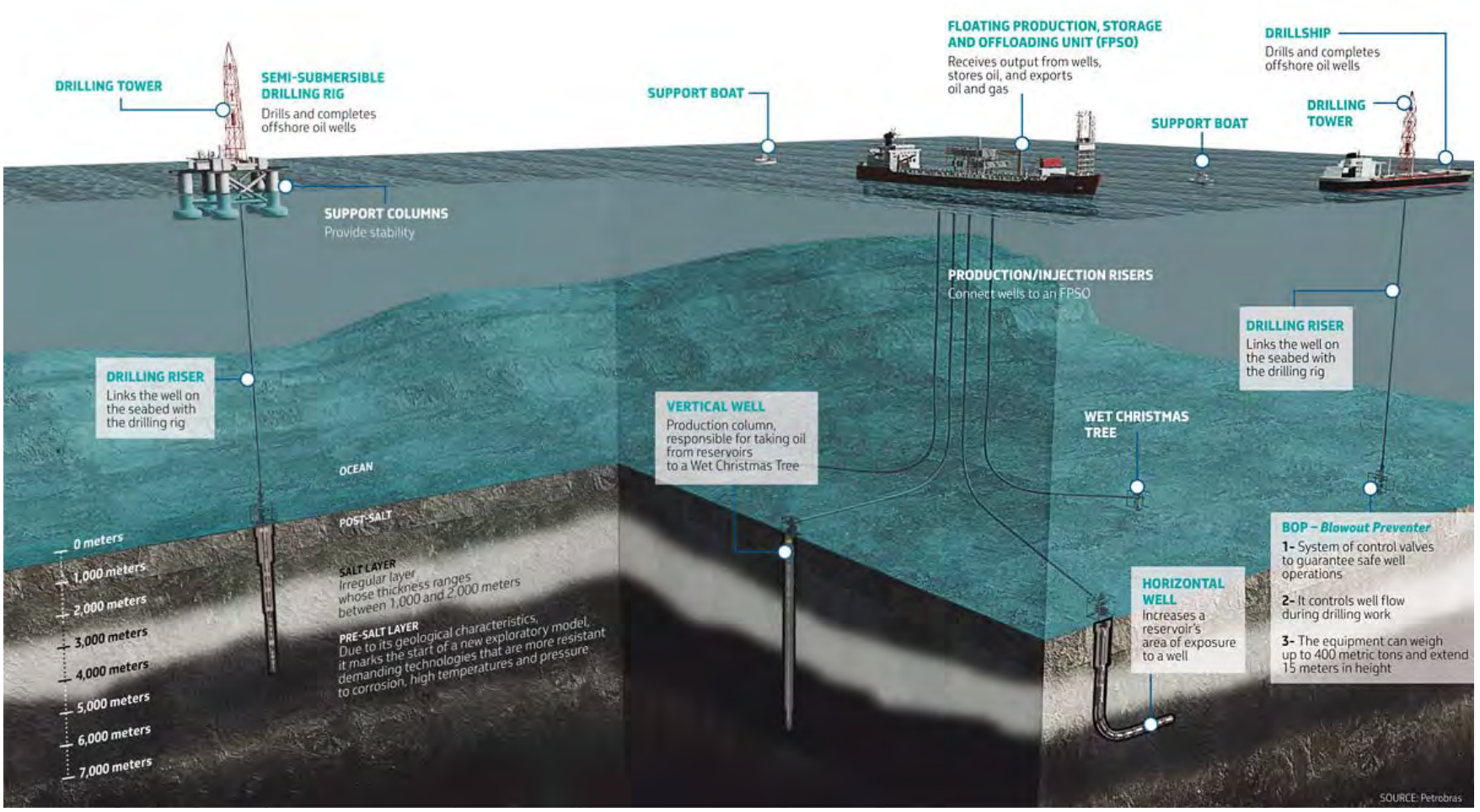
Key Outcomes

- Validation of fracture resistance test procedure jointly developed by USP and Petrobras to measure ductile tearing properties of dissimilar girth welds made of clad pipes
- Crack growth resistance properties for girth welds of C-Mn pipes internally clad with nickel-chromium CRA materials
- Development of digital image correlation (DIC) technique to evaluate CTOD for growing cracks in fracture tests
- Best practice to use CTOD-*R* curves in engineering critical assessment (ECA) procedures in reeled pipes

The Brazilian Pre-Salt Reservoir

Figure 1: Brazil's pre-salt region

The Brazilian Pre-Salt Reservoir



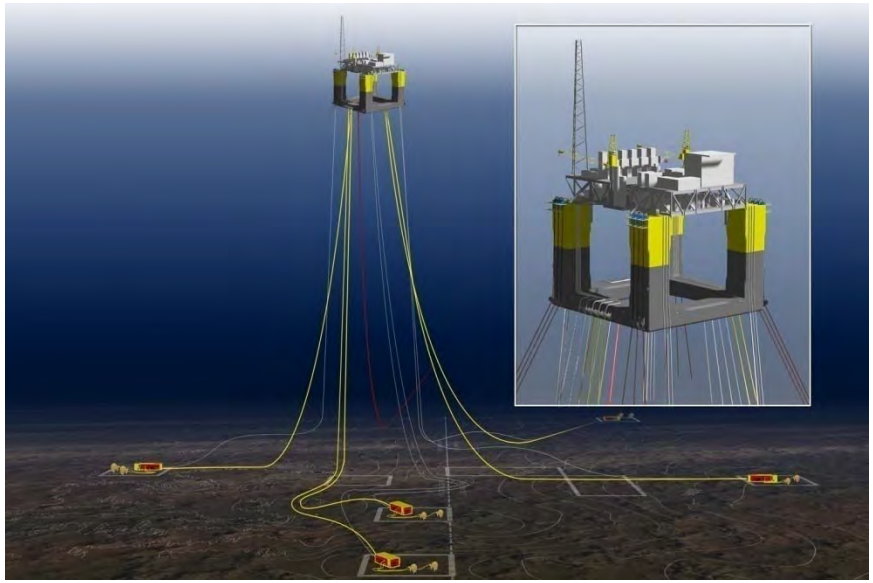
FPSO Technology

Key Characteristics

- More than 2500 m water depth.
- 2000 m thickness salt layer.
- Gas pipeline larger than 18” in 2500 m
- Long distance to shore (300 km)
- *High CO_2 content (8 ~ 20%)*

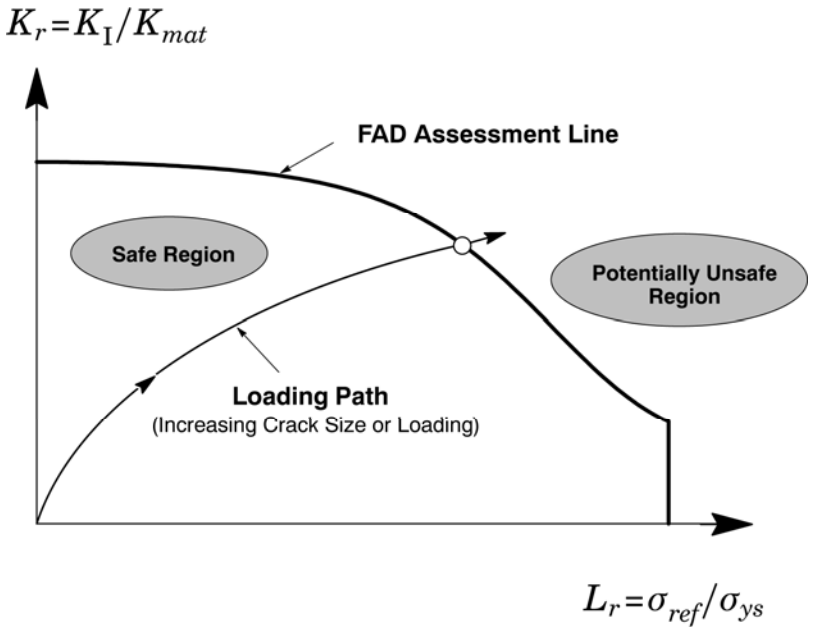
Deep Water Oil & Gas Production

- ***Higher Stresses / Strains During Installation***
- ***Larger Thickness Including Weldments***
- ***Sour Conditions***



Impact on FFS / ECA Procedures and How Does It Affect Tolerable Defect Sizes?

Conventional ECA / FFS Procedures

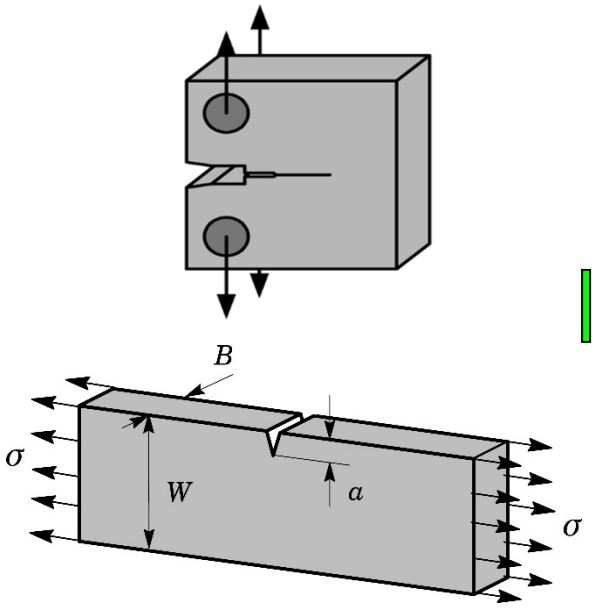


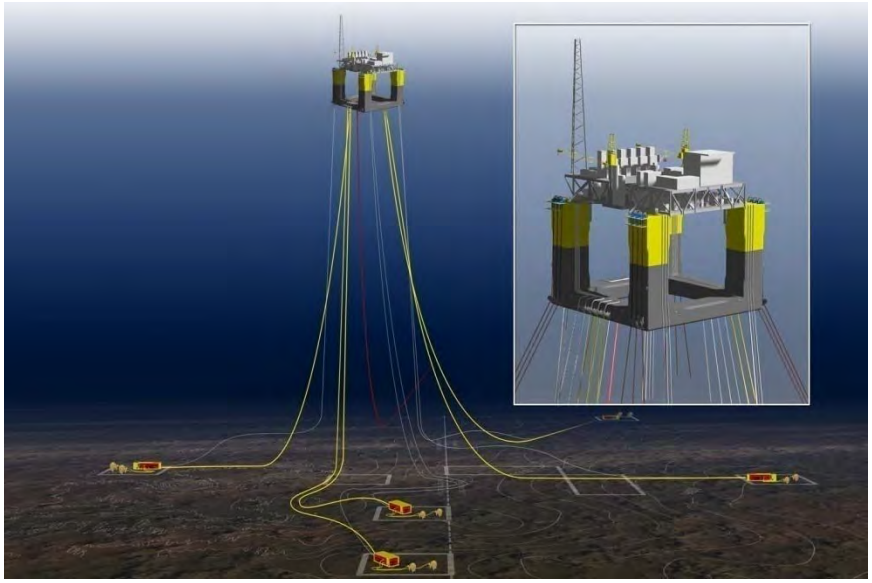
Key Assumption is that Failure Line Does not Depend on Specimen Geometry and Strain Hardening:

- ***High Constraint Conditions***
- ***Low-to-Moderate Ductile Materials***
- ***Often Highly Conservative***
- ***Stress-Based Approach***

How to Increase Tolerable Defect Sizes While Ensuring Acceptable Levels of Safety?

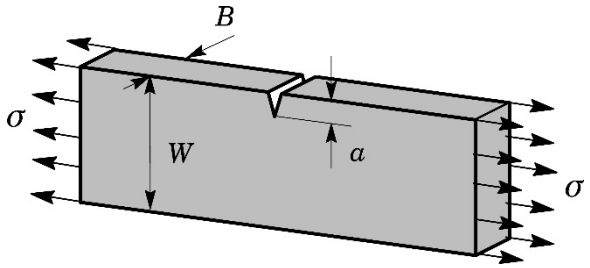
Laboratory to Field Conditions



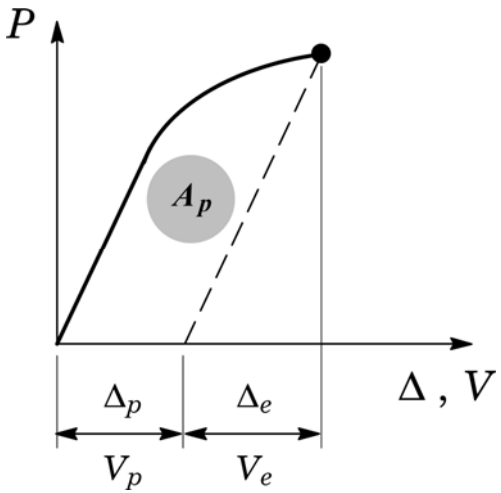


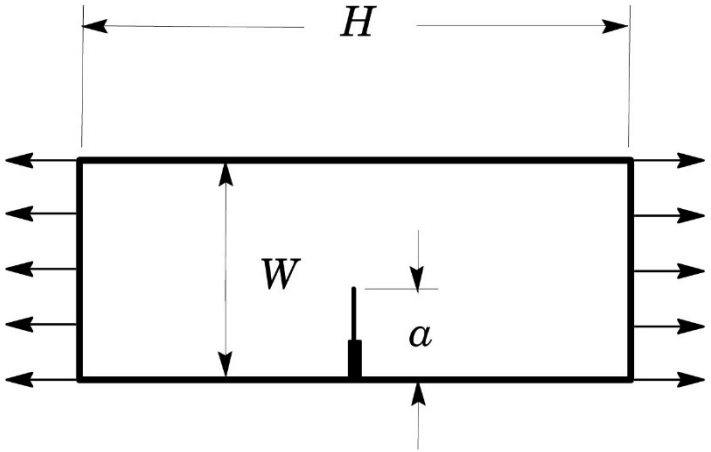
- ***Geometry and Actual Physical Size Much Different***
- ***Imposed Global Loading May Vary Significantly***
- ***Through-Crack Notch vs. Surface Shallow Flaw (Girth Weld)***
- ***Effects of Combined Loading (e.g., Bending and Internal Pressure)***

Mechanical Similitude of SE(T) Specimens



Estimation Procedure for the *J*-Integral



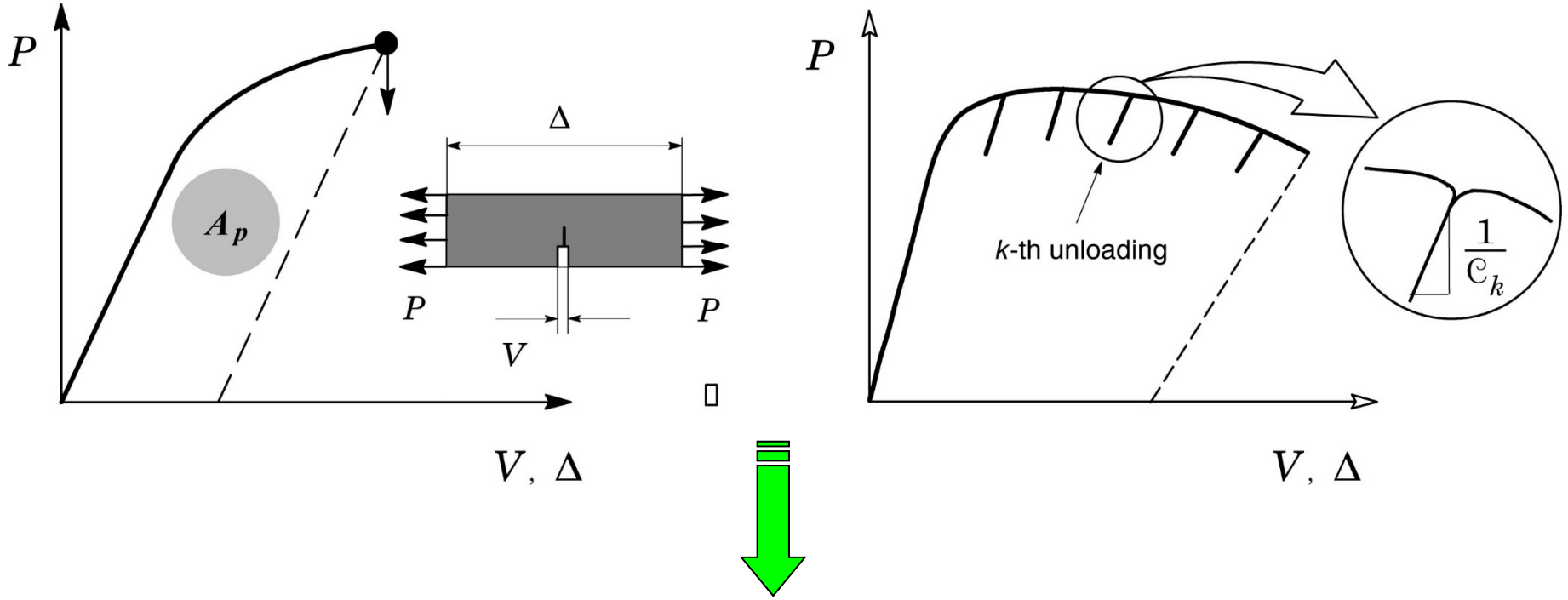


Plastic Contribution to the Strain Energy

$$J = J_e + J_p$$

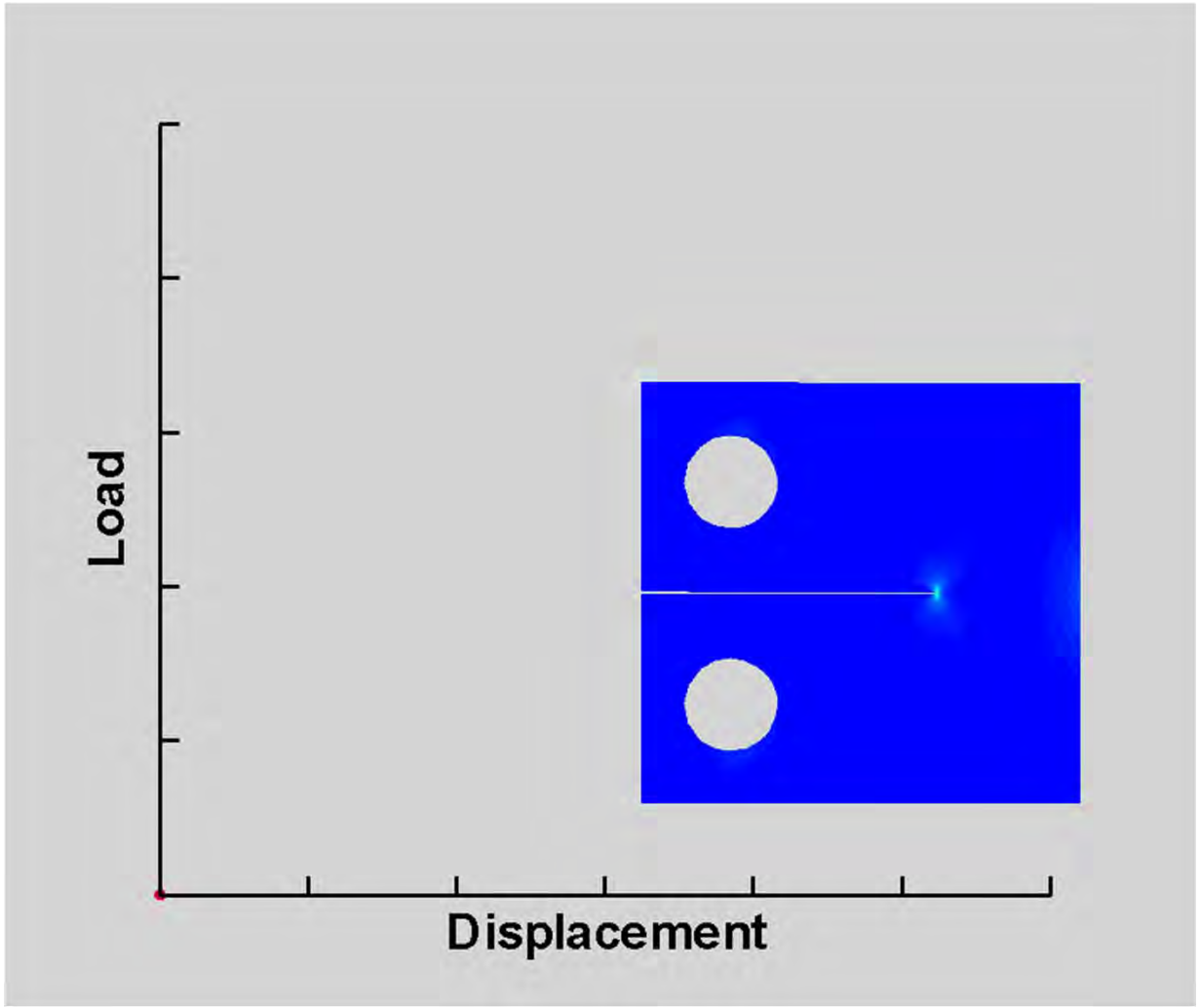
$$J_p = \frac{\eta_J^{\mathrm{CMOD}} A_p^{\mathrm{CMOD}}}{Bb}$$

Unloading Compliance Method

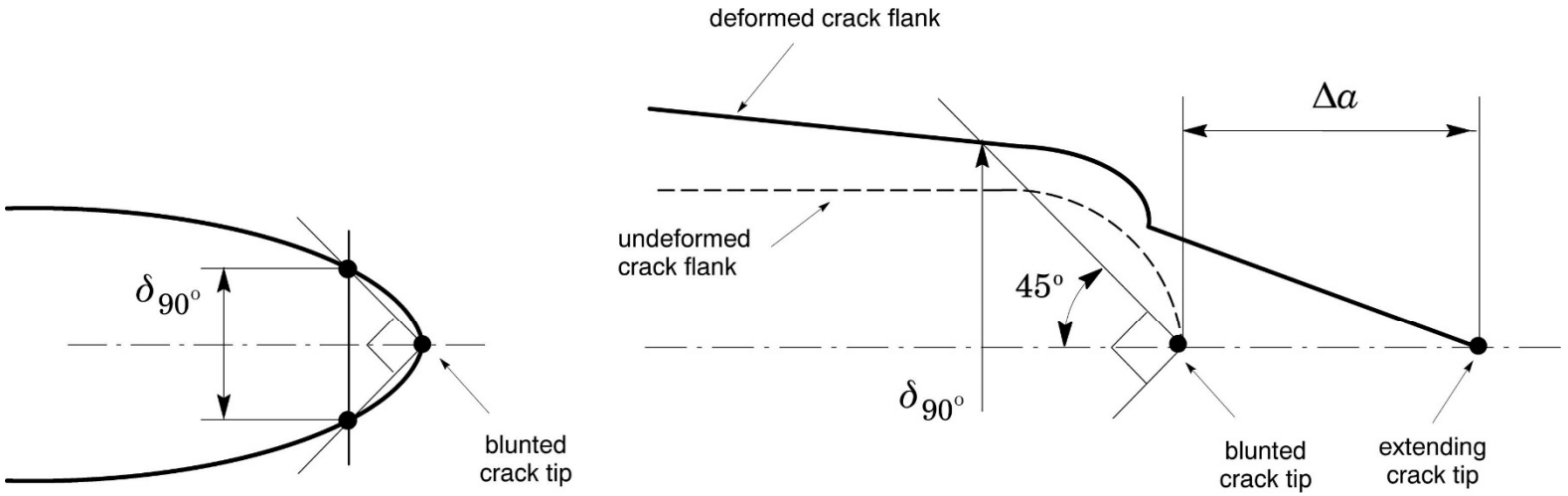


Variation in specimen compliance defines change in crack length

Unloading Compliance Method



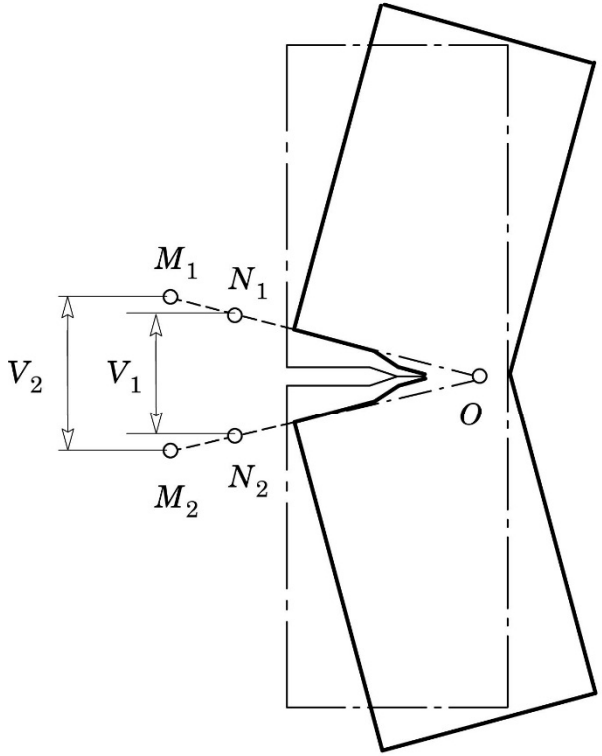
J-CTOD Relationship

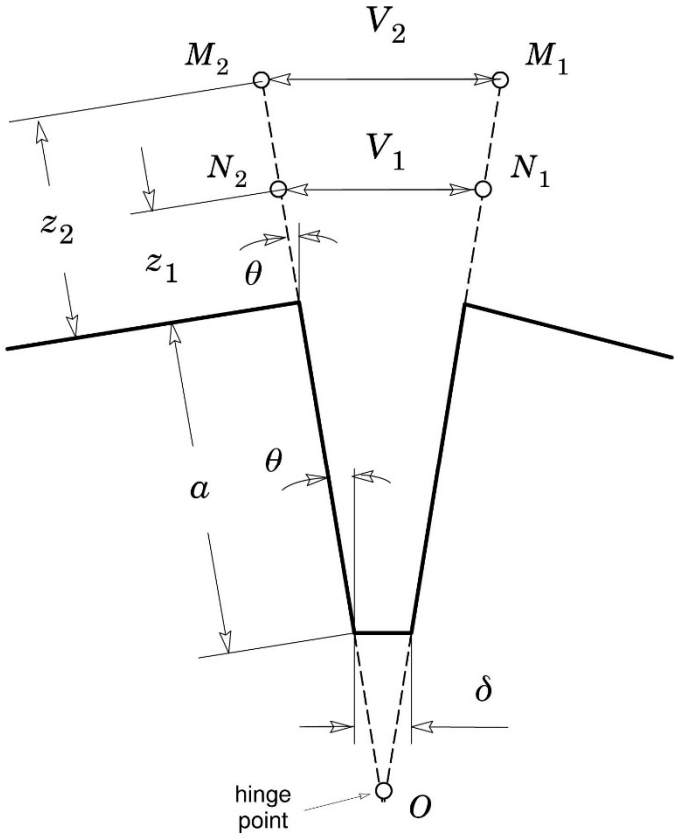


$$\delta = \frac{J}{m\sigma_f} \qquad m = f(a/W, n)$$

The procedure provides the basis for most ASTM standards

CTOD from Double Clip Gage Measures



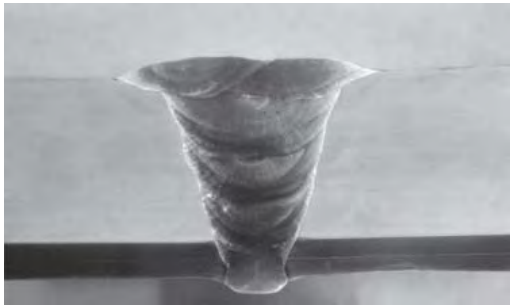


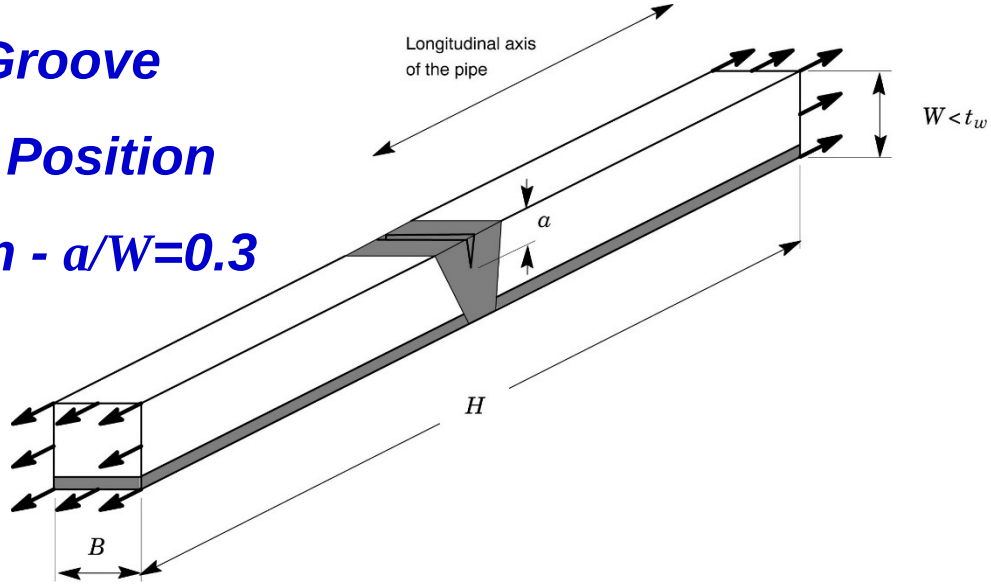
Observations

- ***Under J-controlled growth conditions, J and CTOD should characterize well crack growth behavior in ductile materials***
- ***Crack growth correction is needed to take into account effects of ductile tearing on crack-tip strain energy release rate and, thus, on J***
- ***DCG CTOD (e.g. BS 8571-2014) is defined at the original tip and, further, does not incorporate effects of crack growth***

Fracture Testing of Clad Pipe Girth Weld

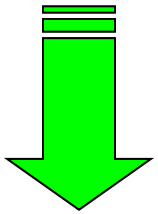
- *API X65 Pipe*
- *ASTM UNS Alloy 625 Clad (3mm thick)*
- *8 in. O.D. / t = 19 mm*
- *Single V-Groove*
- *FCAW 5G Position*
- *B = 15 mm - a/W=0.3*





Mechanical Properties

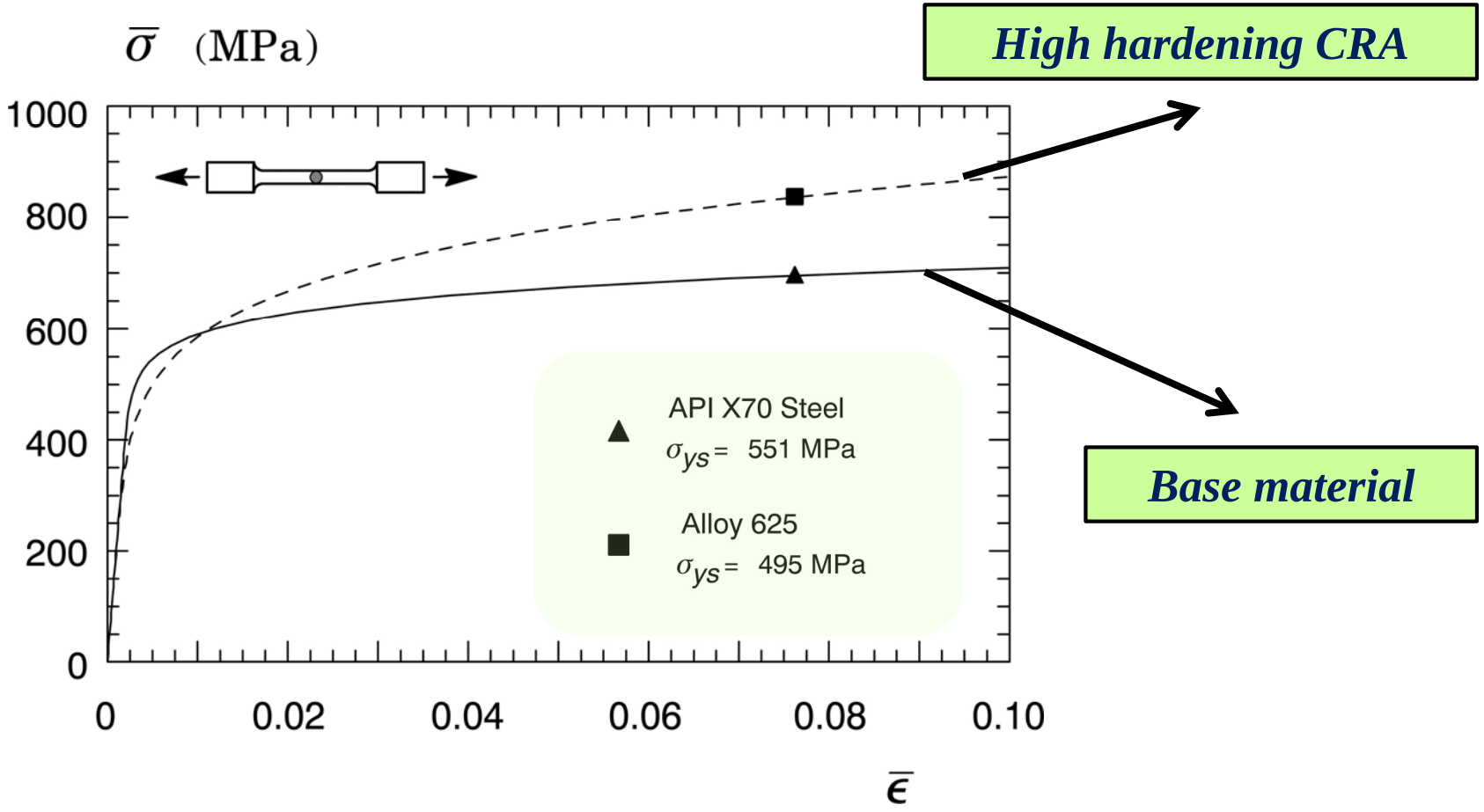
Material	σ_{ys} (MPa)	σ_{uts} (MPa)	E (MPa)	$\sigma_{uts} / \sigma_{ys}$	n
Baseplate	620	700	200150	1.13	18.9
Weld Metal	462	627	157500	1.36	9.7



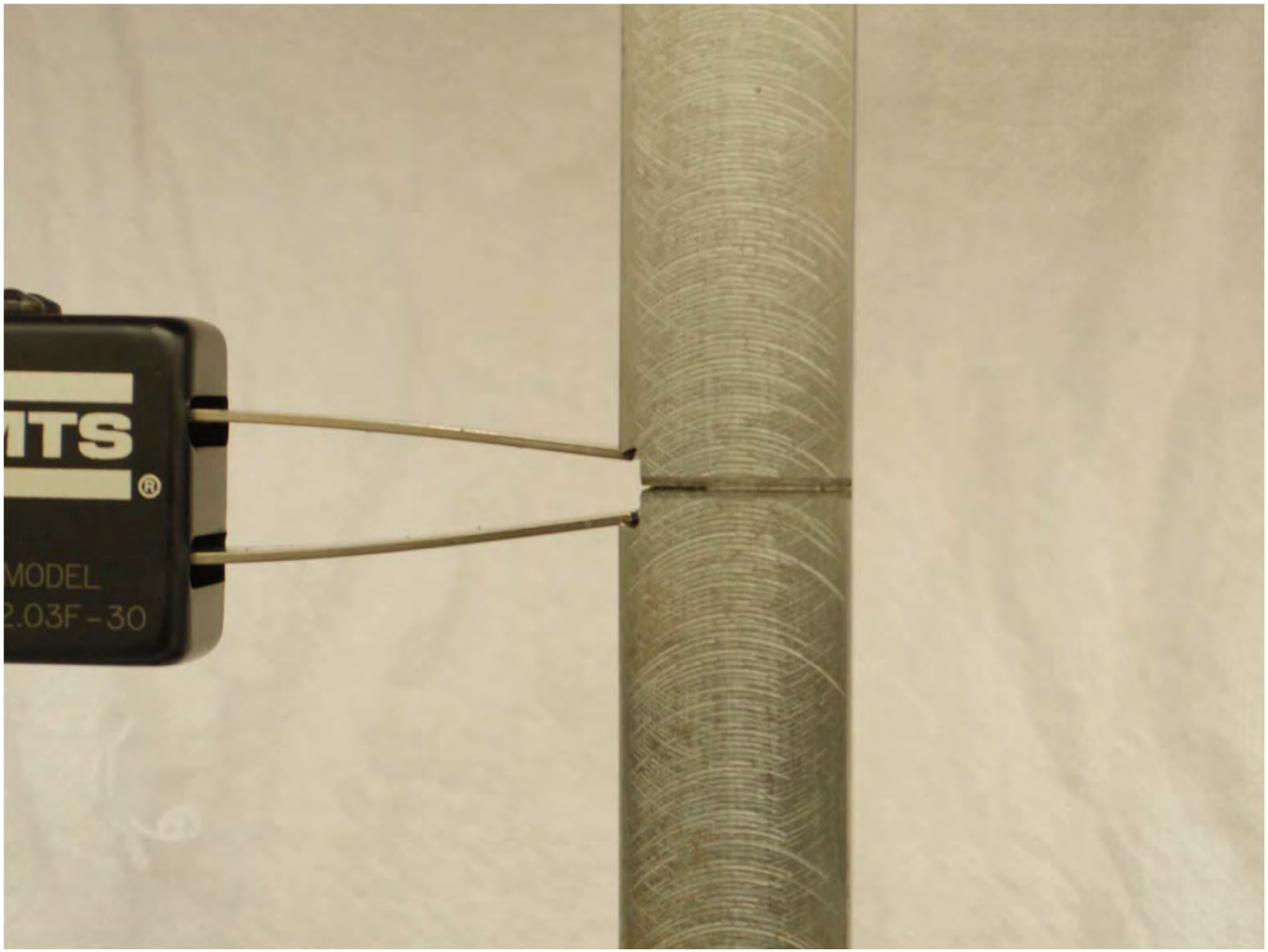
Undermatches at lower strains but overmatches at larger strains (~2%)

Mechanical Properties

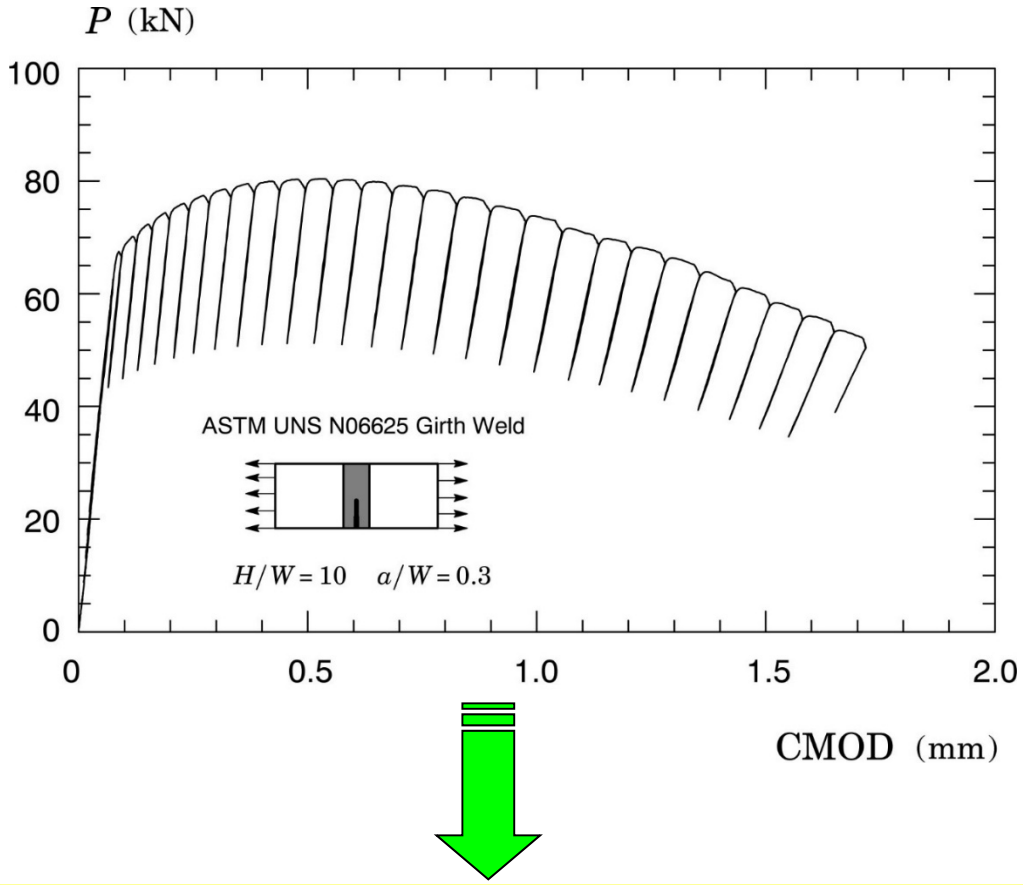
Partial Weld Strength Mismatch



Crack Growth

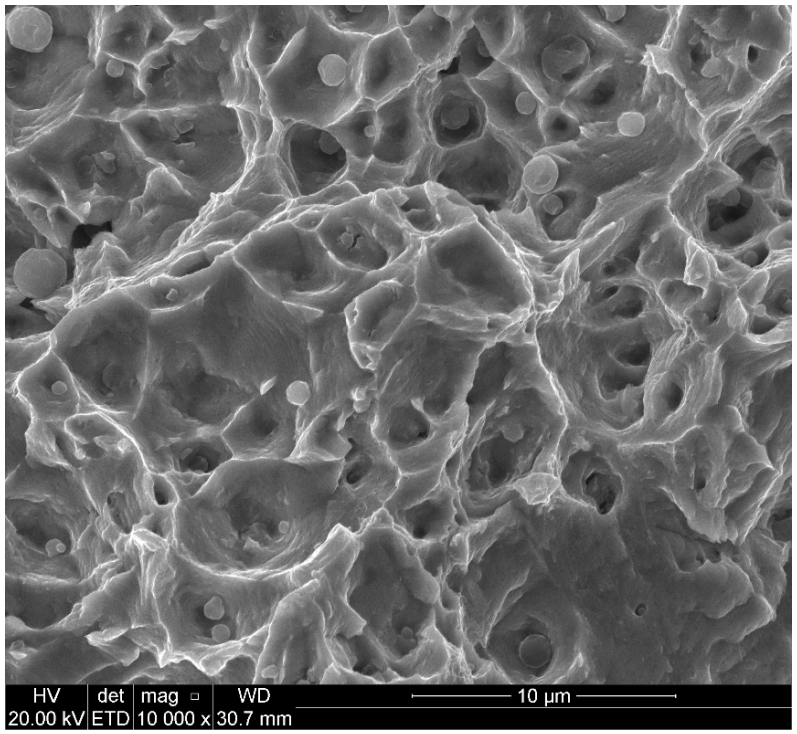


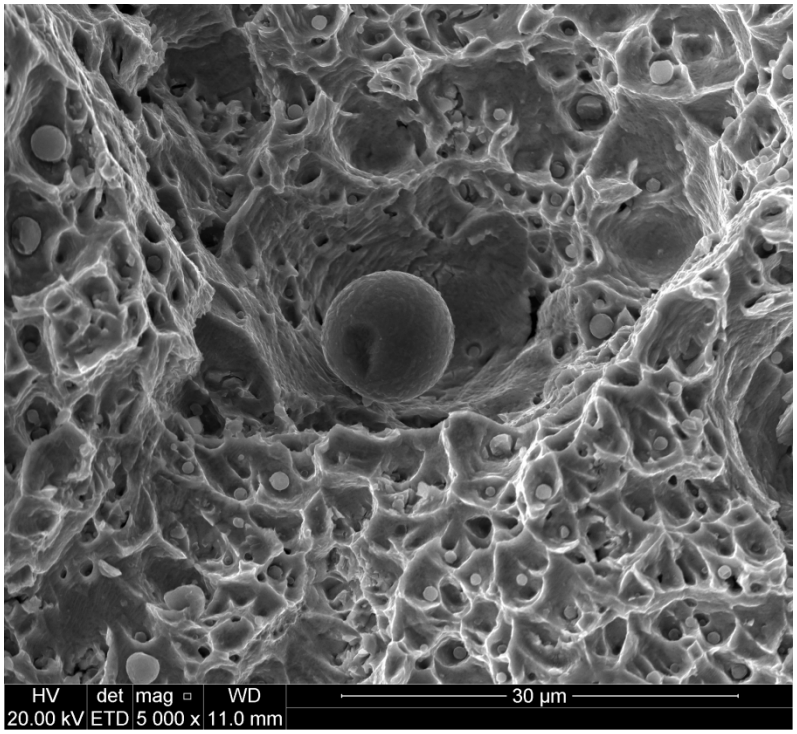
Load-Displacement Response



SE(T) test procedure developed at USP-Petrobras

Fracture Morpholoy



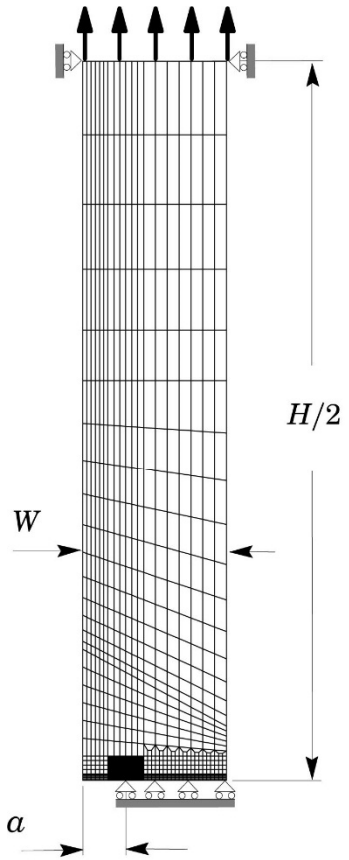


Crack Front Profiles

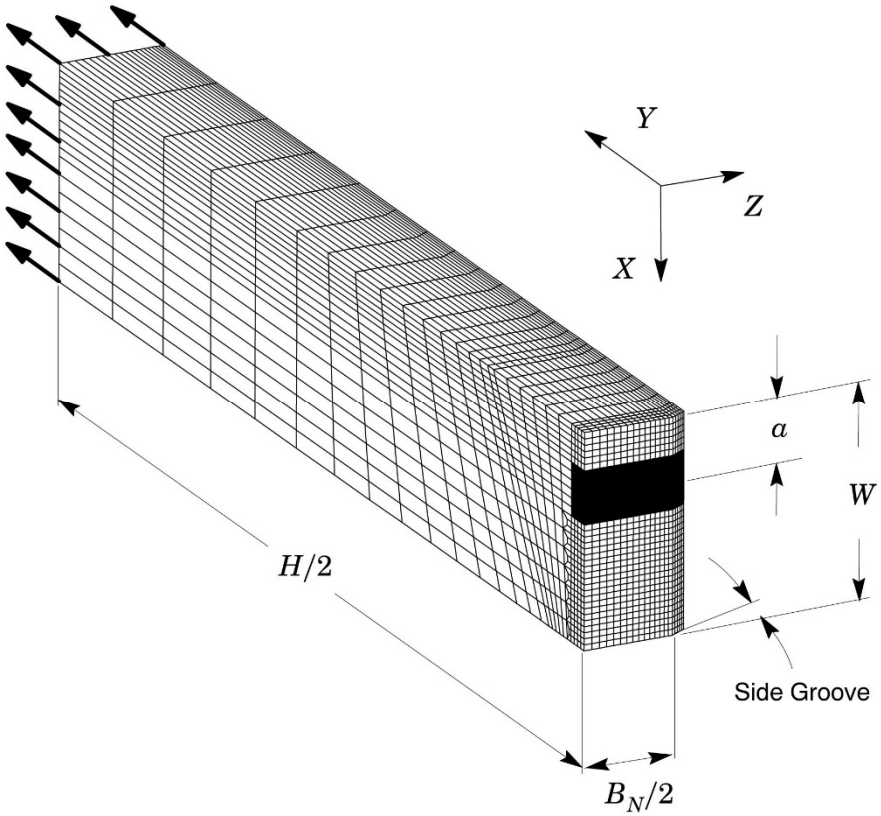
Evaluation Procedure

- *Use of η-factors and compliance solutions, including J-CTOD relationships, derived by Ruggieri & co-workers for plane-strain conditions*
- *Use of η-factors and compliance solutions, including J-CTOD relationships, derived from 3-D analysis for the tested clad SE(T) specimen*
- *Use of double-clip gage (DCG) procedure*
- *Use of digital image correlation (DIC) technique*

3-D FEA: Clad SE(T) Specimens

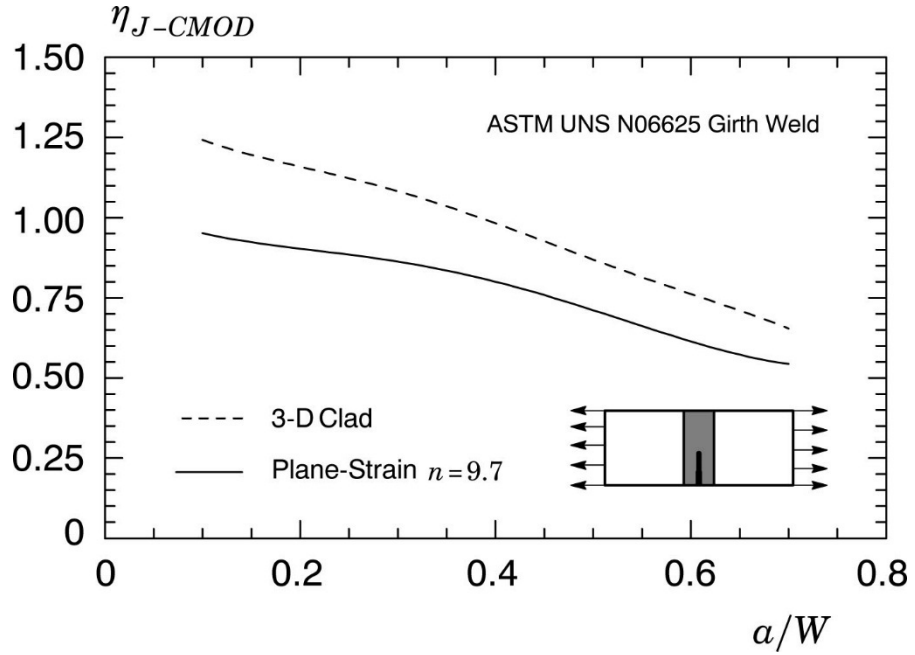


(a)

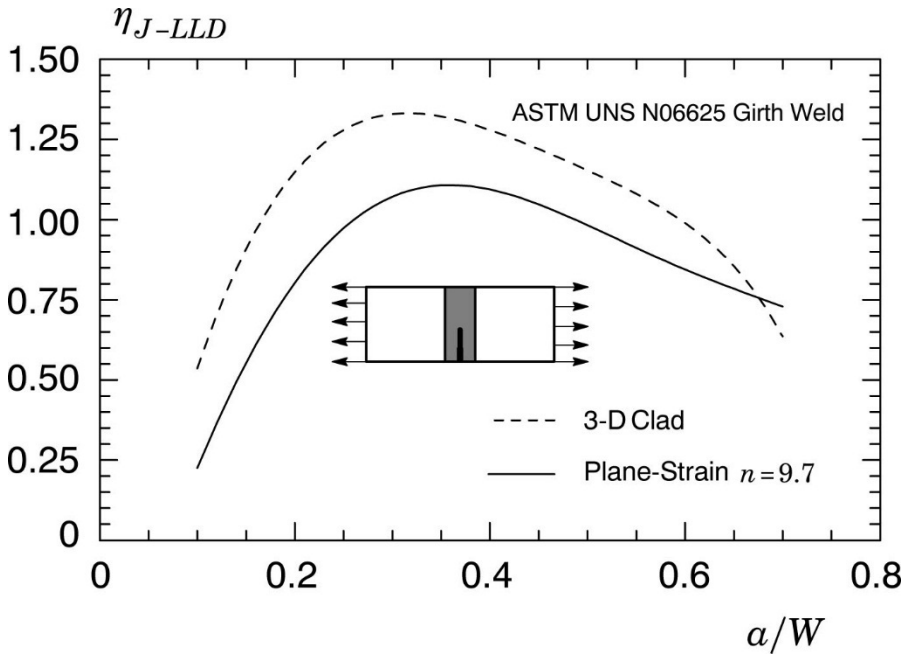


(b)

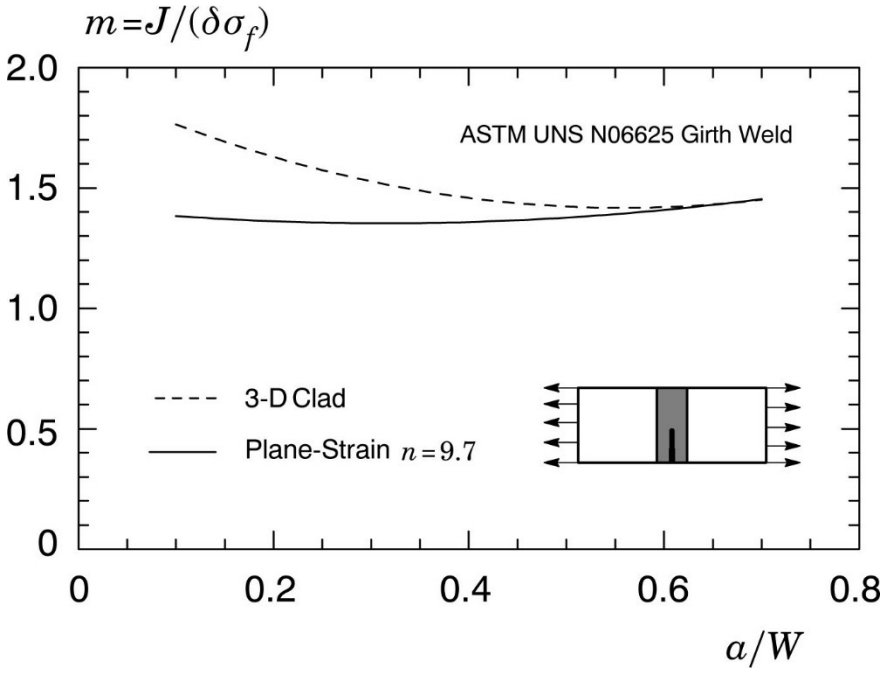
Clad SE(T) Specimens: η_{CMOD}-Factors



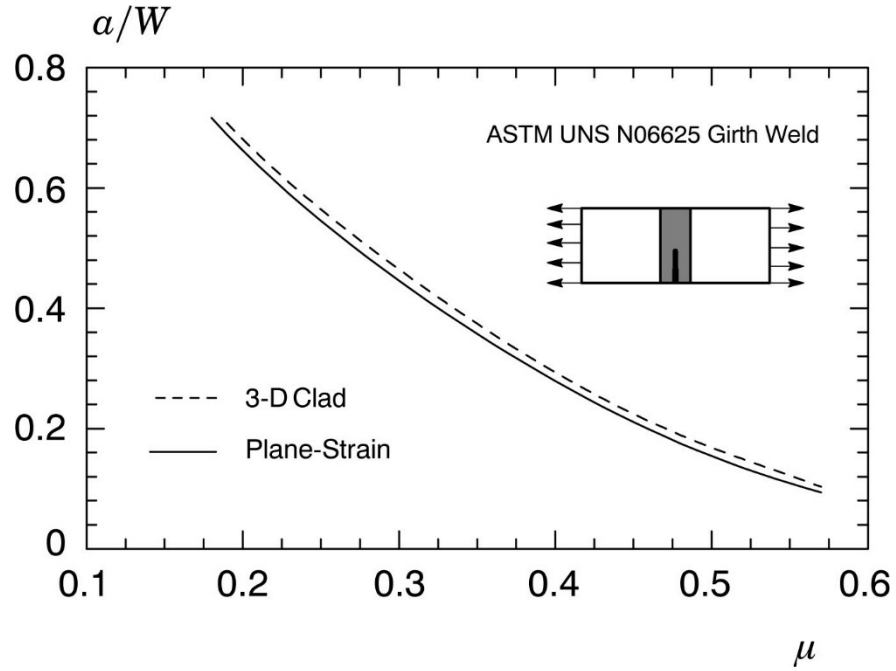
Clad SE(T) Specimens: η_{LLD}-Factors



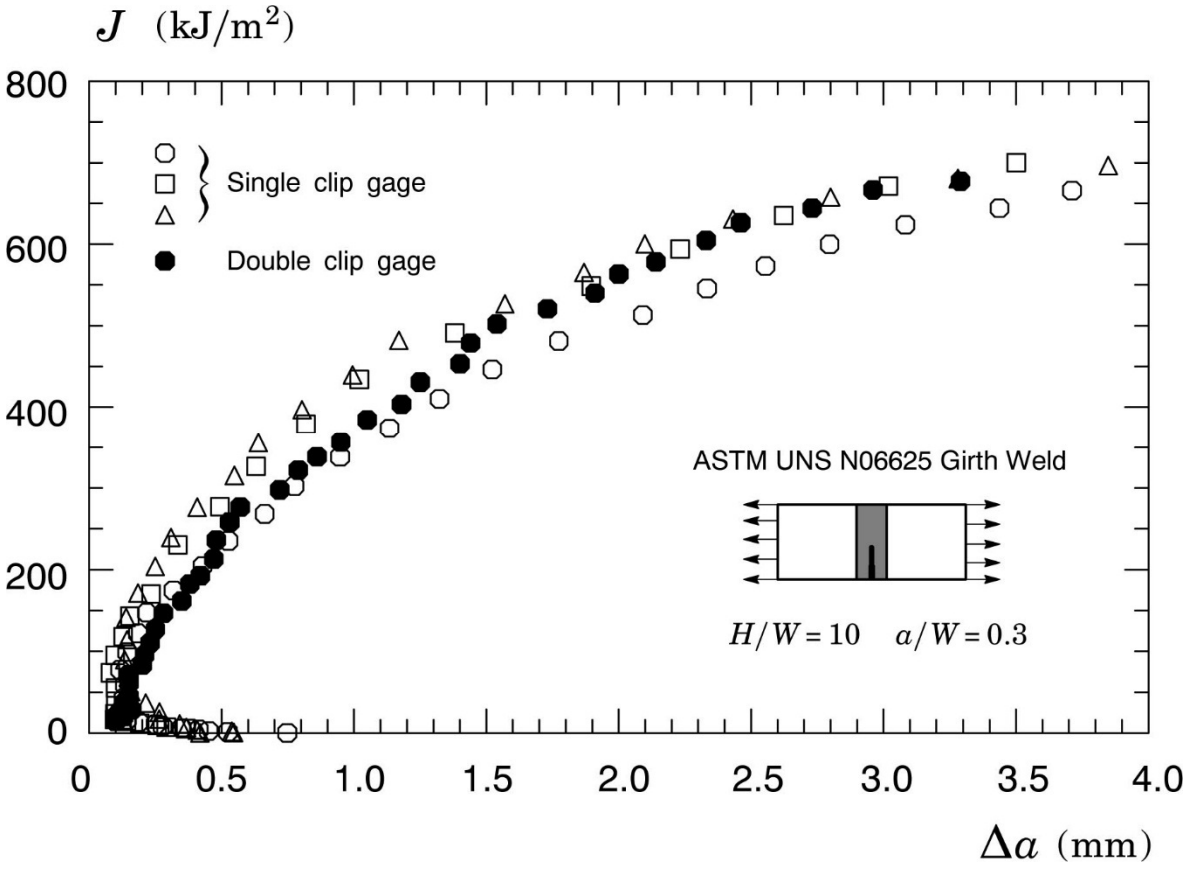
Clad SE(T) Specimens: *J*-CTOD Relationship



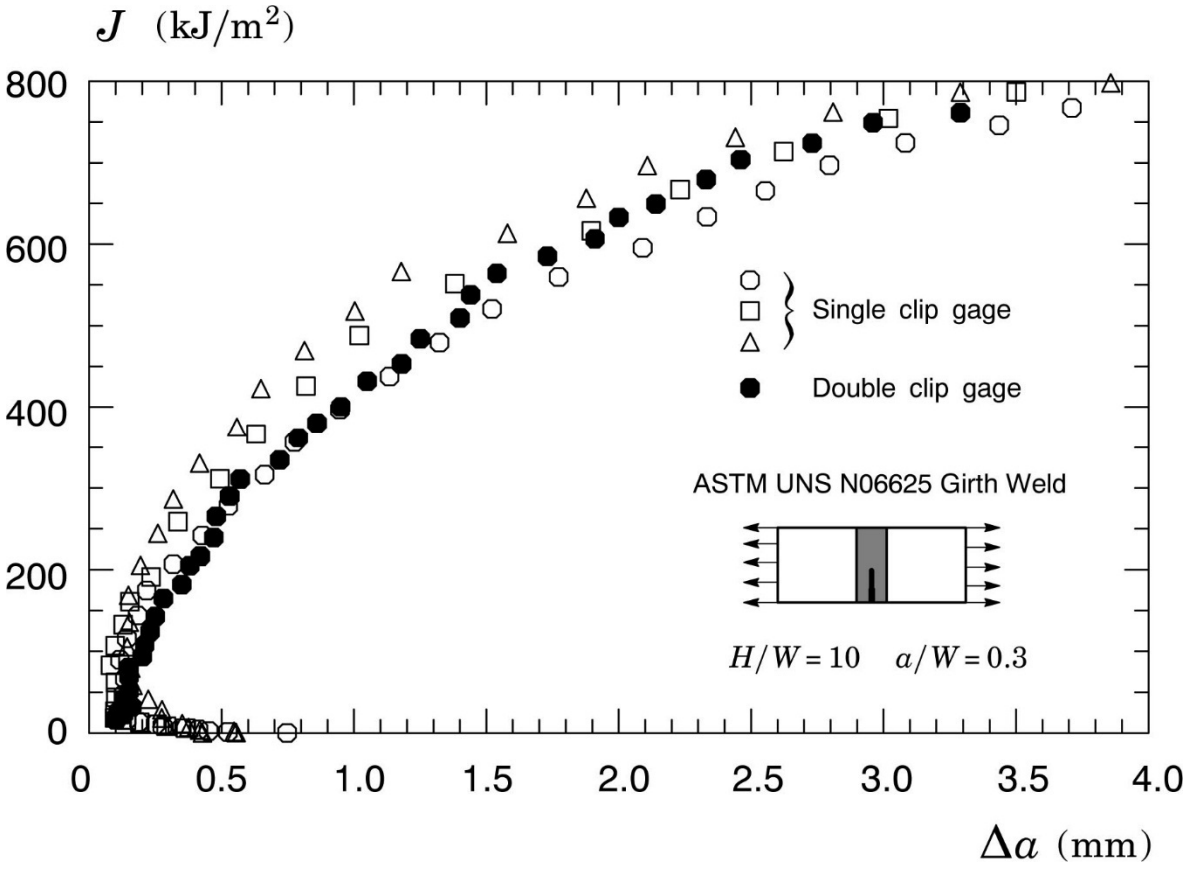
Clad SE(T) Specimens: Compliance



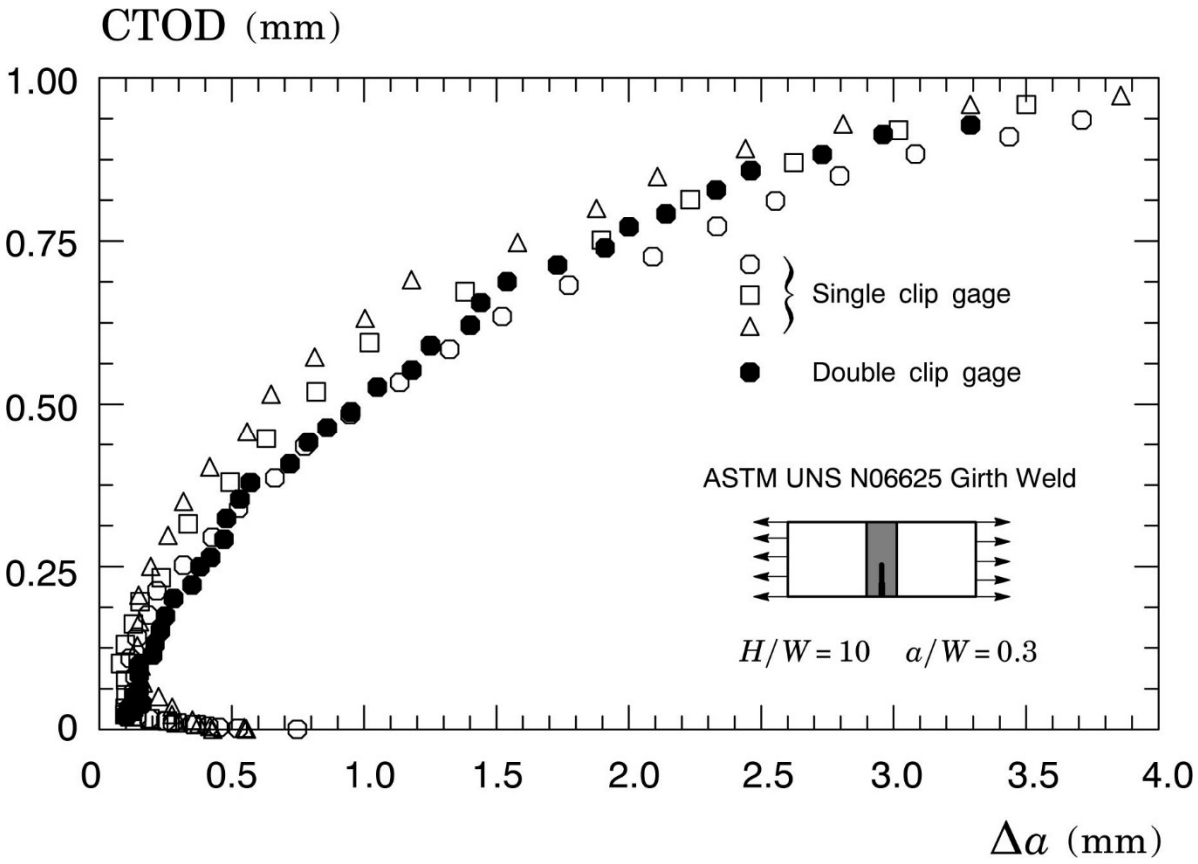
J-Resistance Curves: Plane-Strain



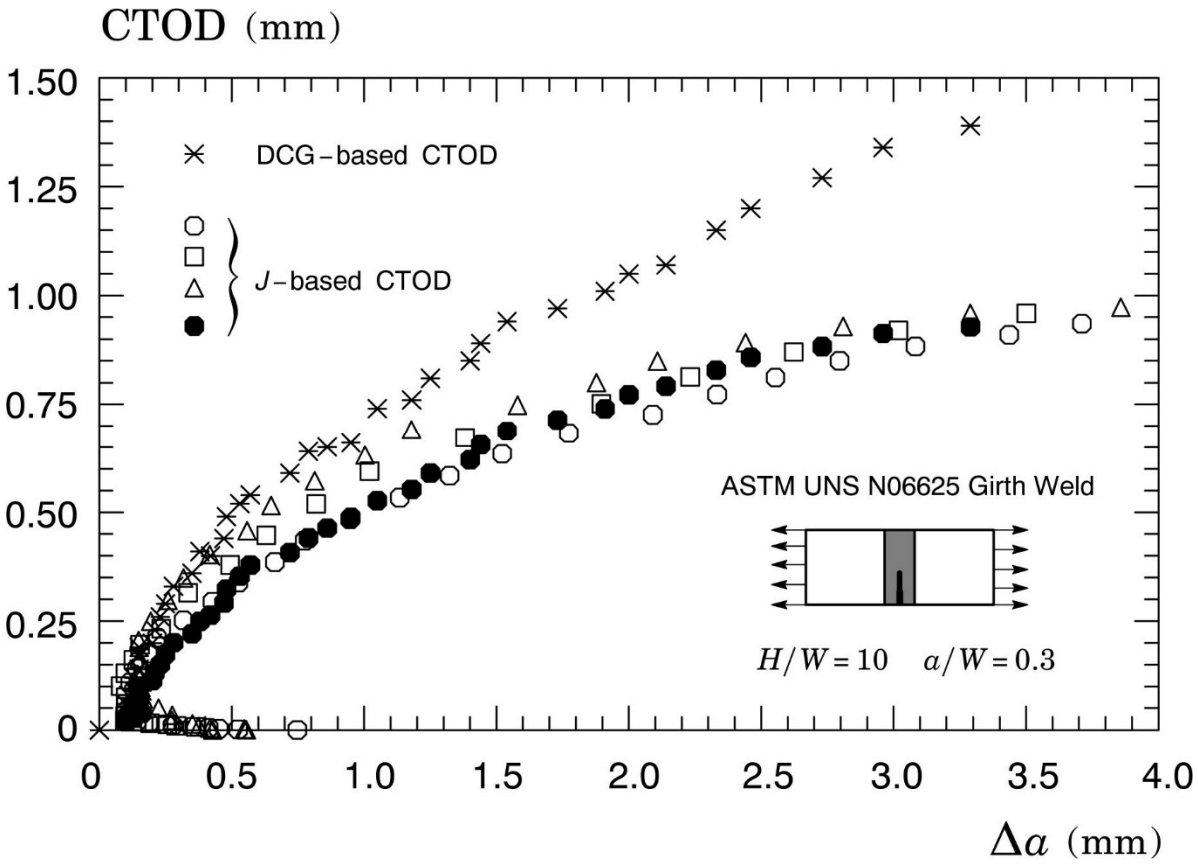
J-Resistance Curves: 3-D Clad



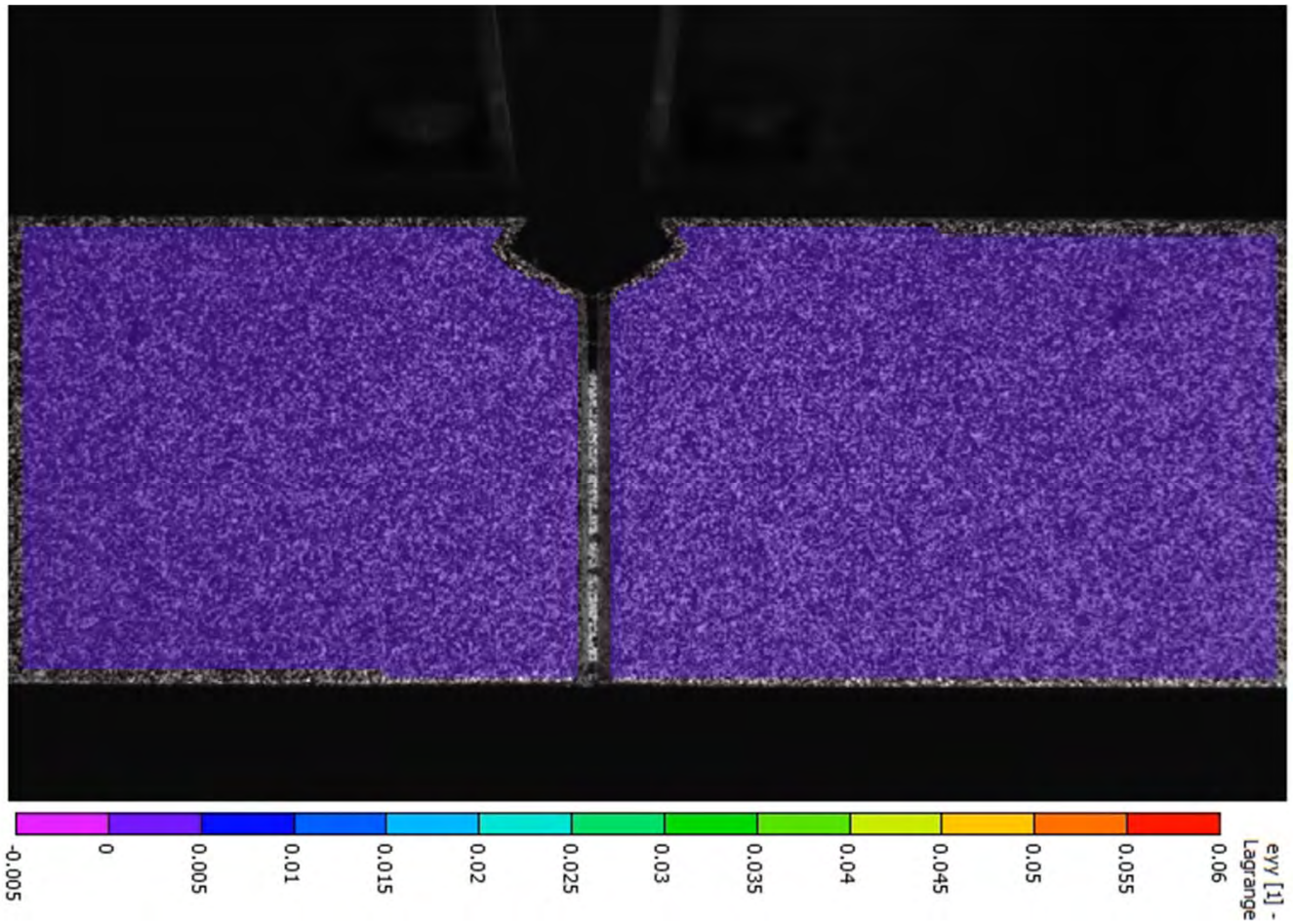
CTOD-*R* Curves: *J*-CTOD Relationship



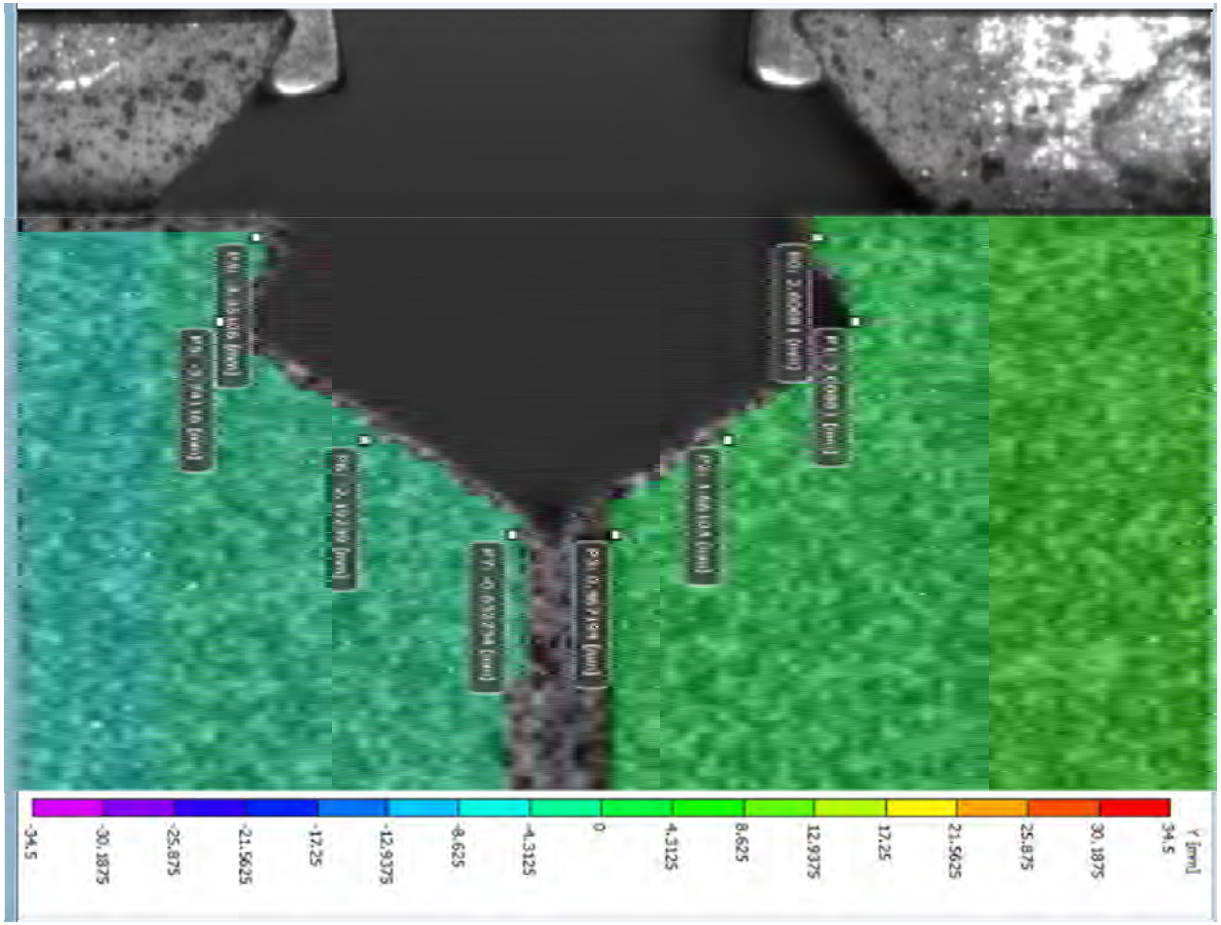
CTOD-*R* Curves: DCG Procedure



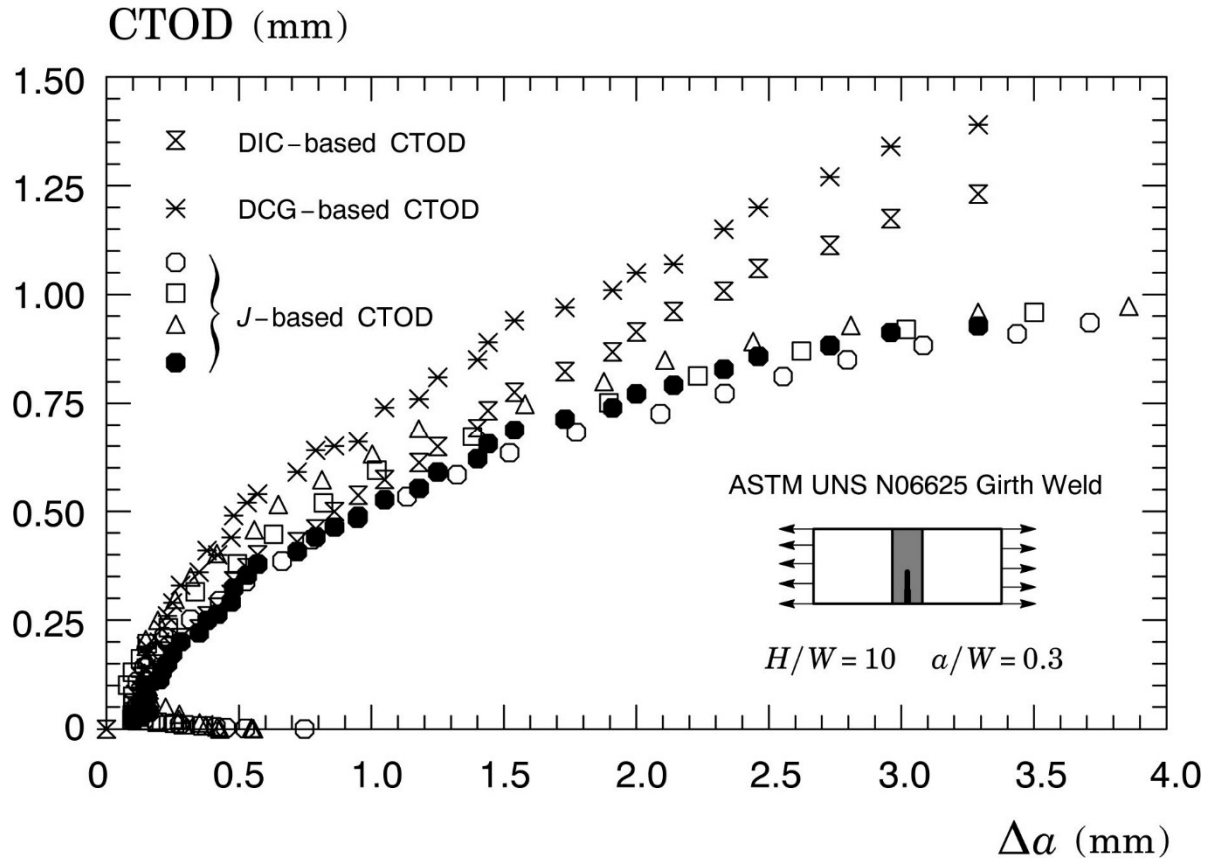
DIC Measurements



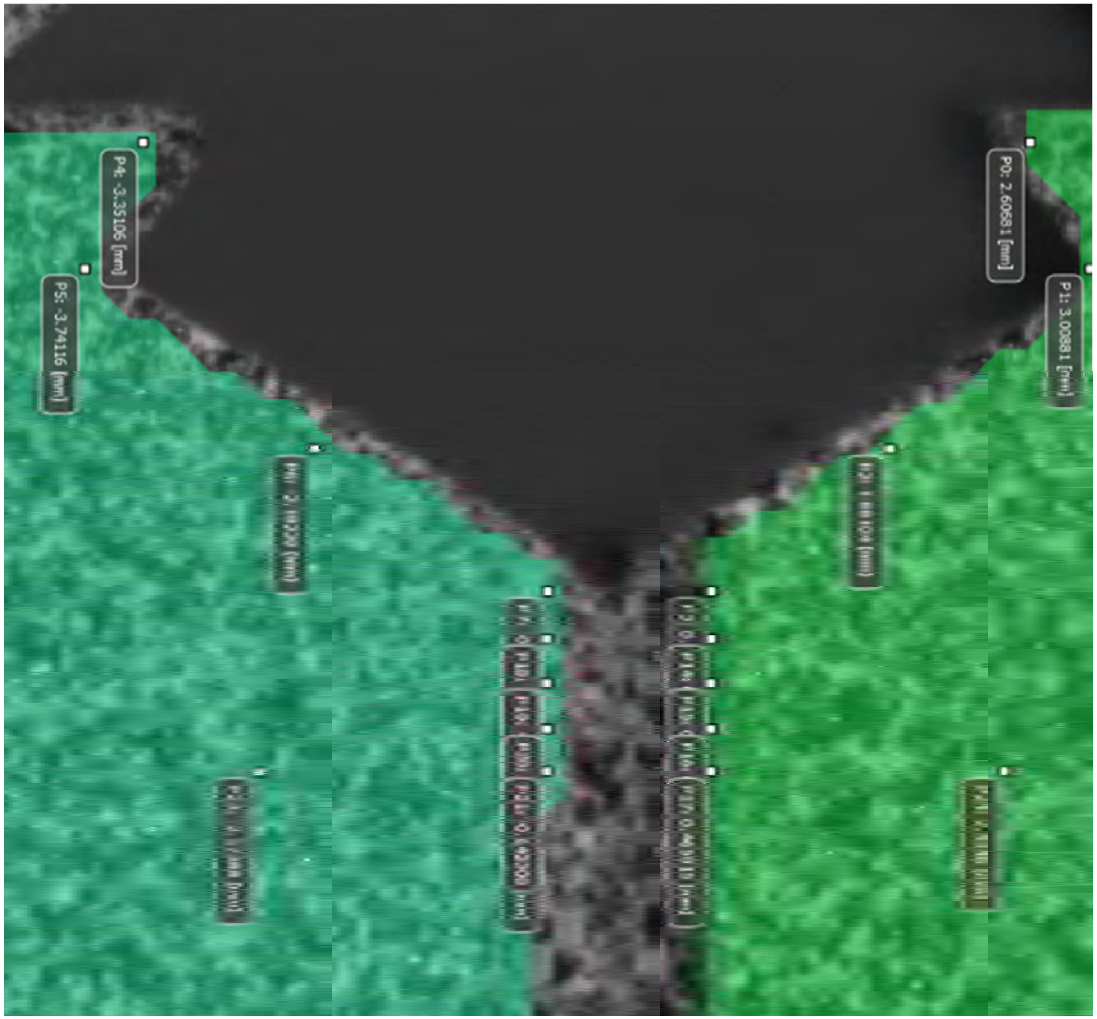
CTOD-R Curves: DIC Notch Flank



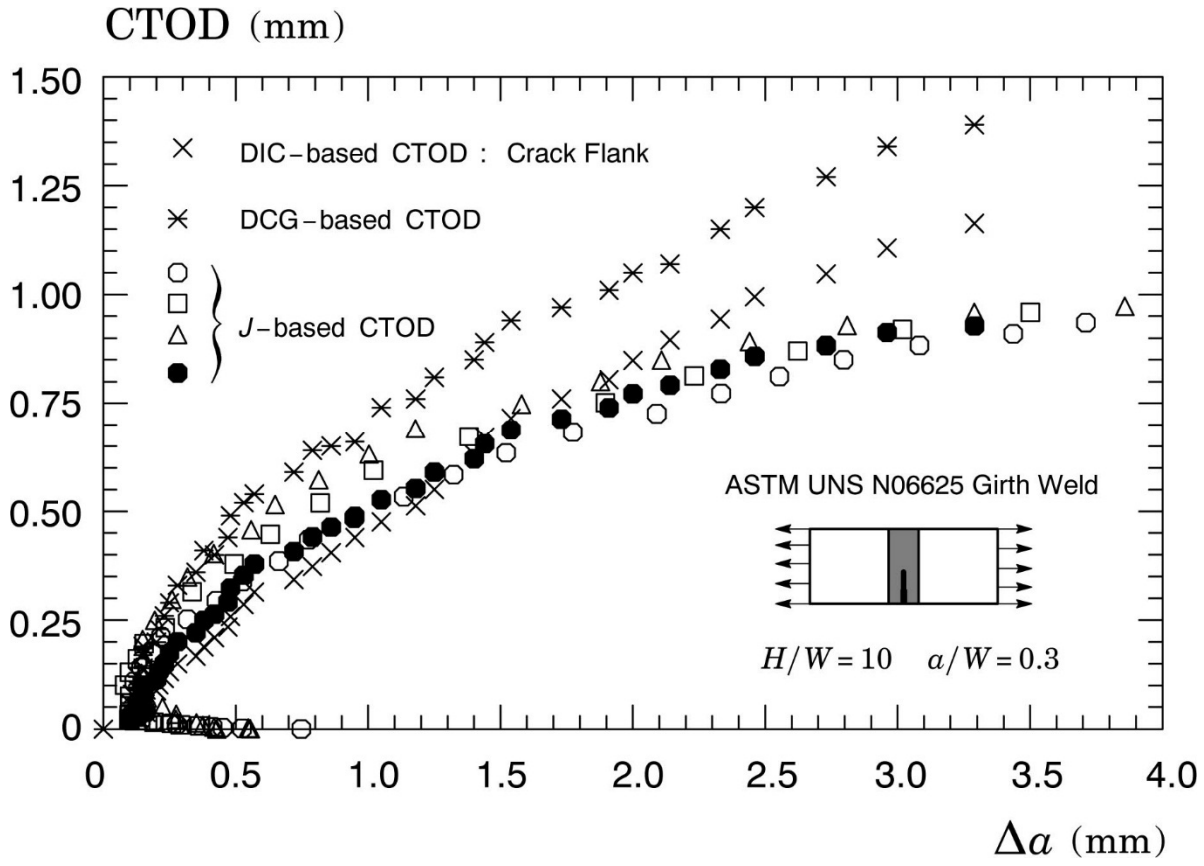
CTOD-R Curves: DIC Notch Flank



CTOD-R Curves: DIC Crack Flank



CTOD-R Curves: DIC Crack Flank



Summary

- *UC procedure is effective to evaluate ductile tearing properties of a dissimilar girth weld*
- *Crack growth correction becomes necessary in J-R curve and CTOD-R curve evaluation*
- *Full 3-D formulas for J-evaluation do improve the corresponding evaluation of CTOD-R curves*
- *CTOD evaluation procedure based on DCG technique always provides higher R-curves and, consequently, non-conservative fracture assessments*
- *DIC measurements of CTOD based on crack flank points provide good agreement with CTOD-R curve evaluation procedure based on J-CTOD relationship*

Pending Issues and On-Going Work

- ***Further assessment of CTOD-R curve evaluation procedure based on more robust J-CTOD relationships***
- ***Effects of strain hardening on the J-CTOD relationship***
- ***Better definition of the DCG CTOD to consider crack growth effects and the current crack tip***
- ***New set of fracture tests to begin by next Spring***

Thank You!

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Pipeline Research Council International, Inc.

PRCI Project Code (SIA-1-7)

Tensile Strain Capacity of Vintage Girth Welds

Bo Wang (presenter), Banglin Liu and Yong-Yi Wang
Center for Reliable Energy Systems

PRCI 2019 Research Exchange Meeting
Houston, Texas
March 6, 2019

Outline

- Overview of the work
- Key output and values to operators
- TSC estimation tool
- Evaluation of the tool against test data
- Application of the tool
- Limitations and follow-on work
- Concluding remarks

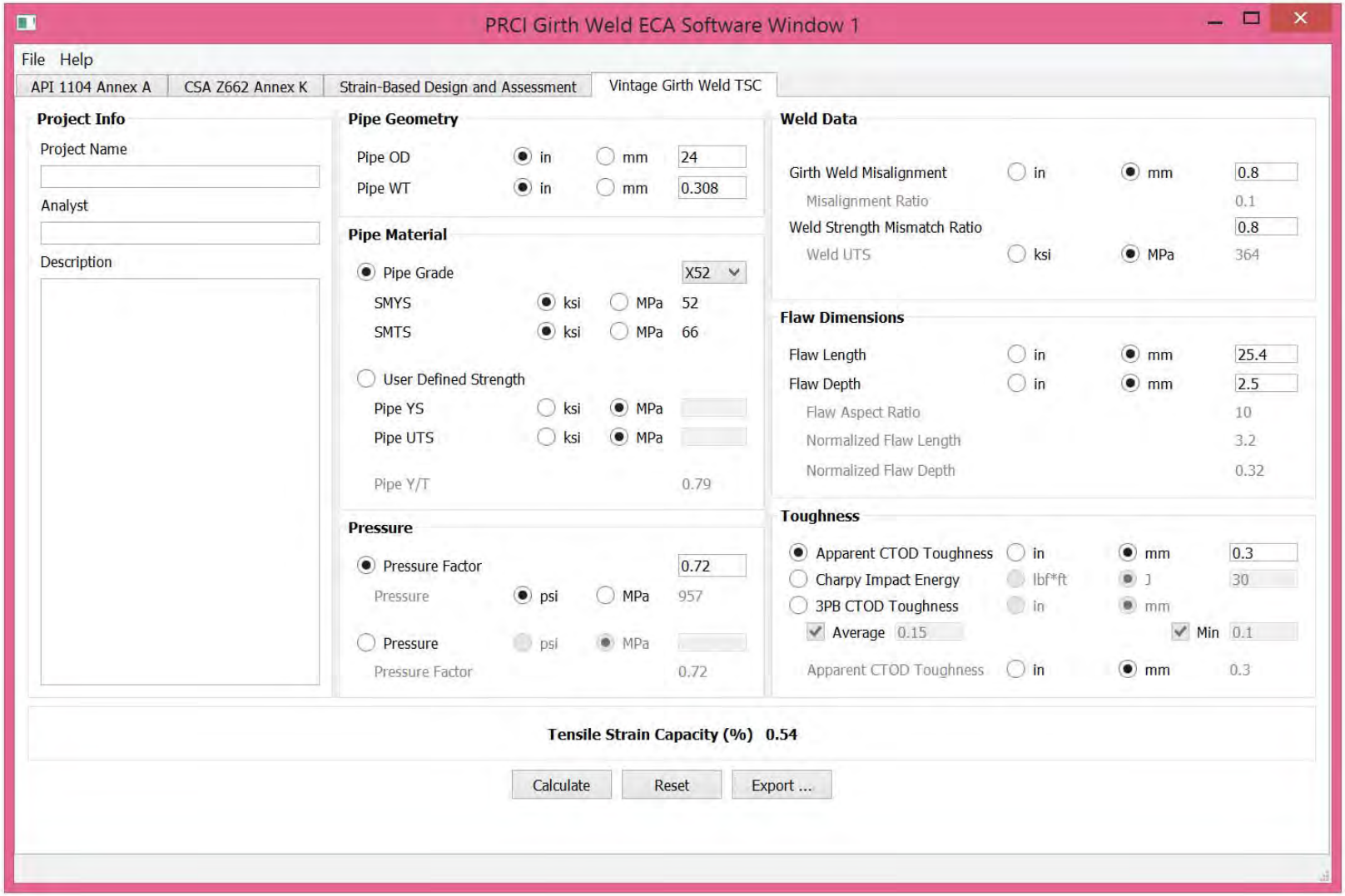
Overview of the Work

- **Objective**
  - To develop a TSC estimation tool for vintage girth welds
- **The tool development**
  - Case-specific TSC analysis using Level 4a procedures of the PRCI-CRES tensile strain design models
    - *Large ranges of material and dimensional parameters*
  - A software tool
    - *Takes the outcome of the TSC analysis*
    - *Has a user interface for easy use*
  - Curved wide plate (CWP) tests for the evaluation of the tool
  - Update the tool as needed

Key Output and Values to Operators

- **Key output**
  - Software tool that computes TSC for given input conditions
  - Recommendations for input values
- **Values to operators**
  - Integrity assessment of vintage pipelines sometimes is needed/required after a ground movement event and/or the discovery of weld anomalies.
  - Most of the existing assessment procedures are not suitable or may produce overly conservative results when the applied stress is close or beyond the yield strength.
  - The ability to assess the TSC of vintage girth welds enables operators to:
    - *Reduce unnecessary digs,*
    - *Make remediation decisions with confidence,*
    - *Justify maintenance decisions to regulators, and*
    - *Allow better integration and use of ILI and other inspection results.*

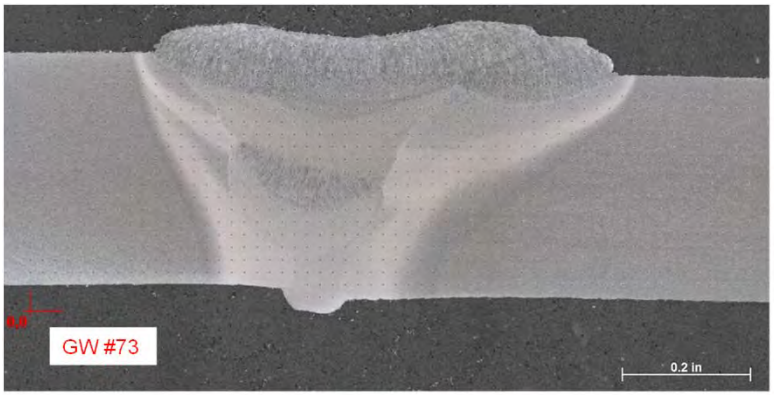
TSC Estimation Tool

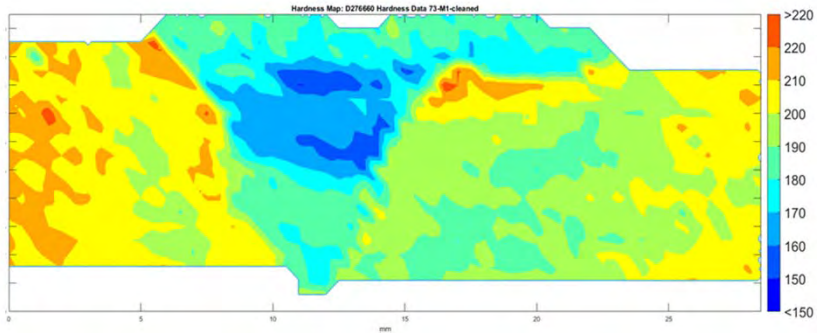


Testing Work for Tool Evaluation

- **Objective**
  - Conduct CWP and accompanying small-scale tests to provide test data for tool evaluation
- **Testing process**
  - Three vintage girth welds
  - NDT
  - Small-scale tests
    - *Mircrohardness mapping*
    - *Chemical composition*
    - *Pipe and weld tensile properties*
  - CWP tests
    - *Eight specimens with machined planar flaws*

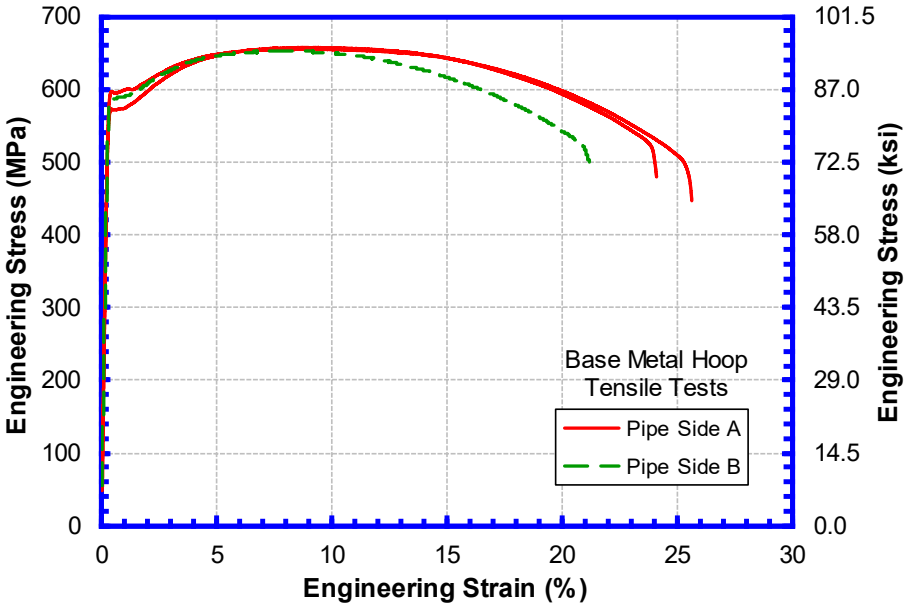
CRES GW #	Nominal OD in	Nominal WT in	Pipe Grade	Pipe Mill	Year of Construction	Seam Type
63, 64	30	0.375	X52	Republic	1955	DSAW
73	36	0.375	X52	Bethlehem Steel	1964	SAWL

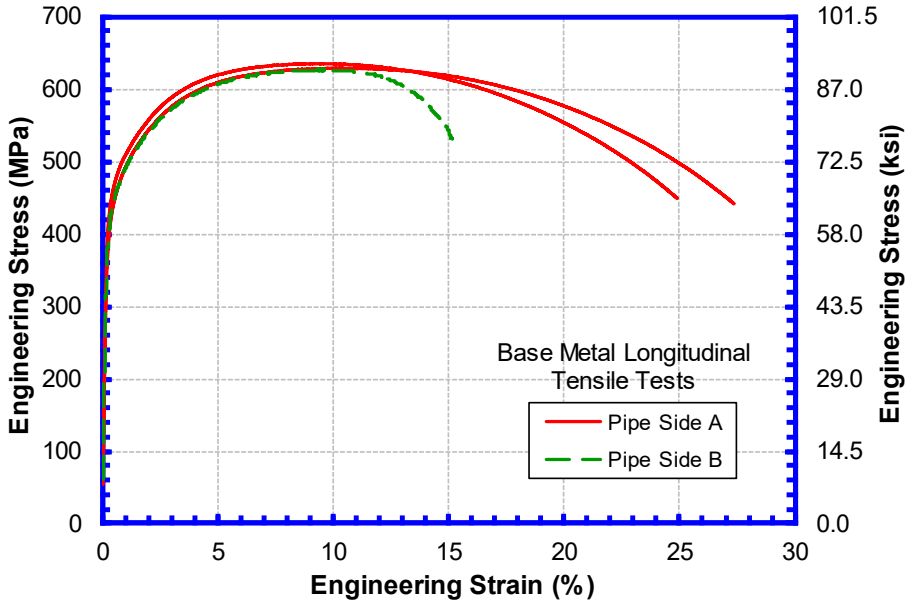




Small-Scale Material Properties

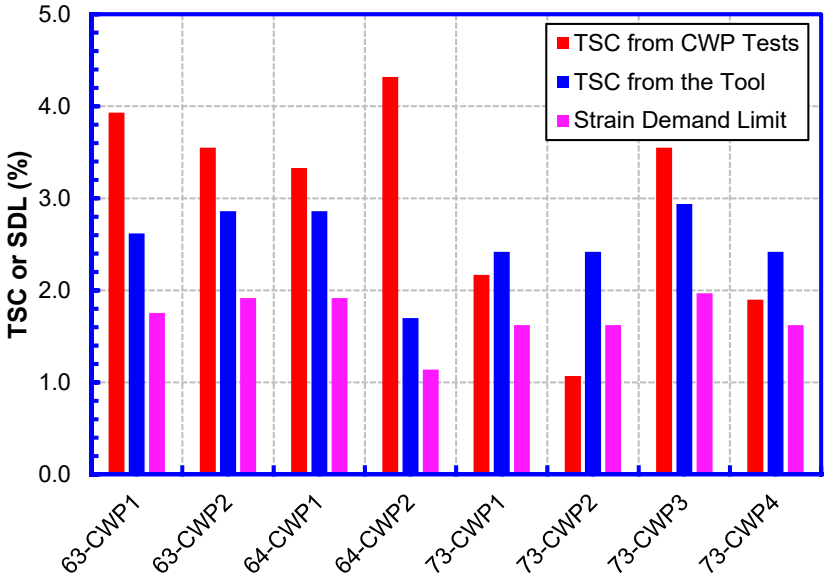
- **GW #73: 15-20% weld strength undermatching**
  - Hoop YS: 83 ksi
  - Longitudinal YS: 63 ksi
- **GWs #63 and #64: weld strength evenmatching**
- **HAZ strength ≈ pipe strength**

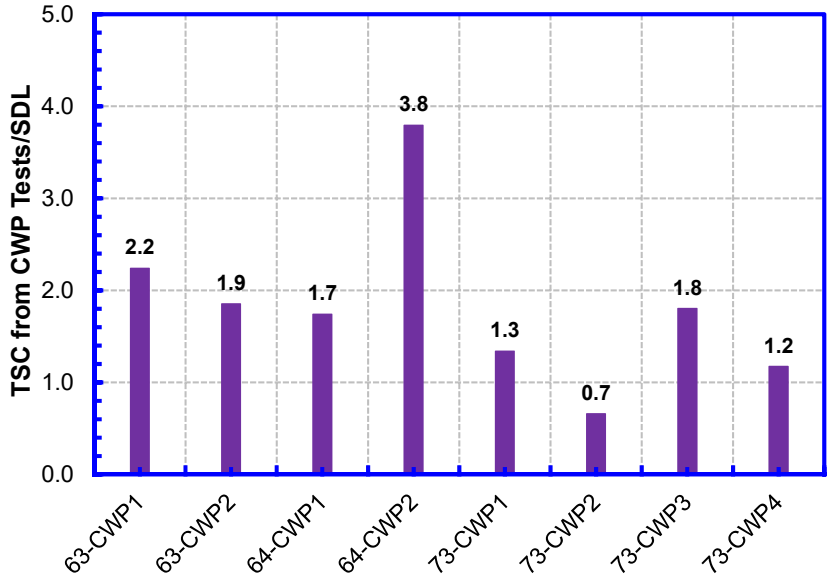




Comparison between Measured and Predicted TSCs

- **The tool is accurate and provides conservative TSC prediction in most cases.**
- **After applying the safety factor, the tool predicts:**
  - Conservative TSCs for 7 of 8 CWP specimens
  - Non-conservative "prediction" for one specimen with unexpected flaws (not reported by X-ray and PAUT)

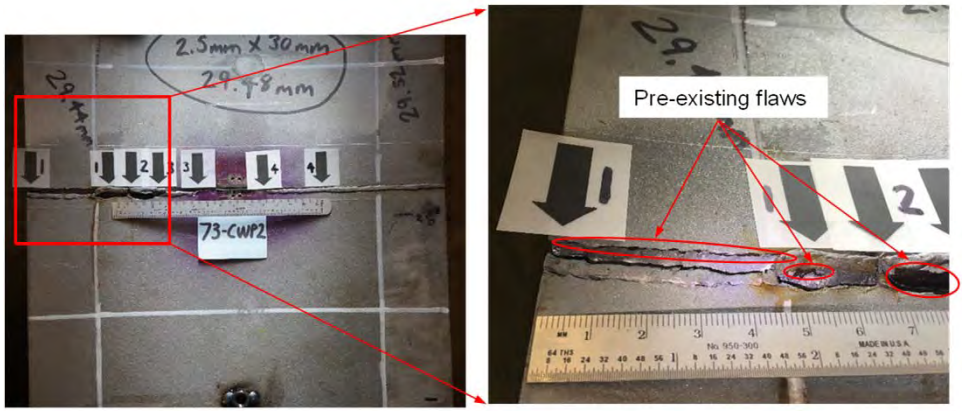


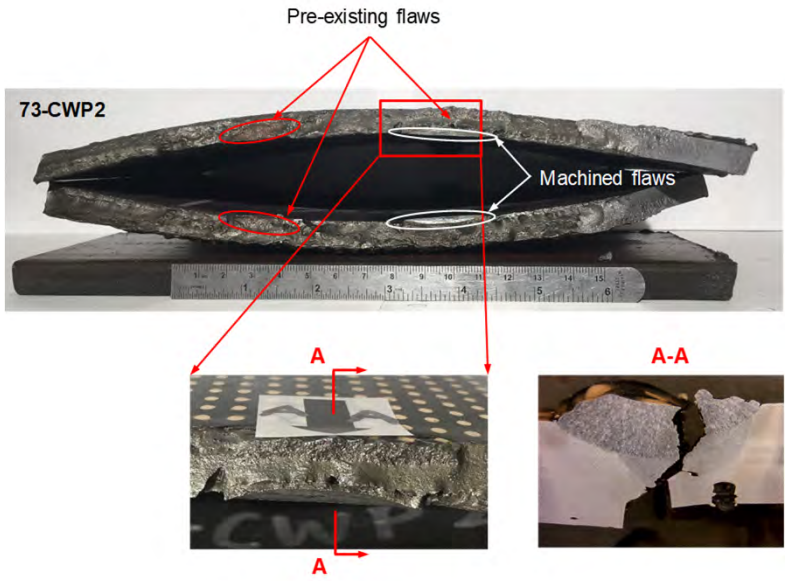


Strain Demand Limit (SDL) (%) = TSC from Tool (%) × SF
where SF is the safety factor and equals 0.67.

Causes for Low TSC in a Test Specimen

- The post-test flaw examination identified large pre-existing weld flaws in the specimen with the lowest TSC from the test.
- The specimen with the lowest TSC also has a high level of weld strength undermatching (GW #73, 15-20% undermatching).





Application of the Tool

- **Pipelines built with linepipe steels manufactured before the advent of microalloying and TMCP, generally having carbon content greater than 0.2%**
- **Girth welds made with SMAW processes using cellulosic electrodes**
- **Girth weld between pipes of the same nominal wall thickness**
- **Surface-breaking flaws (e.g., lack of fusion) and volumetric flaws**
- **Pipe segments subjected to longitudinal strains greater than 0.2% and up to 2.0%**
  - Due to uncertainties associated with material properties, welding/NDT practice, most operators would probably limit the strain demand to about 0.5-0.7%.
    - *TSC up to 0.75-1.0% is the sweet spot.*
  - Without large-scale ground movements, strain demand is unlikely to go beyond 0.5-0.7%.

Application of the Tool – Cont.

- **Exclusions**
  - Girth welds having excessively high level of weld strength undermatching, defined as weld UTS being 80% or lower of the pipe UTS.
    - *Case-specific analysis and/or testing must be performed.*
  - Girth welds interacting with other anomalies, such as corrosion or mechanical damage.

Limitations and Follow-On Work

- **More CWP tests**
  - Vintage girth welds can have large variations in weld profile, weld strength mismatch, toughness, and other characteristics.
  - Although there are limited number of tests of vintage girth welds by others, the test procedures and documentations are lacking for tool validation.
- **More TSC analysis cases**
  - Expand the range of certain parameters, e.g., long and shallow flaws
  - Refine the increment of input parameters to improve the precision of TSC interpolation

Concluding Remarks

- **A TSC estimation tool is developed for vintage girth welds.**
- **Although further validation and refinements are helpful, the current tool provides a sound framework for application.**
- **The tool can be used for**
  - Case-specific assessment and
  - Screening for prioritization of mitigation.
- **More analysis and testing can improve the accuracy of the tool and provide greater confidence when the tool is used.**

Pipeline Research Council International, Inc.

Significance of

Automatic Pipe Dimension Measurement

of Line Pipe for Deep Offshore Pipelines

Jigar Patel

TS Kathayat **G. Chauhan**

WELSPUN CORP
PIPES AND PLATES

PRCI 2019 Research Exchange Meeting
Houston, Texas
March 5 - 6, 2019

Introduction

- **Conventionally done manually**
- **Ambiguity of resolution & accuracy level**
- **Measurements depend mainly on:**
  - Human being
    - *Positioning of instrument*
    - *Methodology used*
    - *Accessibility of the product*

- **Automated system is required to eliminate the measurement error.**
- **Independent of any manual intervention**
  - With impeccable:
    - *Accuracy*
    - *Resolution*
    - *Repeatability & Reproducibility*
    - *Compliance to specs. & standards*

Outside Diameter (OD)

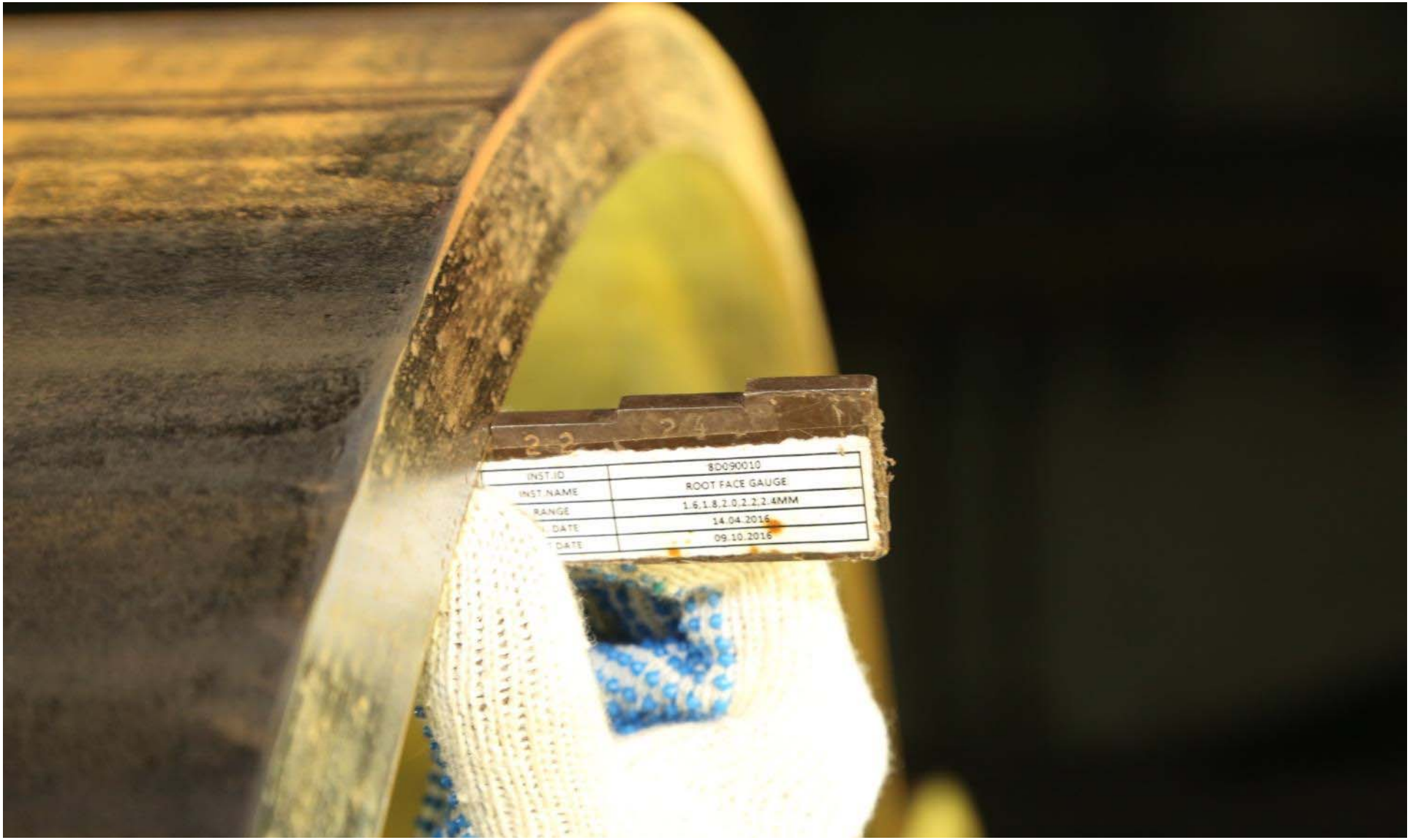
Inside Diameter (ID)

Out-of-Roundness (OOR)

Straightness

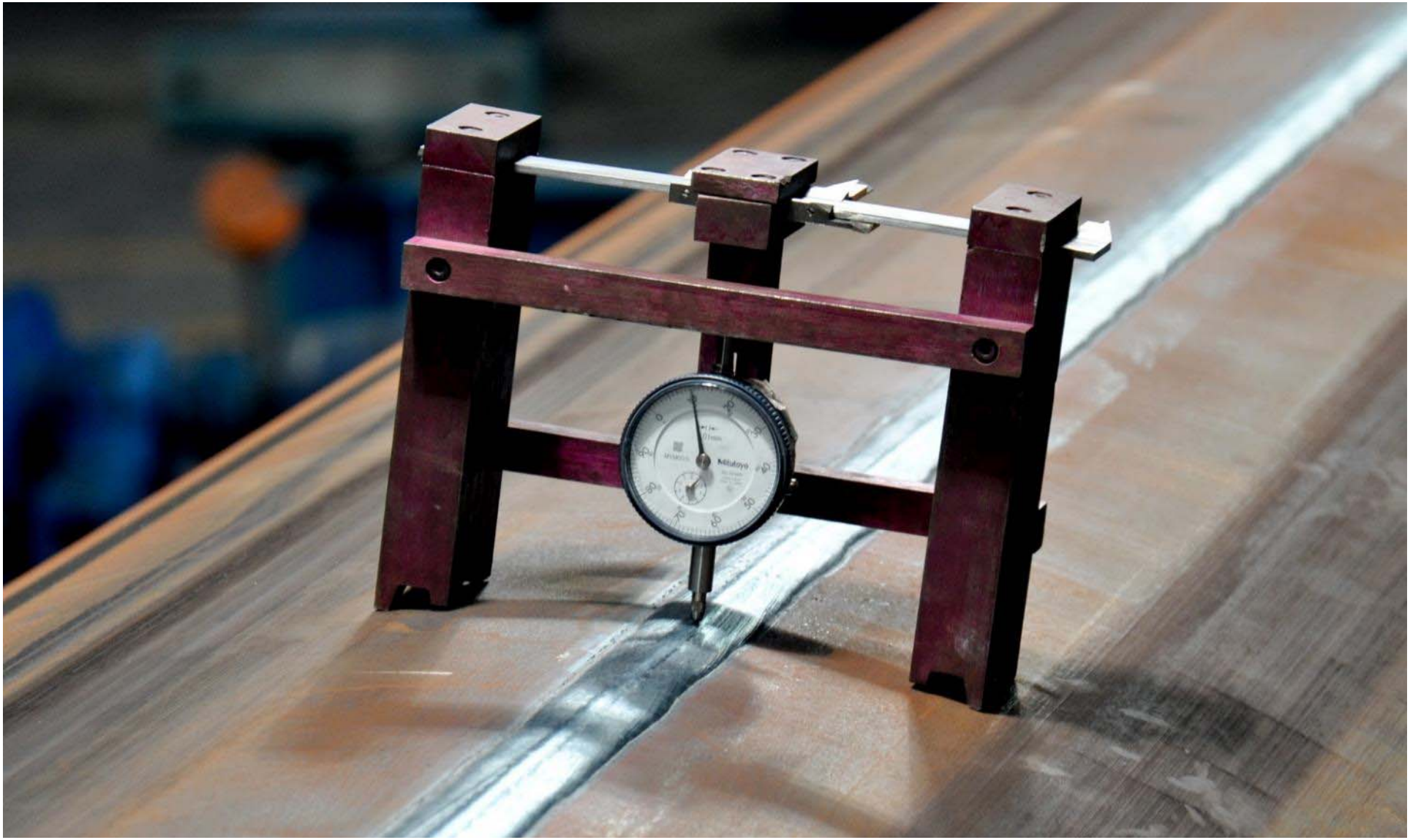
Pipe Length

Root Face

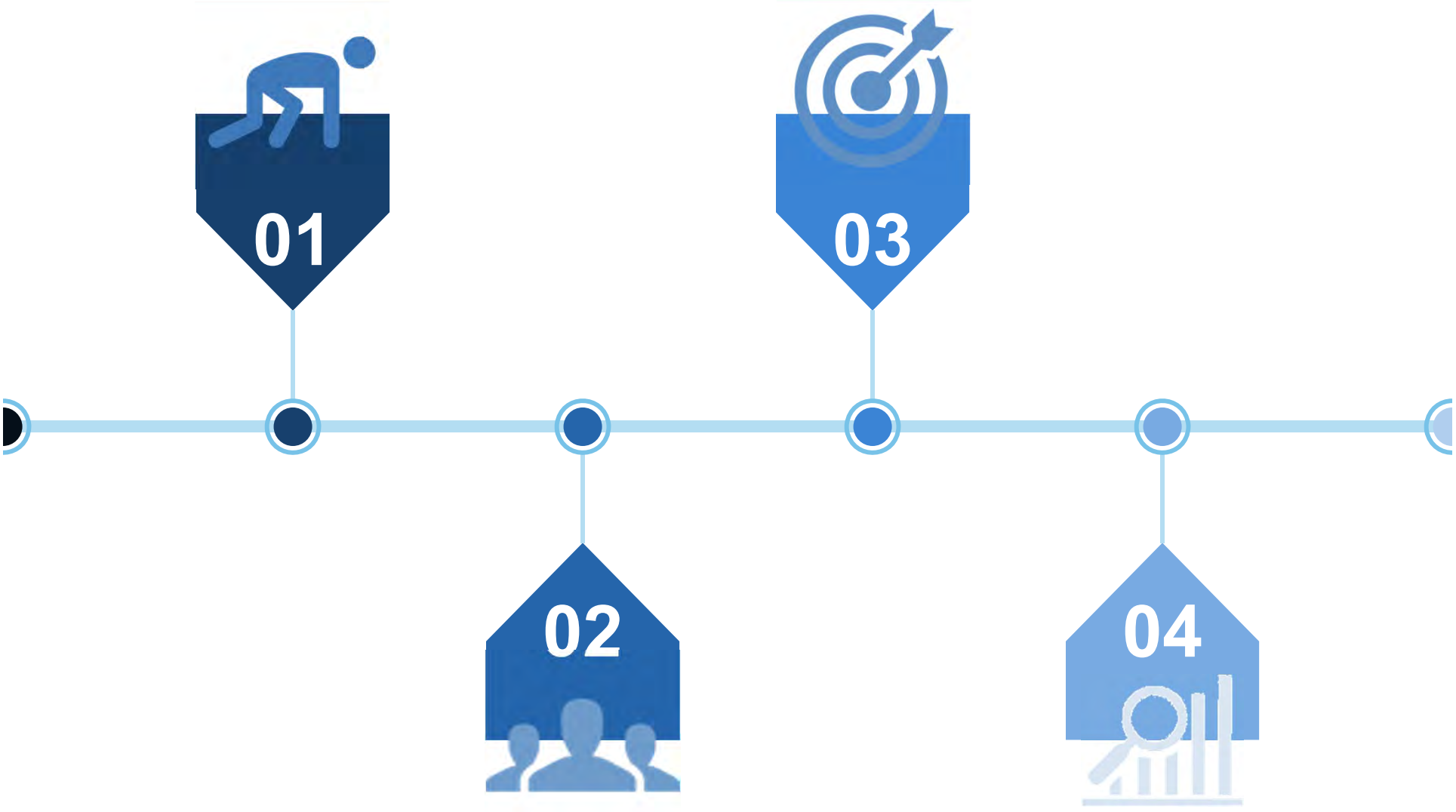

INST.ID
8D090010
INST.NAME
ROOT FACE GAUGE
RANGE
1.6,1.8,2.0,2.2,2.4MM
DATE
14.04.2016
DATE
09.10.2016

Weld Bead Height

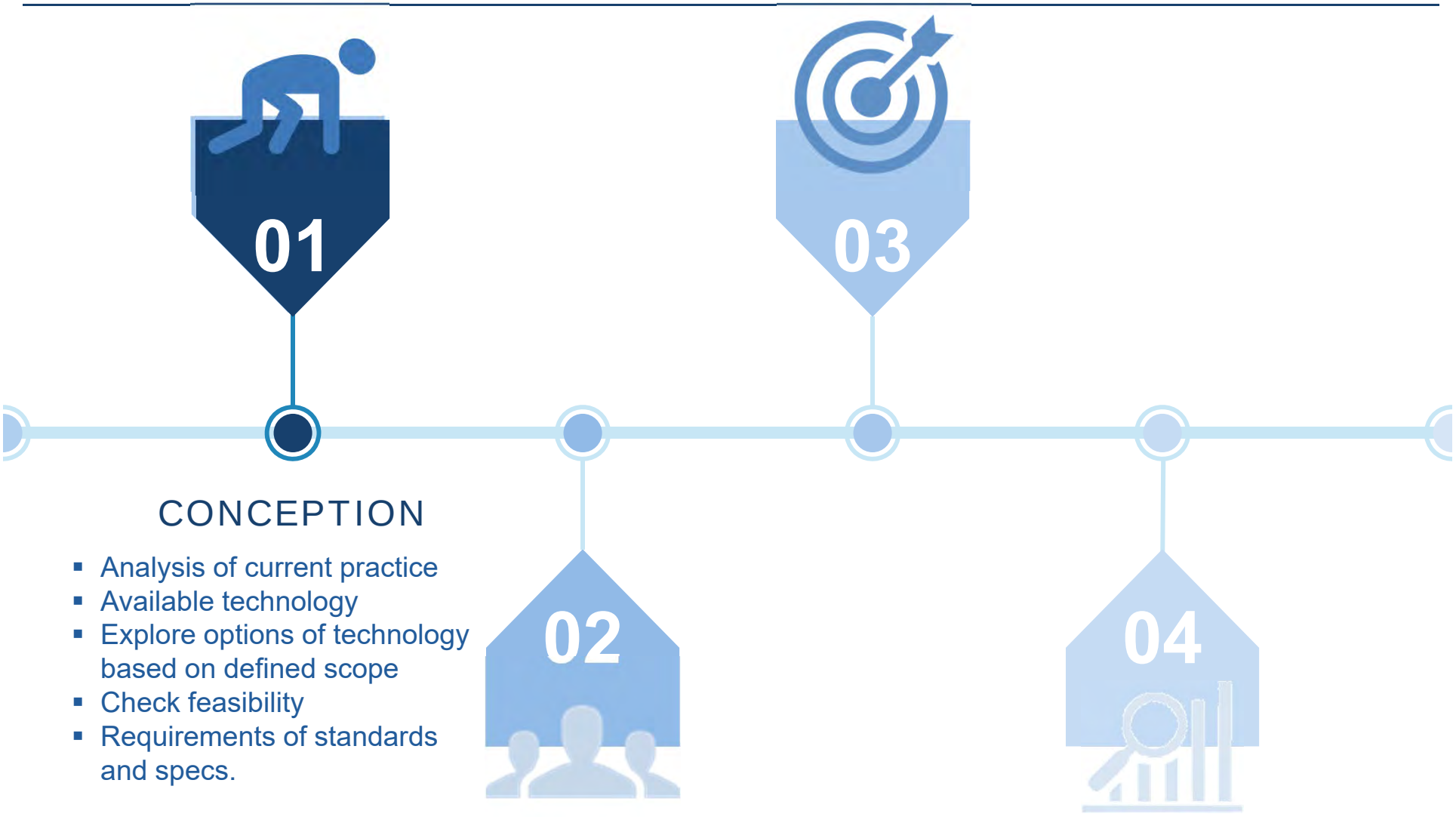
Weld Edge Offset



Overview of Project



Overview of Project



Overview of Project

01

DEVELOPMENT

- with OEM
- as per requirements
- with specific features

03

CONCEPTION

- Analysis of current practice
- Available technology
- Explore options of technology based on defined scope
- Check feasibility
- Requirements of standards and specs.

02

04

Overview of Project

CONCEPTION

- Analysis of current practice
- Available technology
- Explore options of technology based on defined scope
- Check feasibility
- Requirements of standards and specs.

DEVELOPMENT

- with OEM
- as per requirements
- with specific features

IMPLEMENTATION

- Installation & commissioning
- Training of people
- Trials of R&R
- Corrections

Overview of Project

CONCEPTION

- Analysis of current practice
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IMPLEMENTATION

- Installation & commissioning
- Training of people
- Trials of R&R
- Corrections

PERFORMANCE

- transition from manual
- analysis of pipes measured
- troubleshooting
- modifications, where reqd.

Outcomes

Reliability

- Measurements of nearly 70,000 pipes
- > 99% machine uptime
- Self-calibration modules available

Integrity

- No manual intervention in measurements
- Auto evaluation against set acceptable criteria and spray-marking
- Automatic transfer of measured parameters to SAP, without manual interference
- Repeatability and Reproducibility

Analysis

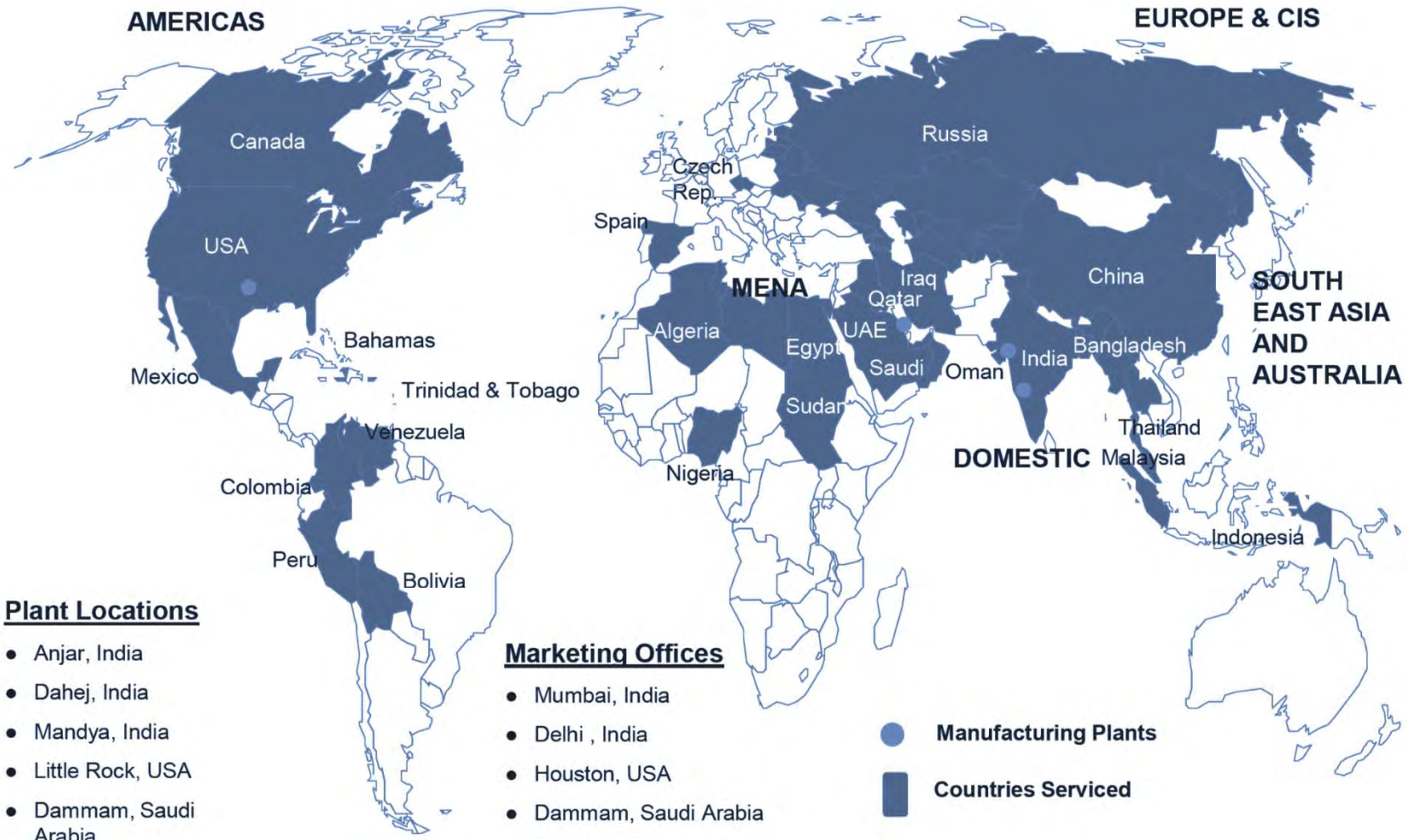
- Provides exact location of min. and max. value of a parameter
- Graphical representation of variation of parameter along length/circumference
- 3D model of pipe available for each pipe tested

Values

- Ensures to maintain the core values of Welspun, which has always strived for customer-centricity, inclusive growth, collaboration and technology

Outcomes – SPECTRA VCP PROJECT

WCL Global Presence



Automatic
Pipe
Dimension
Measurement
System

Key Figures

19
parameters

72
Measurement scanners

104
measurements

2.5
minutes/pipe

SAP
Data Integration

1st
In India
one-of-its-kind in the world

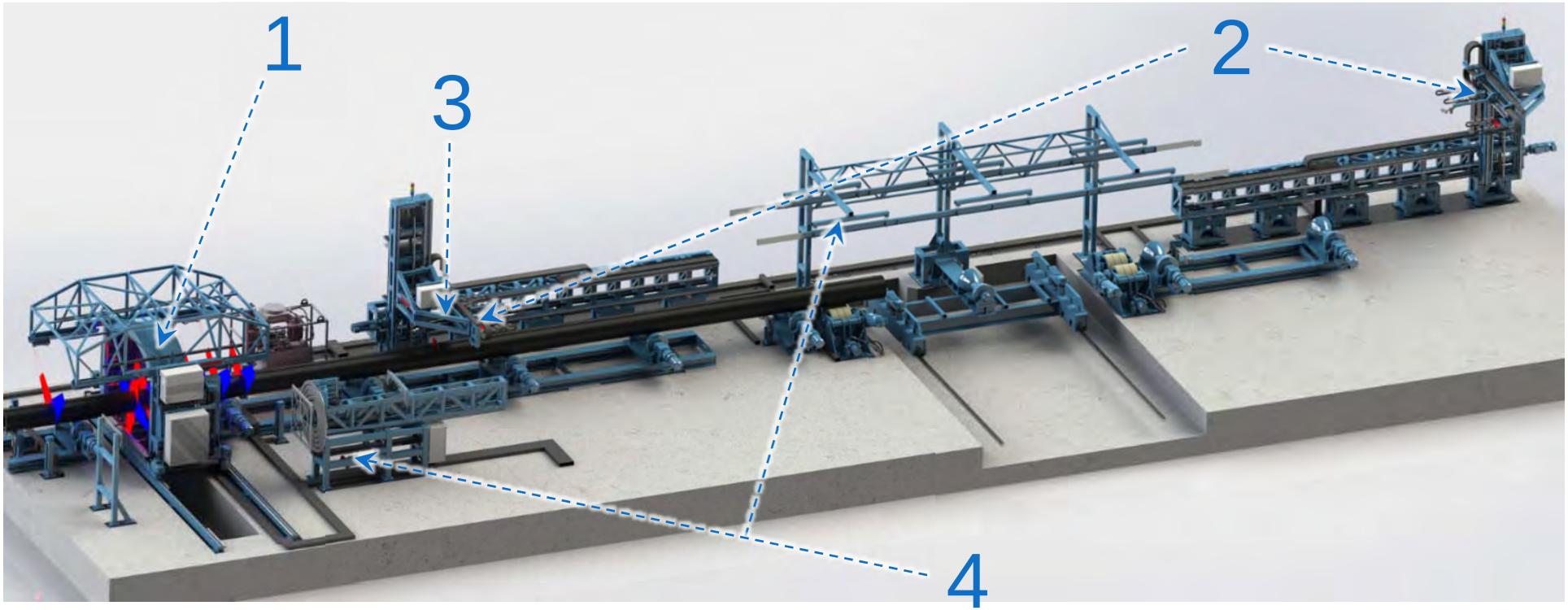
Parameters Measured

Sr.	Parameters	Location for measurement	Values	Accuracy
Parameters - Diameter, Roundness and Straightness Measuring system:				
1	Pipe Outside Diameter	Within 400 mm from Both Ends & Pipe Body	Min, Max, Average	± 0.15 mm
2	Overall Out of Roundness [Difference of Max and Min Diameter]	Measured from OD (within 400 mm from Both ends)	Maximum	± 0.1 mm
3	Overall Out of Roundness [Difference of Max and Min Diameter]	OD - Body	Maximum	± 0.3 mm
4	Local Out of Roundness [Measured as deviation from normal curve]	Within 400 mm from Both Ends	Min, Max, Average [Location w.r.t. weld seam & end	± 0.1 mm
5	Local Out of Roundness [Measured as deviation from normal curve]	Measured from Pipe OD - Body	Min, Max, Average [Location w.r.t. weld seam]	± 0.1 mm
6	End Straightness	Up to 3 m from Each Pipe ends	Min, Max, Average	± 0.1 mm
7	Straightness	Full Length	Min, Max, Average	± 1 mm
Parameters - Pipe End Measurement System (Bevel Profile , Length & End Squareness)				
1	Pipe Wall Thickness	Both Ends	Min, Max, Average	± 0.05 mm
2	Pipe End Inside Diameter	Both Ends	Min, Max, Average	± 0.15 mm
3	Overall Out of Roundness [Difference of Max and Min Diameter]	Measured from ID (For Both ends)	[Location w.r.t. weld seam]	± 0.1 mm
4	Bevel Angle	Both Ends	Min, Max, Average	± 0.5˚
5	Root Face of Bevel	Both Ends	Min, Max, Average	± 0.15 mm
6	Squareness	Both Ends	Min, Max, Average	± 0.15 mm
5	Pipe Length	-	-	± 1 mm
Parameters - Weld Measurement system:				
1	OD Weld Bead Height	OD Weld Seam Full Length	Min, Max, Average	± 0.1 mm
2	Radial Weld Edge Offset (OD Weld Seam)	Full Length	Min, Max, Average	± 0.1 mm
3	OD Weld Bead Width	Full Length	Min, Max, Average	± 0.5 mm
4	Weld OD Undercut	Full Length	Maximum	± 0.1 mm

Measurement Range

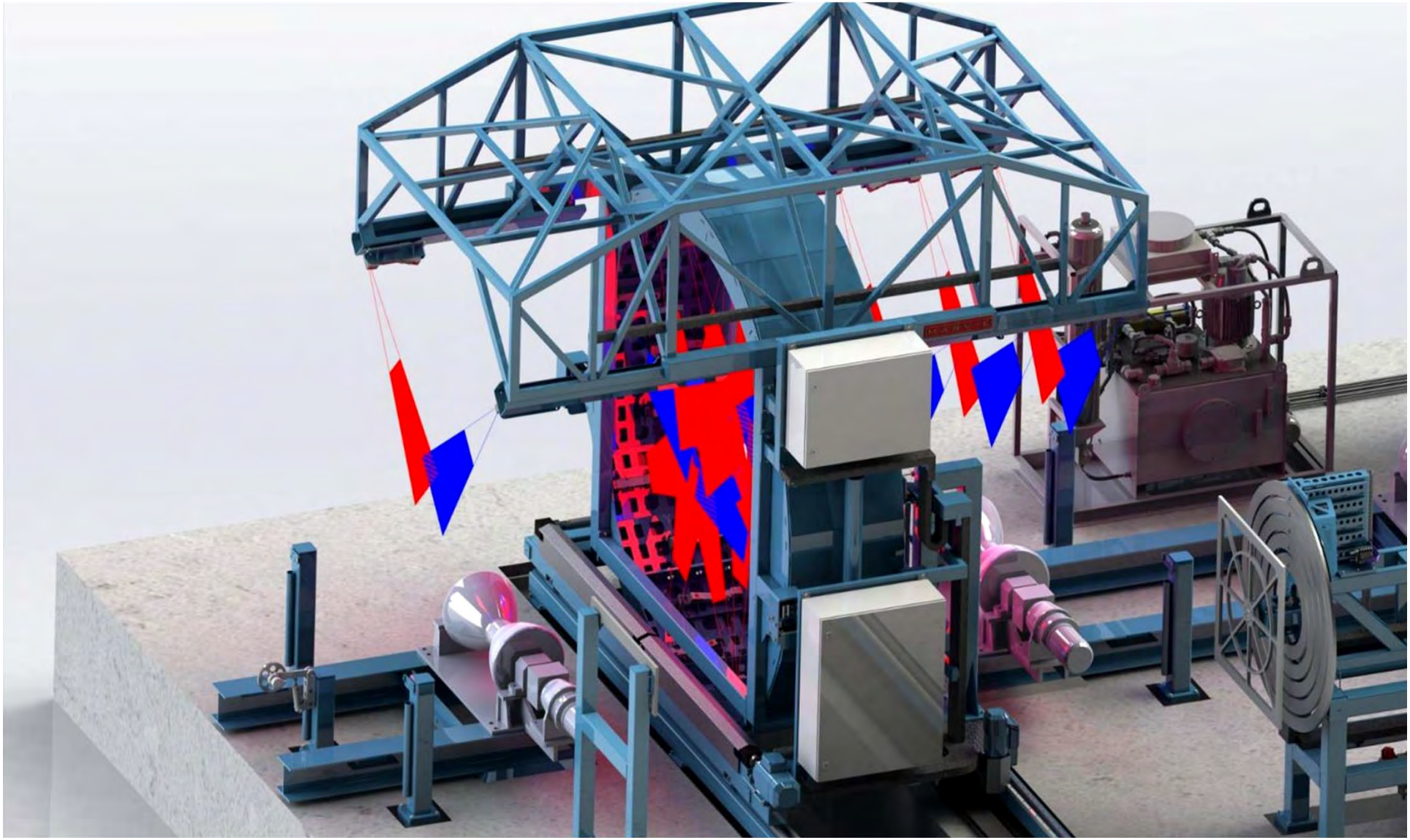
Parameter	Range
Pipe length	9.0 - 18.5 meter
Outside Diameter	457 - 1524 mm 18” - 60”
Wall Thickness	6 - 50 mm
Pipe Weight	Max 35 MT

Machine Layout

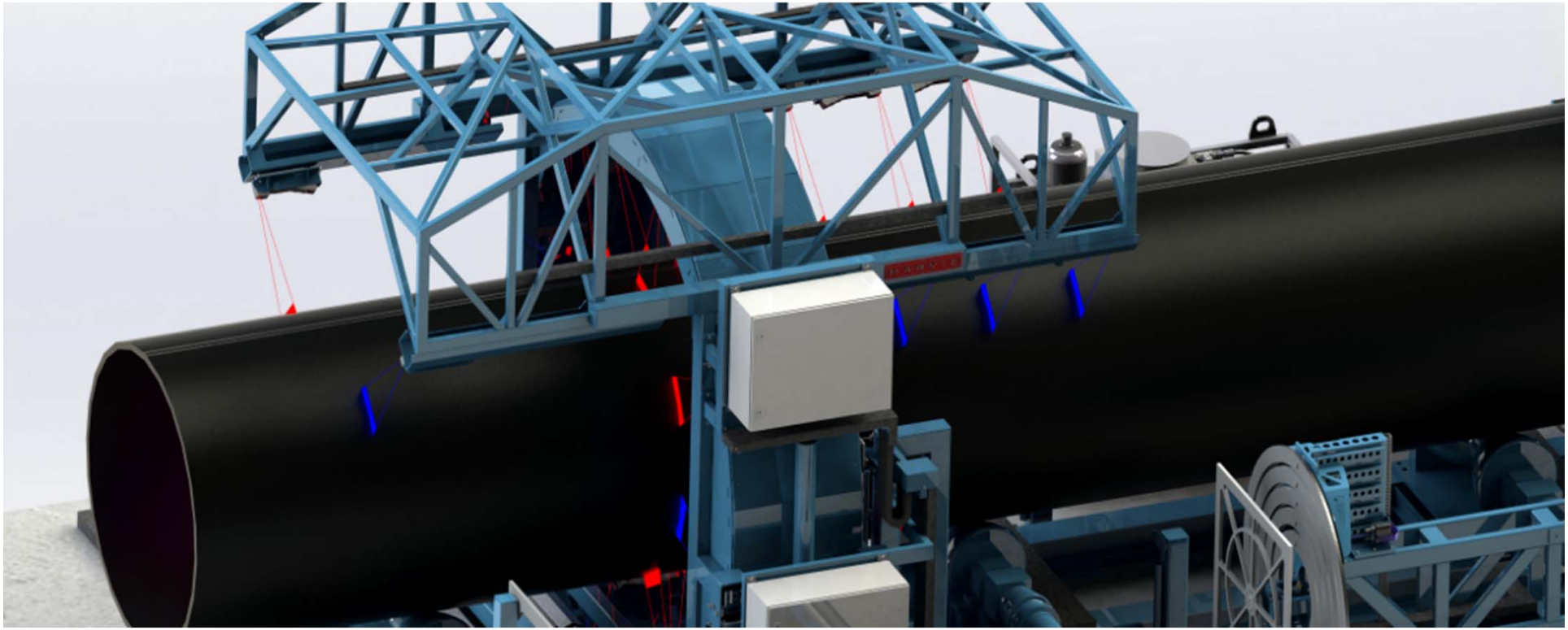


1. DRS unit (Diameter, Roundness and Straightness measuring system)
2. BLS unit (Bevel, Length and End Squareness measuring system)
3. Weld Bead Measurement System
4. Calibration Devices

DRS System



DRS System

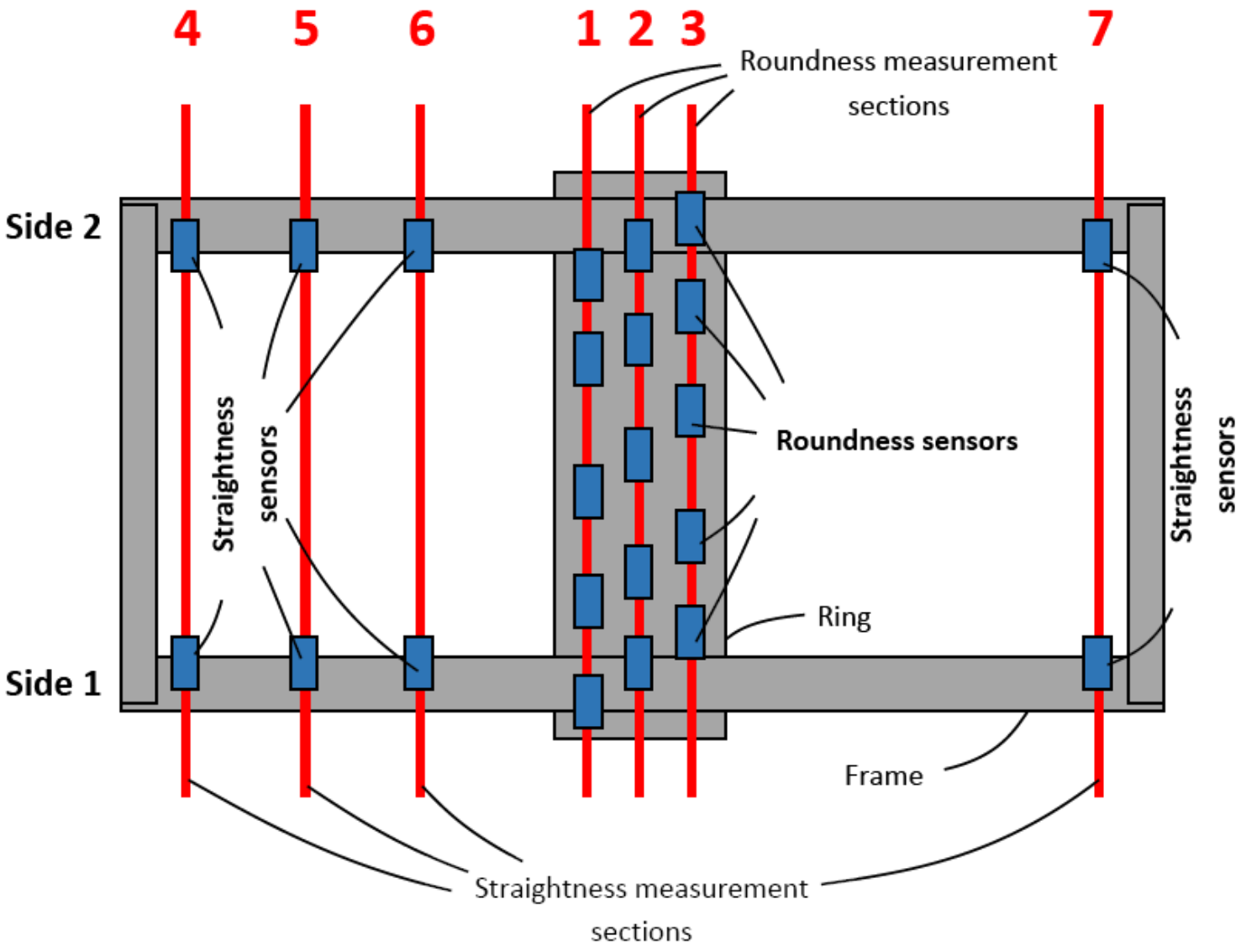


32
2D scanners

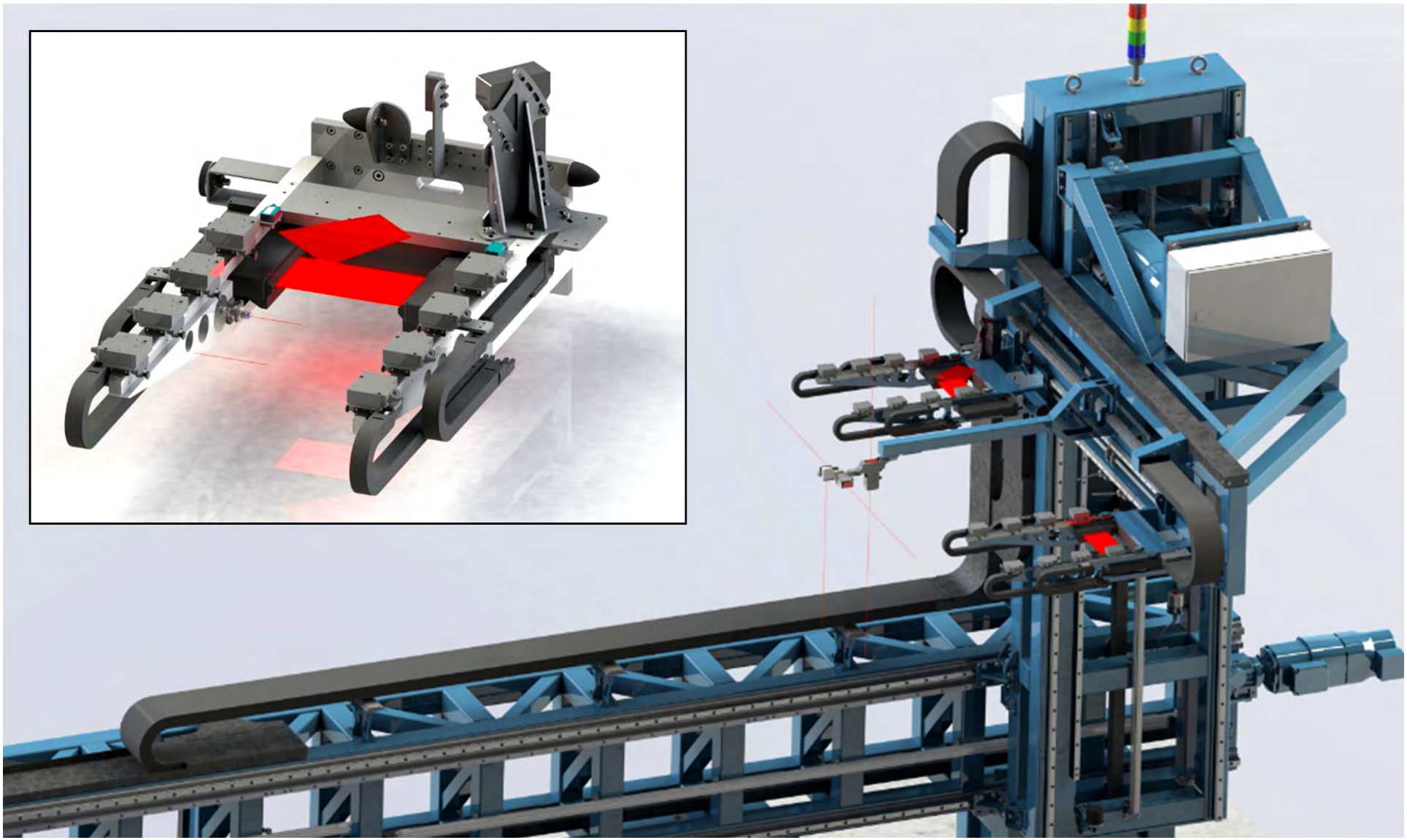
24,576
points captured on the perimeter

Sectional measurements at every
10 mm
along the length of the pipe

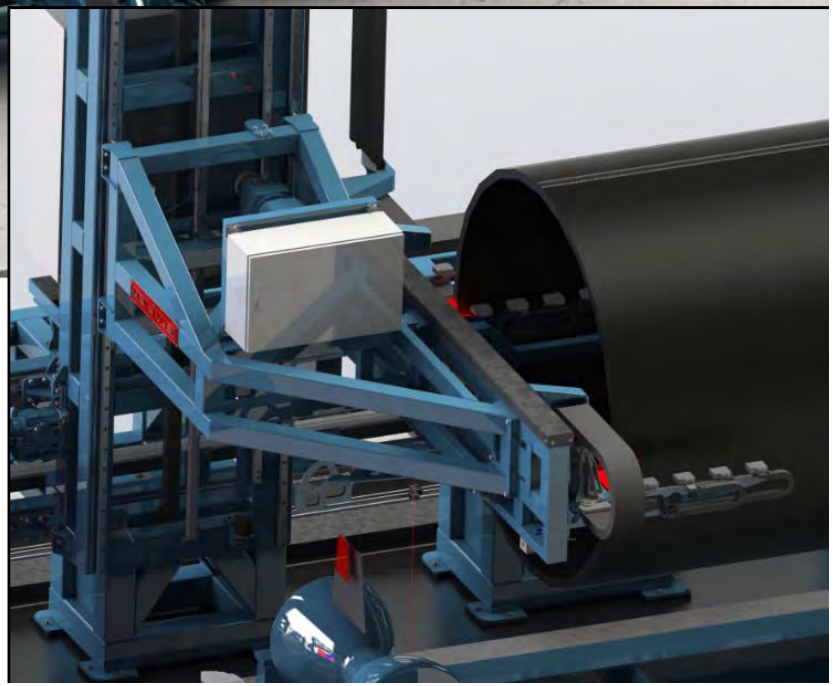
DRS System


4
5
6
1
2
3
7
Roundness measurement sections
Side 2
Side 1
Straightness sensors
Roundness sensors
Straightness sensors
Ring
Frame
Straightness measurement sections

BLS System



BLS System



04

Shadow sensors for length & squareness

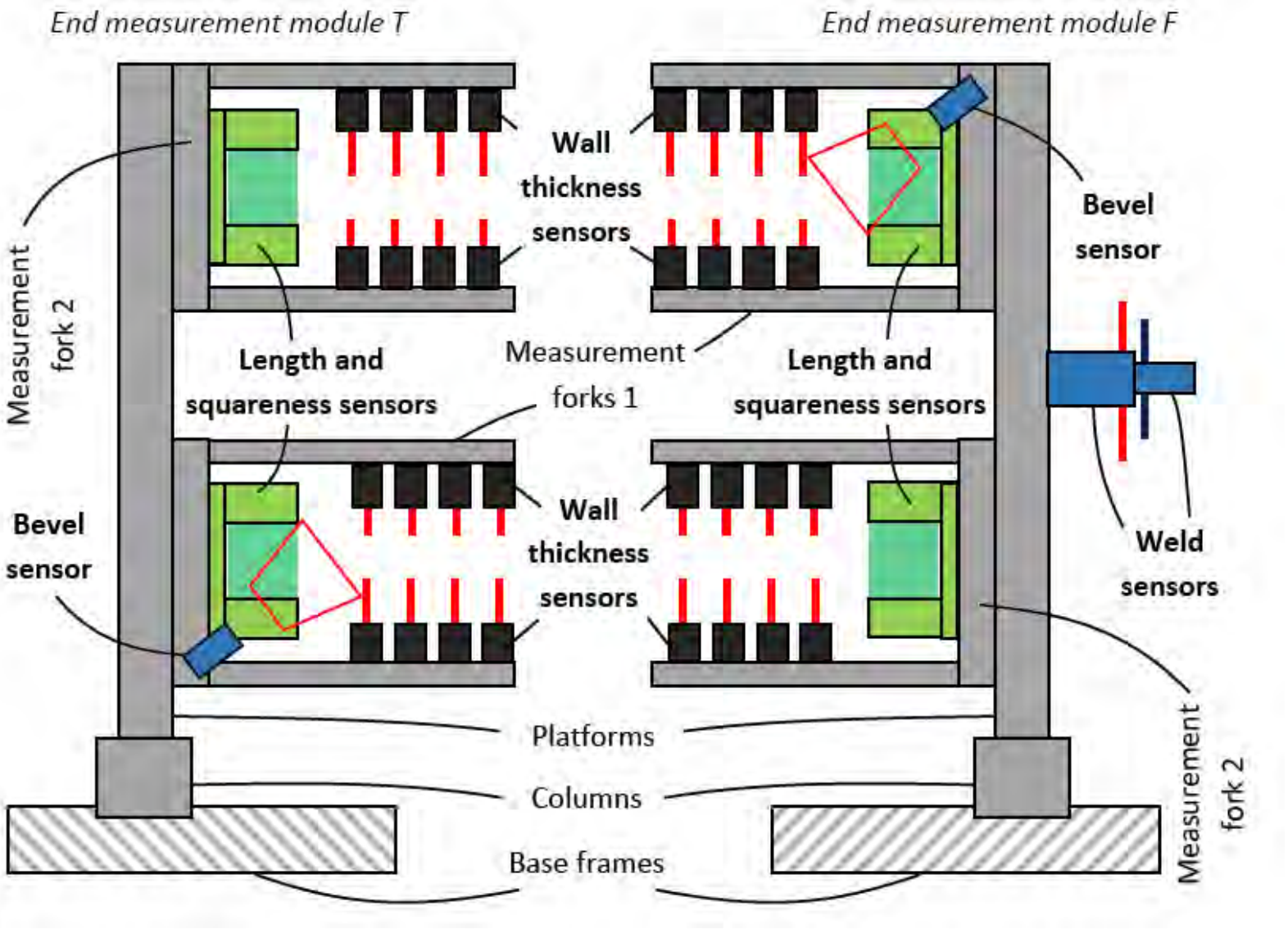
36

1D sensors for wall thickness

02

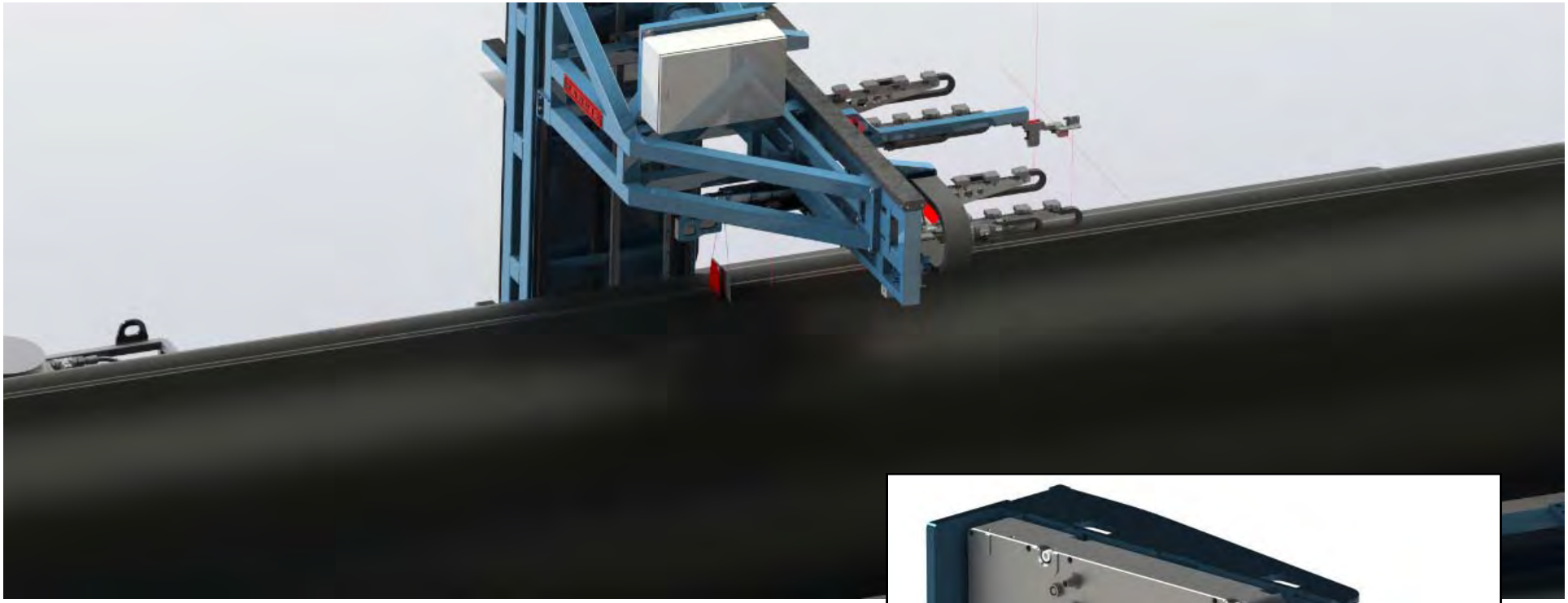
2D sensors for bevel parameters

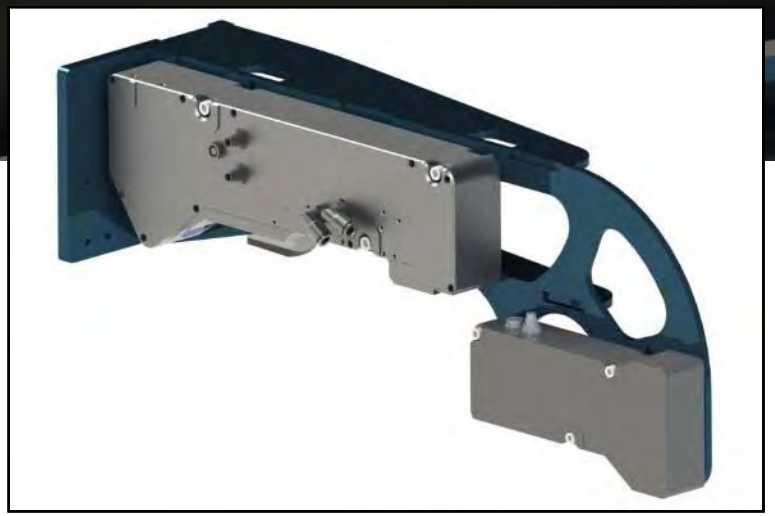
BLS System


End measurement module T
End measurement module F
Wall thickness sensors
Measurement fork 2
Length and squareness sensors
Measurement forks 1
Length and squareness sensors
Bevel sensor
Bevel sensor
Wall thickness sensors
Weld sensors
Platforms
Columns
Base frames
Measurement fork 2

Weld Module System

Weld Module System





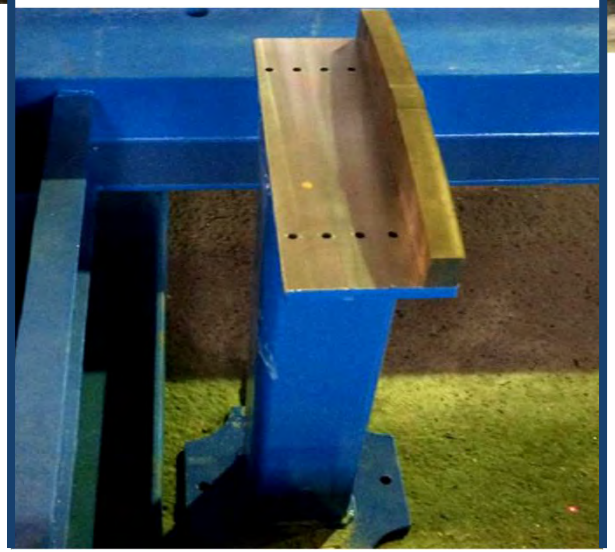
02

2D sensors for weld parameters (width, height, undercut, edge offset)

Calibration (done every 4 hours)

DRS RINGS

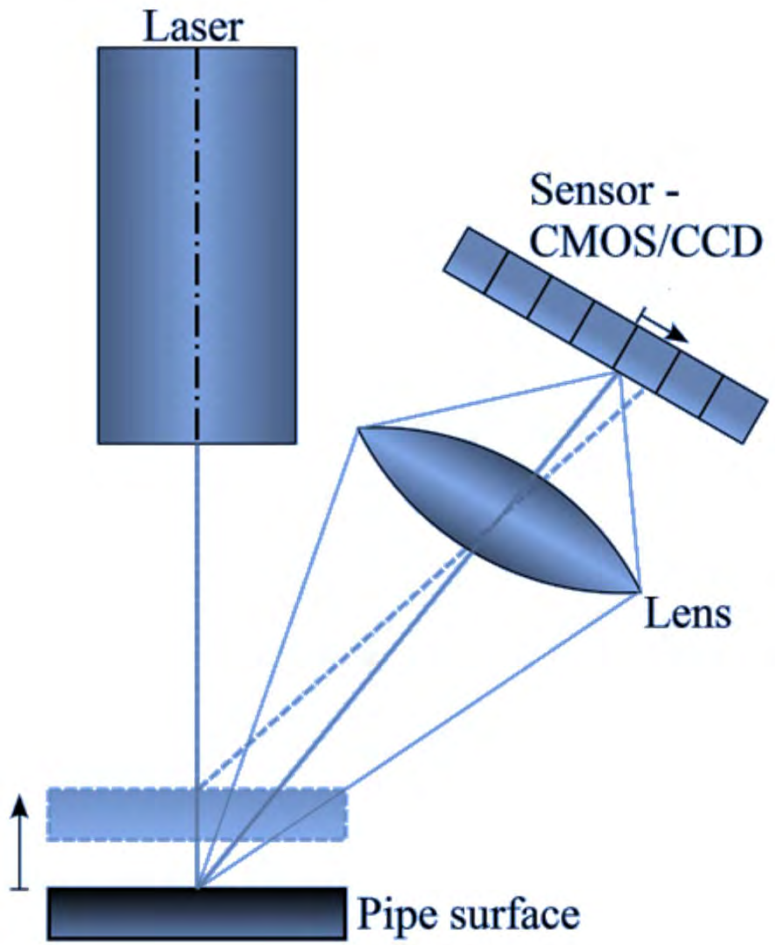
WELD SAMPLE



BLS BARS

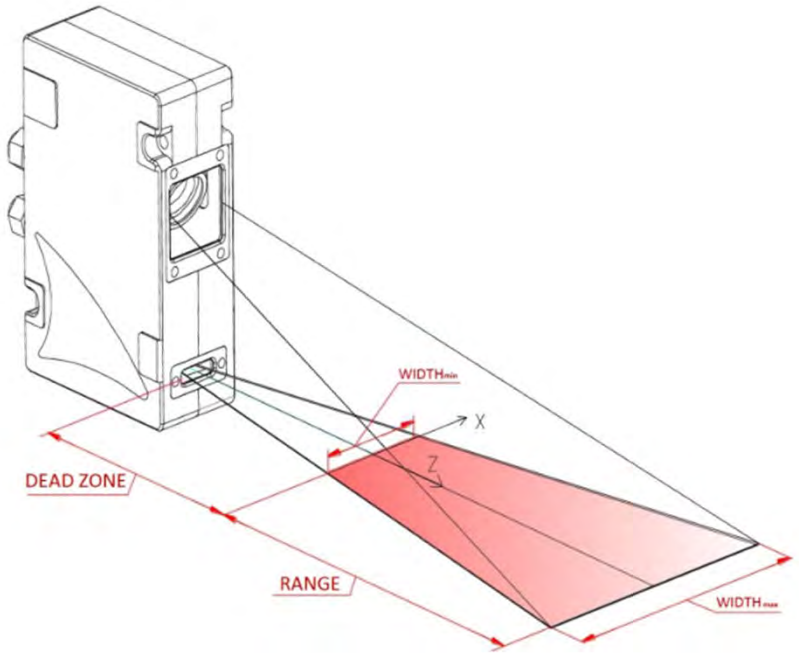
Measurement Methods

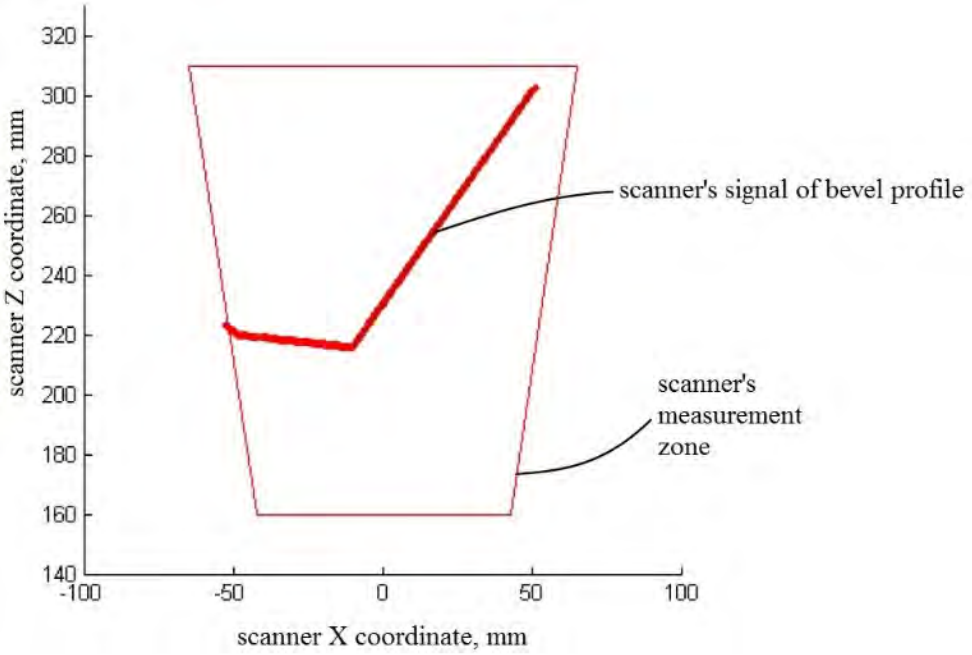
Laser Triangulation:



- **These data points or coordinates are measured at certain control points N, either along the length or around the circumference of the pipe.**

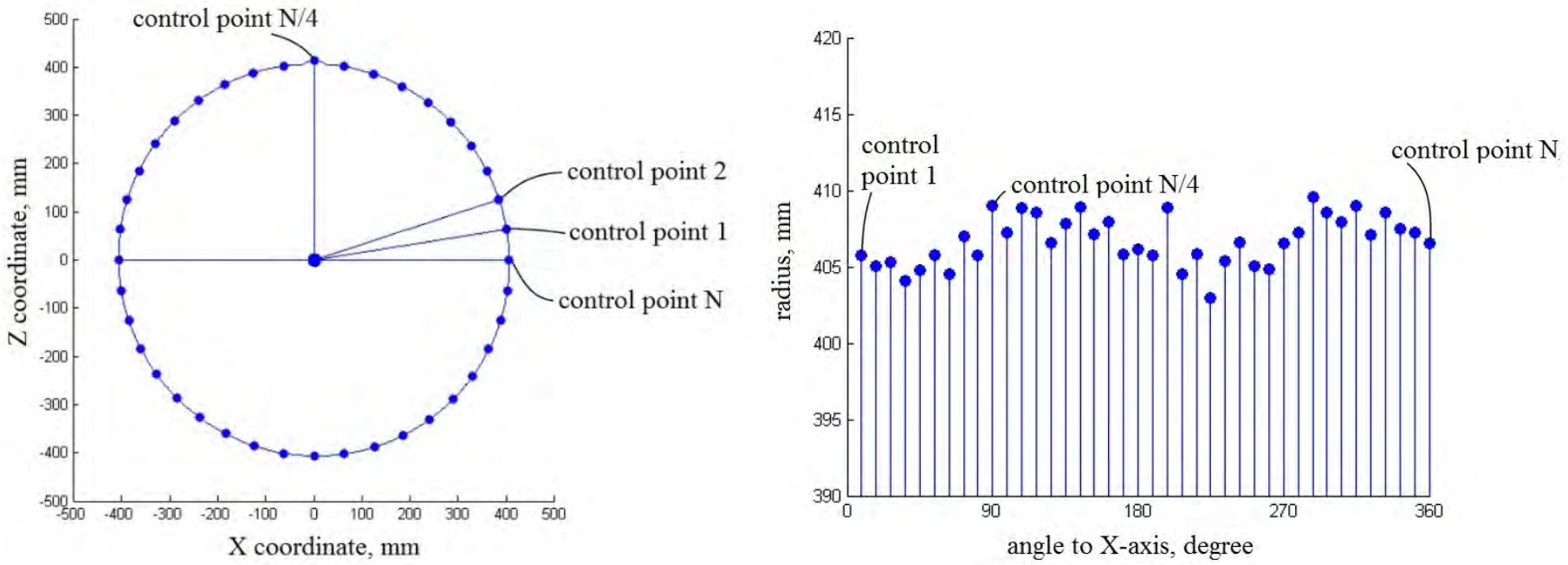
Measurement Methods





- A scanner sees a profile and the cloud of data-points is sent to the software for processing and calculation of the required physical parameters, based on coordinate geometry and simple mathematical calculations

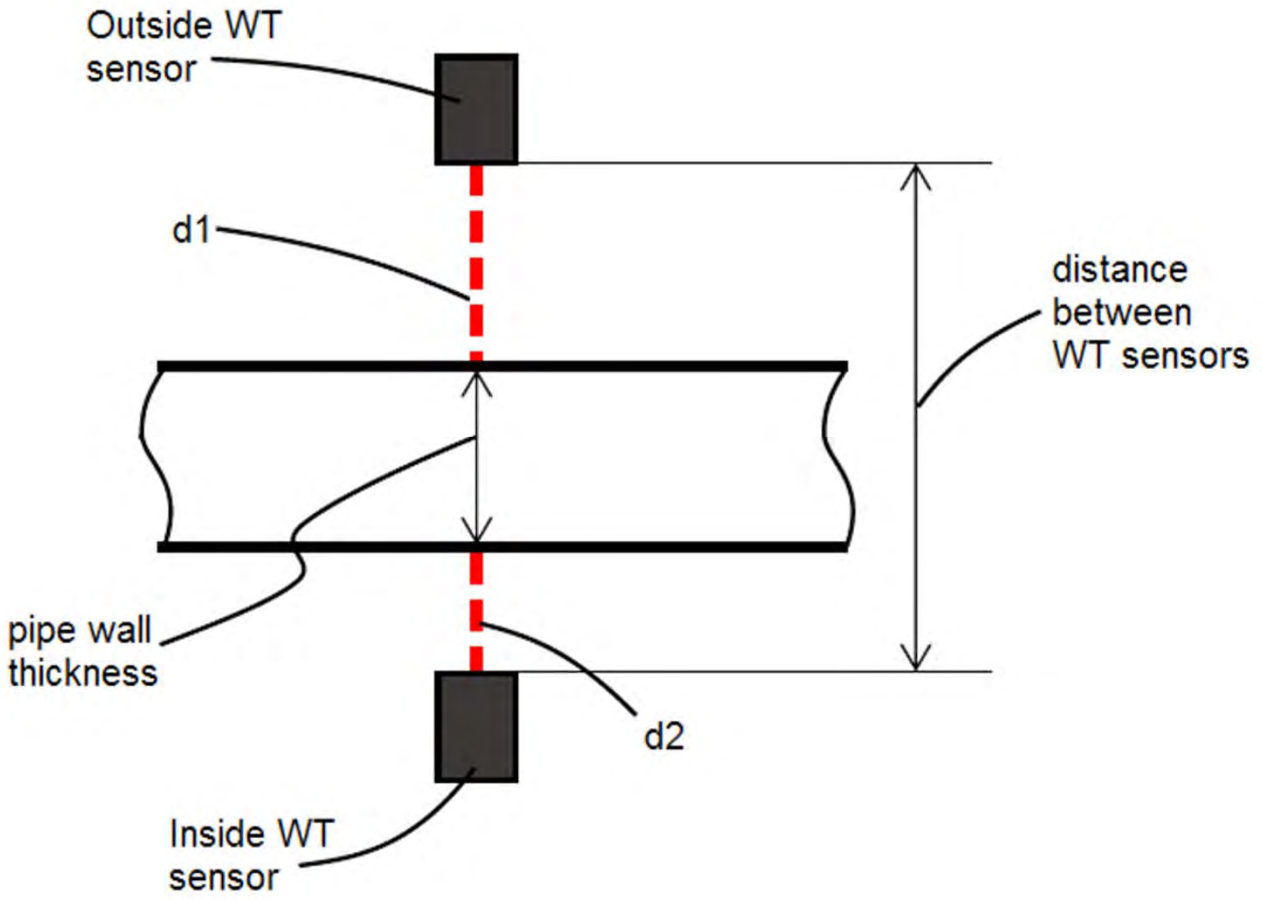
Calculation Logic



- The collected cloud of data points is mapped with reference to linear and angular pipe coordinates
- As an example, the above image shows the mapping of diametrical points on a pipe's outer surface as control points on a coordinate system.

Wall Thickness

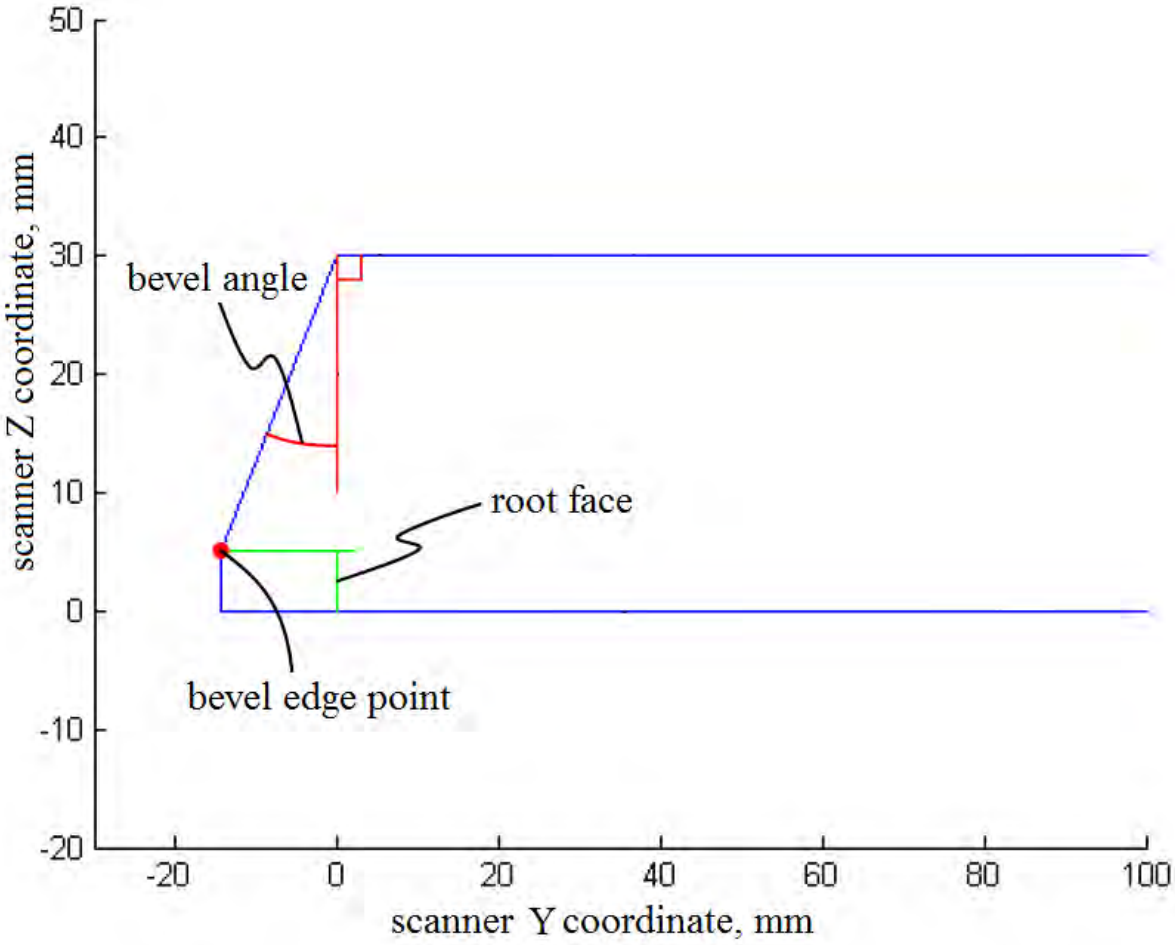
- Measured at eight sections at each end



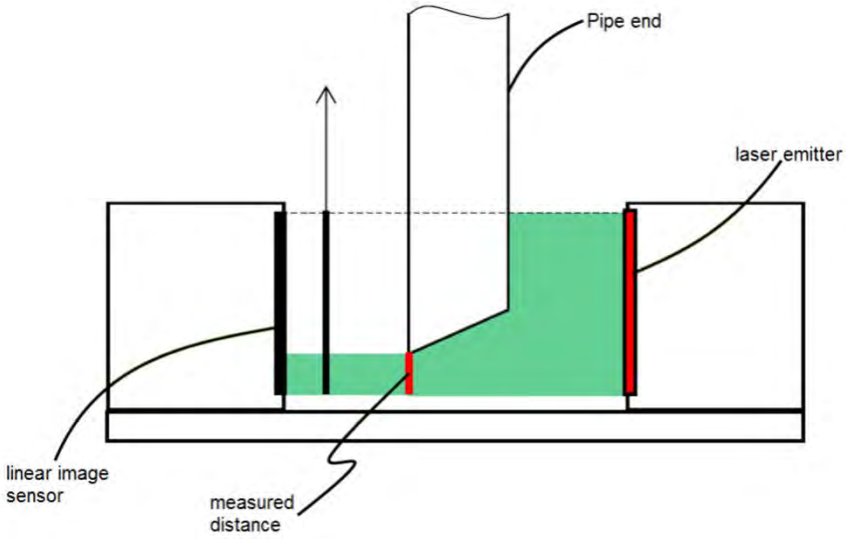
Bevel Parameters

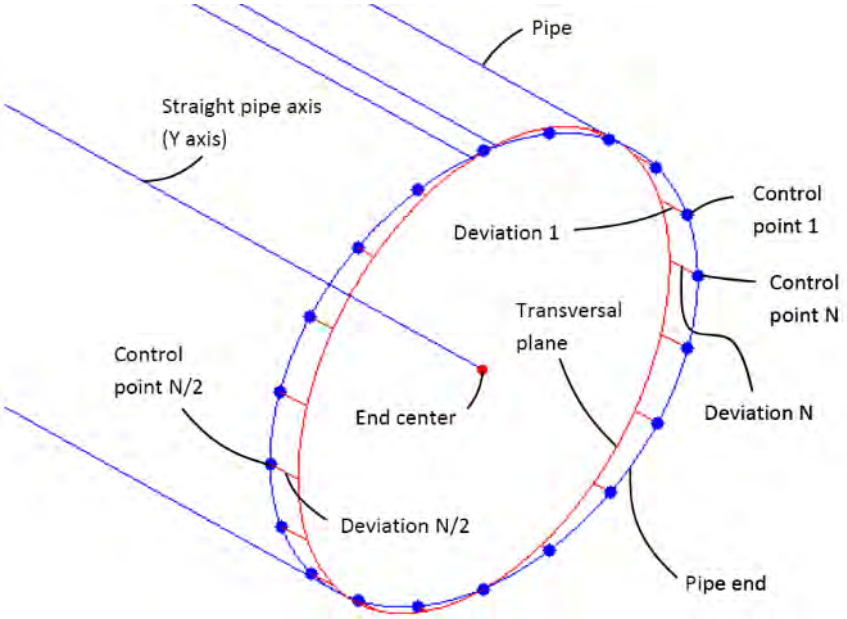
Identifies the bevel edge point in the geometry to calculate:

- Bevel angle
- Root face

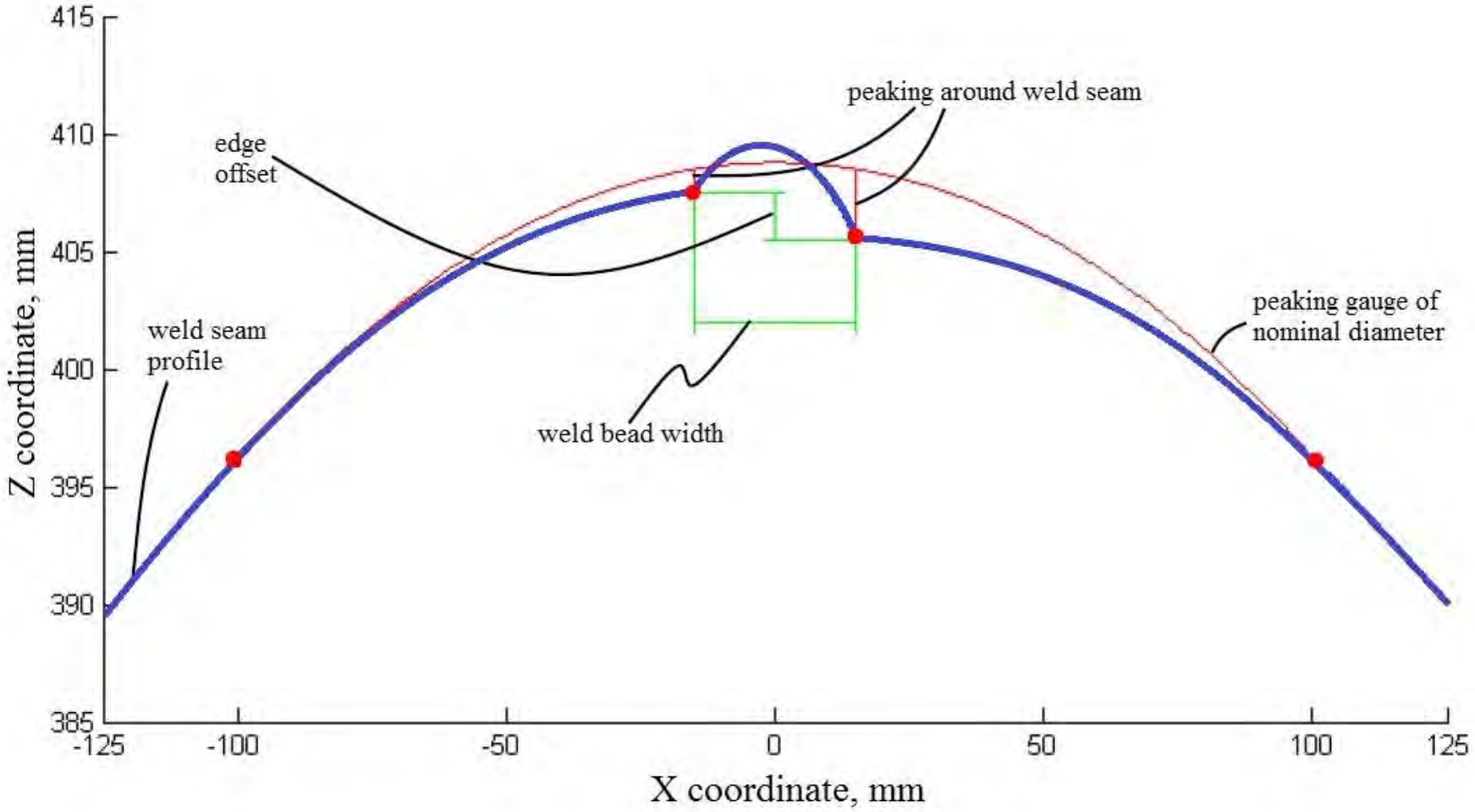


Length and squareness



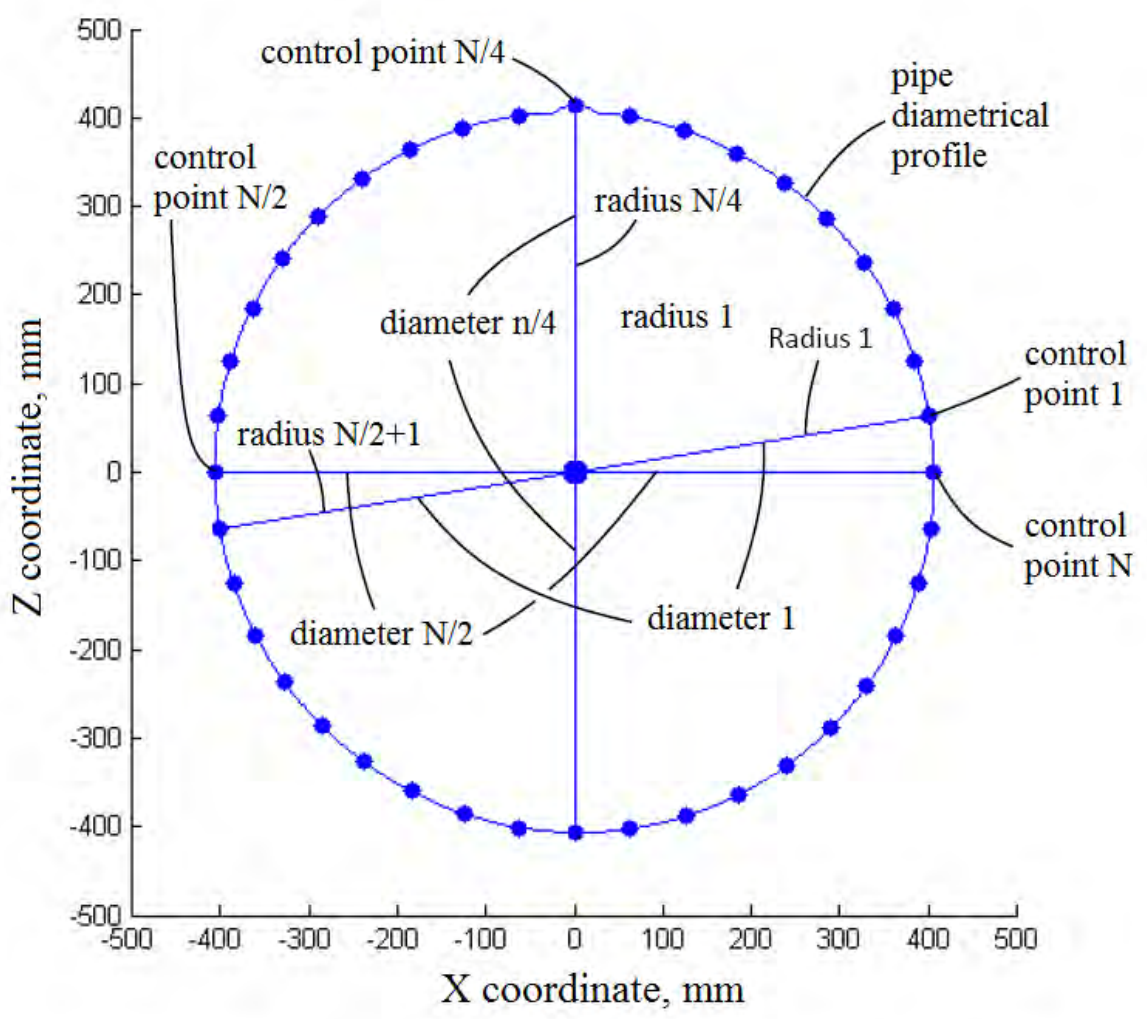


Weld parameters

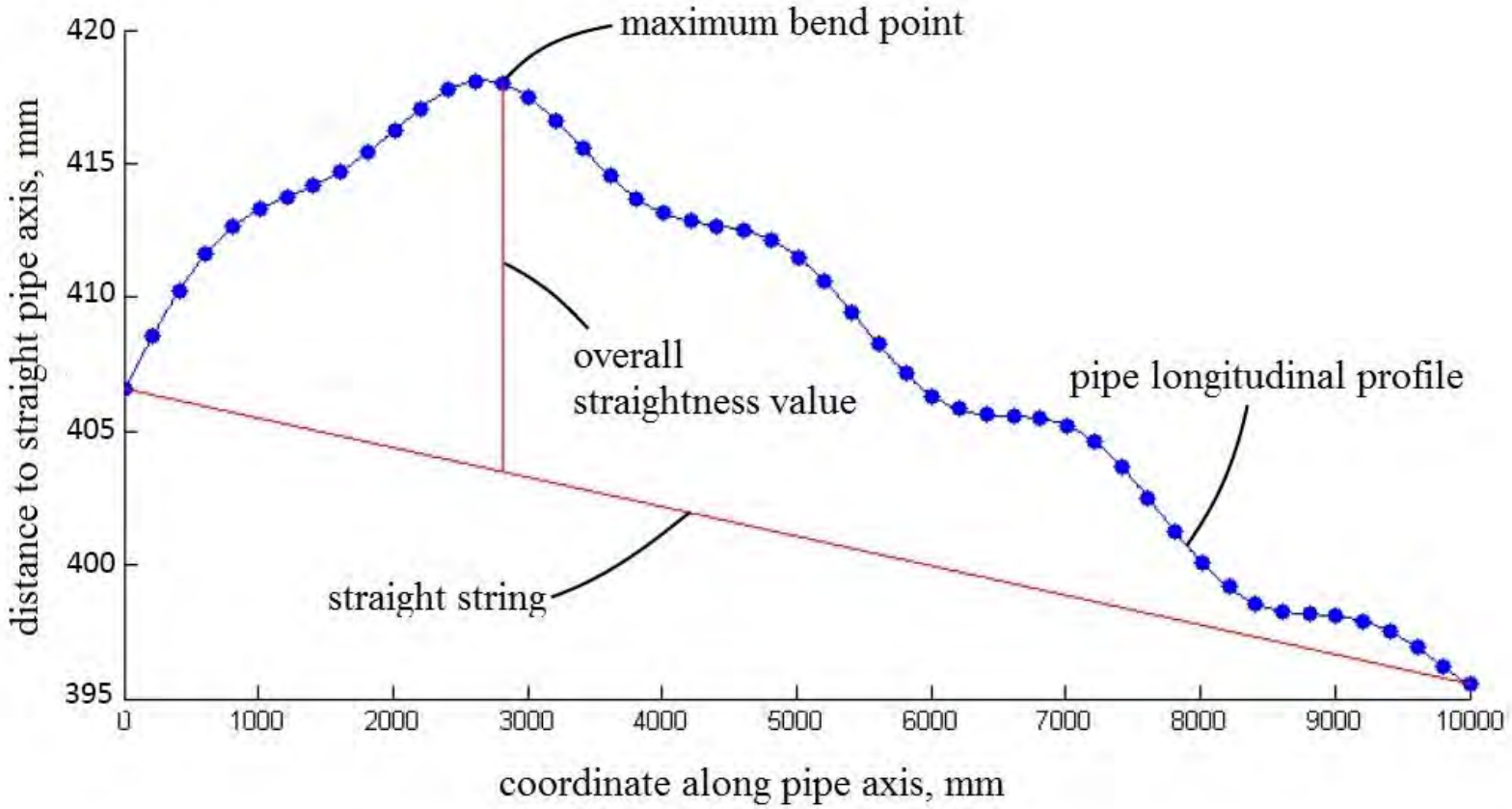


Diameter and Ovality

1. Outside profile is mapped
2. Inside profile is calculated from OD
3. Perimeter is determined
4. Set of diameters are found after removal of weld seam area
5. Ovality is calculated



Straightness



Repeatability

- The accuracy and repeatability of a set of measurements for a parameter are calculated as:

$$\bar{x} = \frac{1}{n}\sum_{i=1}^{n} x_i$$

n – number of measurements
x_i – measured value
$\bar{x}$ – average value

$$\sigma = \sqrt{\frac{\sum_{i=1}^{n}(x - \bar{x})^2}{n \cdot (n-1)}}$$

σ – RMS deviation

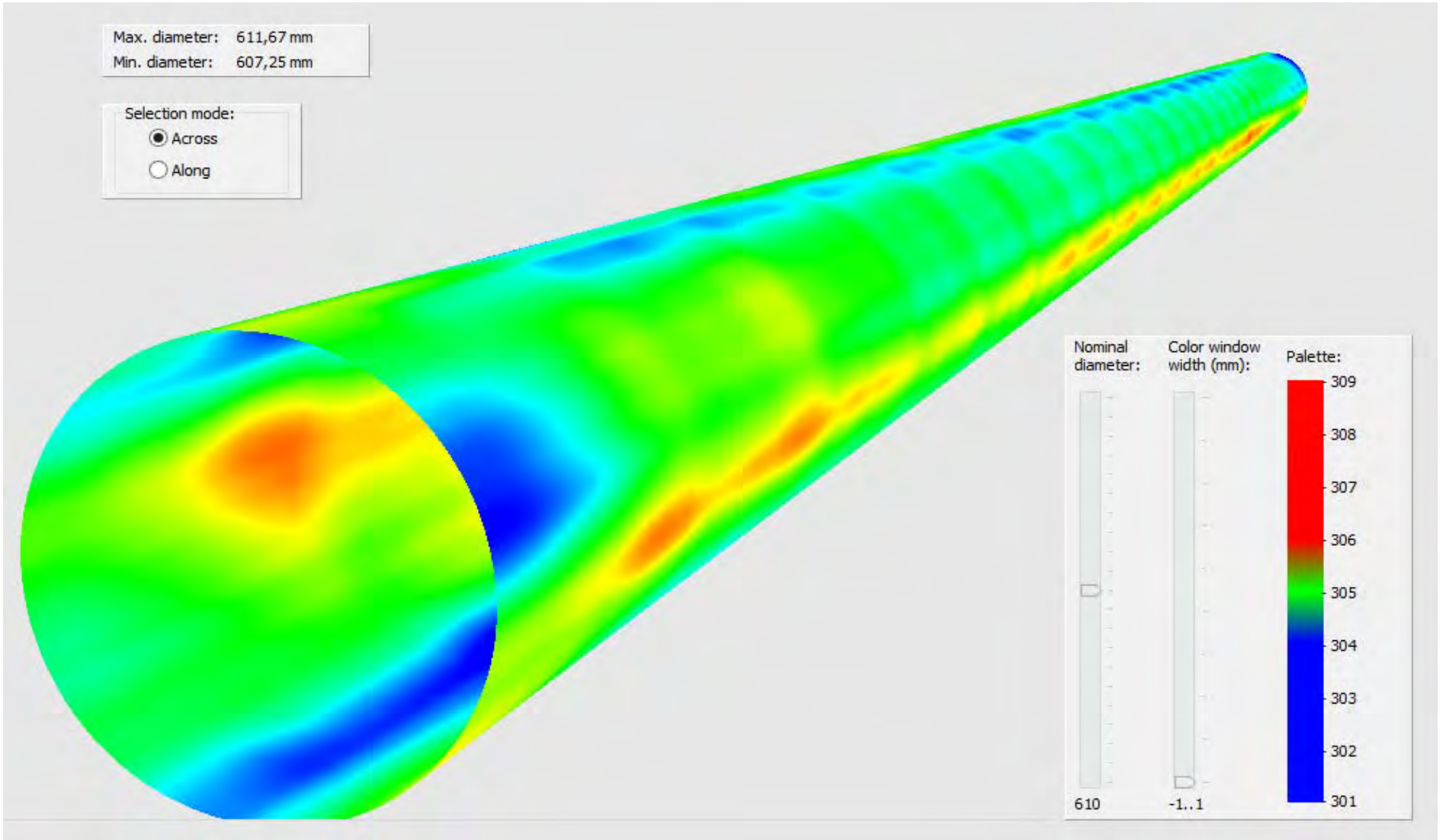
$$\Delta = t \cdot \sigma$$

t = 1.96 (standard deviation found as per GOST 8.207-76)

Parameter	Defined accuracy	Achieved accuracy
Diameter (end)	± 0.15 mm	± 0.04 mm
Diameter (body)	± 0.15 mm	± 0.03 mm
OOR (end)	± 0.10 mm	± 0.04 mm
OOR (body)	± 0.30 mm	± 0.03 mm
Straightness (body)	± 1.00 mm	± 0.11 mm
Wall thickness	± 0.05 mm	± 0.03 mm
Bevel angle	± 0.5˚	± 0.21˚
Root face	± 0.15 mm	± 0.03 mm
Length	± 1.0 mm	± 0.11 mm

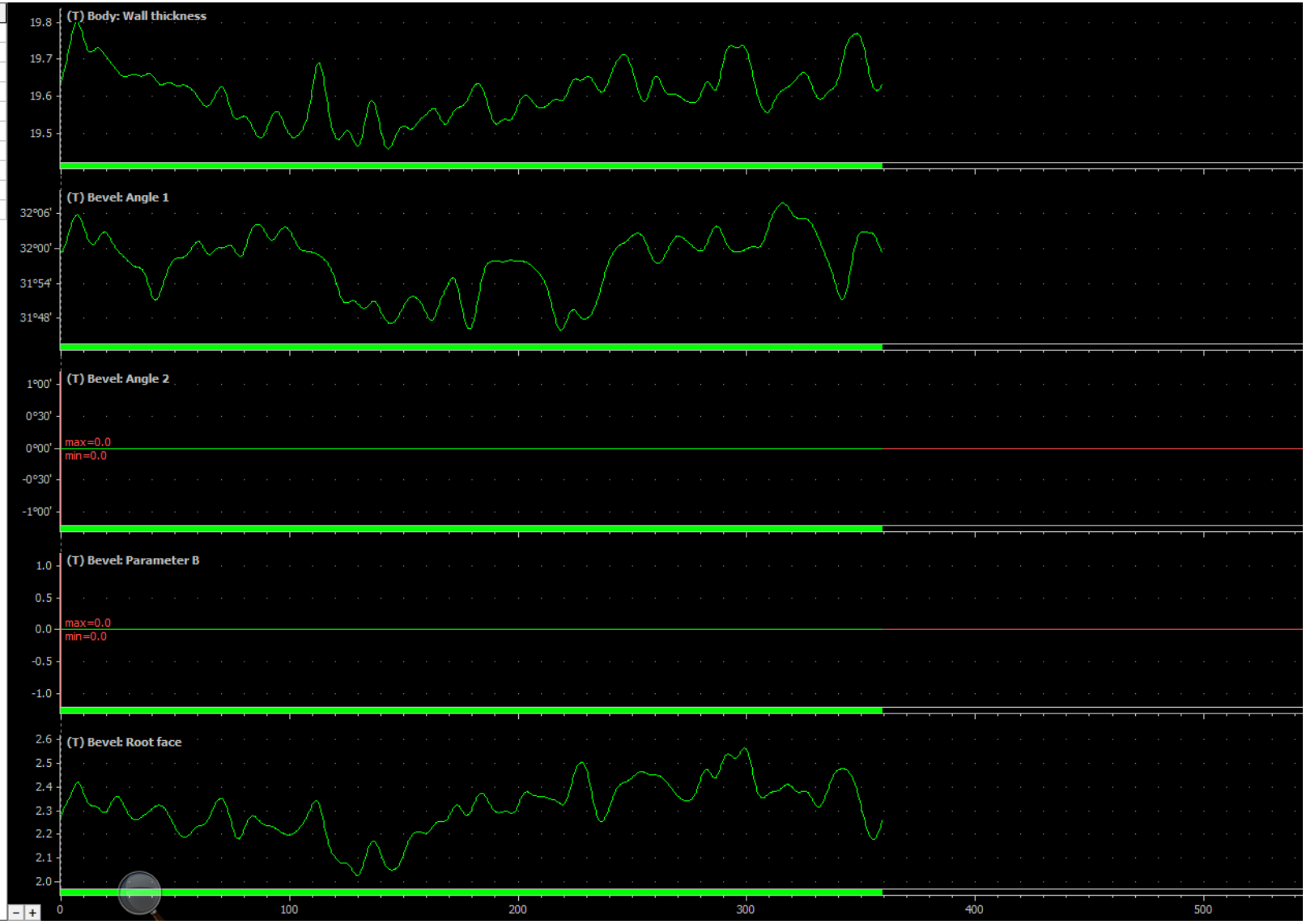
✻ average of 67 repeatability tests

3D Model of Pipe



Trend of Parameter Variation

Parameter	Value
Pipe number	J16012386
Location(deg.)	0.00
Location(mm)	0.00
Body:Thickness 1	19.64
Bevel:Angle 1	31°59'
Bevel:Angle 2	0°00'
Bevel:Root face	2.27
Squareness	0.40
Squareness loc.(deg.)	0.36
Squareness loc.(mm)	3.35



Traceability

SAP availability of pipe number is shown on screen

Barcode is read at entry of APDMS

APDMS tests the pipe and records all dimensional parameters.

Pipe number along with dimensional parameters will be transferred back to SAP after analyzing & acceptance from APDMS.

Next in scope...

Replicate

similar technology for edge milling geometry measurements

Reverse engineer

to understand which set of machine settings give better and more closer dimensional tolerances

Design a

Best Fitment system

which gives a plan of pipe numbers that need to be joined in sequence on site, for ease of installation

THANK YOU!

"Quality matters....even when no one is looking...!"

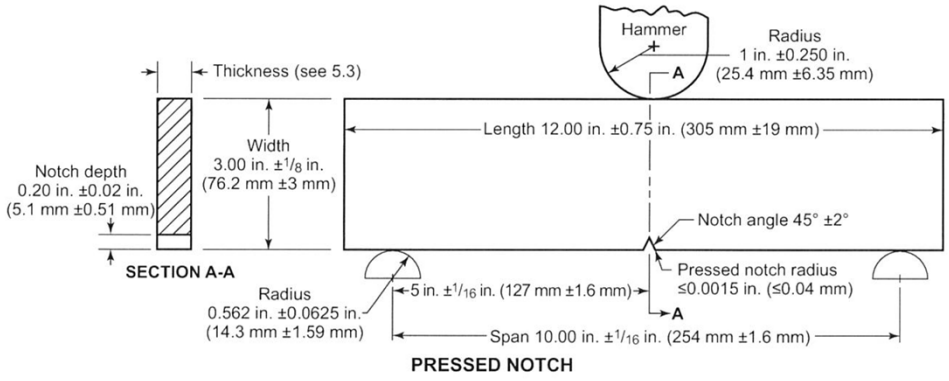
WELSPUN GROUP
LEADING TOMORROW TOGETHER

EPRG approach to assess avoidance of brittle fracture in presence of ductile initiation in DWT tests

06 March 2019

The role of DWT tests

API 5L3 4th Edition Drop Weight Tear Tests on Line Pipe



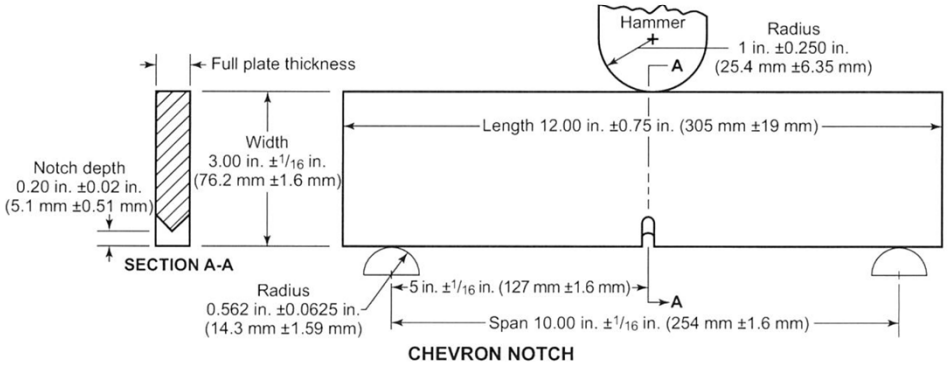


Figure 1—Drop-Weight Tear Test Specimen and Support Dimensions

- DWT tests are conducted to estimate the Ductile-to-Brittle Transition Temperature [DBTT]
  - operation above this temperature ensures ductile fracture propagation
  - DWTT as a laboratory test correlates to the pipe transition temperature

Fracture surfaces

Testing standards and codes

API 5L3 4th Edition Drop Weight Tear Tests on Line Pipe

7.1 Valid specimens exhibit cleavage fracture from the notch tip with the exception being those specimens that exhibit ductile fracture on the complete fracture surface. Specimens shall be invalid if the fracture under the notch is ductile and changes to a cleavage fracture, a phenomenon known as inverse fracture.

NOTE Drop-Weight Tear Testing pipe with upper shelf Charpy impact energies greater than 200 J (148 ft-lb) often results in invalid tests, making the test method ineffective.

DIN EN 10274 Metallic materials – Drop Weight Tear Test

No requirements concerning crack initiation

Standards and codes

API 5L 46th Edition Specification for Line Pipe

9.9 DWT Test for PSL 2 Welded Pipe

9.9.1 For each test (of a set of two test pieces), the average shear fracture area shall be ≥ 85 %, based on a test temperature of 0 °C (32 °F) or, if agreed, a lower test temperature. For wall thickness > 25.4 mm (1.000 in.), DWT test acceptance requirements shall be by agreement.

NOTE 1 Such shear-fracture area ensures a sufficiently ductile fracture at or above the test temperature.

NOTE 2 A sufficient combination of shear-fracture area and CVN absorbed energy is an essential pipe-body property to ensure the avoidance of brittle fracture propagation and the control of ductile fracture propagation in gas pipelines (see Annex G and Table 20).

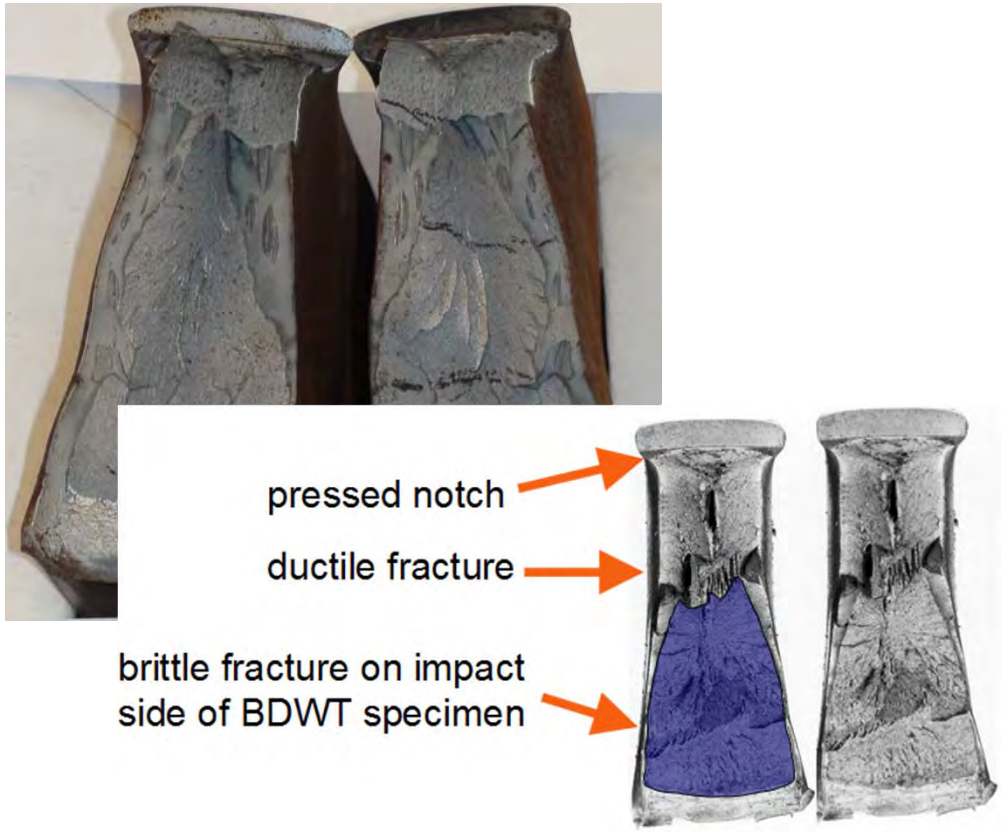
DNVGL ST-F101

B.2.7.2 Full thickness specimens shall be used where possible. Reduced thickness specimens may be used subject to Purchaser agreement. The testing temperature reduction given in API RP 5L3 shall apply.

The specimens shall be taken transverse to the rolling direction or pipe axis, with the notch perpendicular to the surface.

For high toughness steels ductile crack initiation from the notch tip shall be acceptable (contrary to API RP 5L3, Clause 7.1).

Problem



Inverse fracture used to be limited in occurence (e.g. heavy wall thickness)

most recent material produced for large gas pipelines does show inverse fracture

if material is inverse, it tends to show it in almost every specimen

you cannot test your way out of the issue

is it an issue?

Development DWT test

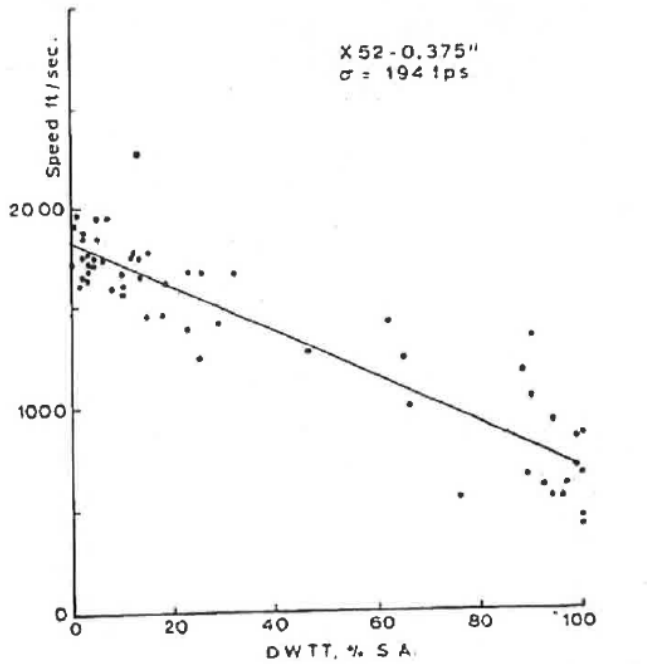


Fig. 2. Relationship between fracture speed and DWTT fracture appearance.

- First observations
  - DWTT shear area could be linked to fracture speed
  - Speed vessel and DWTT correlated, CVN different

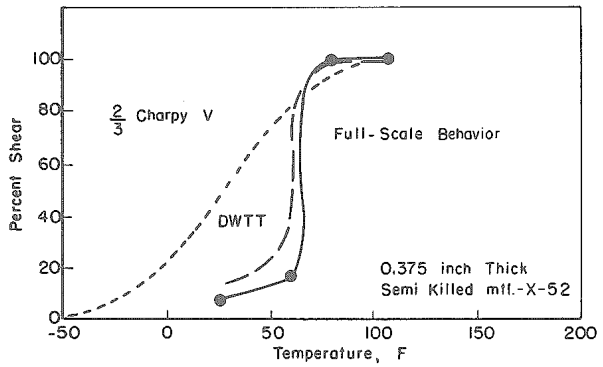
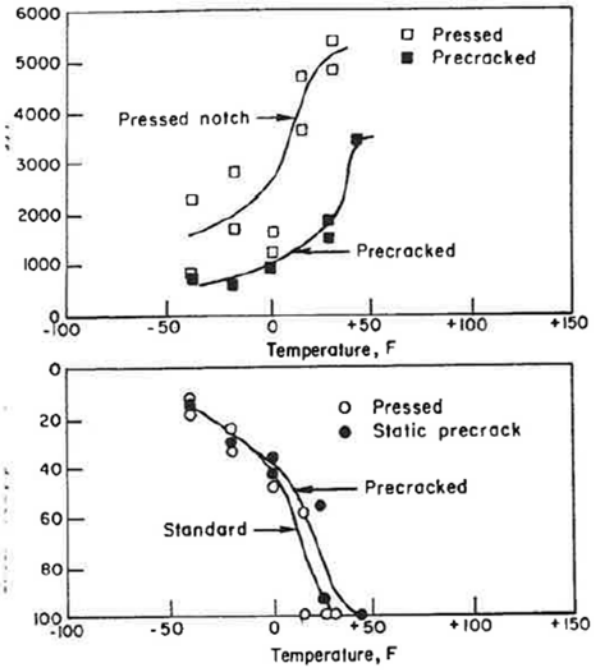


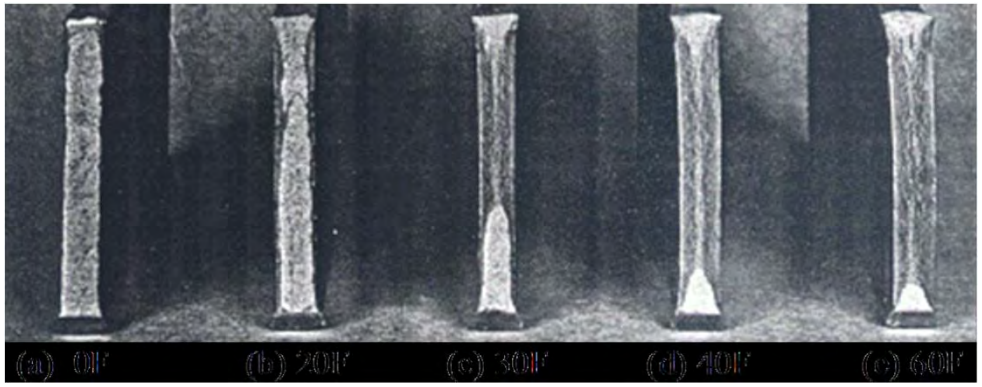
FIG. 3—*Summary of DWTT, Charpy, and vessel fracture appearances.*

Early comparison QT and controlled rolled steel



16. Shear Area Percent and Impact Energy Versus Temperature for Pipe DH-1 (CVP = 150 ft-lb)

- Controlled rolled steel
  - Transition curve pressed and pre-cracked specimens equivalent
  - Pre-cracked specimens consumed less energy



Early comparison QT and controlled rolled steel

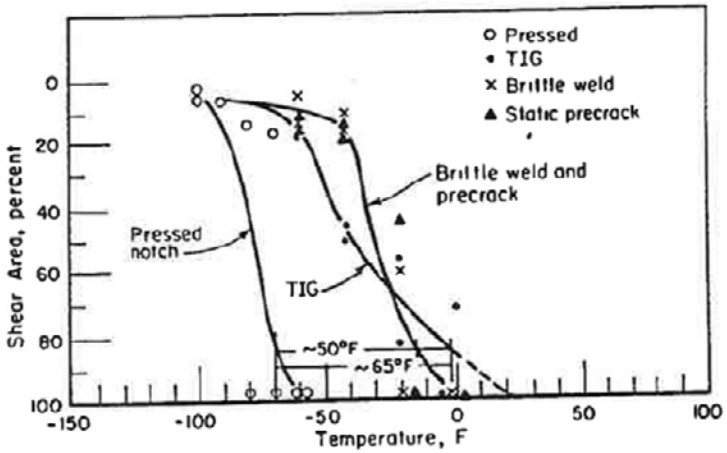


Figure 12. DWTT Shear Area Percent Versus Temperature for Pipe DO-1 (CVP = 200 ft-lb)

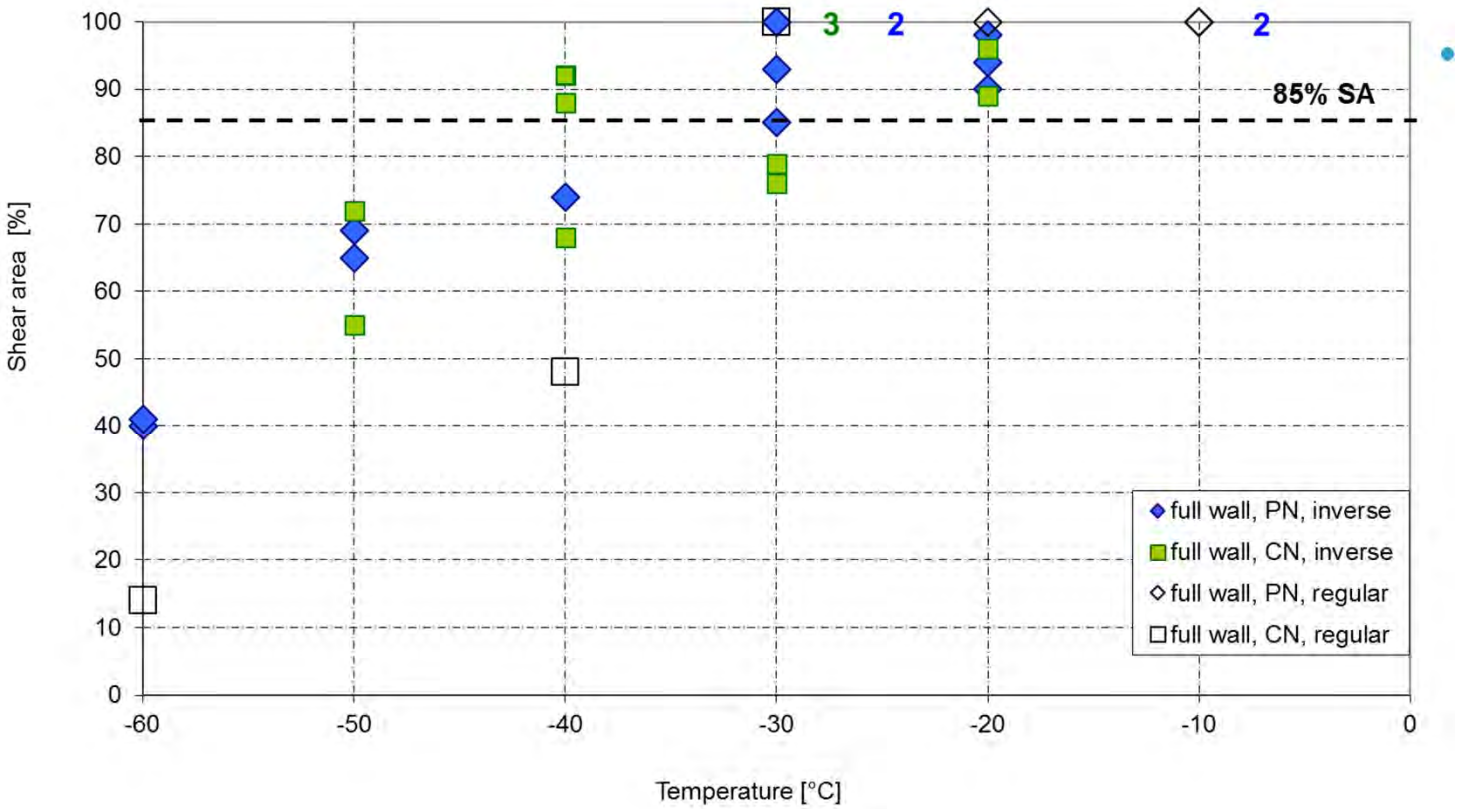
- Quenched and tempered steel
  - Ductile initiation in pressed notch specimens
  - Different methods of embrittlement were studied
  - Ductile initiation was successfully supressed
  - Expressed difference in transition temperature
- When curves do **not collapse vessel** behaved like **embrittled** specimen

Investigations

No	Dimension	Grade	DWTT							CVN	Hardness	WJ
			Full thickness			Reduced (both sides		Reduced (one side)				
			PN	CN	BW	PN	CN	PN	CN			
1	457 x 25.4	X65	X	X		X	x	x	x	X	X	
2	813 x 32.5	X 70	X	X	X					X		X
3	920 x 25.4	X 65	X	X	X					X		X

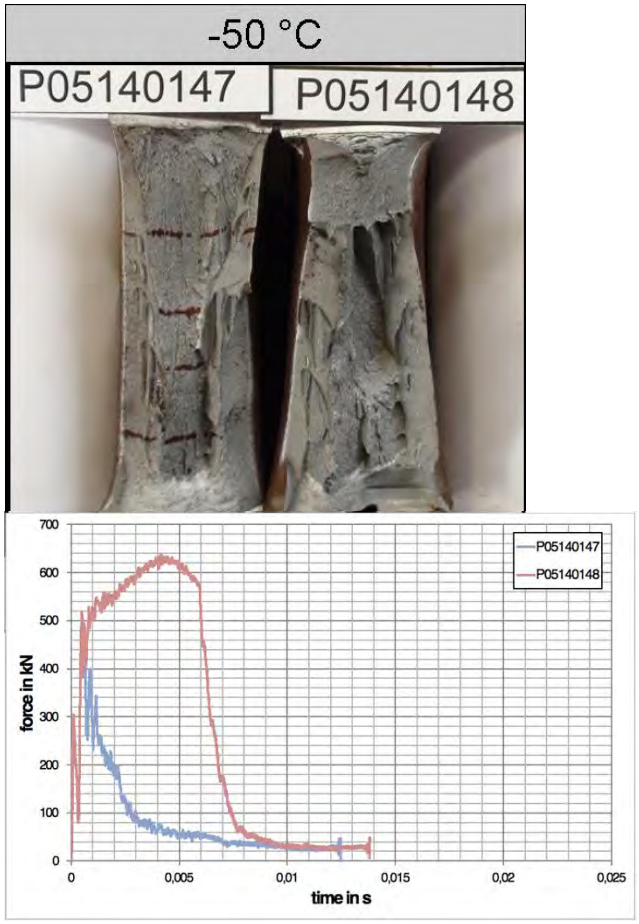
- DWTT
  - Standard pressed and Chevron notch
  - Brittle weld notch
  - Additional assessments
    - Lateral expansion
    - Hardness
- West Jefferson tests
  - Comparison @ test temperature

DWTT investigations I



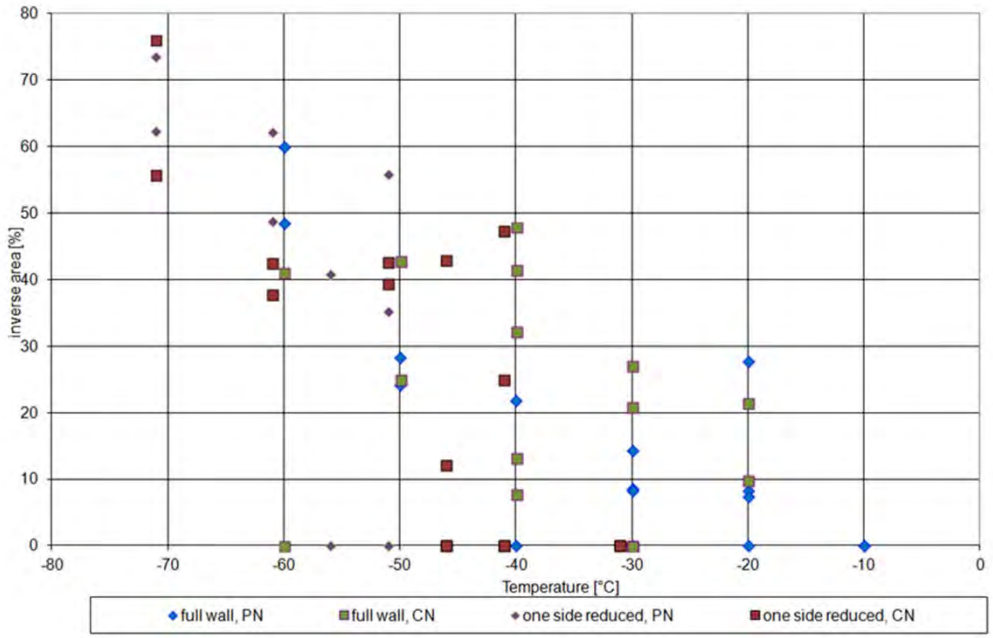
- DWTT
  - inverse specimens from upper transition to lower shelf
  - PN and CN curves follow a common trend

DWTT investigations II



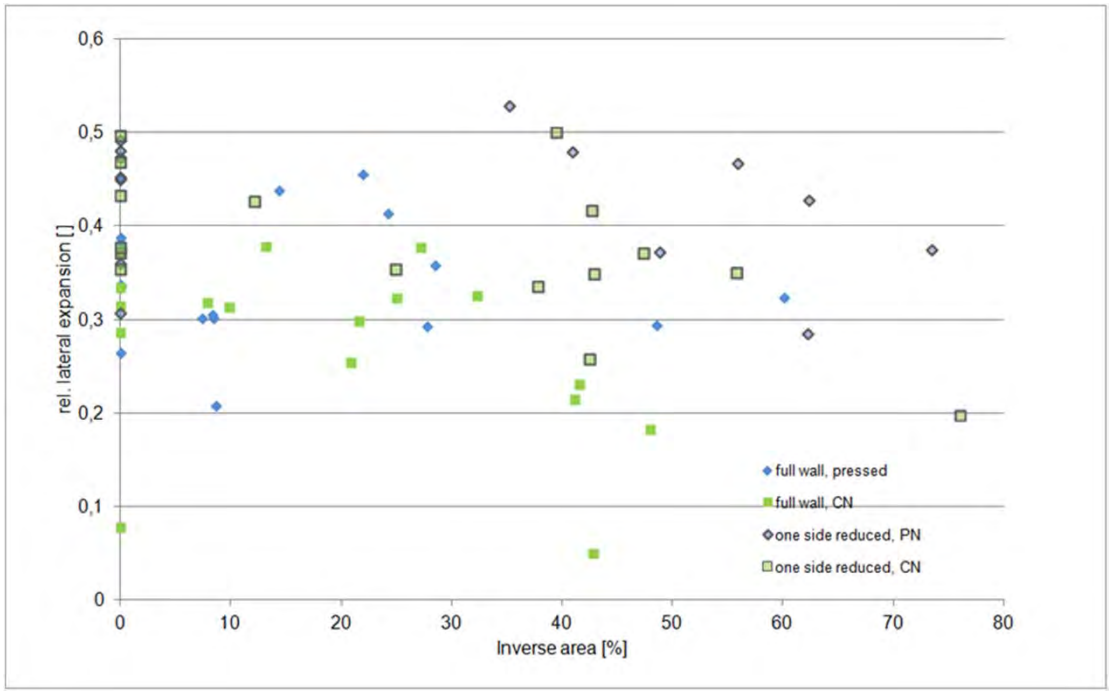
- @ test temperature: similar shear area of inverse and regular specimens
  - Behaviour reflected by enery measurement
  - fracture surface independant of initiation mode

DWTT investigations III



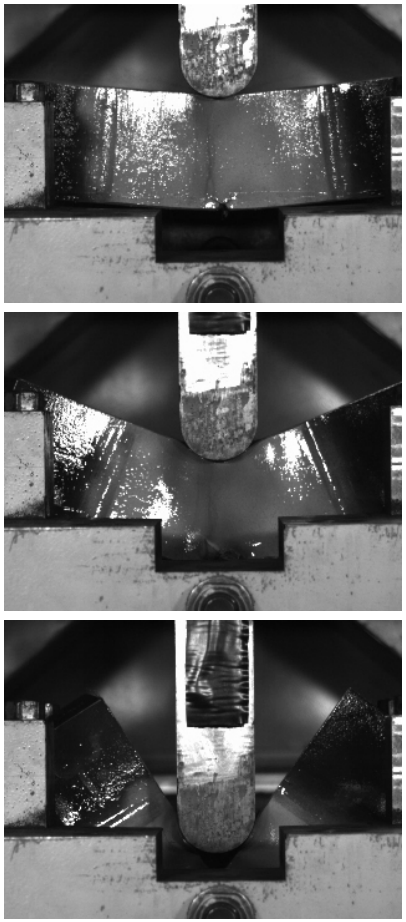
- inverse area increases as temperature decreases
  - brittle areas formed on impact side must have an element of material toughness @temperature
  - it is not possible to distinguish between brittle area formed by testing effect and brittle fracture initiating from the notch side (regular behaviour) @ temperature

DWTT investigations IV



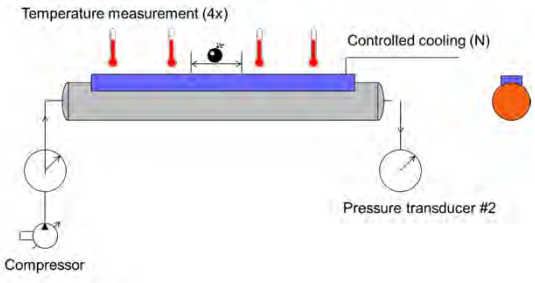
- lateral expansion did not add information
  - large scatter in data
  - date from both regular specimens and inverse material showed large scatter and was within the same scatter band

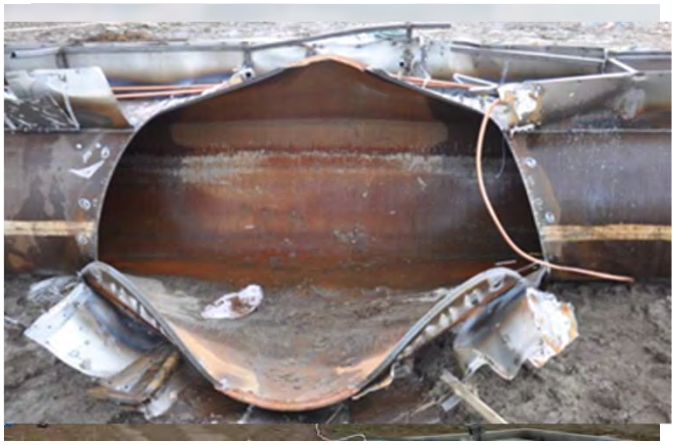
DWTT investigations I



- delayed initiation
- strong deflection
  - plastic pre-deformation of the material
  - shifts transition curve

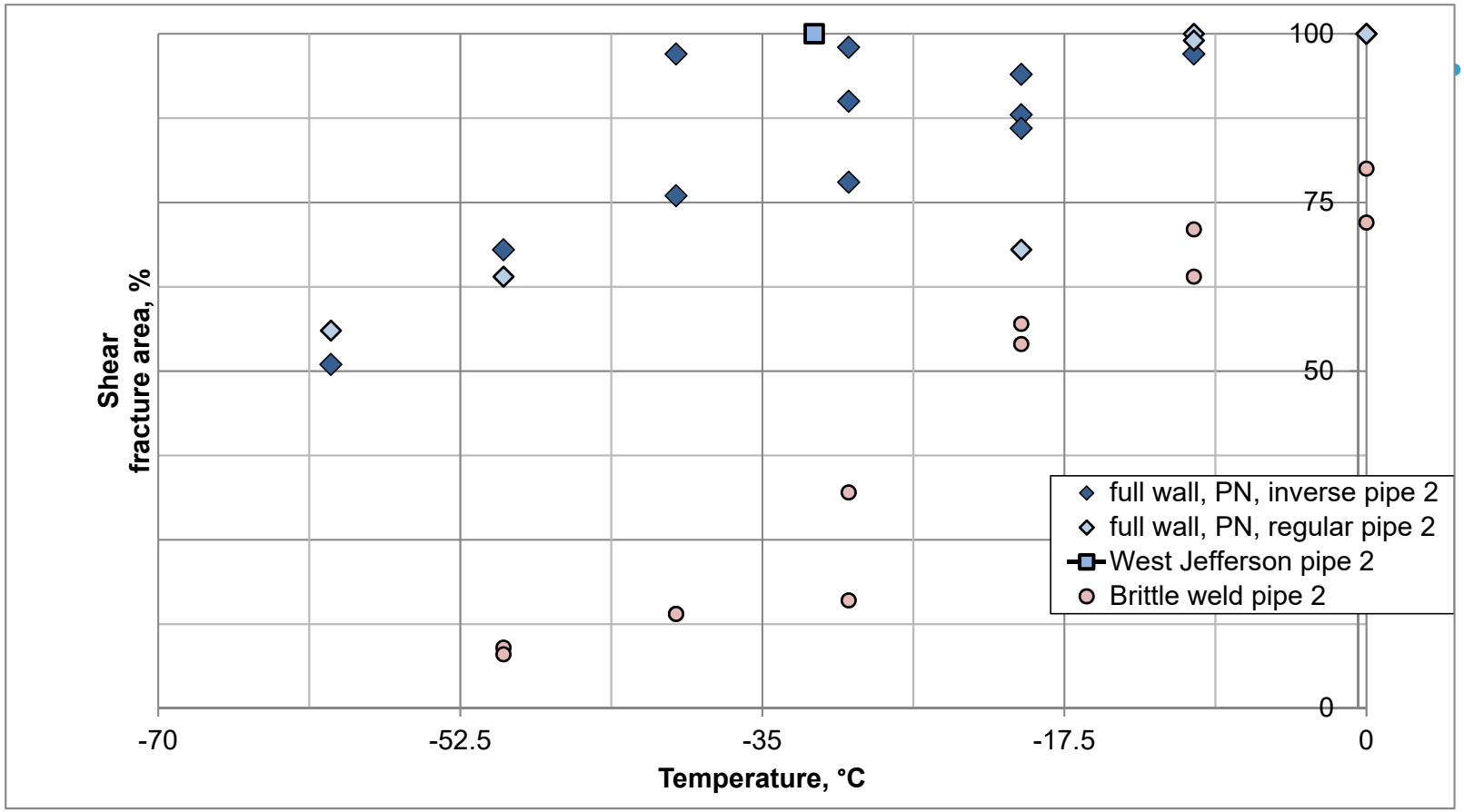
Partial gas (West Jefferson) test





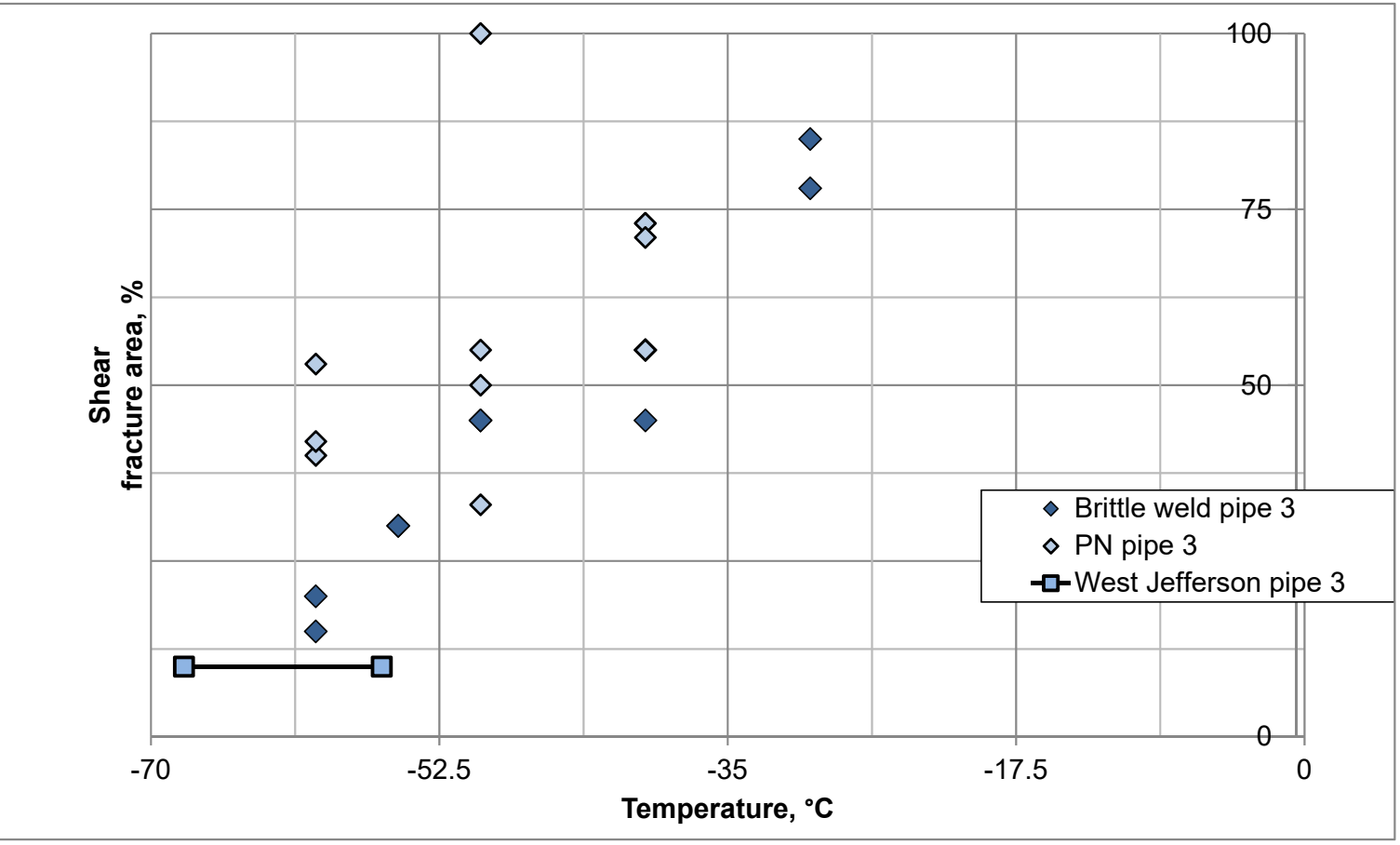
- pipe is cooled to desired test temperature
- explosive charge to initiate fracture
- fracture surface is assessed
  - transition temperature of pipe is assessed
  - comparison to DWT test results

Comparison of DBTT



- First WJ test
  - Test temp @ 85% SA
  - Difference PN and BW
  - Vessel follows PN

Comparison DBTT II



- Second WJ
  - Temperature to capture transition
  - brittle weld and PN curves collapse

Conclusions I

- provisions in API 5L3 apply to material exhibiting ductile initiation
  - temperature shift to compensate for wall thickness reduction
  - single side reduction gave far more consistent results
- clear indications of test-specific influence
  - delayed crack initiation
  - plastic pre-deformation which should lead to a shift in transition curve (conservative aspect)
  - strain hardening ability of the material seems to play a role (superior strain hardening leads to delayed initiation)
- influence of initiation mode
  - mostly all results in the upper transition were invalid
  - in case of valid and invalid specimens at the same temperature, they often displayed the same SA fraction
  - in one case, there was a distinct difference in dependence of the initiation mode
  - no notch type could reliably supress ductile initiation

Conclusions II

- correlation between pipe and DWT tests
  - @ 85% shear area, DWTT in presence of ductile initiation is a **conservative** estimate **if**
  - **all** brittle area is **rated**
  - transition curve in DWTT is shallow therefore
  - **intersection** with pipe DBTT was not clearly found but
  - no clear evidence to relax any requirements
- based on the (empirical) results
  - Brittle fracture can be avoided in pipe formed of TMCP plate by accepting ductile initiation and prescribing 85% SA counting all brittle features in the (standard) rated area of the fracture surface

Thank you for your attention.

Pipeline Research Council International, Inc.

Evaluation of cracked in-service welded 4 inch stub end

O.J.C. Huising
N.V. Nederlandse Gasunie

PRCI 2019 Research Exchange Meeting
Houston, Texas
Date March 5 - 6, 2019

Overview

- Introduction
- In-service welding qualification
- Situation
- Analysis of fracture
- Analysis of possible causes of fracture
- Conclusion

Introduction

European gas infrastructure company

15,500 km pipeline network

Groningen

TTF biggest European HUB

Transport 1,213 TWh/ 124 bn. m³ volume

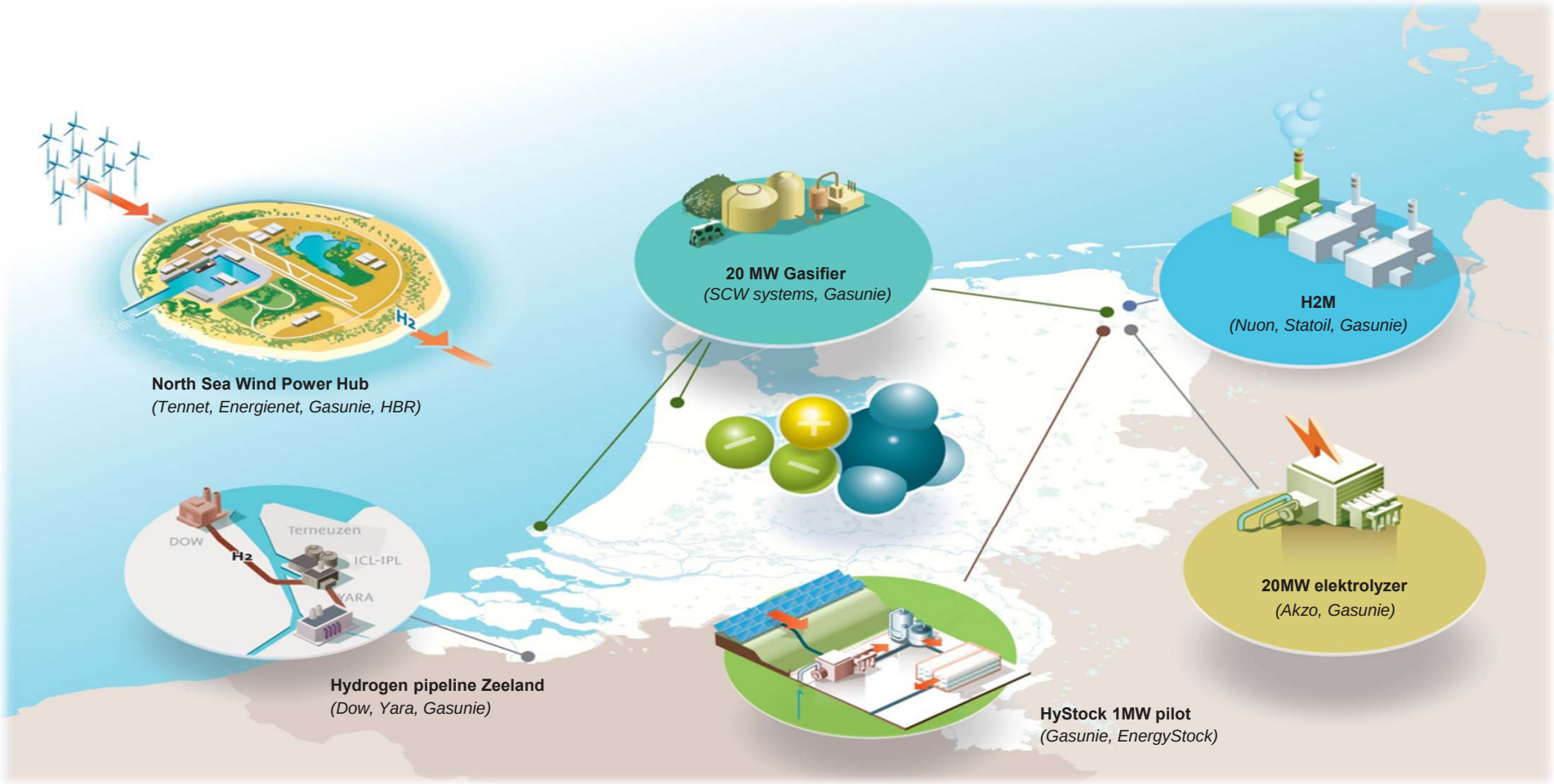
Profit €259 m

Sales €1,241 m

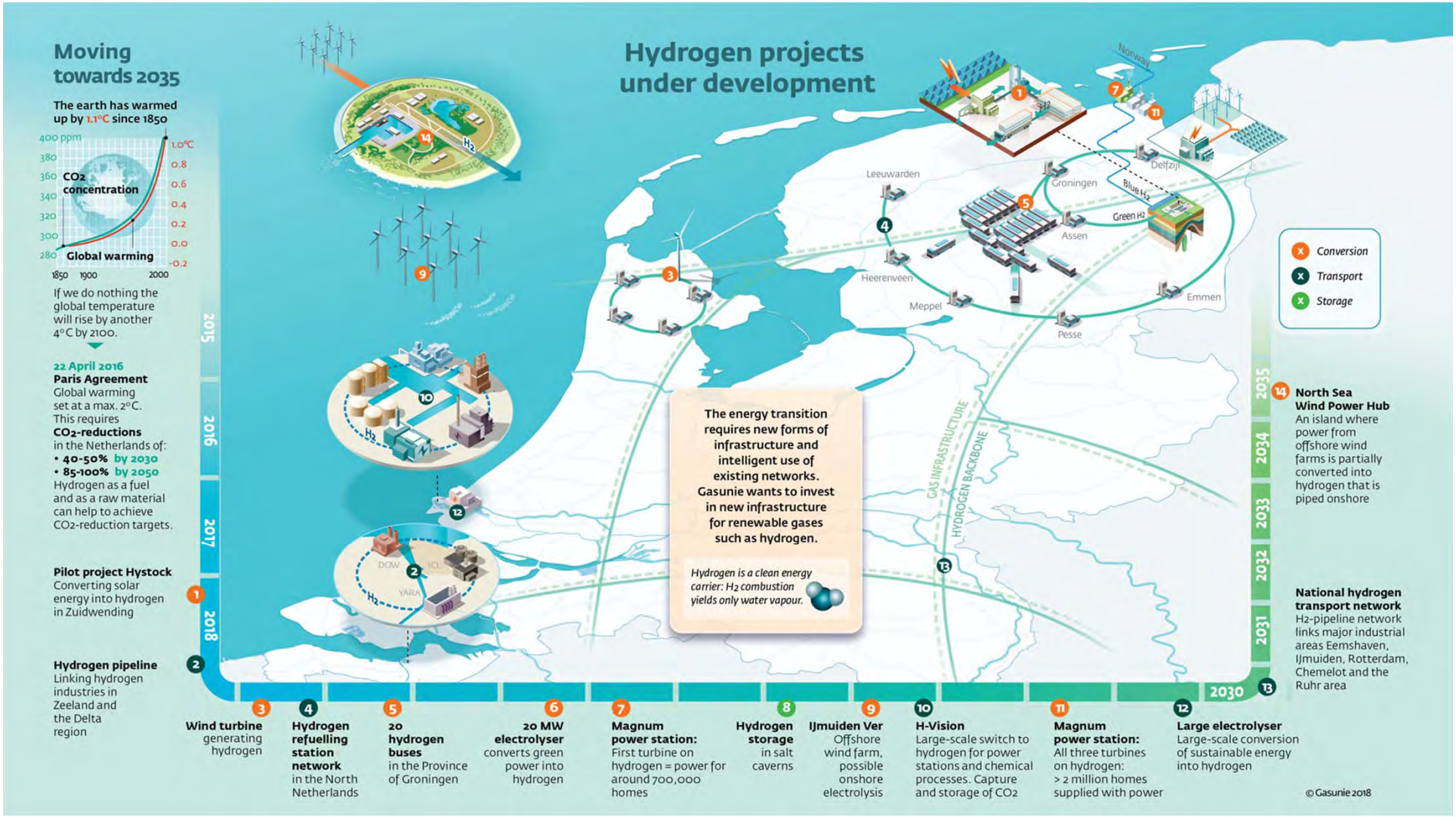
Brisbane

Figures of 31 December 2017

Developments in Alternative gases



Hydrogen projects under development



Gasunie practice/qualification

Ing. Tim BLOK

(N.V. Nederlandse Gasunie, The Netherlands)

IN-SERVICE WELDING AND REPAIR OF PIPELINES

17 th International School of Welding

October 1985

The High Tatras

Open Grid Europe
The Gas Wheel

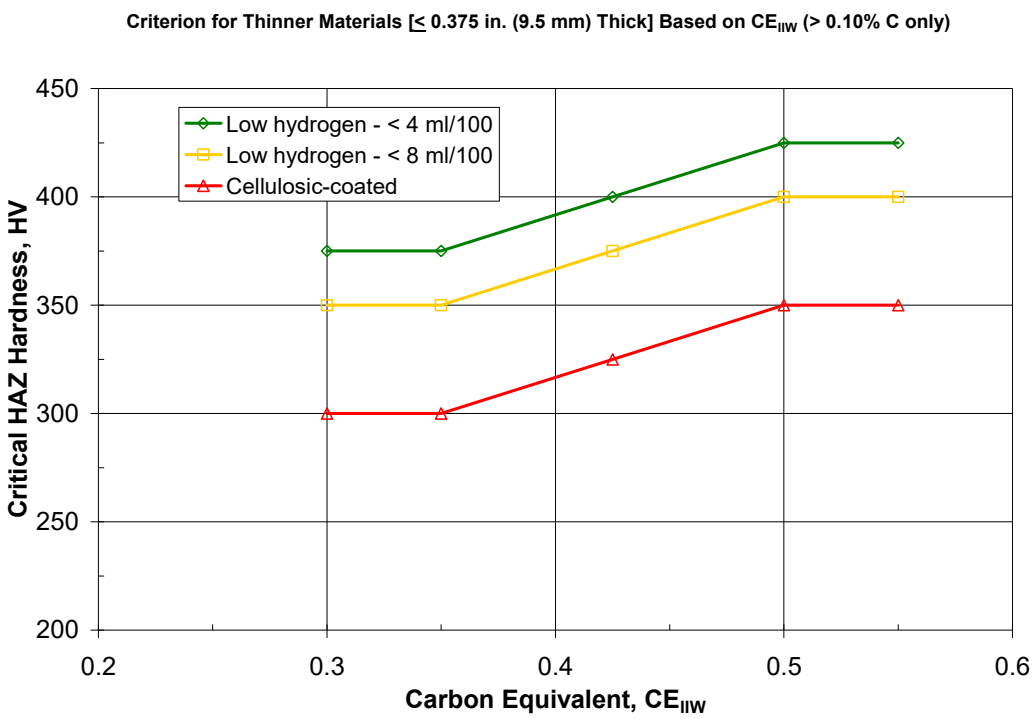
FLUXYS

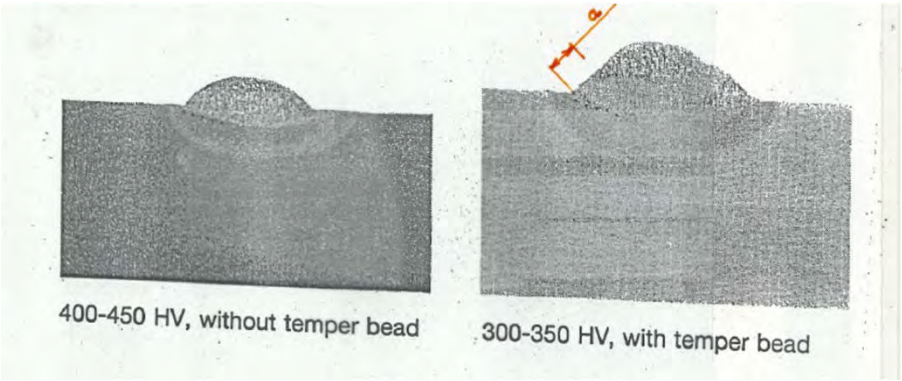
eni snam rete gas

Pipeline Research Council International

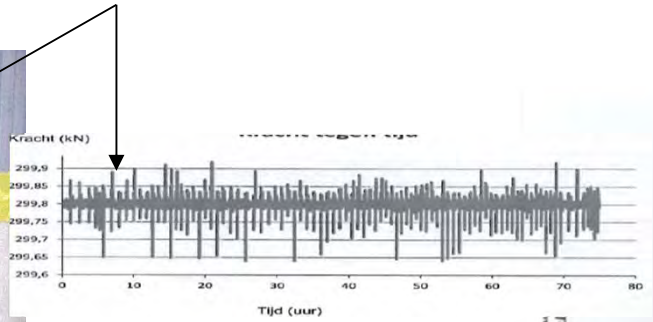
LEADING PIPELINE RESEARCH

Hardness Evaluation for In-Service Welds





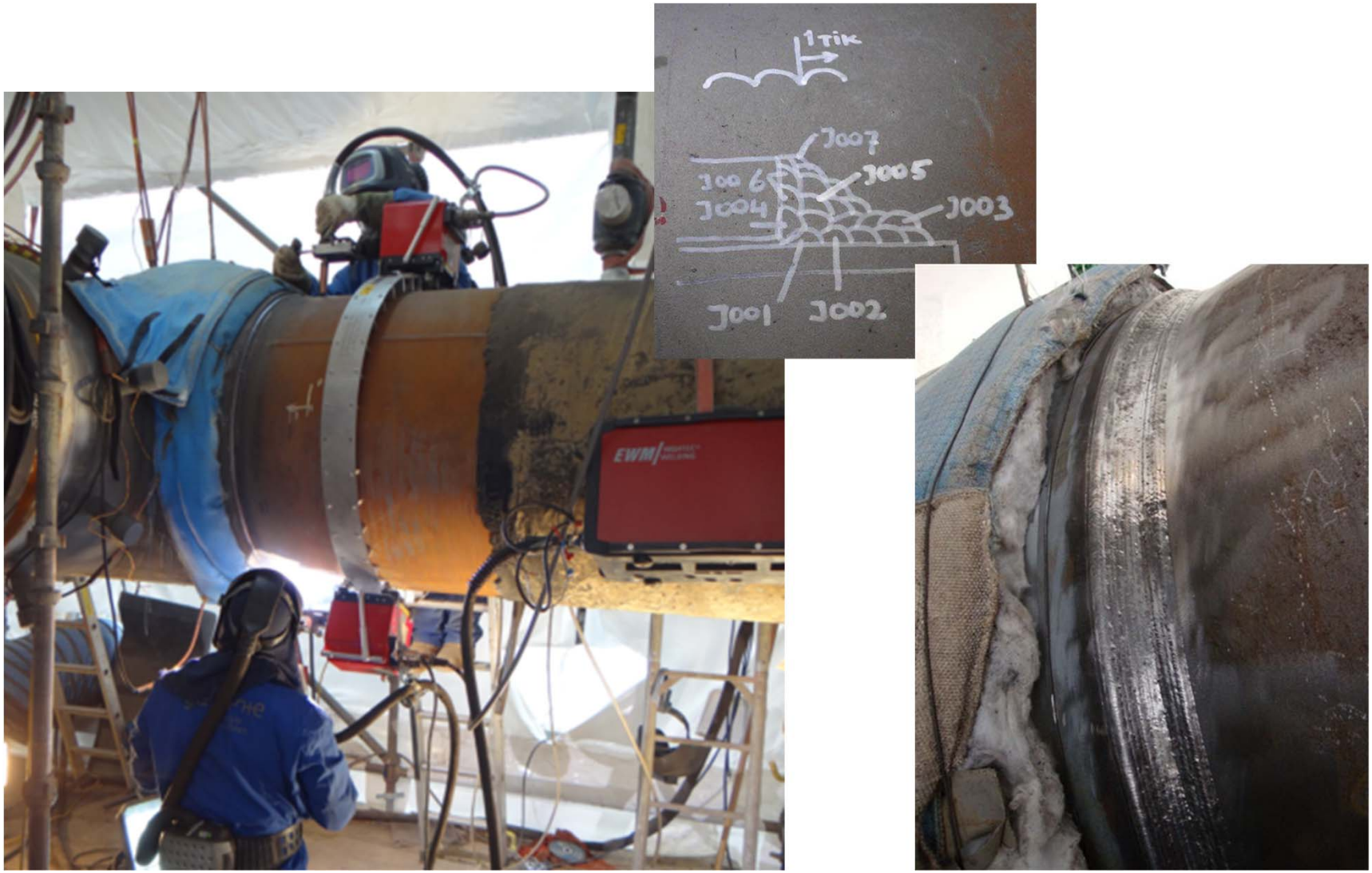
proof test of applied welding process



X56-1964 Ceq=0,52 σV~0.85SMYS-72 hrs.

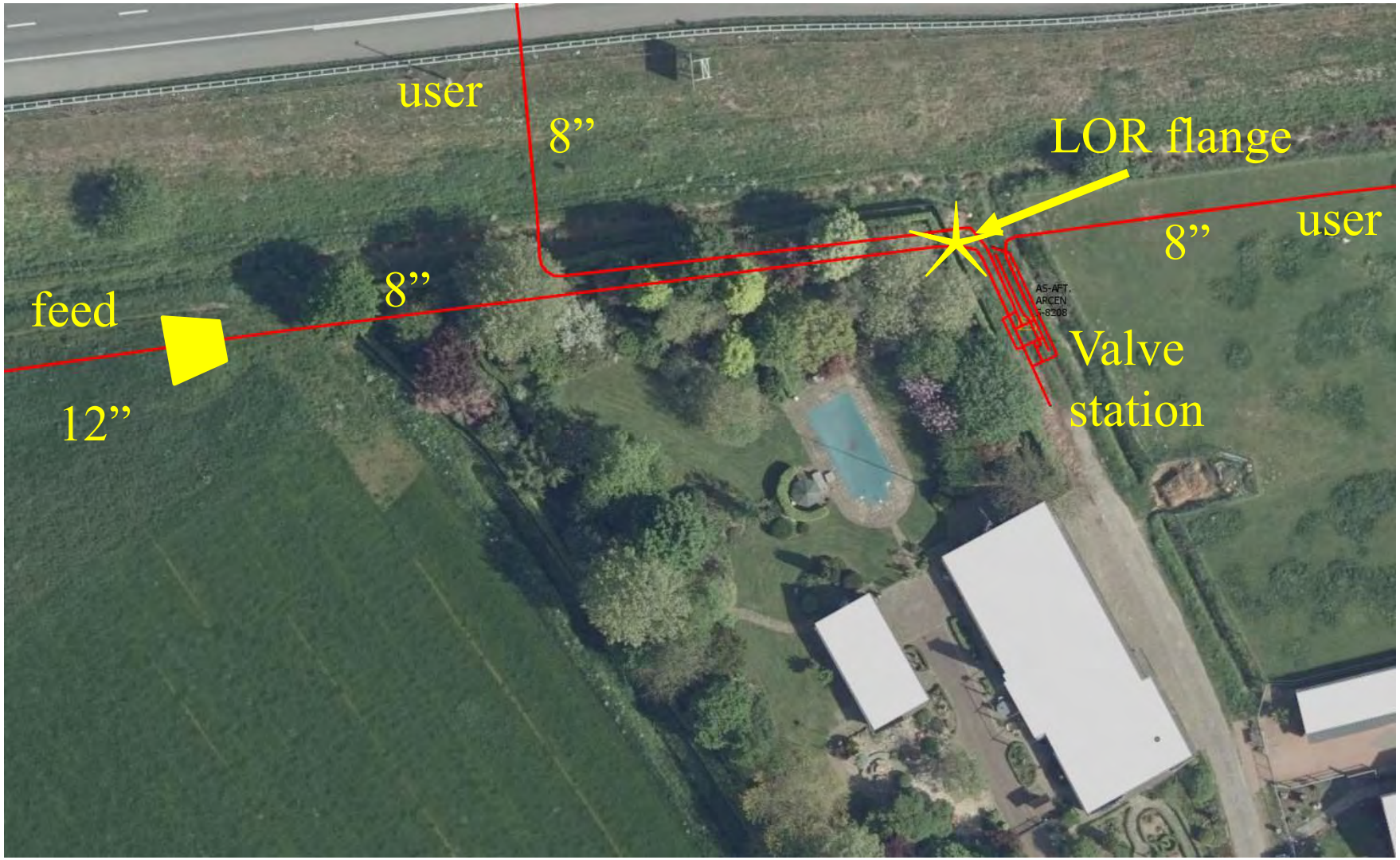
Cooling time equivalent to or lower as actual values during in-service welding

FCAW-mechanized in-service welding



Major critical parameter

Situation



Inbox friday afternoon 3 pm

Archive of stub, welded in 2008

Lasproces	Langs-naad	1e laag 2 t/m t/m			= = =	- - -	
	Rond-naad	1e laag 2 t/m CAP t/m	Kardo / 3HH Kardo / 3HH	2.5 mm 3.25 mm	= = =	- - -	65-90 90-100

Warmte behandeling		gecontroleerd		Laspositie 5F
		Pijp	NOK DN100	
	Voorwarmtemp.	20 °C	50 °C	Lasrichting PF
	Interpasstemp.	230 °C	240 °C	
	Isolatiedeken	☐ ja / ☒ nee		

Lasmachine	LINCOLN				
Lassers	Naam/legitimatienummer F. Post / 778 Naam/legitimatienummer		Naam/legitimatienummer Naam/legitimatienummer		
NDO	Maat "a" temperbeadmethode:		1 ☒ 3	2 ☒ 3	3 ☒ 3 4 ☒ 3
	US rapportnr. UT-01		Magn./pen. rapportnr. MT-01		
Drukverlaging	☐ ja	van bar tot bar	☒ nee		

Situatieschets

a = b= c=

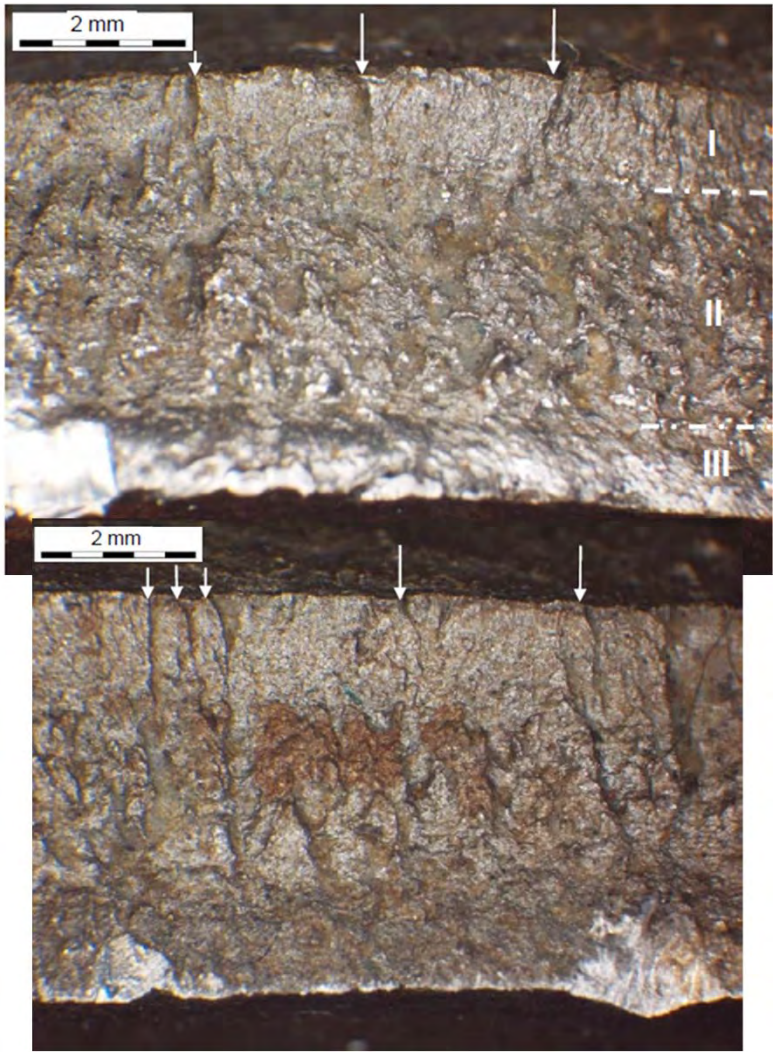
Werk	Leidinonr. Z-513-07 Install.nr. S-8208	Routekaartnr. KR-014 Locatie ARCEN-VELDEN	Datum lassen 06-10-'08
Uitvoerende dienst TOTU Datum 22-10-'08 Naam A. BRUNSVELD Handtekening	Aanvaard ☒ Niet aanvaard wegens .... Genomen actie		Ingeval van niet aanvaarden de gewijzigde procedure vastleggen ☒ REVIEW ☐ VERIFY ☐ WITNESS Date: 27-10-05 N.V. Nederlandse Gasunie Naam .....

N.V. Nederlandse Gasunie A. Brunsveld Speciale Opdrachten

gasunie

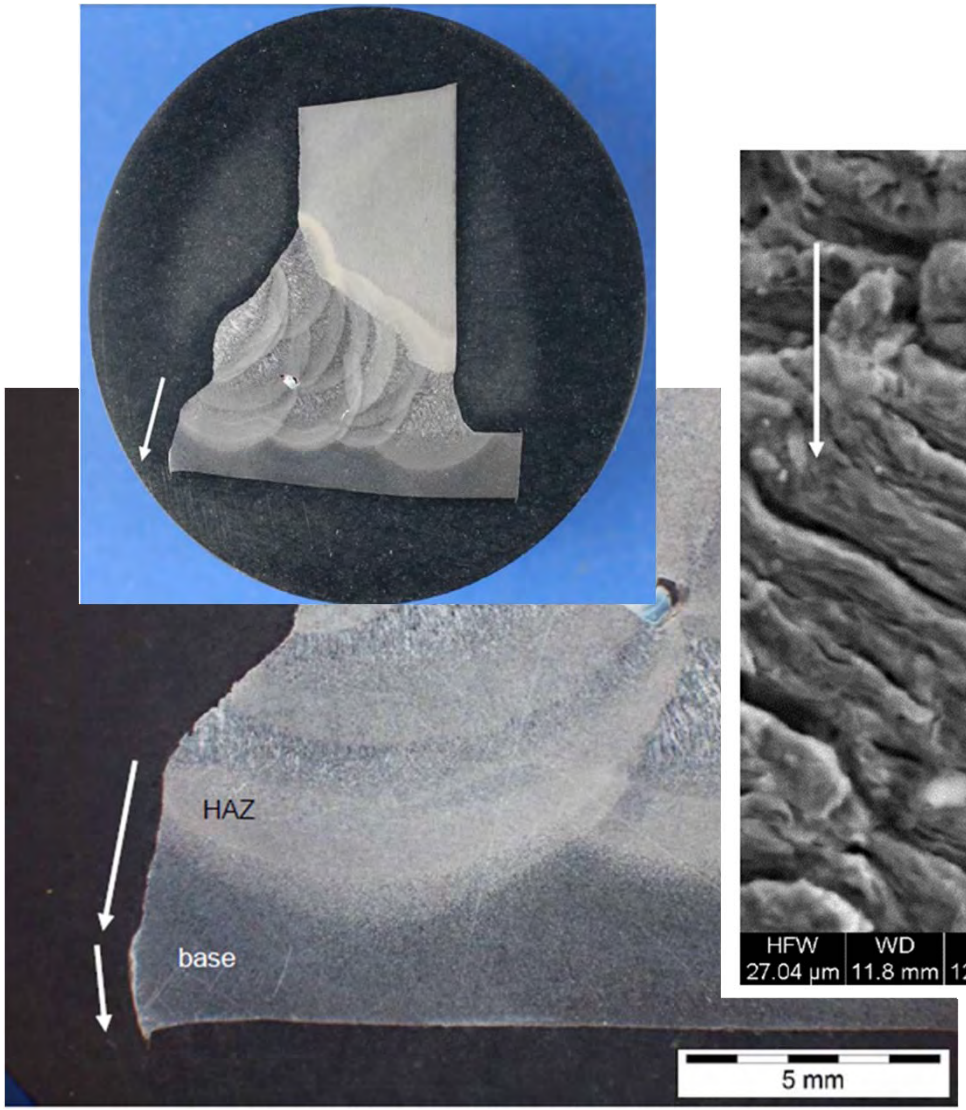
GTS-W-018, versie 6, 27-10-2005, blad 1 van 1

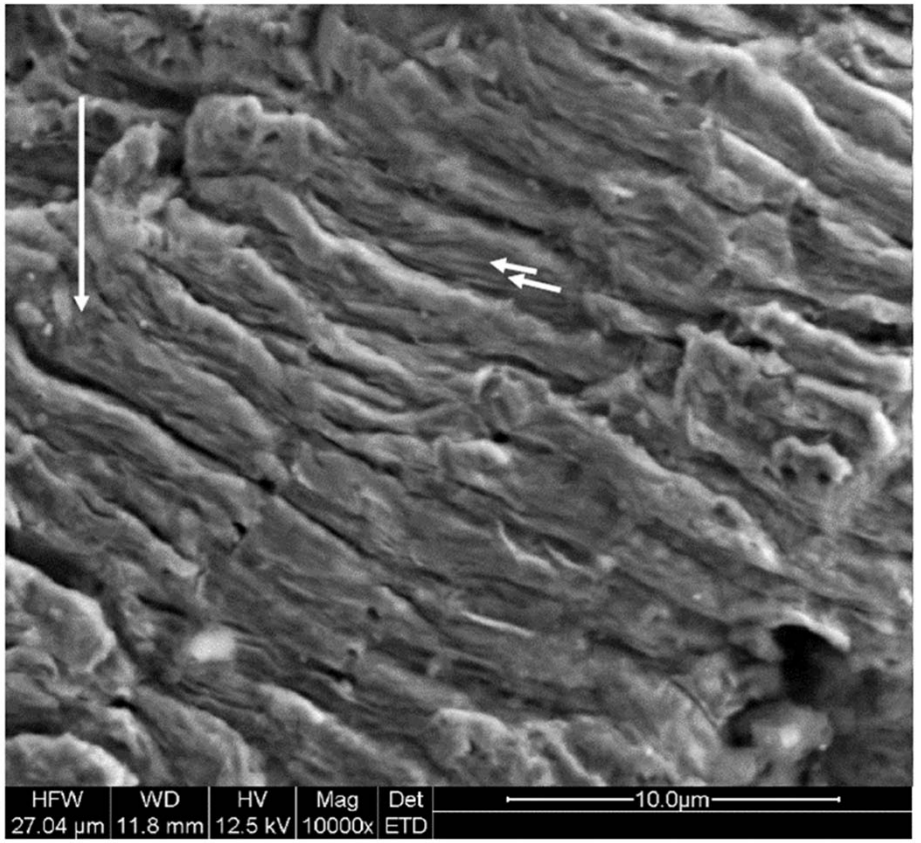
Laboratory examinations



2mm = 0,08”

Conclusion fatigue damage



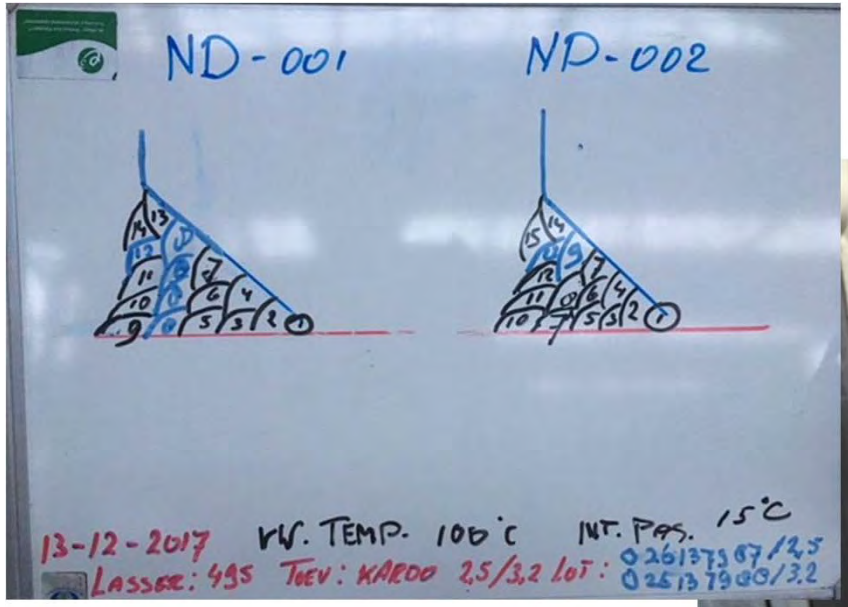


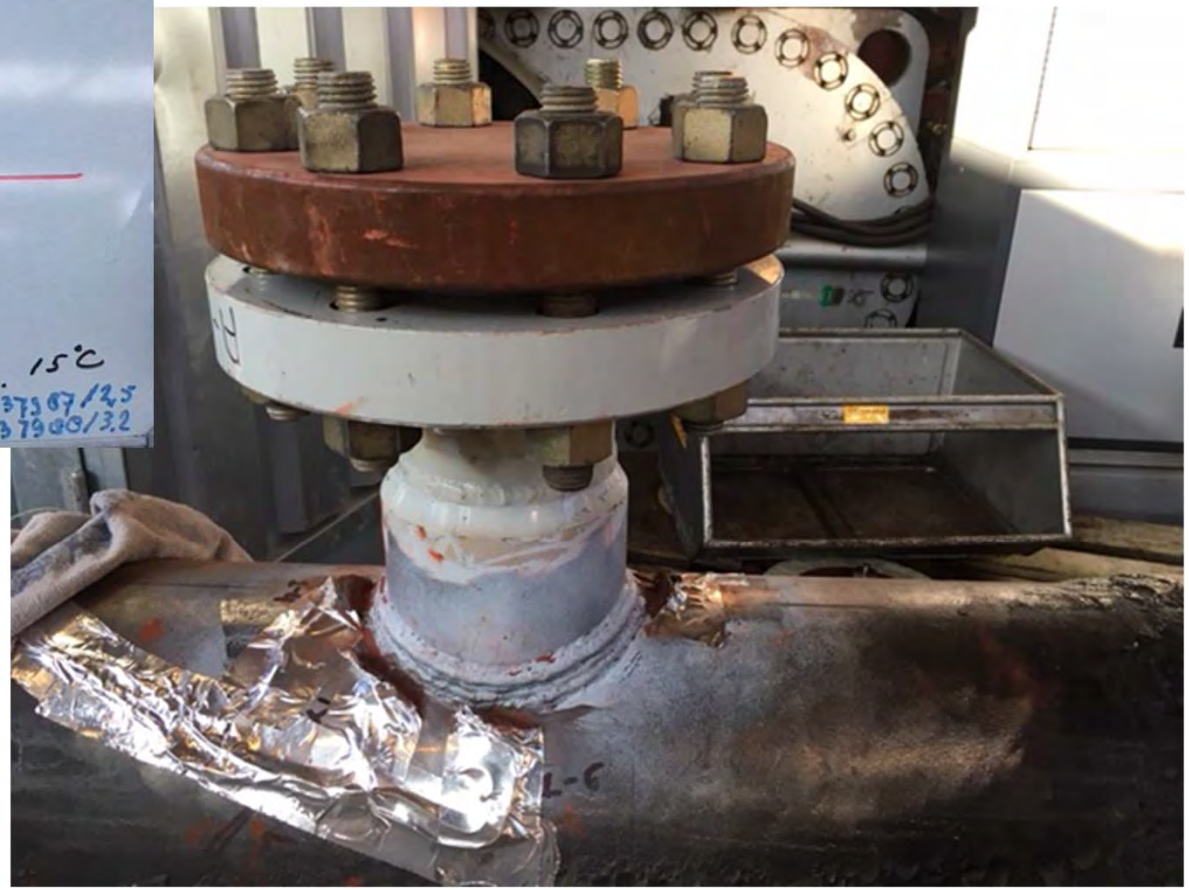
Search for origin of fatigue damage

During:

- welding and drilling this stub
- use with the temporary line attached (the reason why it was installed)
- normal use 2008-2017
- replacing the line

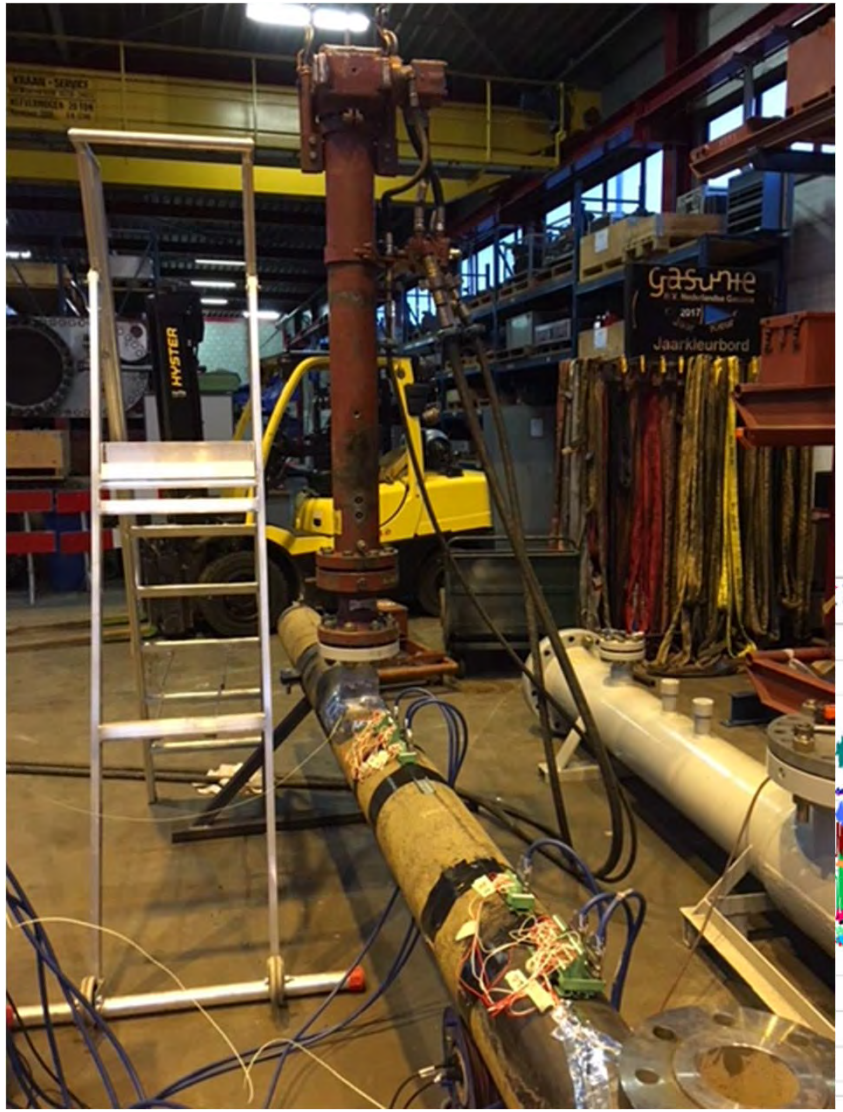
Welding in accordance with original procedure



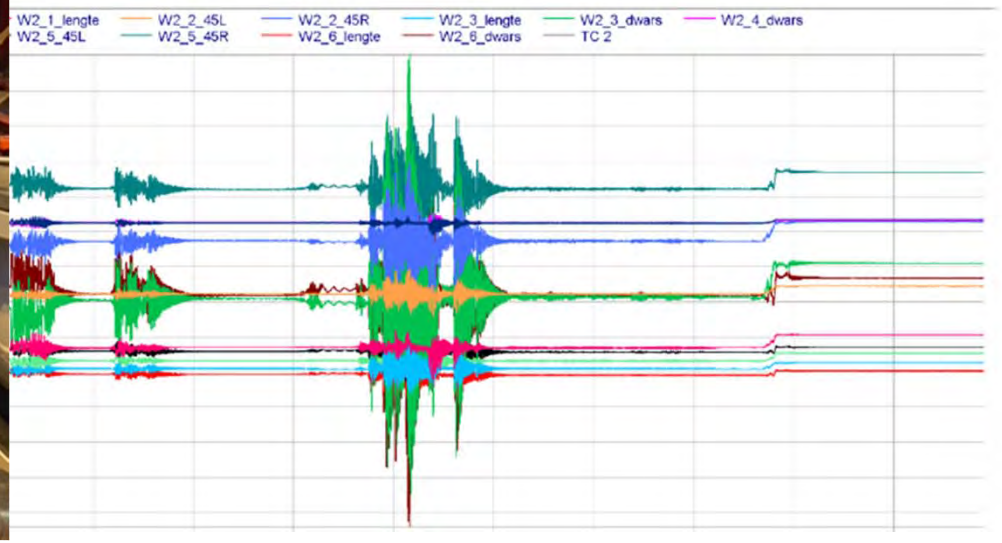


After welding
VT and MT

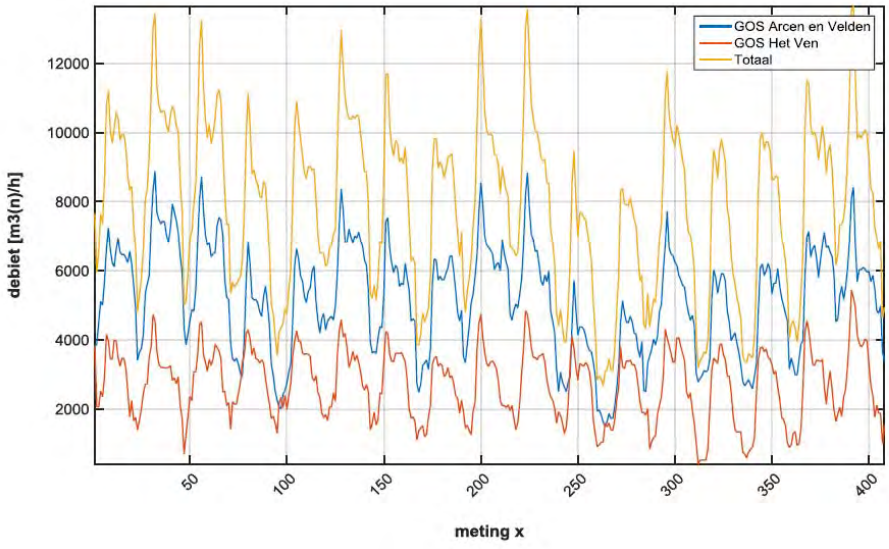
Drilling in accordance with original procedure

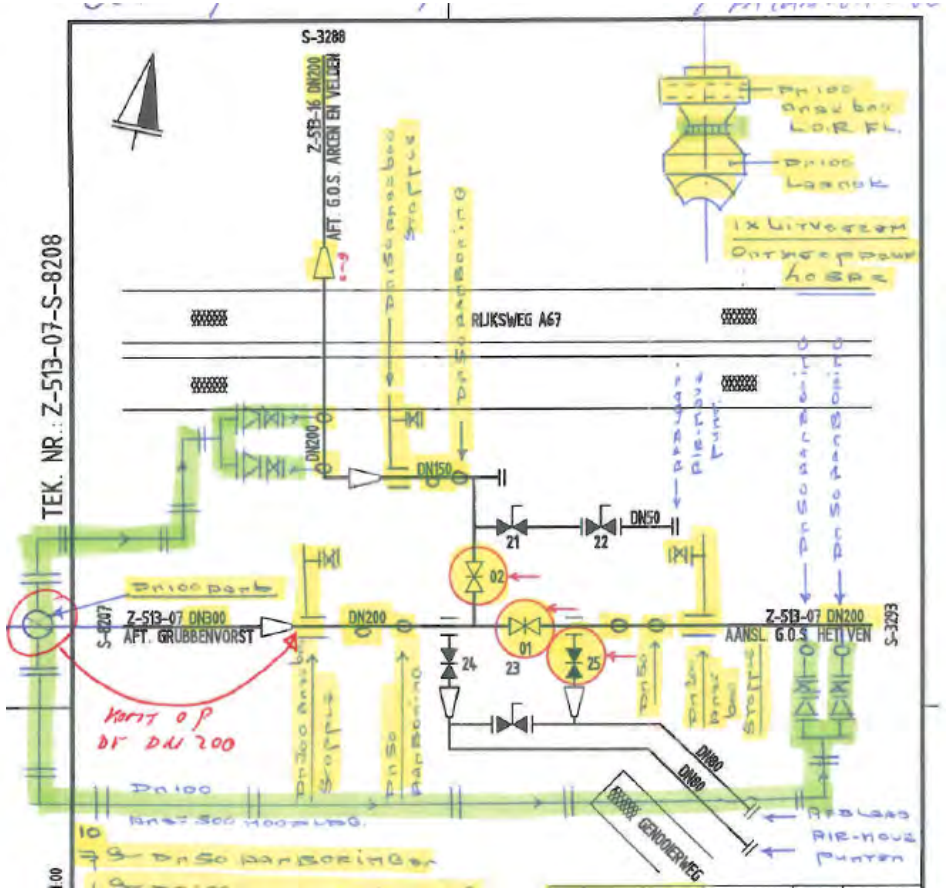


Max value	Min Value	Max delta
121 MPa	-129 Mpa	250 MPa
17.5 ksi	-18.7 ksi	36 ksi



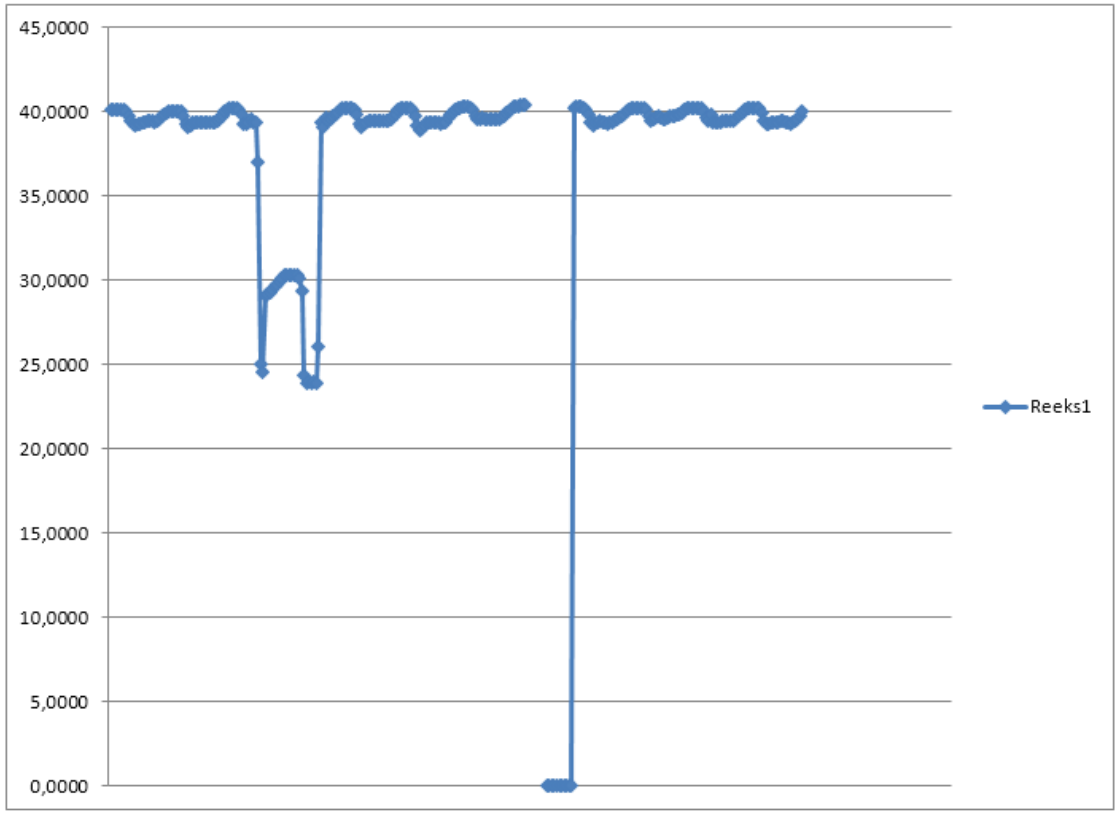
During temporary line operation





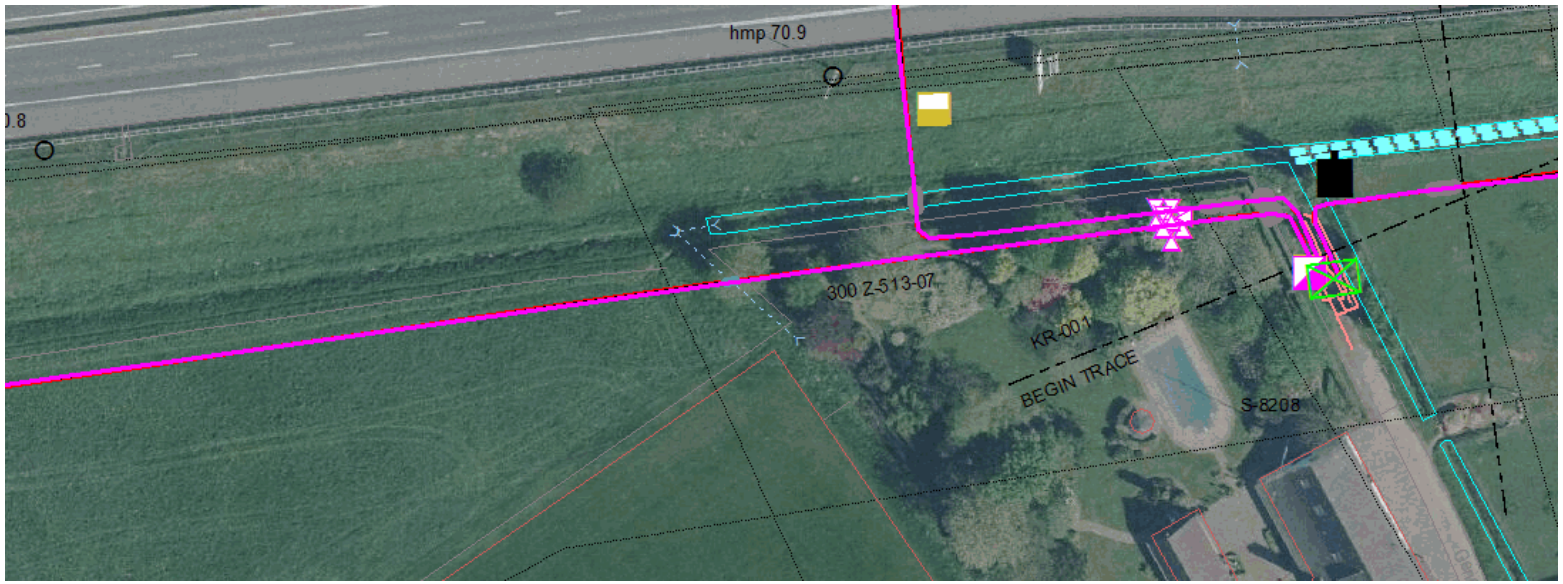
Flow induced pulsations?

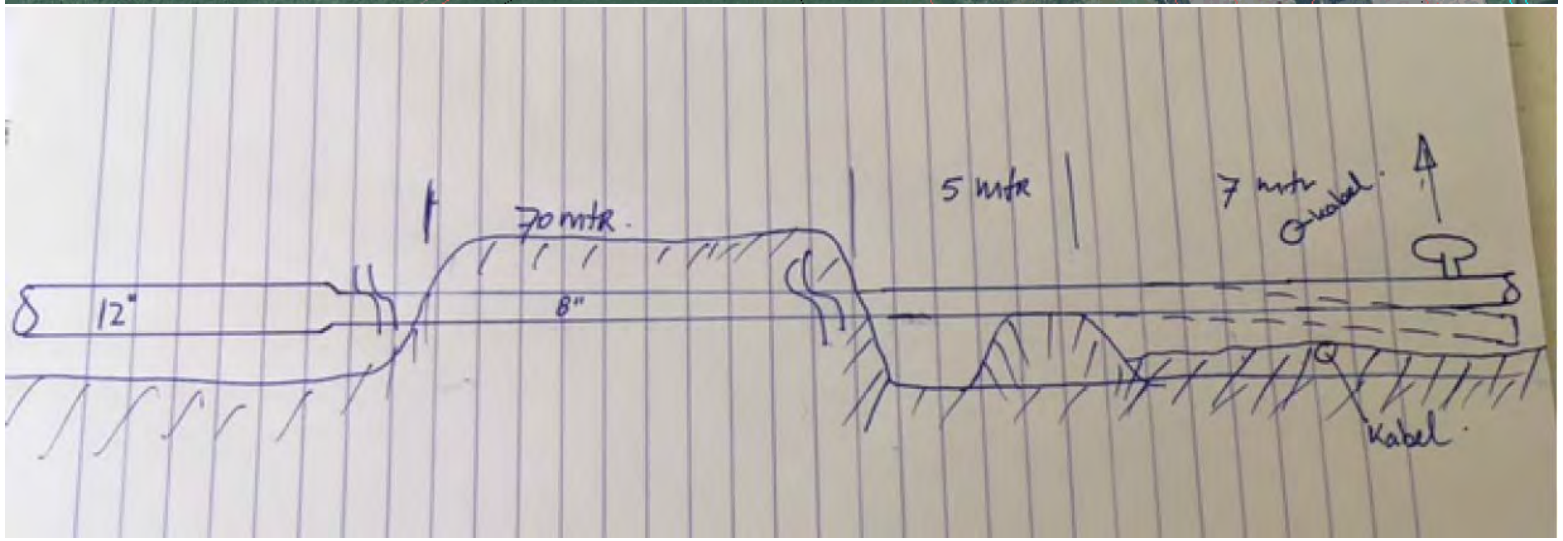
Analysis of pressure differences



Line pressure from 2008 to 2018

Replacement plan





70 mtr

=

76 yd

5 mtr

=

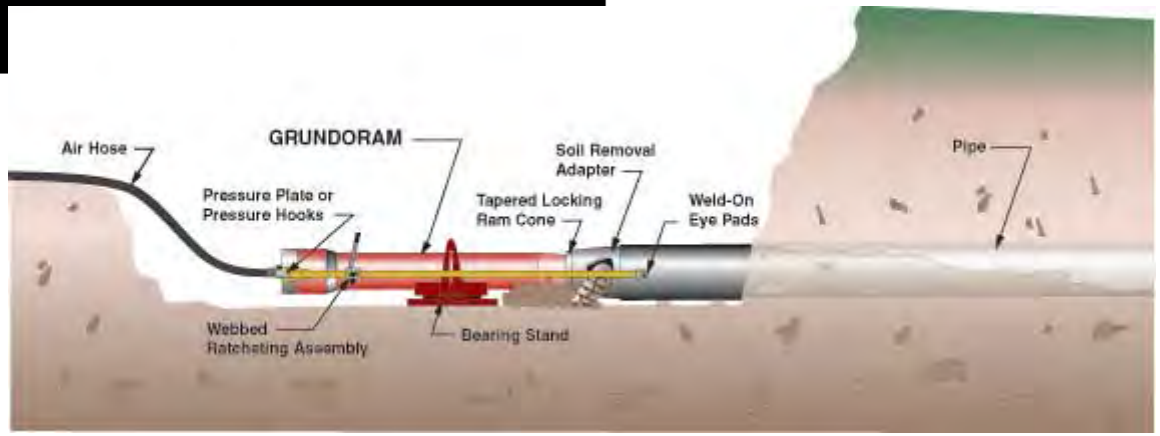
5 yd

7mtr

=

7 yd

Execution of replacement



Root cause

- The root cause for the stub end to “fall out” of the pipe is a fatigue crack along the full length of the weld in the pipe wall.
- The fatigue crack was caused by the pneumatic hammer in combination with the attached sling used for pushing the new pipeline replacing the existing smaller diameter line.
- Based on this conclusion there is no reason to doubt the stubs welded in service with the current practice.

So, we can leave the tulips undisturbed

Pipeline Research Council International, Inc.

Soil-pipe interaction in Muskeg Soils for Design of Buried Energy Pipelines - Characterization of Muskeg: Preliminary Results

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University of British Columbia, Vancouver, B.C.
Canada

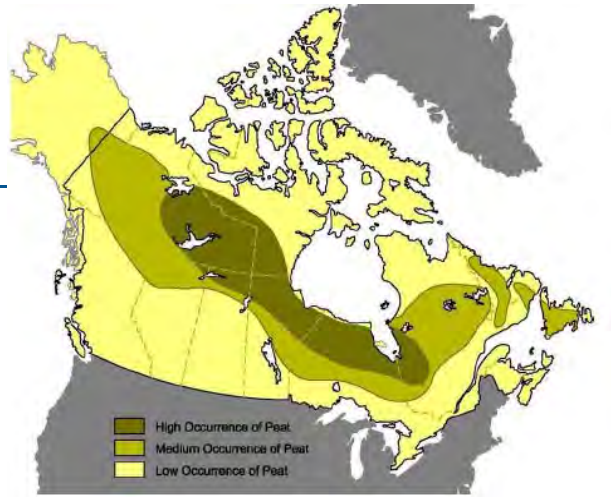
PRCI 2019 Research Exchange Meeting
Houston, Texas
March 5-6, 2019

PRCI™

UBC

PIPELINE INTEGRITY INSTITUTE
INSTITUT D'INTÉGRITÉ DE PIPELINE

Introduction & Impetus



Distribution of peat lands in Canada (MacFarlane 1969)

Muskeg:

- Covers > 1.5M km^2 of Canadian landscape
- Soft in stiffness and weak in strength
- Many energy pipelines cross muskeg soils
- Thermally-induced movements and ground subsidence
- Current approaches (e.g., PRCI 2009) address sand/clay-like soils but not organic soils.
- Significant variability of soil properties.
- Lack of knowledge on the behaviour
- Specific guidance needed for the assessment of pipelines

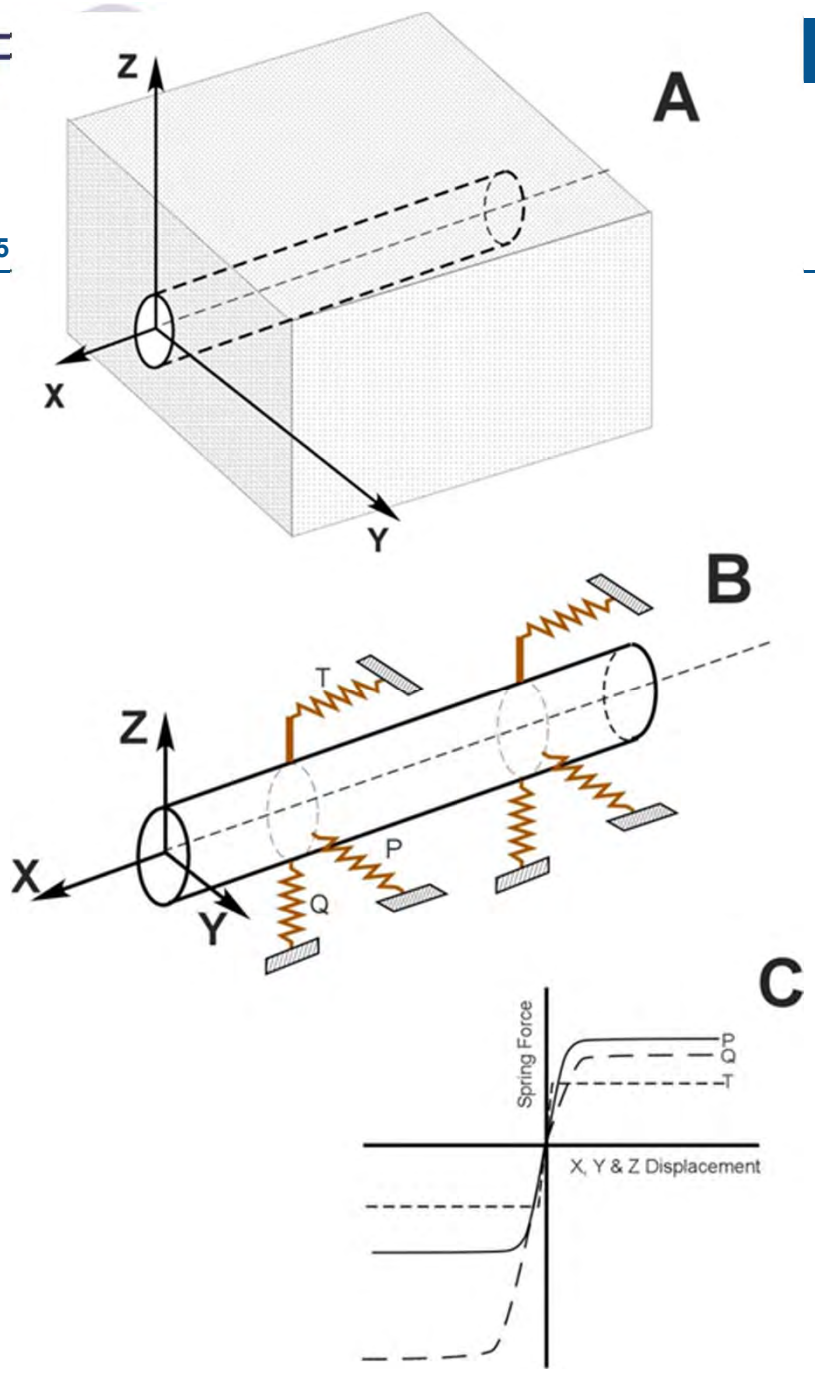
Objectives

In support of soil-pipe interaction assessments in muskeg soils, a research program undertaken to develop:

i. optimal approaches to characterize the variable mechanical response of muskeg soils;
ii. models to simulate the soil-pipe interaction for pipes buried in muskeg soils
iii. verify/calibrate the developed soil-pipe model to justify suitability for engineering evaluations.

Research Tasks - Quick Overview

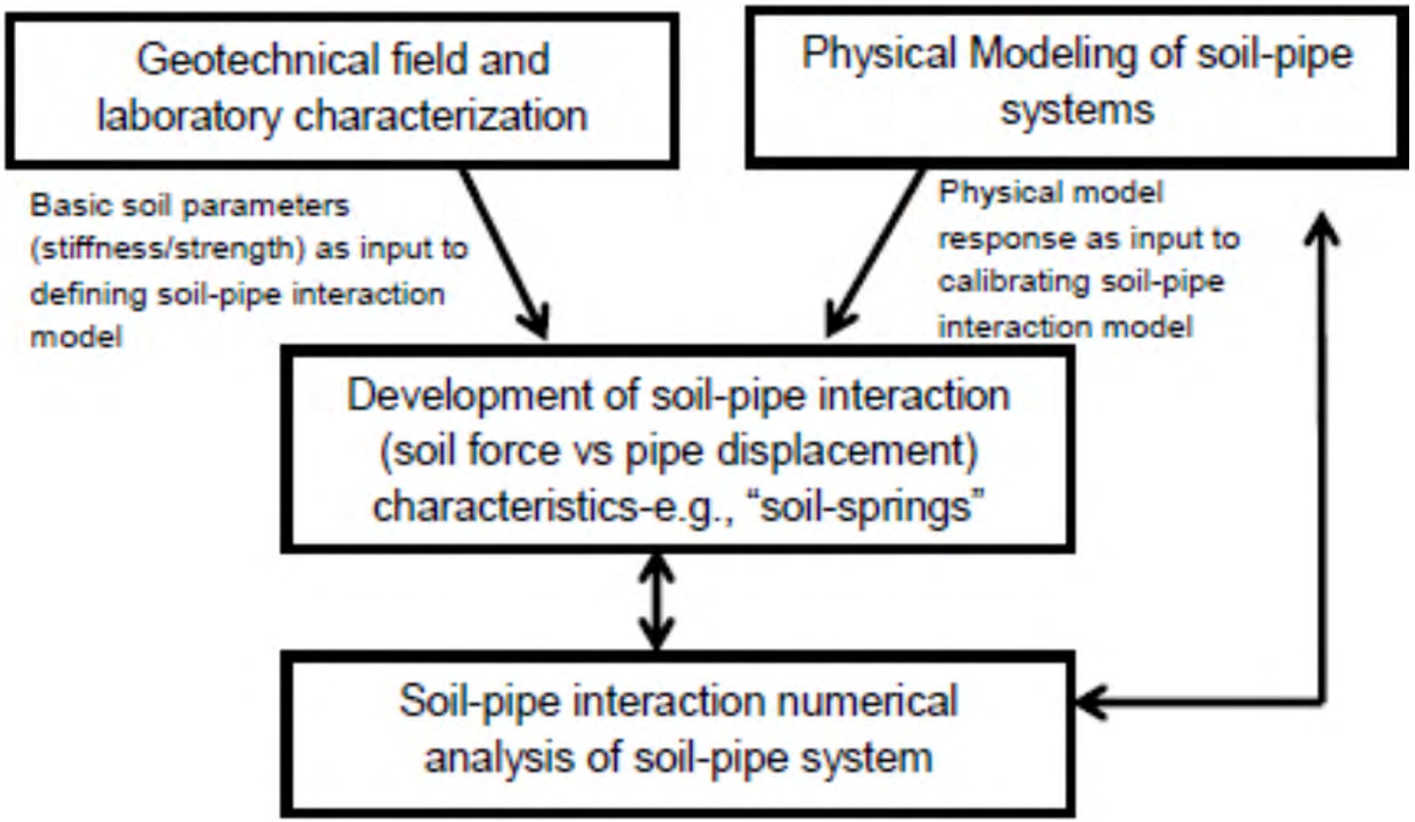
- **Field Investigation:** to characterize soil behaviour to addressing soil-pipe interaction concerns in muskeg soils. (obtain basic soil parameters; i.e., define stiffness/strength).
- **Laboratory Experiments:** to study axial soil restraints on pipes buried in Muskeg soil.
- **Numerical Investigation:** to study the applicability of stiffness and strength parameters obtained from field investigations to soil-pipe analysis



Development of P-Y Curves Soil Springs

PRCI (2009)

Overall Research Approach



Overall Research Approach

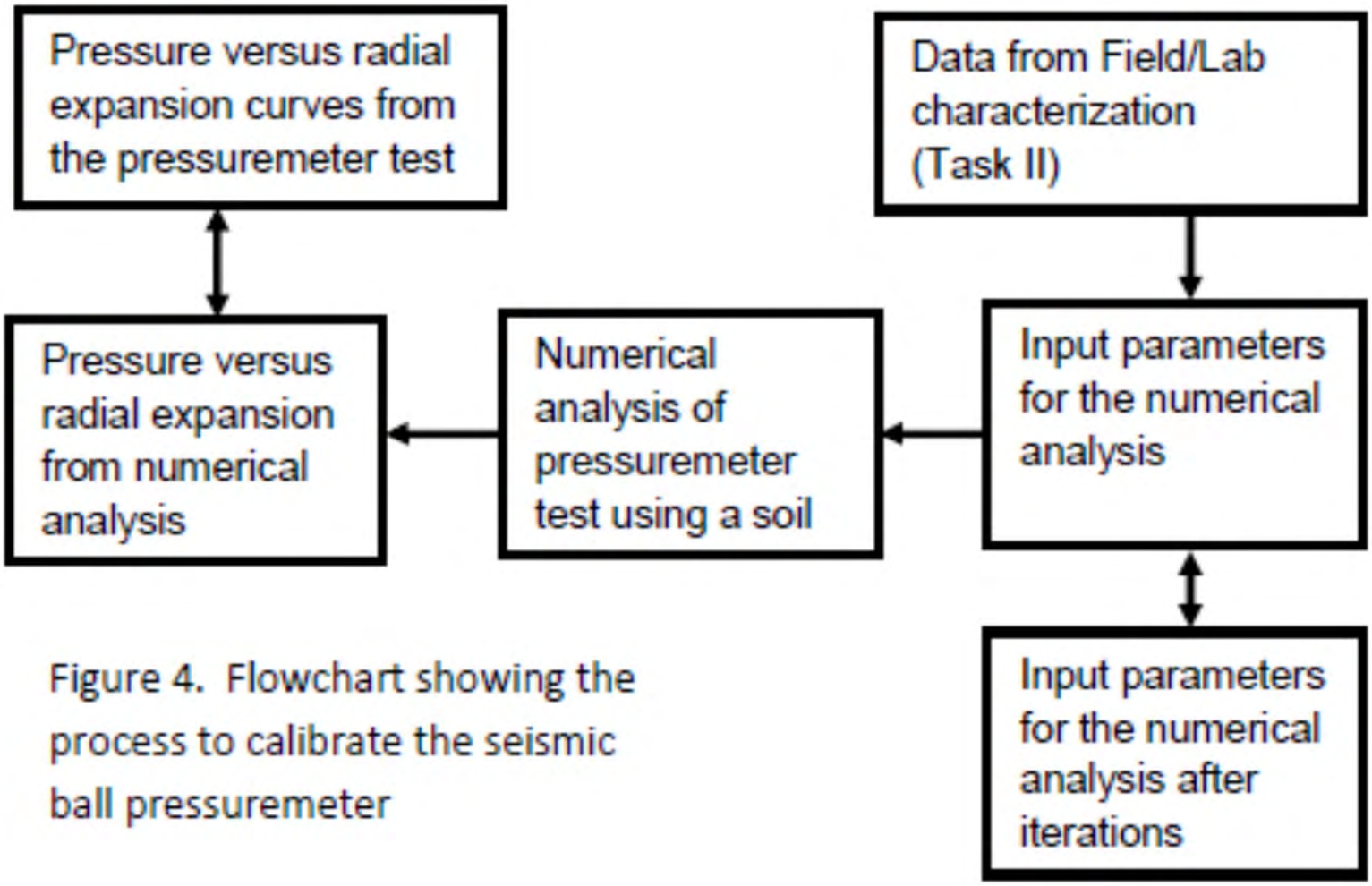
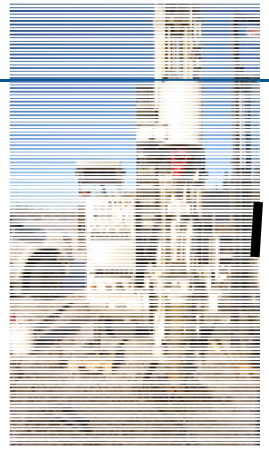
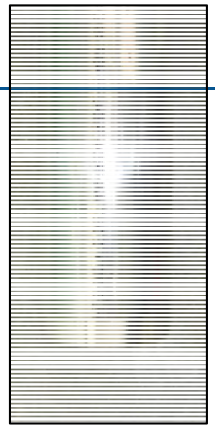


Figure 4. Flowchart showing the process to calibrate the seismic ball pressuremeter

Geotechnical Characterization Tools



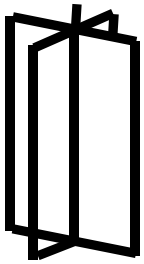
Auger Sampling



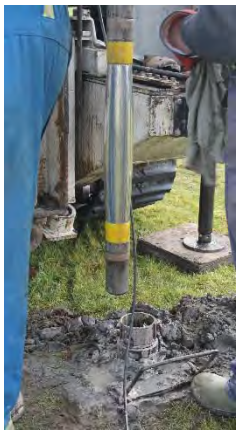
Tube sampling

Seismic Cone Penetration Testing (SCPT)

Ball Penetration Testing (BPT)



Vane Shear Testing



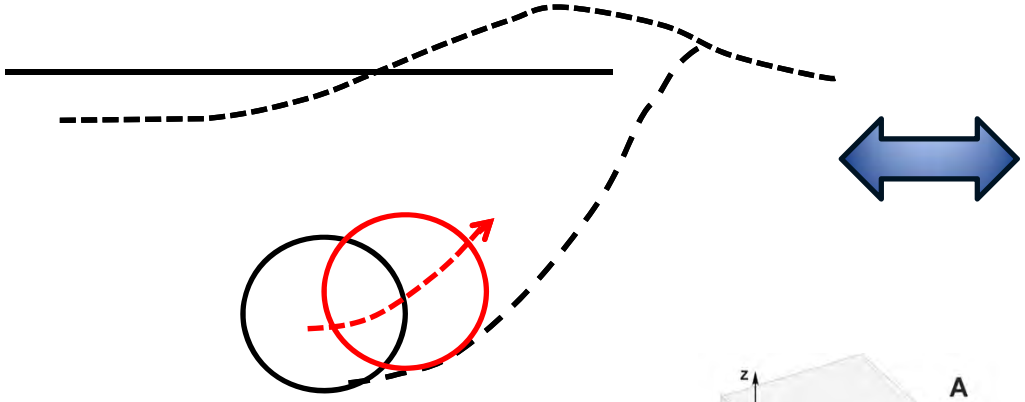
Pressuremeter Testing (PMT)

Laboratory Shear and Deformation Testing

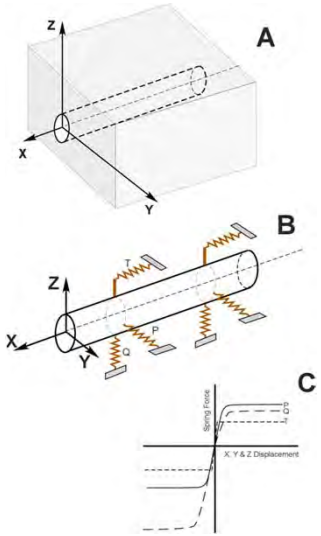
Laboratory Physical Modeling

Pipe Movement Relative to Soil

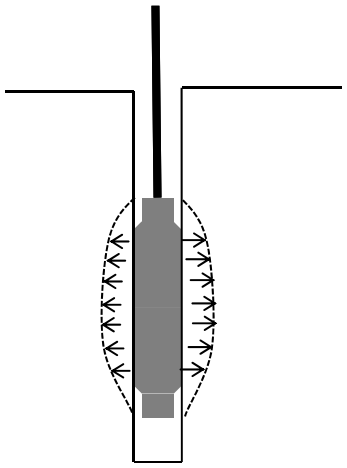
Need to get the right soil stiffness and strength for soil-springs for pipeline stress/strain analysis



Real-life



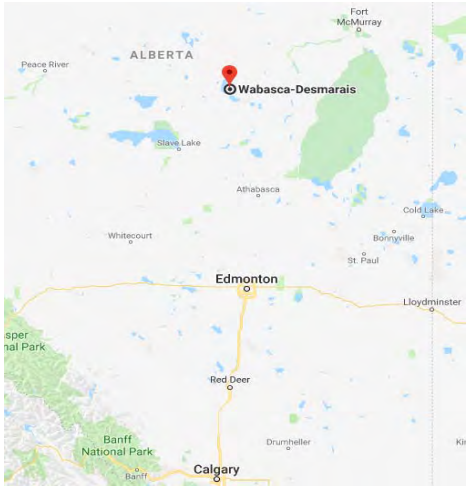
Computer
Numerical Model

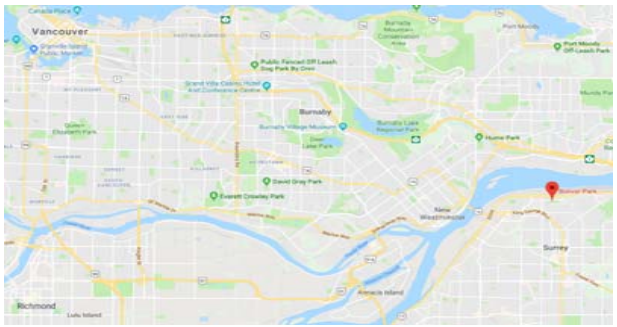


Field Pressuremeter
Test

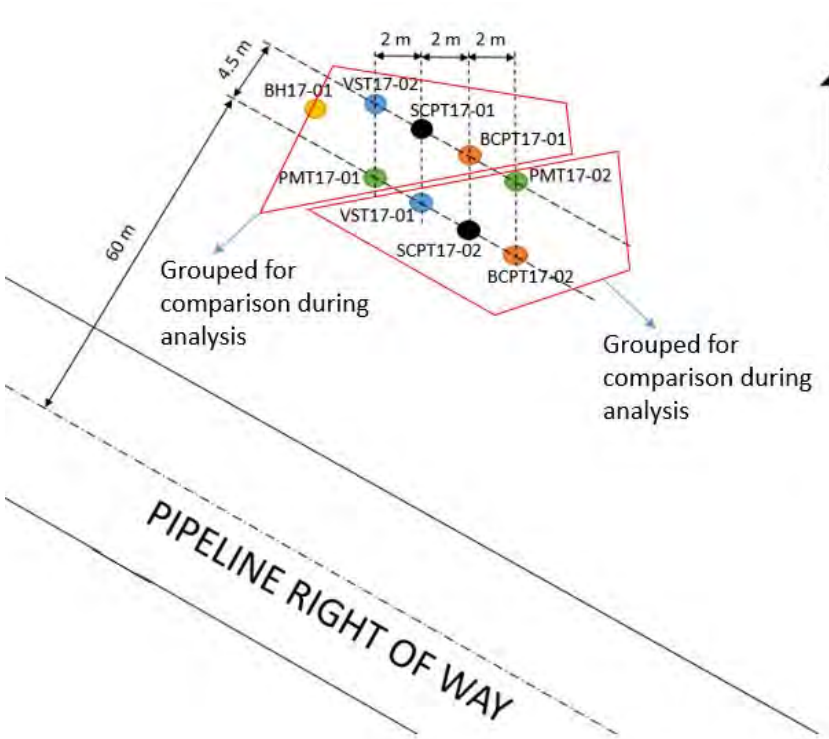
Geotechnical Field Investigation

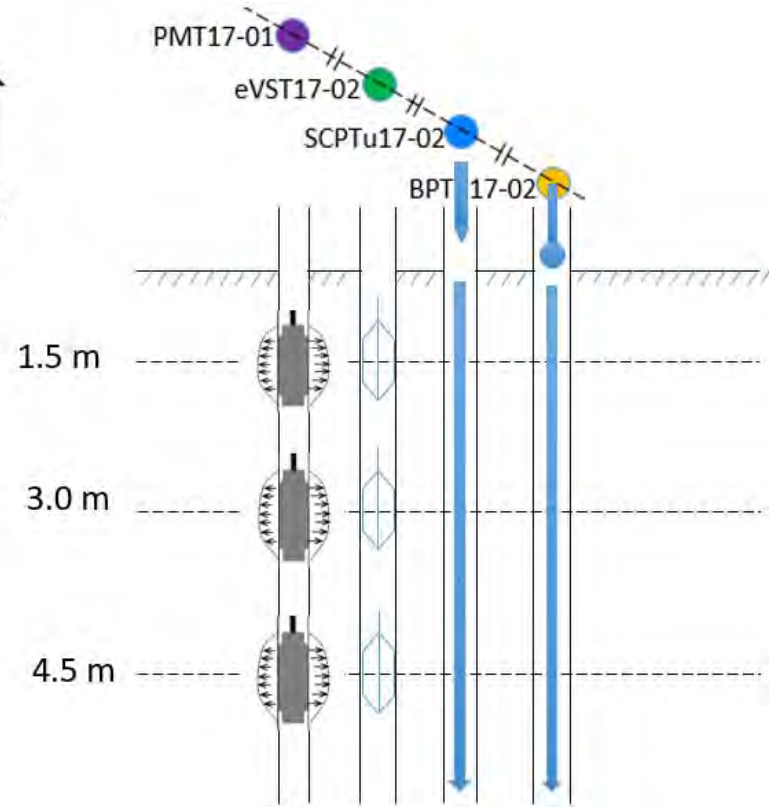
	Location	Date of Testing	Number of Completed Tests	Max. Depth of Testing	Type of Soil Present
Site 1	Northern Alberta, near Wabasca	Feb - 2017	2 SCPTu 2 BPTu 4 eVST 4 PMT	1.50 m 3.00 m 4.50 m	Muskeg soil (fibrous)
Site 2	Southern British Columbia, in Surrey	Nov - 2017 and Jan - 2018	2 SCPTu 2 BPTu 6 eVST 6 PMT	3.50 m 5.00 m 6.50 m	Muskeg soil (amorphous)





Testing Program and Details –Site 1

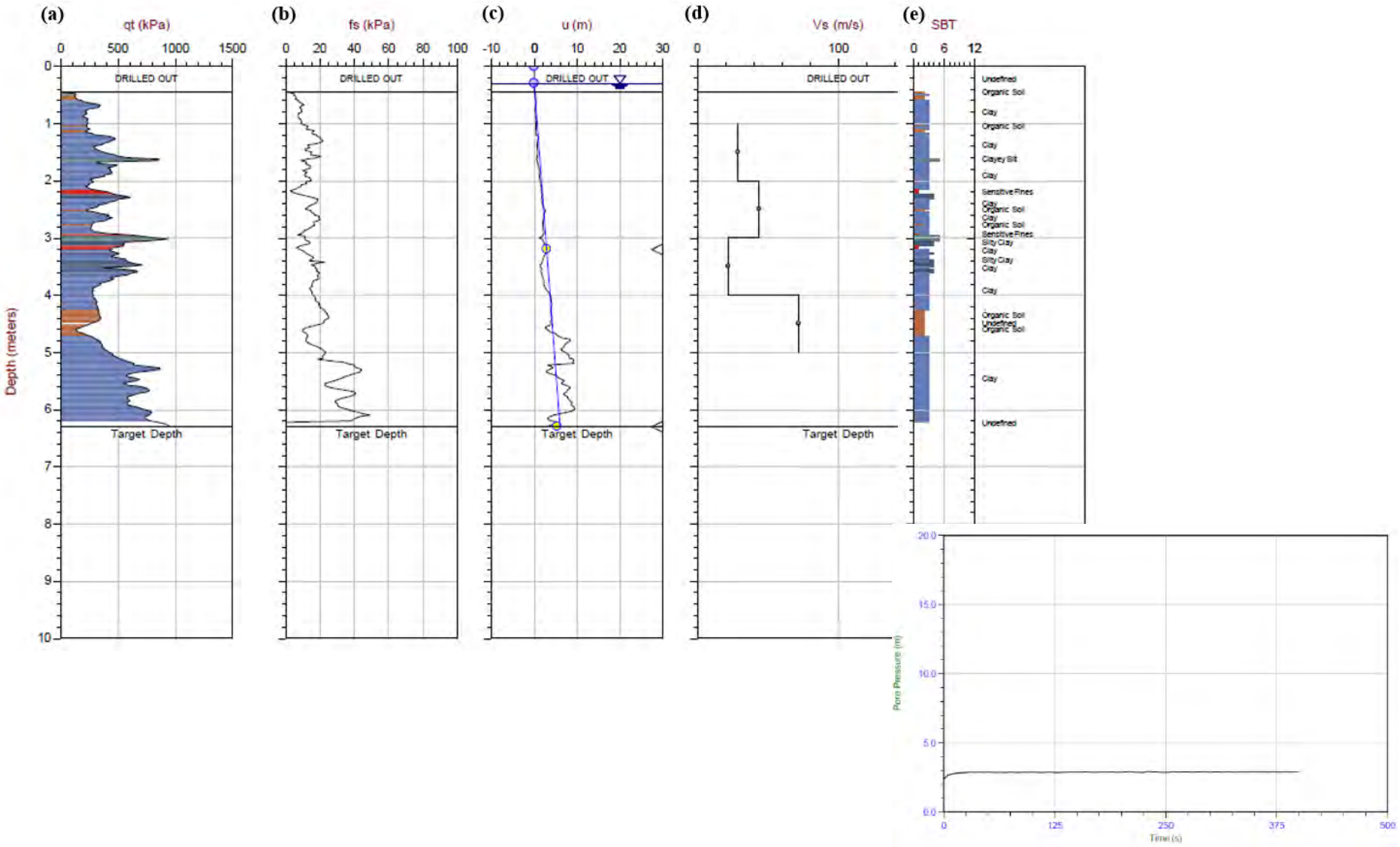




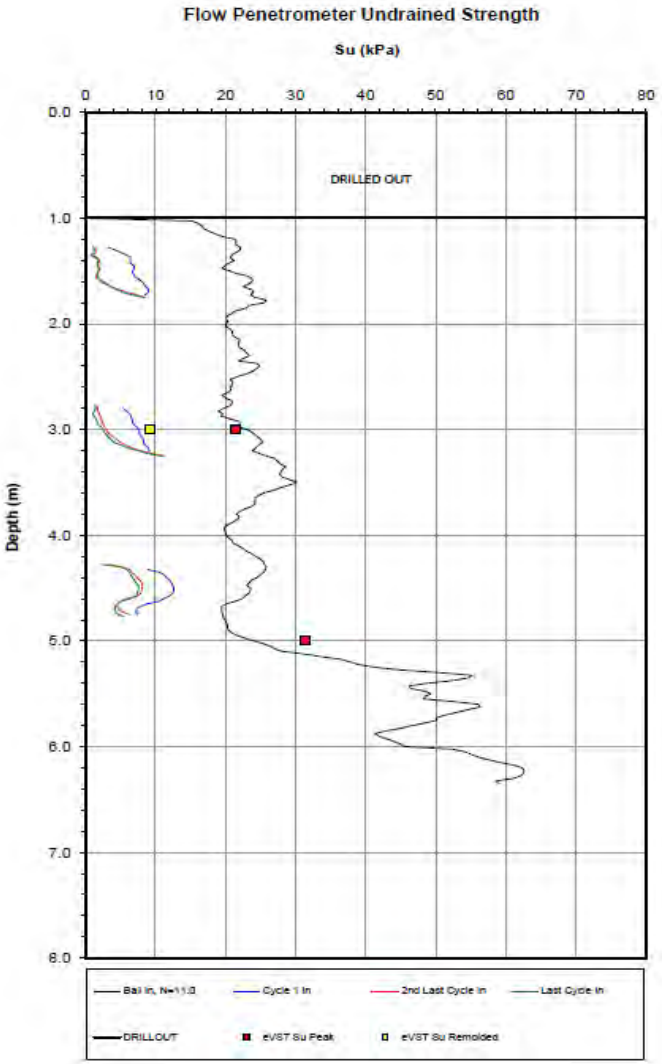
Site Specific Difficulties

- Access to the site, due to the “bog” like nature of the soil
- Must be accessed in cold weather via ice-roads
- Difficulties in operating instruments and data login equipment in freezing weather
- Freezing point of diesel: ~ -15 o C to -20 o C
- Difference in stiffness between the frozen top layer and underlying soil causes need to adapt seismic aspect of CPT

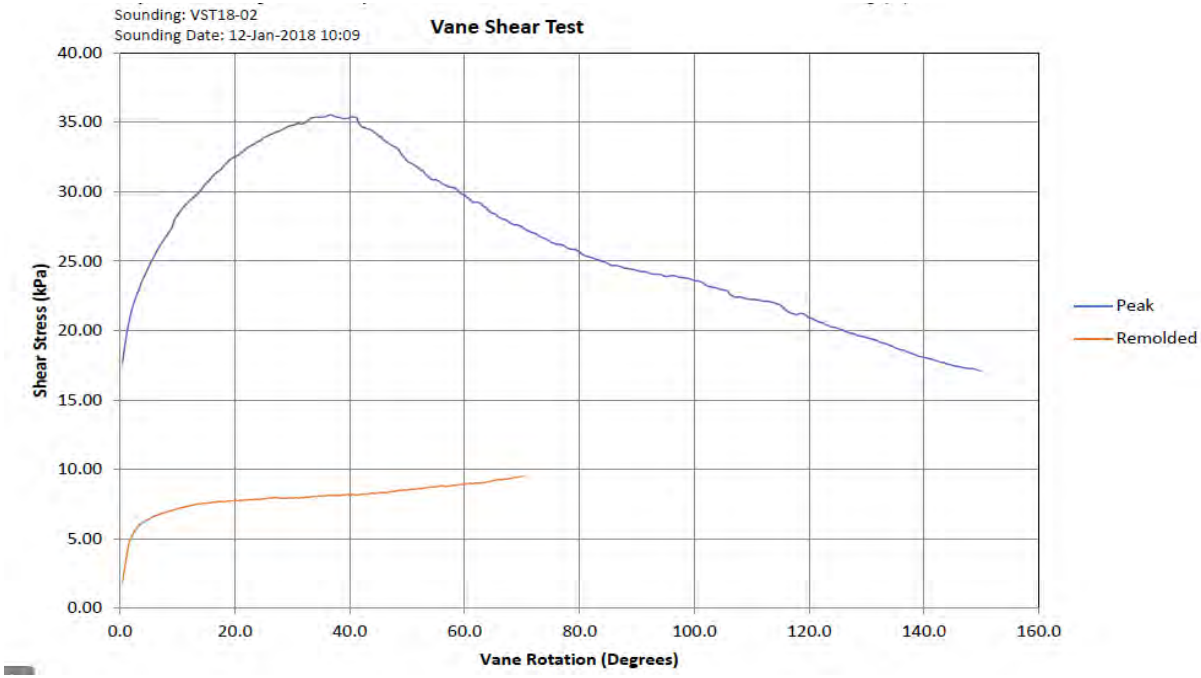
Seismic Cone Penetration Test (SCPTu)



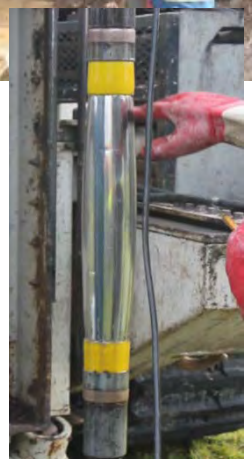
Ball Penetration Test (BPTU)

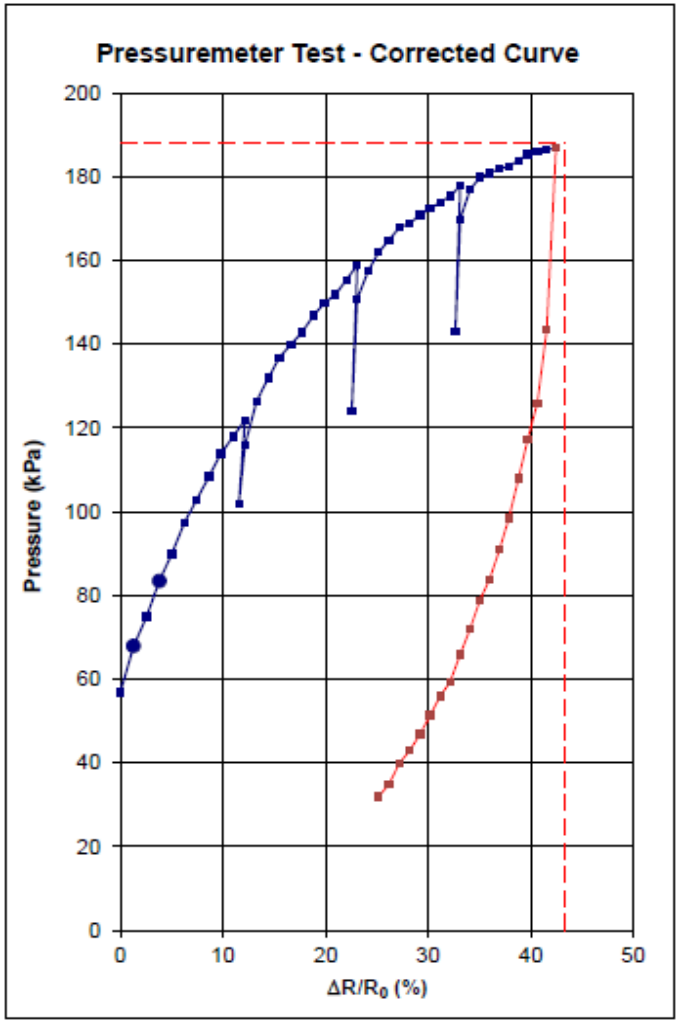


Electronic Vane Shear Test (eVST)



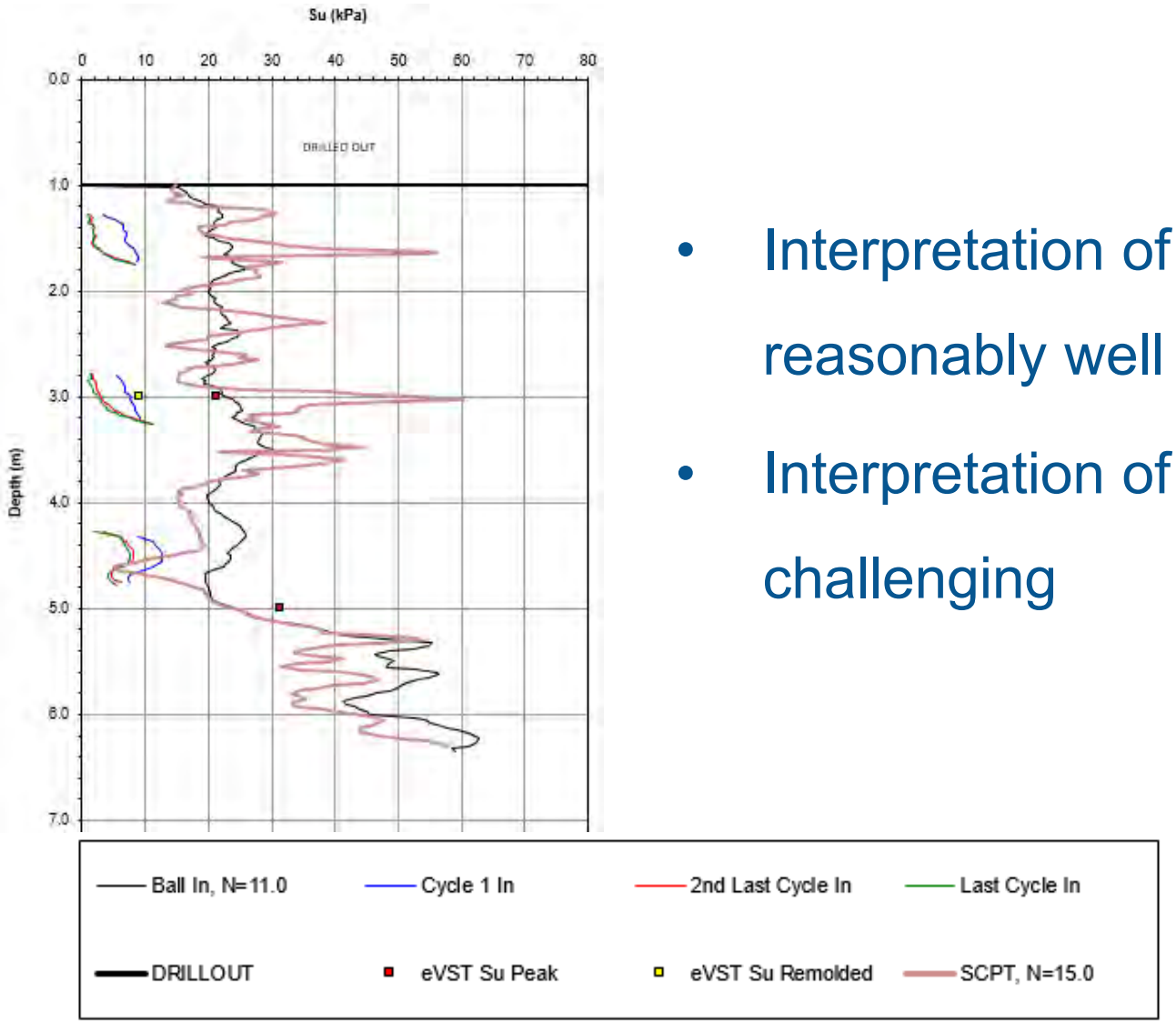
Pressuremeter Test (PMT)





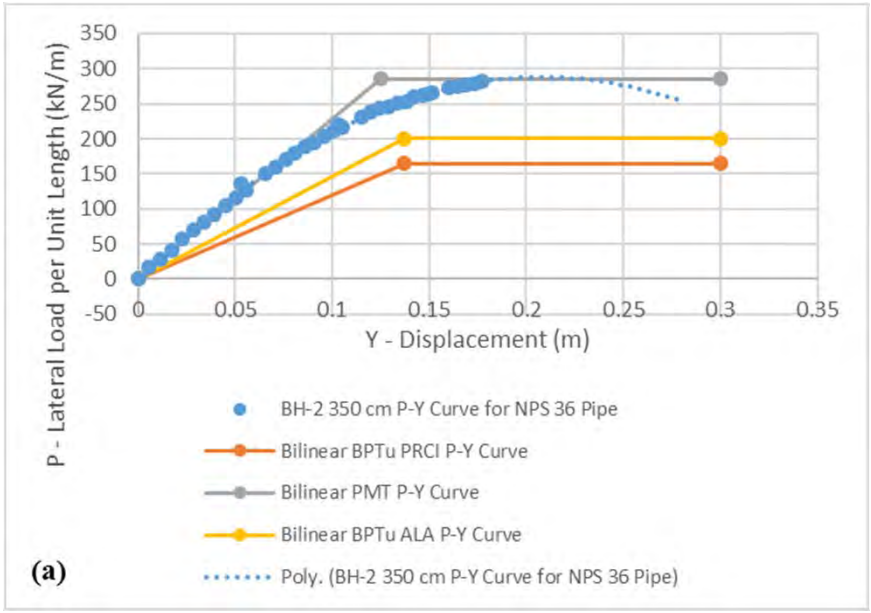
Auger Sampling

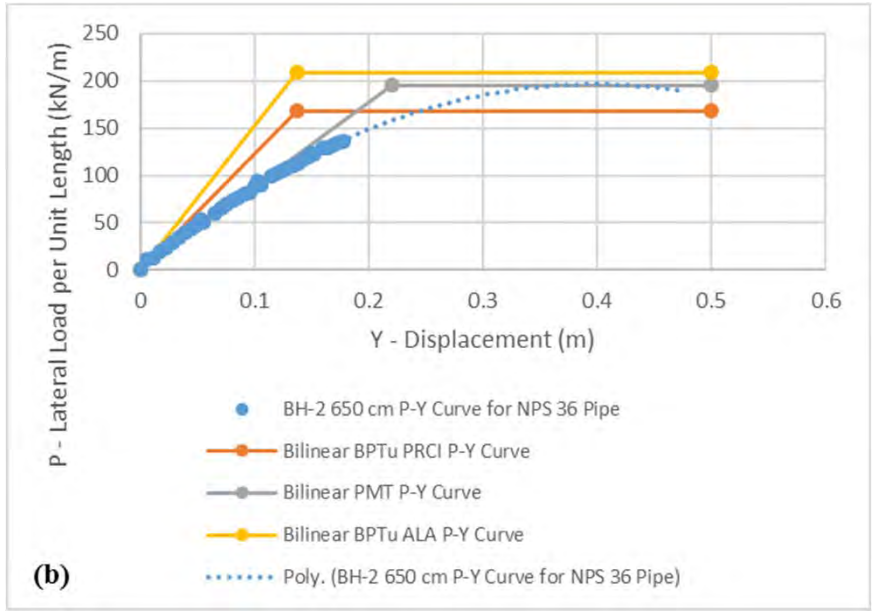
Comparison of Undrained Shear Strengths (Preliminary Findings)



- Interpretation of s_u values agreed reasonably well
- Interpretation of stiffness was challenging

Example P-Y Curves Comparisons from PMT vs Current Guidelines





Example Comparisons Only

P-Y Curves for NPS 36 pipe at depths of muskeg:
(a) 3.5 m (b) 6.5 m

Axial Soil Restraints in Muskeg

Small Axial Pipe Pullout Chamber (1.5 m x 0.8 m x 0.75 m**)**

Test materials:

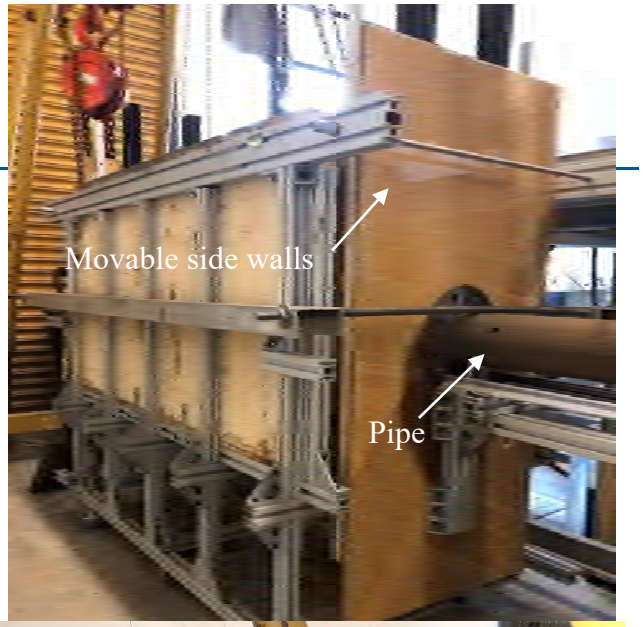
Pipe: Steel pipe 115-mm dia., 6-mm thickness, Length 2.4 m

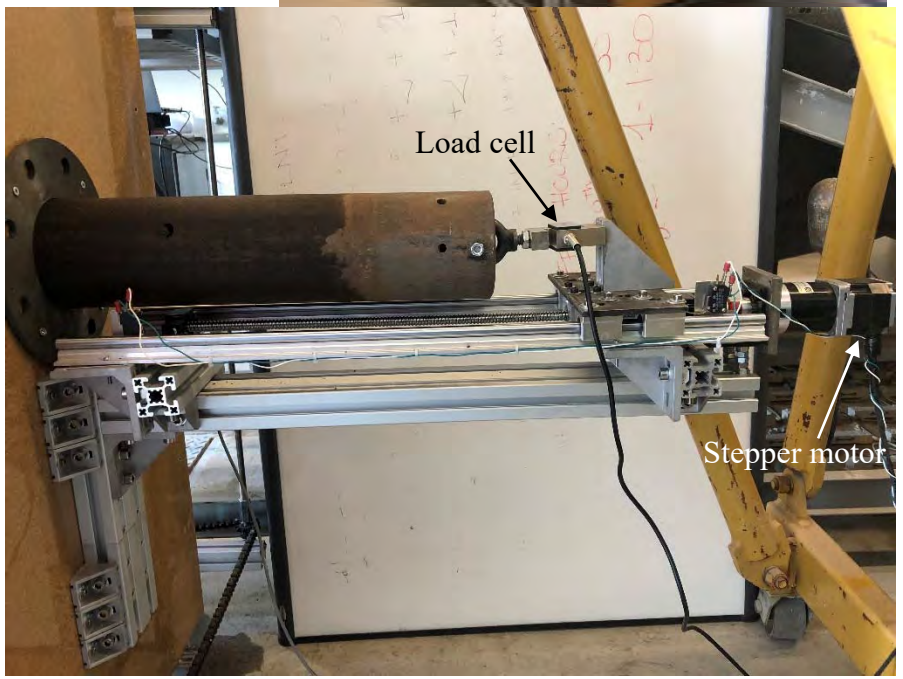
Soil: Muskeg from N. Alberta

Instrumentation:

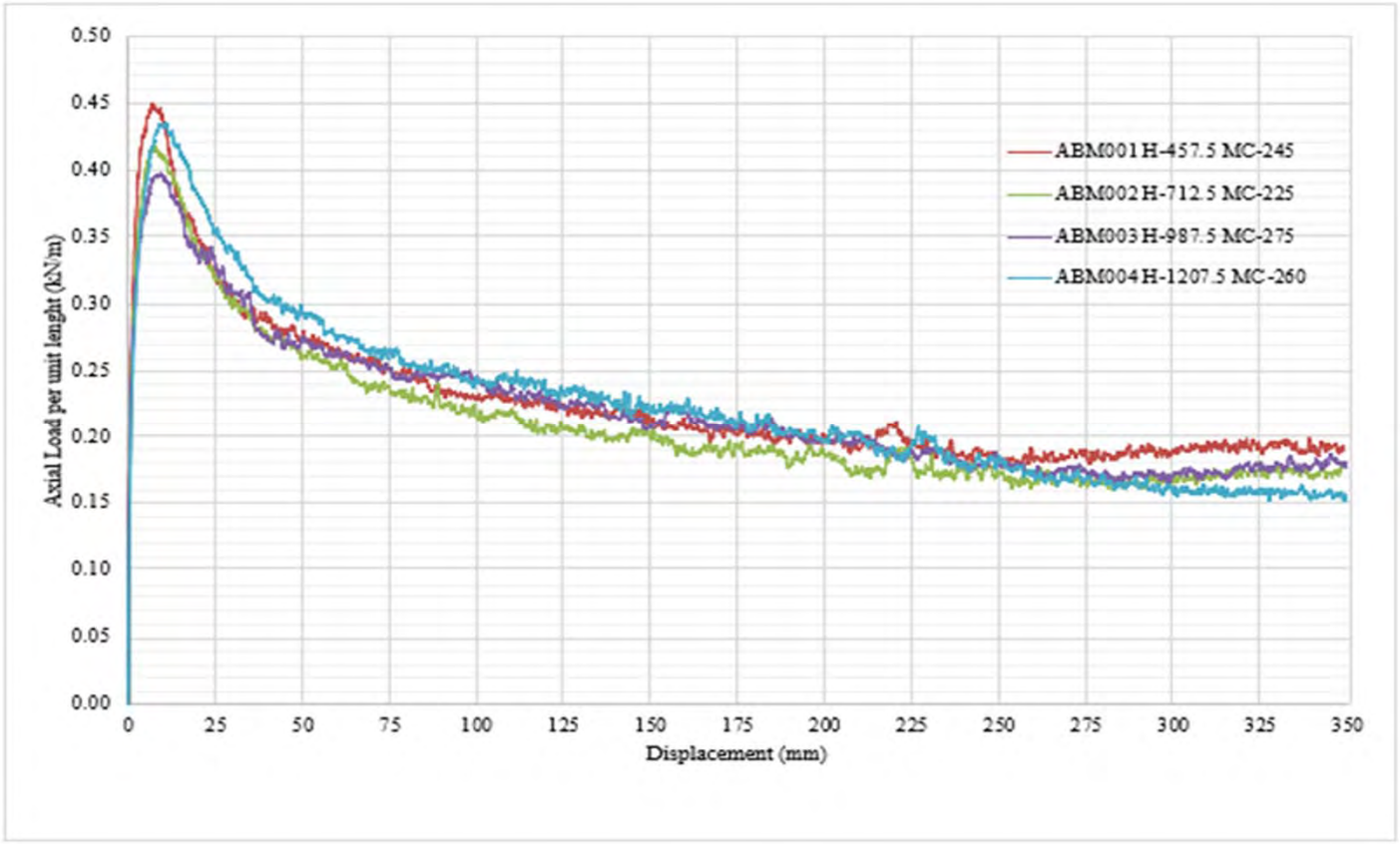
Load cell (5 kN) and String potentiometer (500 mm)

Actuator with stepper motor (0.1 mm/s -25 mm/s)





Axial Load Displacement Response (NPS 4 pipe in muskeg)



Preliminary Test Results - Summary

Test No	ABM001	ABM002	ABM003	ABM004
Test date	21/08/2018	22/08/2018	28/08/2018	30/08/2018
$H_{EQ,}$ Equivalent muskeg cover (mm)	400	655	930	1150
Avg. density of soil* (kN/m^3)	9.7	10.5	9.7	9.8
Avg. moisture content** (%)	245	225	275	260
H (mm)	457.5	712.5	987.5	1207.5
H/D	4.0	6.2	8.6	10.5
Peak axial soil restraint (kN/m)	0.44	0.42	0.39	0.43
Large displacement axial soil restraint***(kN/m)	0.19	0.17	0.17	0.16

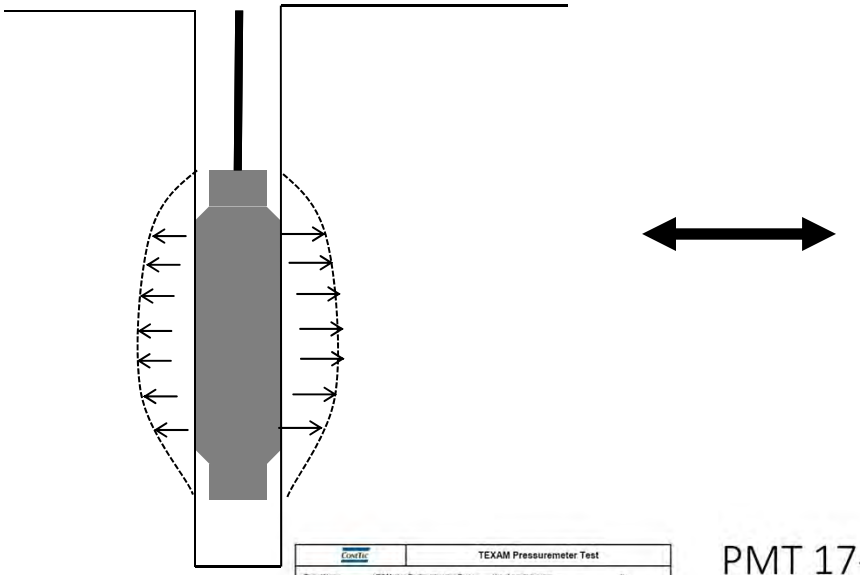
* Average bulk density based on 6 samples extracted within 100 mm proximity of the pipe from two different depth levels.

** Average moisture content calculated using 6 different samples extracted as described above.

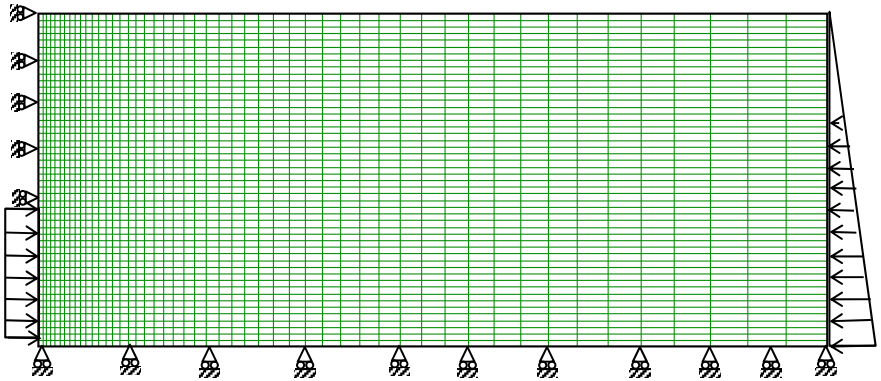
*** Measured at pipe displacement of 300 mm

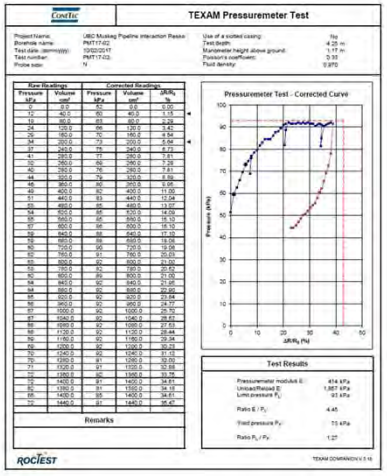
Numerical Modeling : P-Y Curve – Calibrations (For Illustration Purposes Only)

Field Pressuremeter Test



Numerical Analysis



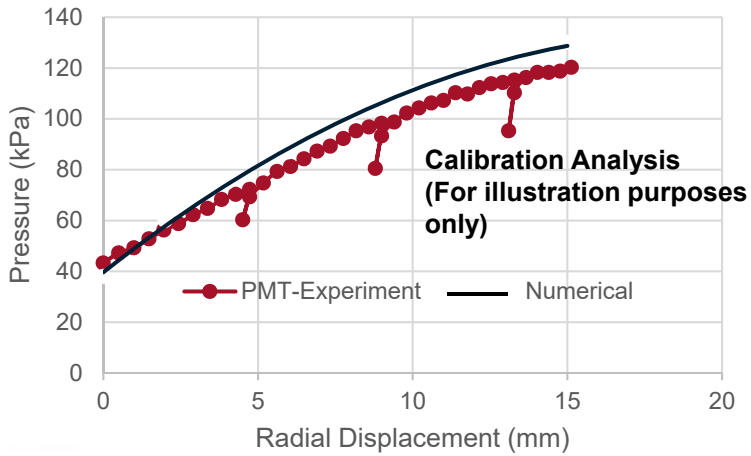


PMT 17-02
4.25 m

- σ_{v0} = 53.1 kPa
- u_0 = 41.7 kPa
- σ'_{v0} = 11.4 kPa
- $(s_u)_{fv,ball}$ = 18.7 kPa
- $(q_t-\sigma_{v0})$ = 241 kPa
- $(P_L-\sigma_{h0})/(q_t-\sigma_{v0})$ = 0.19
- $E_p/(q_t-\sigma_{v0})$ = 1.7

Soil type	PMT parameter	Correlation to CPT
Sand	P_l	$0.2q_c$
	E_p	$2.5\ q_c$
Clay	P_l	$0.11\ q_c$
	E_p	$1.15\ q_c$

Table from Hamidi et al. (CPT'10)
Based on a 1985 report from Briaud et al. (1985)



Preliminary Findings/Anticipated Outcomes Muskeg soils

Very Preliminary Findings:

a) Interpretation of s_u values agreed reasonably well
b) Interpretation of stiffness is challenging
c) P_u from the PMT results are higher than from guidelines
d) Limited observations on muskeg-pipe interface friction

Anticipated Findings:

a) CPT, BPT, FV, PMT – data correlations – interrelationships w.r.t. strength and stiffness (S_u, G) → fundamental parameters → P-Y curves from BPT
b) P-Y curves from PMT (need to further refine with numerical modeling)
c) P-Y curves from BPT through anticipated correlations → contribute to State-of-practice

PRELIMINARY

Acknowledgements

UBC Pipeline Integrity Institute (PII)

Research Team

Jennifer Liu (Graduate Student – UBC)
Thushara Jayasinghe (Graduate Student – UBC)
Sadana Dilrukshi (Research Associate, UBC)
Dharma Wijewickreme (Principal Investigator, UBC)

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- TransCanada
- Ledcor

Industry Collaborator - In-kind Support

- ConeTec Investigations

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PIPELINE INTEGRITY INSTITUTE
INSTITUT D'INTÉGRITÉ DE PIPELINE
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PIPELINE INTEGRITY INSTITUTE
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Pipeline Research Council International, Inc.

Continued Advances in the Use of Composite Materials: Reinforcement of Crack-Like Defects

Chris Alexander | ADV Integrity, Inc.
Richard Kania | TransCanada Pipelines

PRCI 2019 Research Exchange Meeting
Houston, Texas
March 6, 2019

Presentation Overview

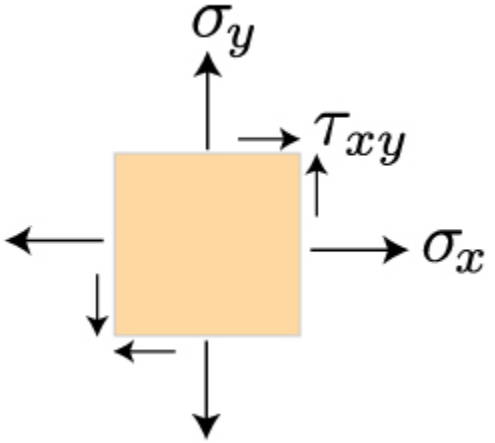
- Composite state-of-the-art
- Key variables for reinforcement
- Fundamental composite design
- Full-scale testing
- Knowledge gains & gaps
- Path forward concepts

Composite state-of-the-art

- Composite materials are an economic alternative to steel sleeves
- Able to accommodate unusual pipe geometries
- Offer the added safety in not having to weld
- Advanced resins and fiber architectures are changing the game
- The magnitude of verification work and testing is impressive, but we're not done…

Key Variables for Reinforcement

- **Defect characterization**
- **Understanding required level of reinforcement**
  - Acceptable pipe stress
  - Desired burst pressure
  - Design life (i.e., how many years?)
- **Composite stiffness**
  - Elastic modulus
  - Thickness
- **Understanding composite material degradation**



Fundamental Composite Design

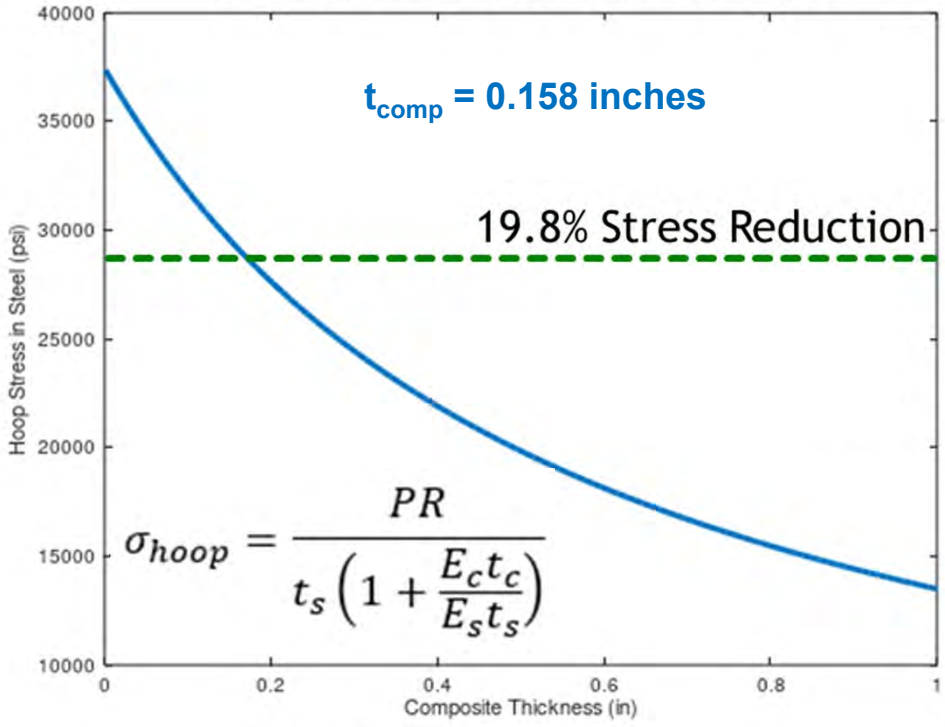
Given

Crack geometry and pipe material → Estimate unreinforced $P_{failure}$ → Composite thickness to achieve UTS → Calculate Pipe Stress Reduction → Estimate Cycles to Failure

Iterate if necessary

End Result

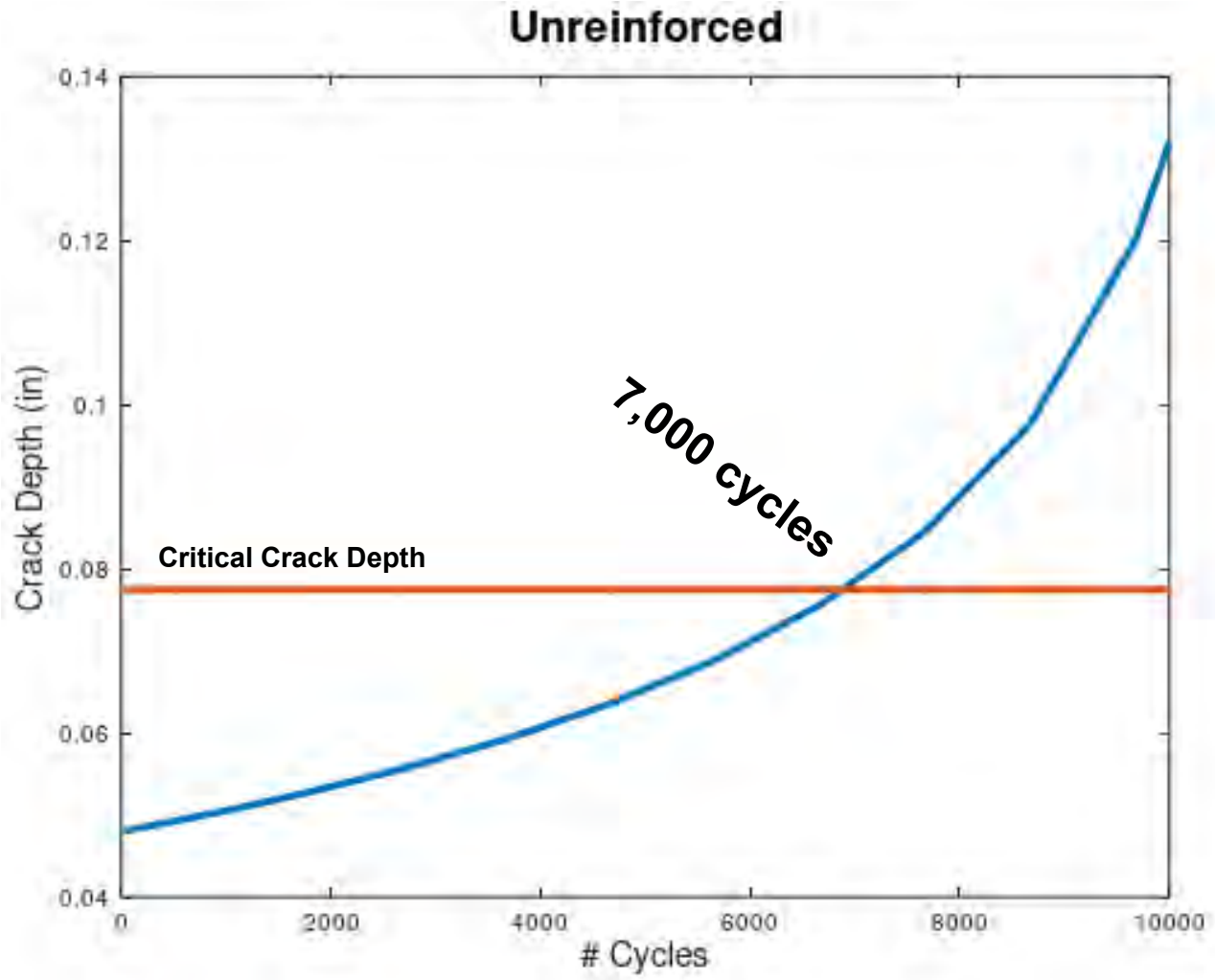
Reinforcement of 12.75-inch x 0.188, Grade X52 pipe



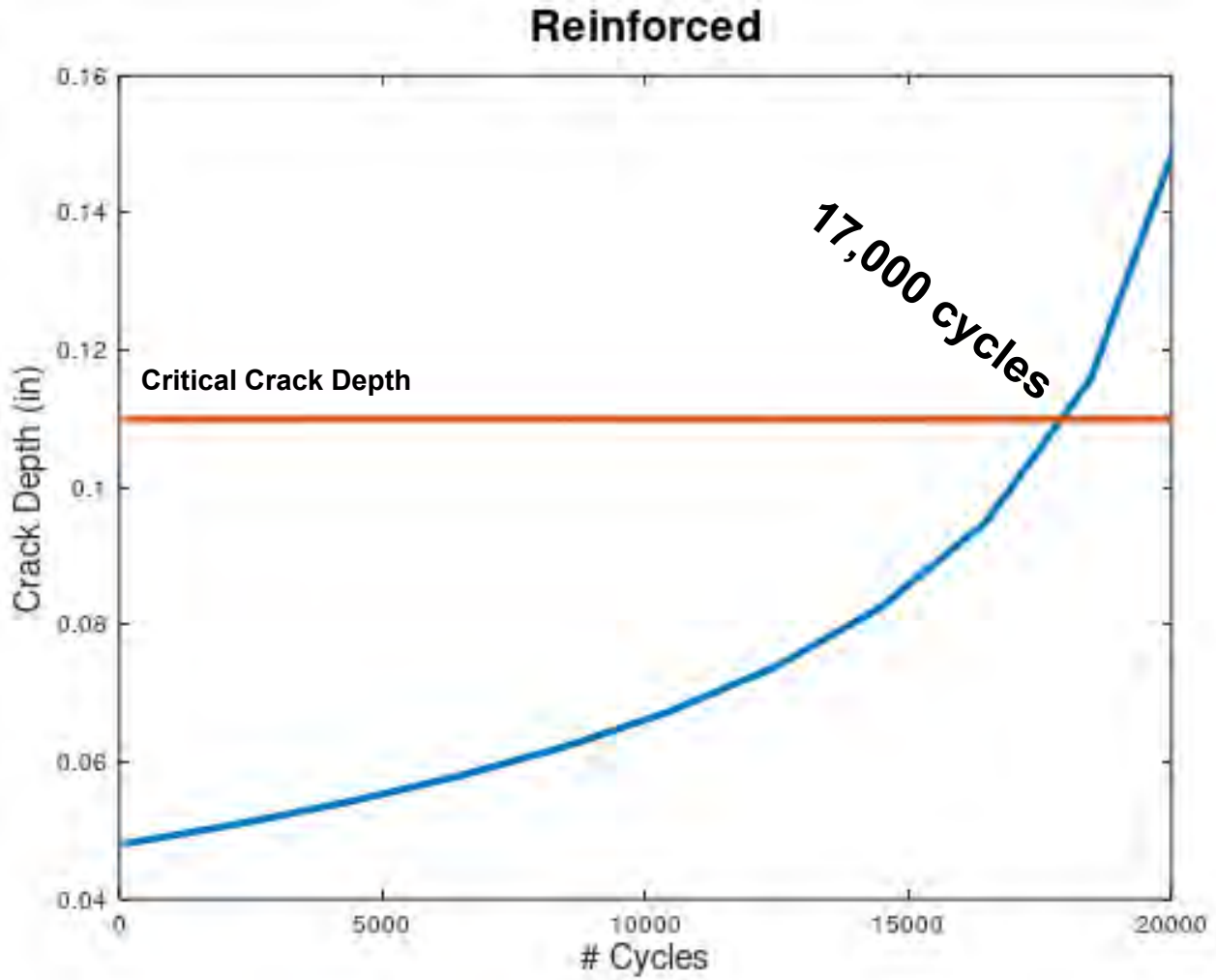
Example Problem

- 12.75-inch x 0.,188-inch, Grade X52
- 3-inch long x 40% deep cracks
- Estimate required composite geometry to achieve a 20-year design life

Fundamental Composite Design



Fundamental Composite Design



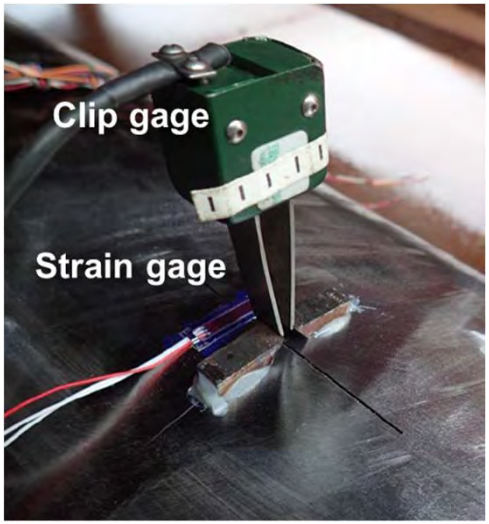
Full-scale Testing

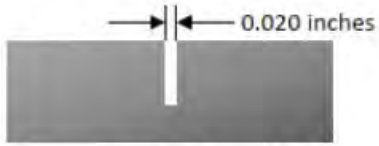
- **Testing conducted involving four (4) carbon-epoxy systems**
- **Program involved cracks having 15% and 50% of pipe's nominal wall thickness**
- **Results presented for Citadel's system***
  - E = 9.7 Msi | UTS = 110 ksi
  - Composite thickness values:
    - *0.14 inches for 15% deep cracks*
    - *0.20 inches for 50% deep cracks*
- **Cycled to failure (ΔP = 10% to 72% SMYS)**

* All test results and associated images in this presentation provided by Citadel.

Test Sample Configuration

12.75-inch x 0.188-inch, Grade X42 pipe

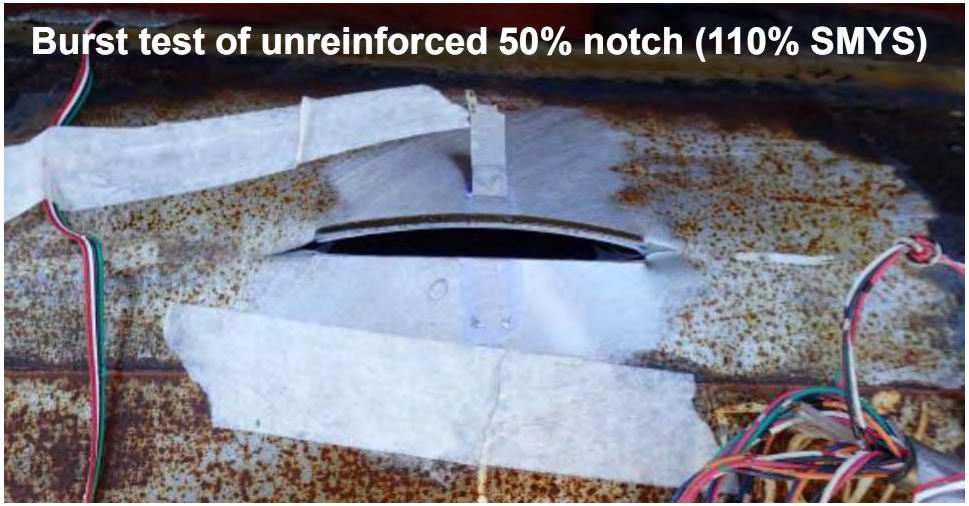




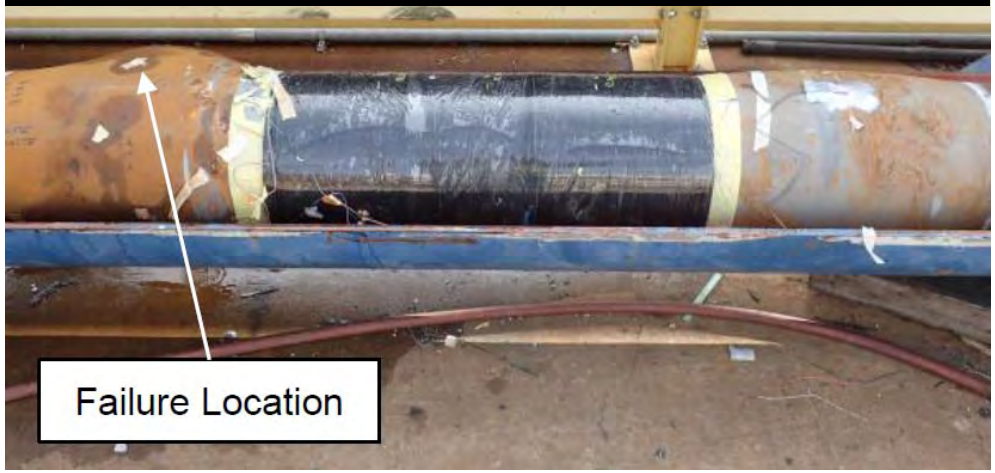
Cross-sectional profile

Axial view of pipe cross section

Burst Test Results



Burst test of unreinforced 50% notch (172% SMYS)
At 72% SMYS, 1,393 με at notch

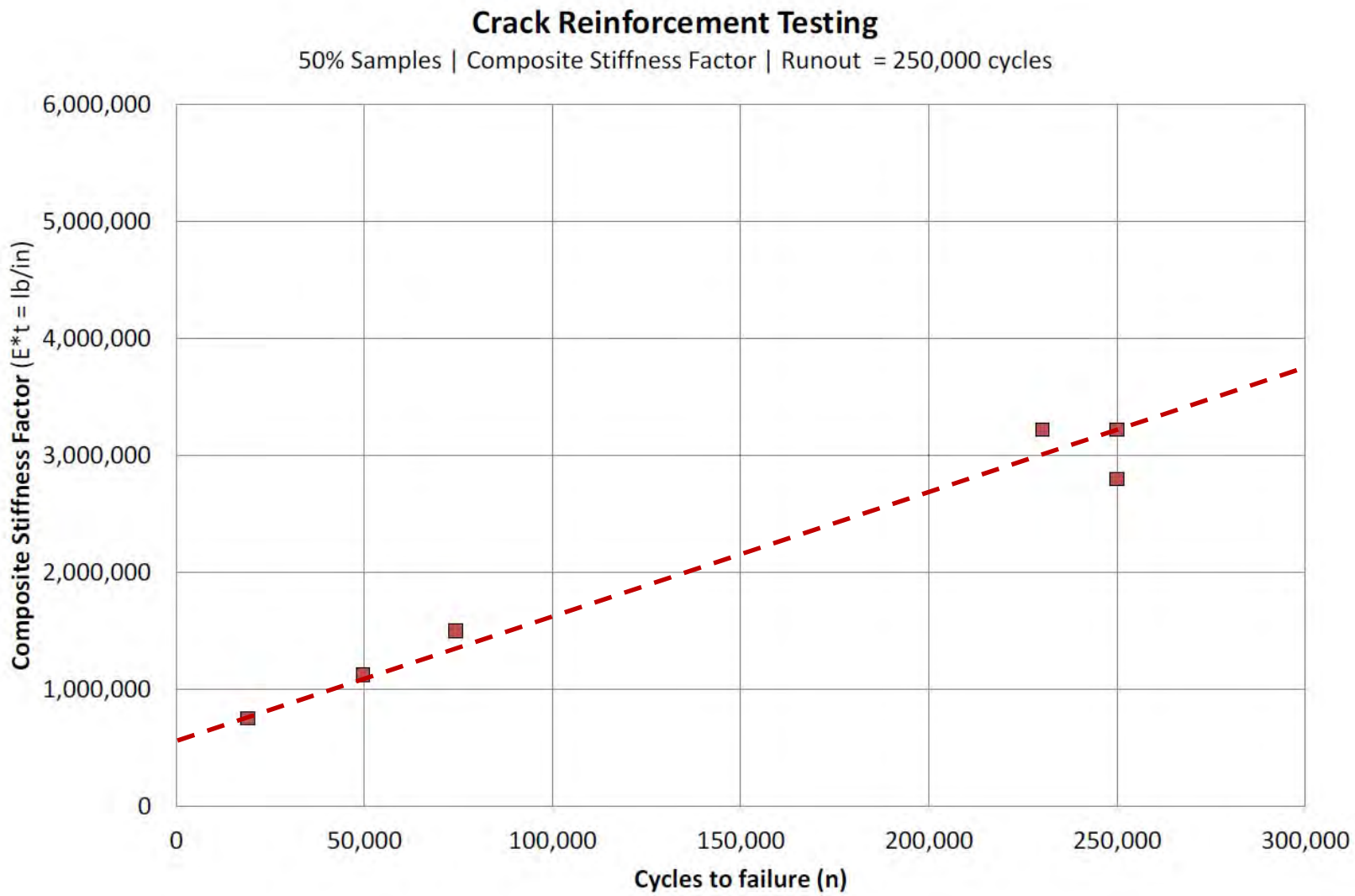


Pressure Cycle Test Results

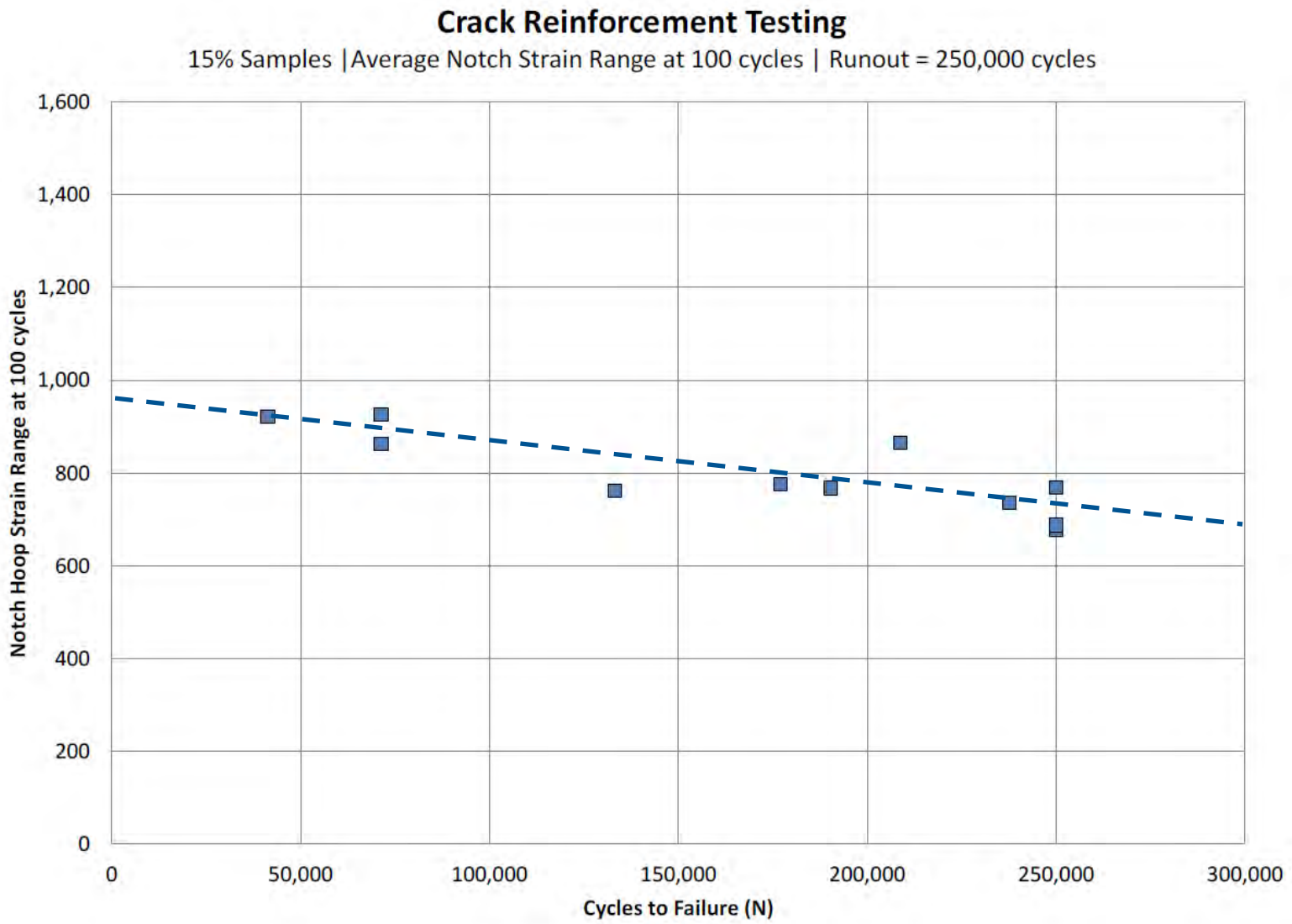
Sample Type	Sample Number	Composite Stiffness (k = E x t; lb / in)	Cycles to Failure	Average Cycles to Failure
Unreinforced	**UR-1**	N/A	1,728	1,048
Unreinforced	**UR-2**	N/A	532	
Unreinforced	**UR-3**	N/A	883	
Reinforced	**CIT-R-4**	748,440	**19,040**	**47,657**
Reinforced	**CIT-R-5**	**1,122,660**	**49,578**	
Reinforced	**CIT-R-6**	**1,496,880**	**74,353**	

Notice correlation between composite stiffness and fatigue life.

Correlations: Stiffness vs. Life



Correlation: Strain Reduction



Knowledge Gains & Gaps

- **Gains**
  - Carbon-epoxies can reinforce crack-like defects
  - A preliminary design approach has been developed
  - As a minimum, these are acceptable temporary repairs
- **Gaps**
  - Incomplete verification of design method
  - Need additional work on reinforcement of low toughness materials Low Frequency ERW seams
  - The best approach is to verify composite repairs via testing using “vintage” pipe material before actual use

Path Forward Concepts

- **The reinforcement of cracks using composites is warranted, at least for temporary repairs**
- **Additional work is required, especially with regards to a design method**
- **Proposed path forward**
  - Develop a *White Paper* to capture existing knowledge
  - Operators can (and are) test select pipe materials
  - A joint industry effort is warranted, involving operators and select composite repair companies

Pipeline Research Council International, Inc.

Local Hard Zone Formation in Sour Service Pipeline Steels

Doug Fairchild
ExxonMobil Upstream Engineering

PRCI 2019 Research Exchange Meeting
Houston, Texas
March 5-6, 2019

Contents

- **Failure of Kashagan Pipelines**
- **Background**
  - Sour Service Engineering
  - Local Hard Zones (LHZs)
  - Thermomechanical Control Processing (TMCP)
- **LHZ Formation Mechanism Hypothesis**
  - Water, oxide, and heat transfer
- **New approach to TMCP plate qualification**
- **Summary**

Kashagan Pipelines Failure

- **What:** failure of two 28” x 95km carbon steel pipelines
- **When:** Sept. 2013
- **Where:** North Caspian, Kazakhstan
- **Cause:** “Materials experts indicated the cause of the problem was sulfide stress cracking due to unexpected formation of hard spots in the steel” [1]
- **Remediation:** Pipelines replaced with CRA clad pipe [2, 3]
- **Cost:** ~$3.6 billion [2, 3]

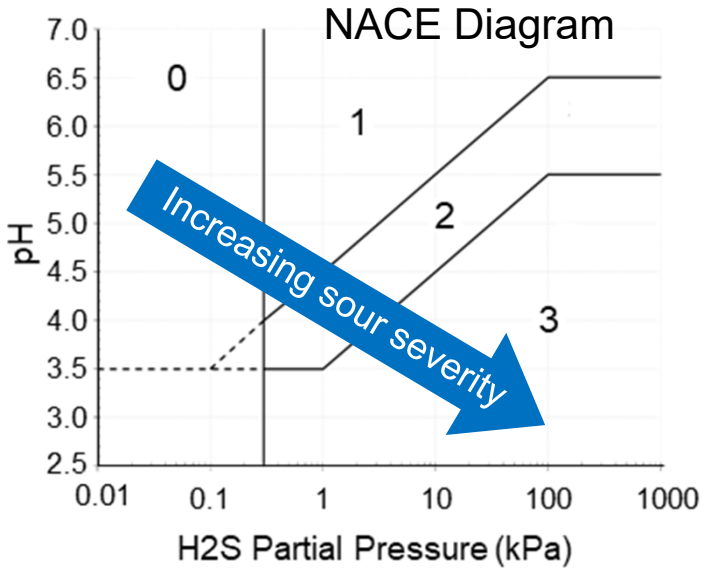
[1] https://www.offshoreenergytoday.com/kashagan-not-getting-back-on-line-in-2014/

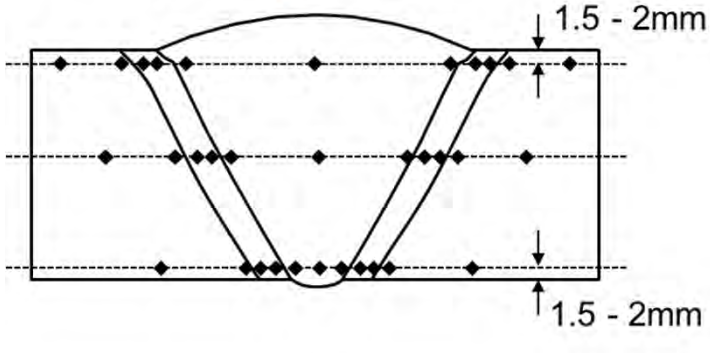
[2] D. Baxter, E. Ostby, S. Chong, A. Venas, “Use of C-Mn Linepipe for High H2S Service”, 37th Int’l Conf. OMAE, June 17-22, 2018, Madrid, Spain.

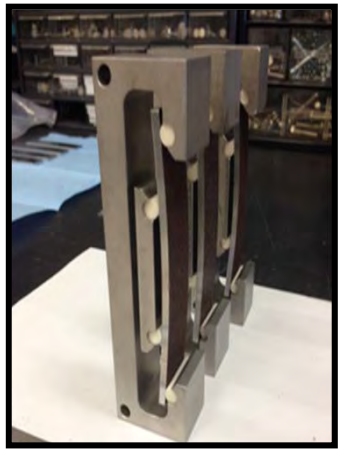
[3] https://www.reuters.com/article/oil-kashagan-idUSL6N0S52P420141010

Background – Sour Service Engineering

- **The Risk: hydrogen ingress then sulfide stress cracking (SSC) and/or hydrogen induced cracking (HIC)**
- **Common Engineering Approach:**
  - ANSI/NACE MR0175/ISO 15156-2015
  - X60-X65 sour grade linepipe
    - *Thermomechanical control processing (TMCP)*
  - Steel chemistry control (S, P, C, Mn)
  - Hardness control (248 HV 10kg)
  - SSC and HIC testing
    - *4 pt. bend tests exposed to sour fluid (30 days)*







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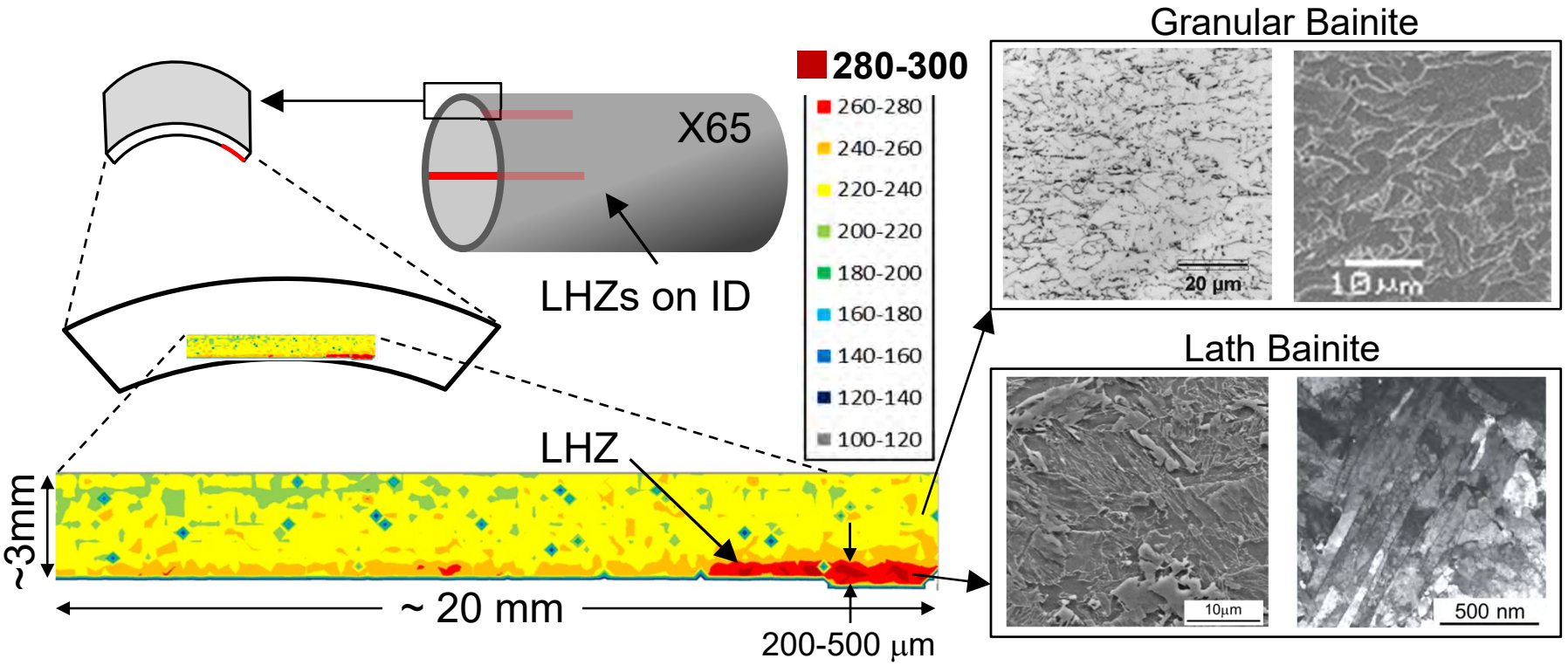
Local Hard Zones (LHZs) in TMCP Pipe

- **LHZ hardness: up to ~300 HV0.1 (i.e., 100g)**
- **Target microstructure & cooling rates: Granular Bainite, 10 - 40 °C/s**
- **LHZ geometry: 200 - 500 μm thick. Often streak-like in pipe axial direction.**
- **LHZ microstructure & cooling rates: Lath Bainite, ≥ 200 °C/s**



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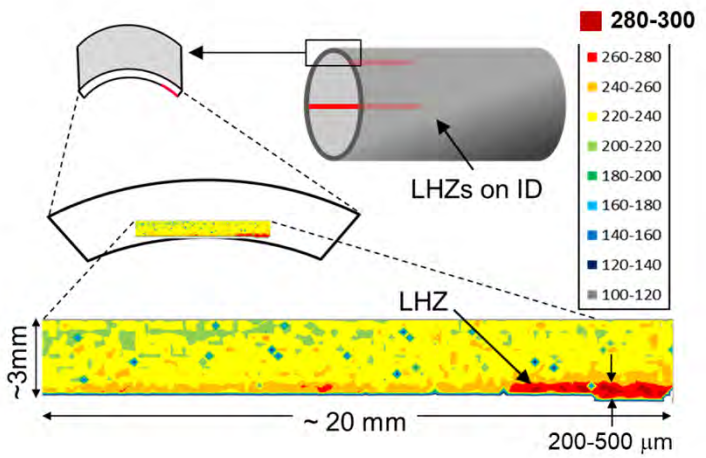
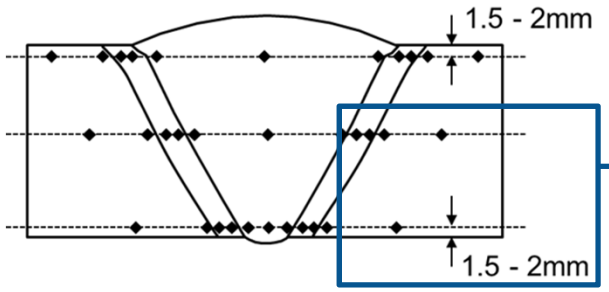
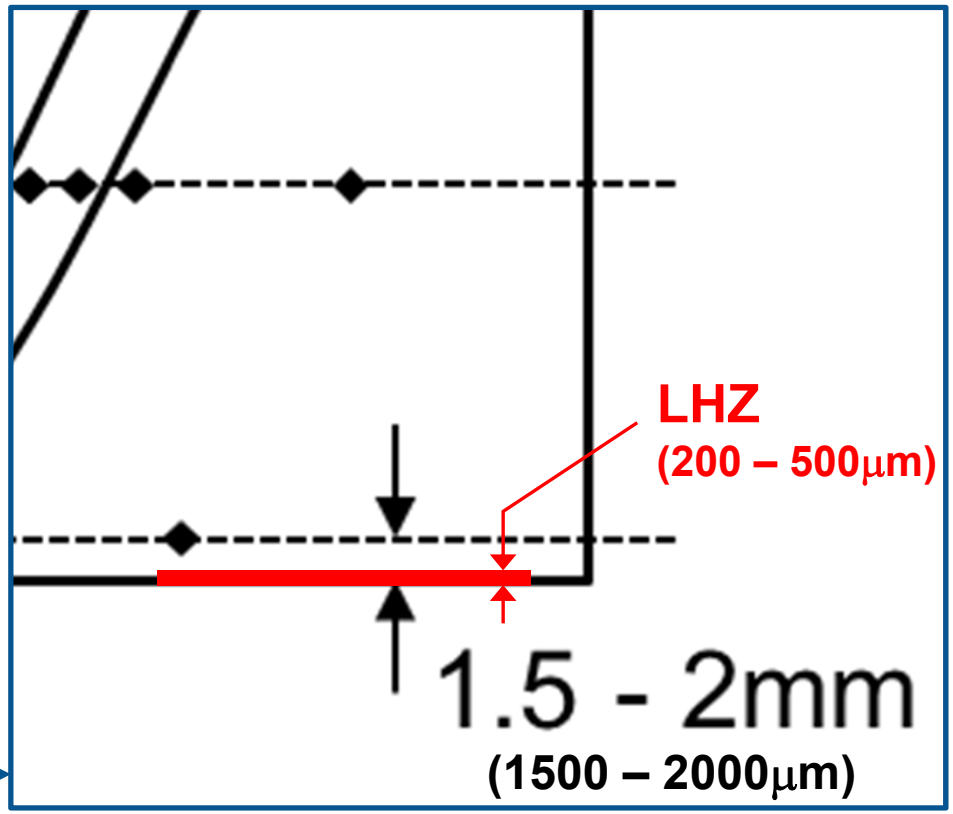
Local Hard Zones (LHZs) in TMCP Pipe







- 10kg indents too big for thin surface layer
- 100-500g load indents needed

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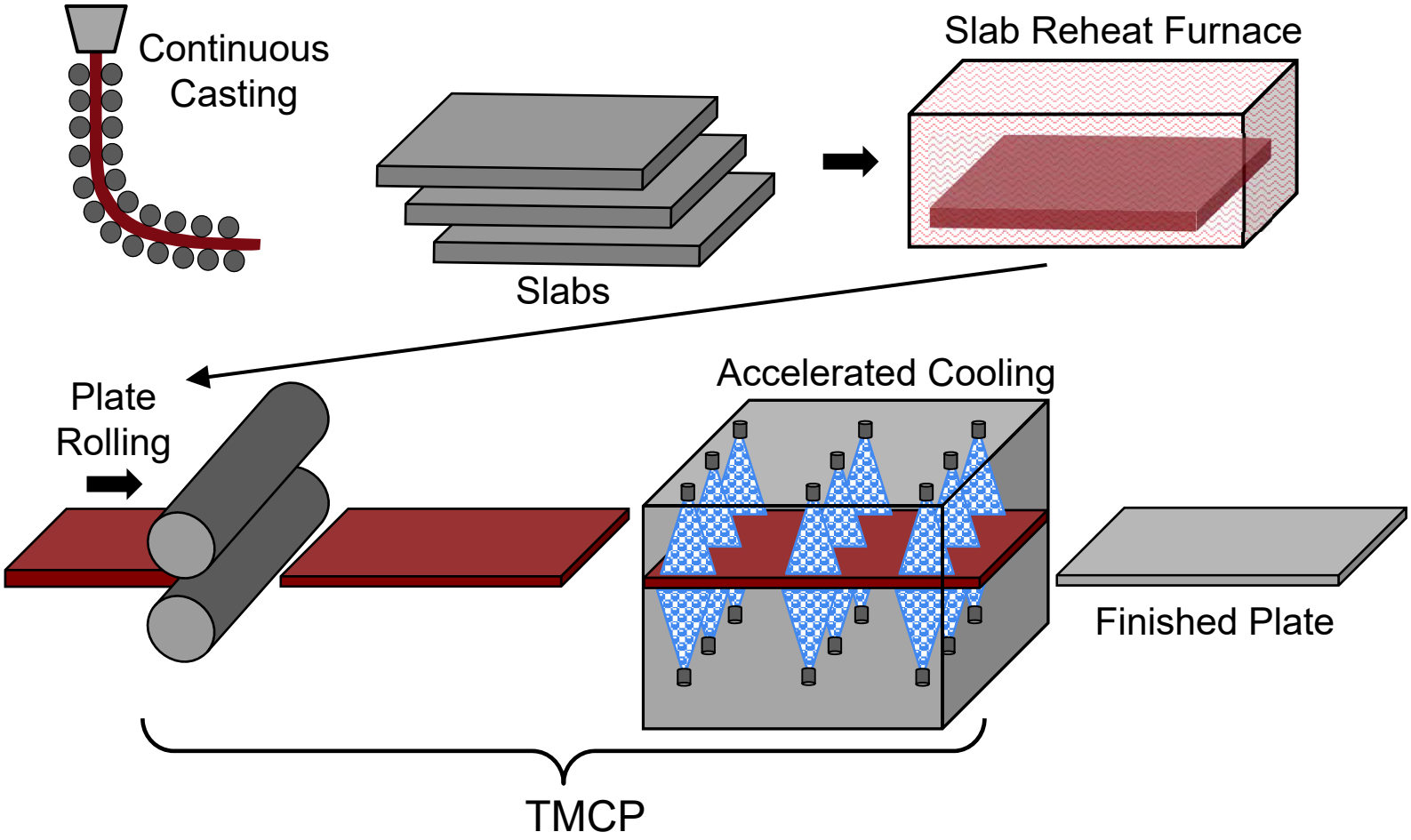
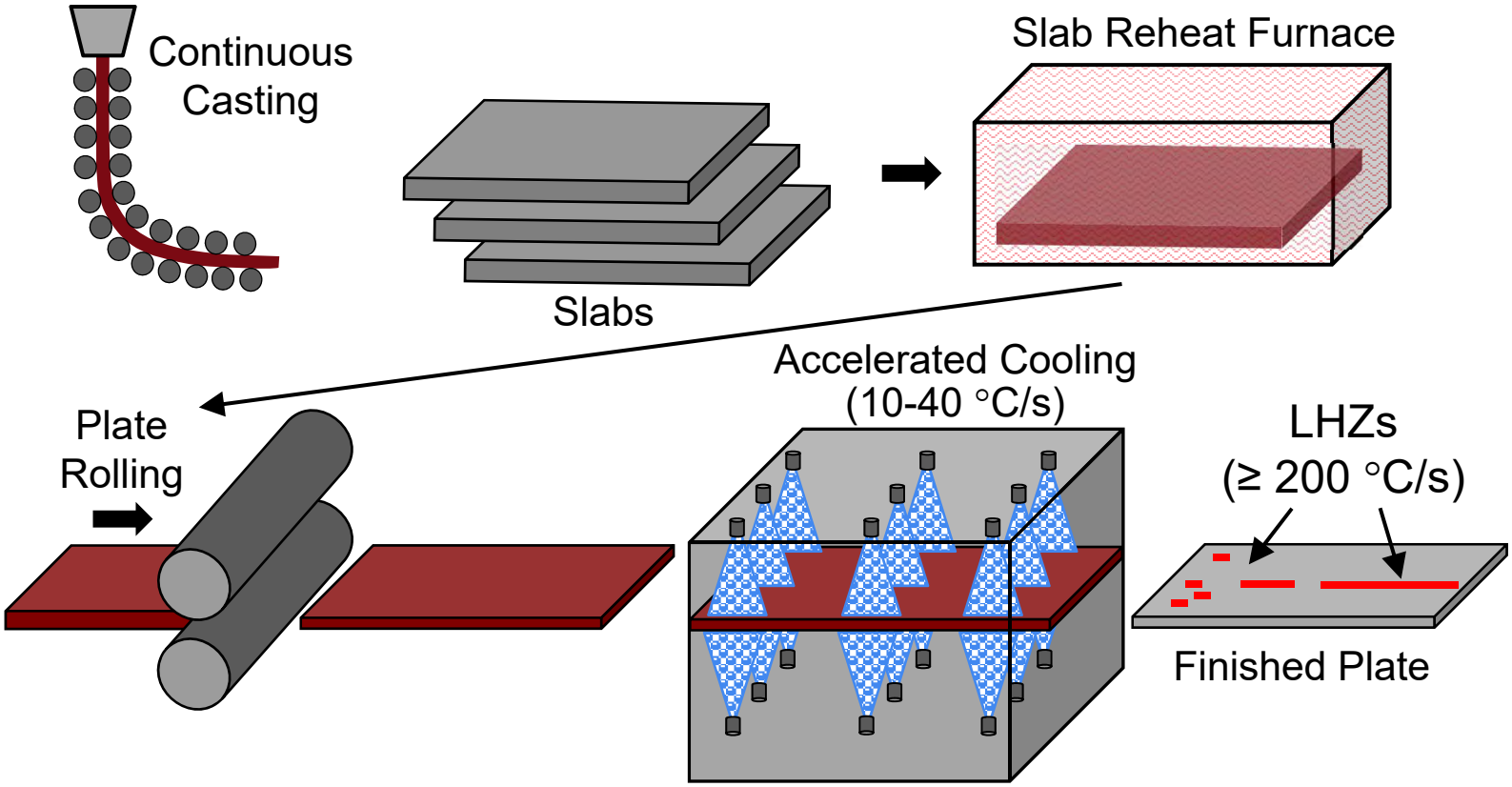
Thermomechanical Control Processing (TMCP)



- **TMCP = controlled rolling, then accelerated cooling (ACC)**

Thermomechanical Control Processing (TMCP)



Key Questions:

- **Typical ACC: 10-40 °C/s. How can ≥ 200 °C/s occur?**
- **How can very different cooling rates occur within close proximity?**

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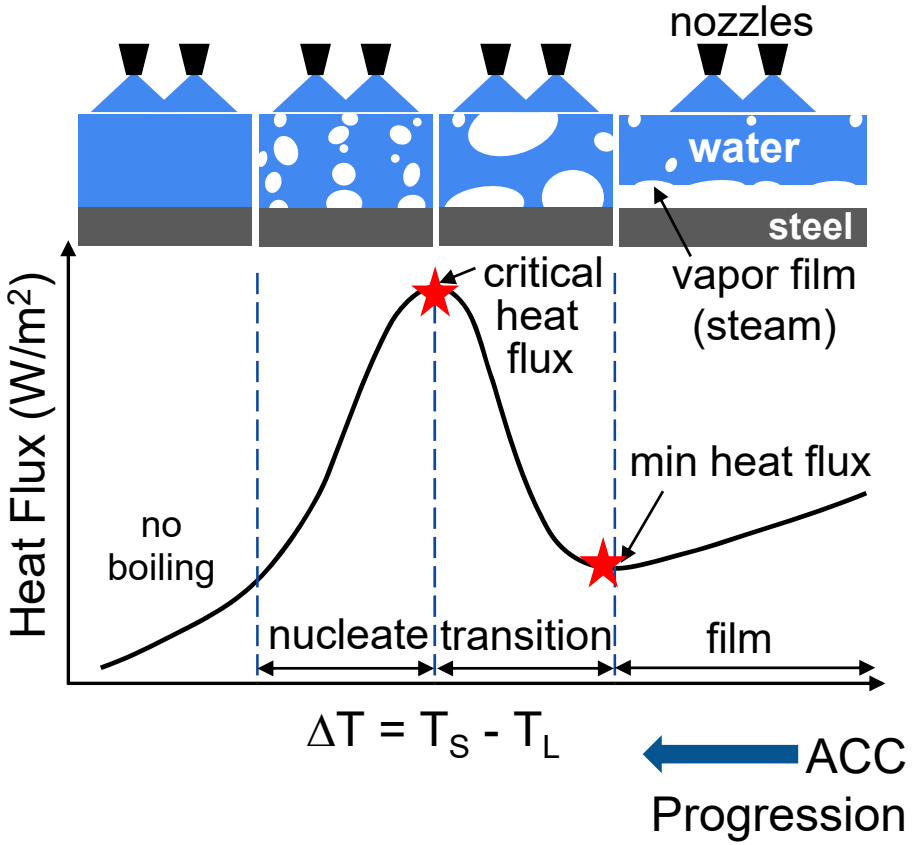
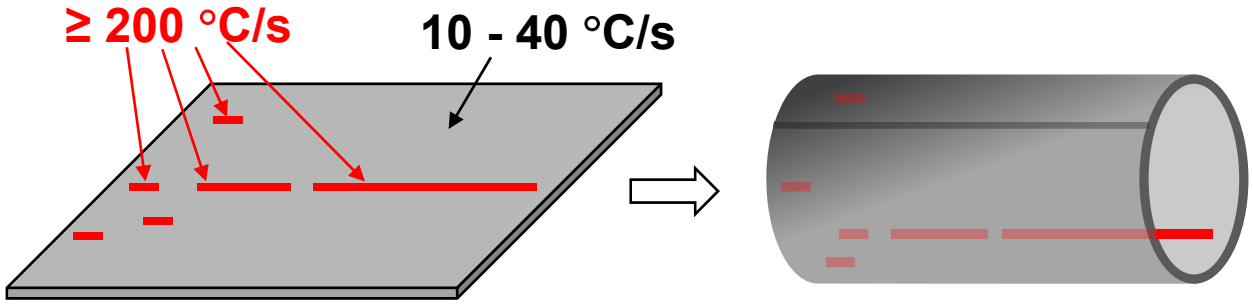
How can ≥ 200 °C/s occur?

- **Boiling has 3 modes**
  - Film, transition, nucleate boiling
- **ACC primarily utilizes film boiling**
- **If peak transition/nucleate boiling occurs somehow, then heat flux increases dramatically (3X – 6X)**
- **Boiling mechanics provides a means for large heat flux differences ★**
- **How can min & max heat flux regions exist in close proximity to each other?**





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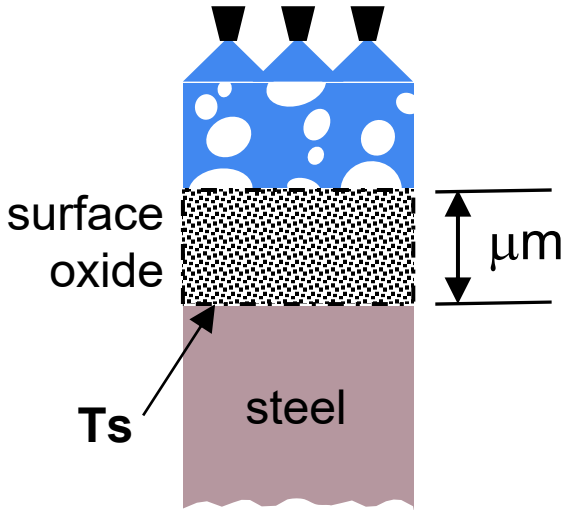
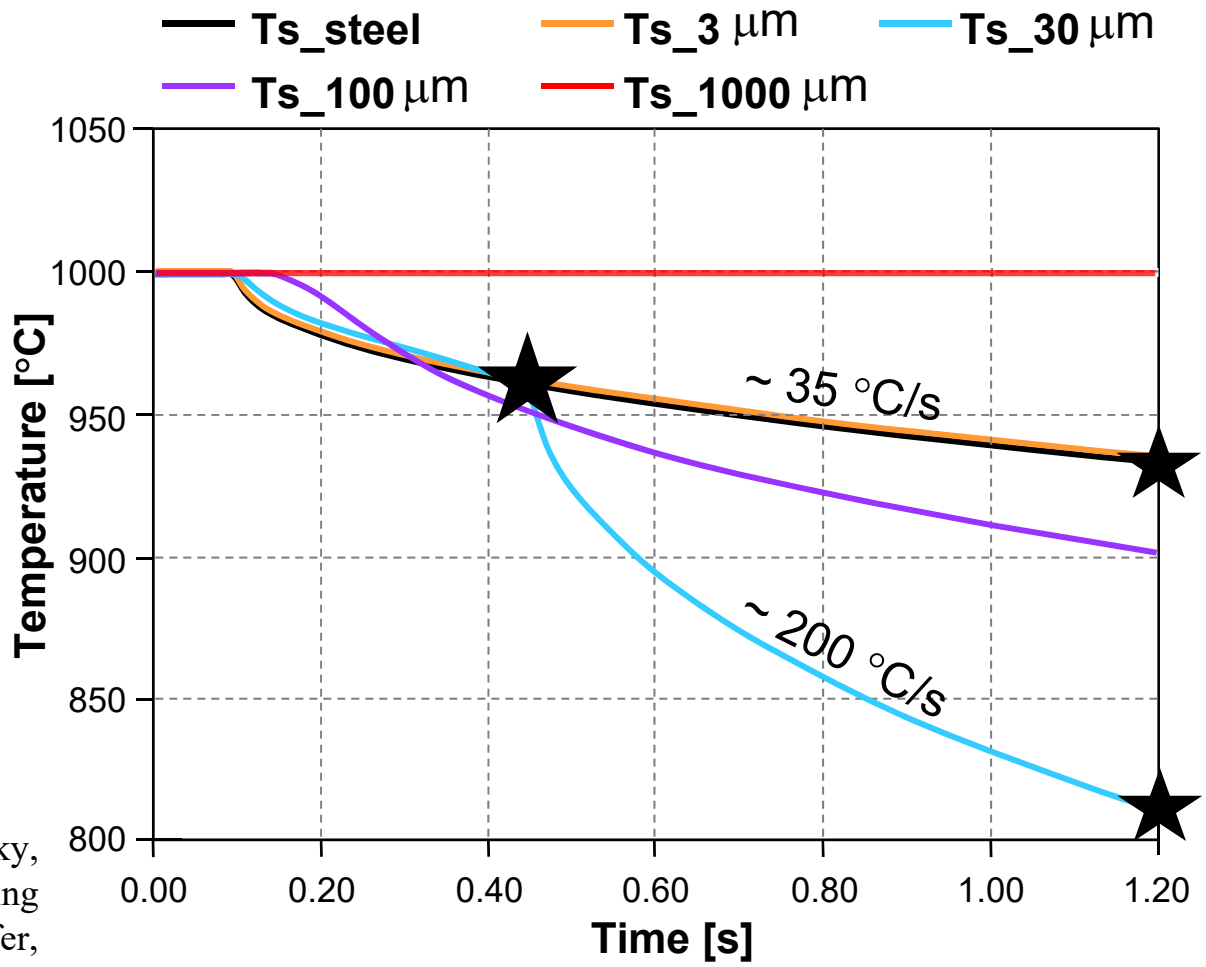
How can large cooling differences co-exist?

- Water spray cooling study; Horsky, et al *
- Focus: the effect of oxide thickness on cooling





- Minor oxide thickness variations can cause large cooling variations

* J. Horsky, J. Hrabovsky, M. Raudensky, "Impact of the Oxide Scale on Spray Cooling Intensity", 10th. Int'l Conf. Heat Transfer, Fluid Mech. & Thermo., 2014, Orlando.

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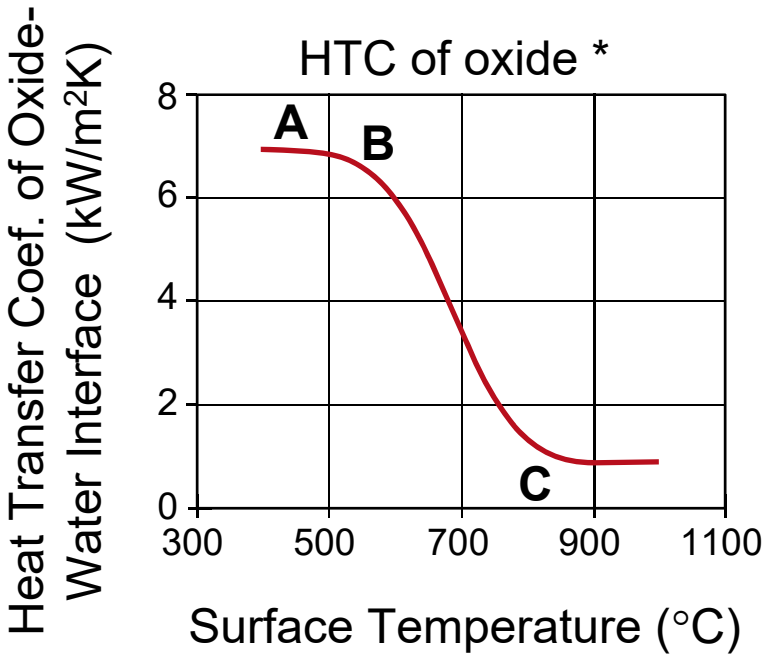
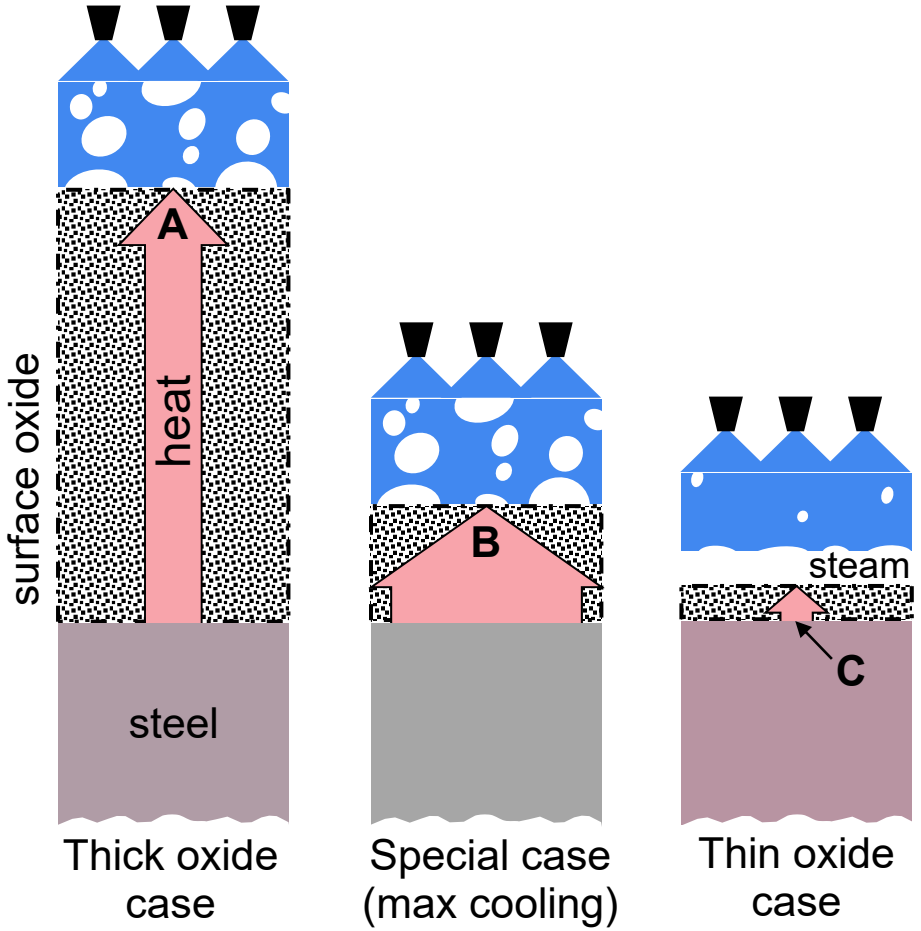
Oxide Thickness and Maximum Cooling

- **Due to temp dependent HTC, a special case of oxide thickness exists where cooling rate is maximum**





* J. Horsky, J. Hrabovsky, M. Raudensky, "Impact of the Oxide Scale on Spray Cooling Intensity", 10th. Int'l Conf. Heat Transfer, Fluid Mech. & Thermo., Orlando.

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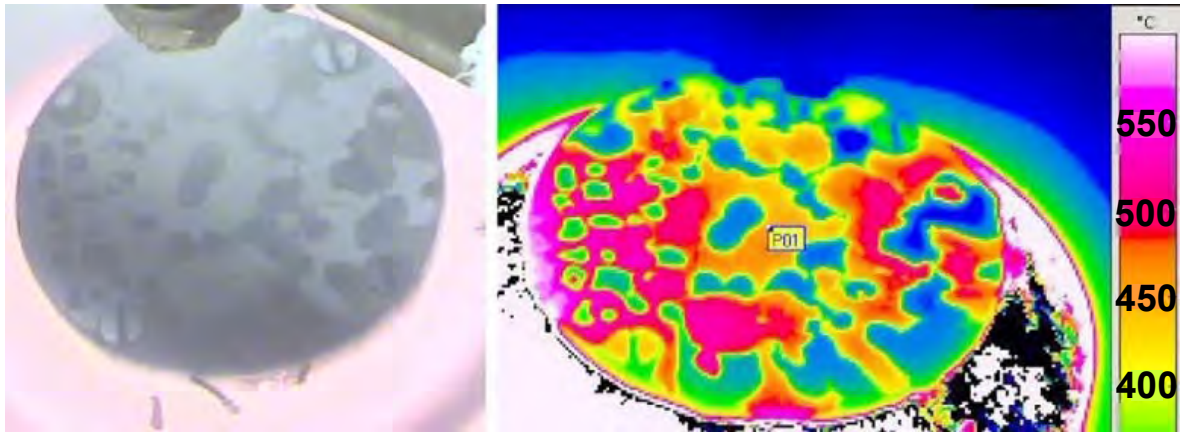
Oxide thickness and temperature correlation

- **Another water spray cooling study; Wendelstorf ***
- **Focus: effect of oxides on cooling (70mm dia. steel discs)**
- **Results:**
  - Water spray caused oxide fracture/spalling
  - Created variation in oxide thickness
  - Temperature variation recorded with thermal camera
  - An exact correlation between oxide and temperature pattern exists

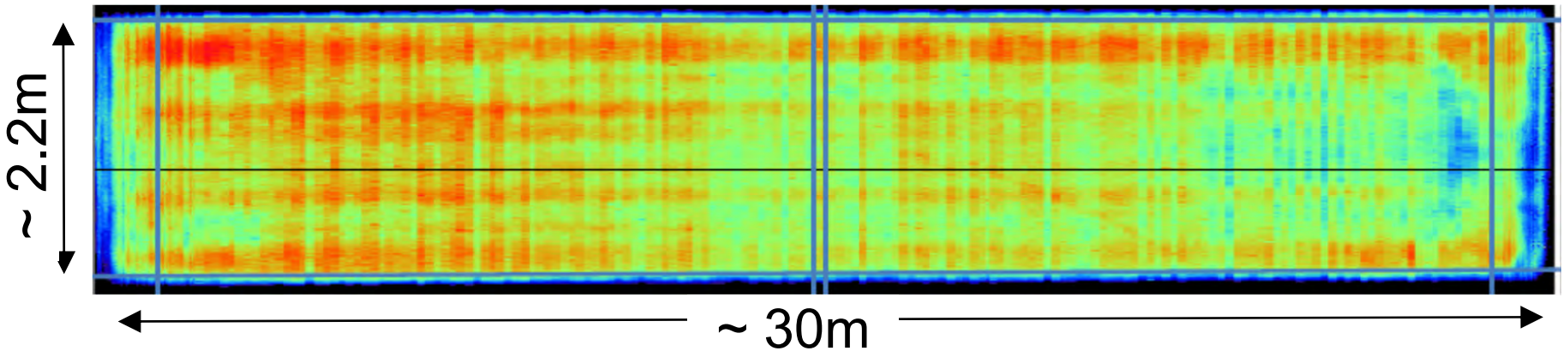


* R. Wendelstorf, K.H. Spitzer, and J. Wendelstorf, (2008) “Effect of Oxide Layers on Spray Water Cooling Heat Transfer at High Surface Temperatures”, Int. Jour. Heat Mass Transf., vol. 51, pp. 4892–4901.

Pipe Qualification Program Underway

- **LHZ is a "needle in haystack" problem**
  - Random testing ineffective
  - Method needed to manage statistical challenges
- **TMCP plate thermal maps being used to locate material to be tested**
  - Used to locate coldest areas, this material expected to contain LHZs should they exist
- **Thermal maps also to be used for production control**
- **Additional details: 2019 OMAE, Glasgow**

TMCP plate thermal map



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Summary

- **LHZs are a new challenge for TMCP steel use in sour service**
- **LHZ Hypothesis. LHZs are:**
  - Rare and random
  - Thin
  - Sometimes streak-like in surface geometry
  - Created during TMCP accelerated cooling
  - Caused by a special combination of oxide thickness and temperature
- **ExxonMobil currently qualifying TMCP plate/pipe**
  - Using thermal cameras (and maps) to select test material
  - Using thermal cameras for production control

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Computationally Efficient Irregular Wave Fatigue Simulations of Flexible Riser High Fidelity Finite Element Models

Arya Majed, Nathan Cooke, Kirsten Oliver, Mac McKee
INTECSEA

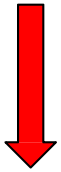
PRCI 2019 Research Exchange Meeting
Houston, Texas
March 6, 2019

Outline

- Introduction
- Challenge
- Reduced Order Models and NDS
- NDS advantages
- Verification & Validation
- Overviews
  - NDS Process
  - FlexIQ
  - Case History: Shell Bonga Flexible Riser Life Extension
- Concluding Remarks

Introduction

- **Variety of methods available to model kinematics and compute tensile armor stress**
  - High-fidelity detailed FE models
  - Simplified FE models
  - Analytical models

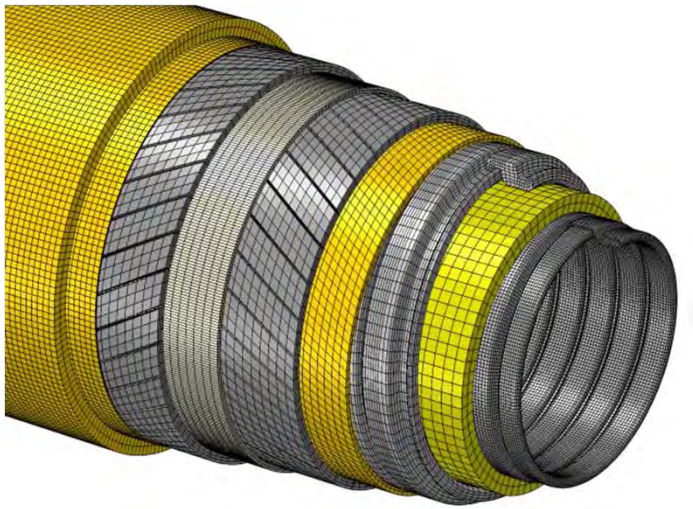


Increasing assumptions / reduced accuracy

- **Meaningful fatigue life predictions rely on accurately capturing irregular wave (stochastic) stresses utilizing high fidelity FE models**

The Computational Challenge

- Computing with these high fidelity FEMs in commercial FE solvers is the major hurdle:
  - Technip/IFP (2012): Abaqus nonlinear quasi-static analysis of a 7 meter flexible for one bending cycle took **48 hours on 36 CPUs in parallel**
  - ExxonMobil/Seaflex (2007): “direct use of local analysis tools [based on the finite element method] for long time-domain simulations is very computationally intensive and impractical.”



Model efficiently generated via Python scripts

The challenge is COMPUTATION, not modeling.

Reduced Order Models and NDS

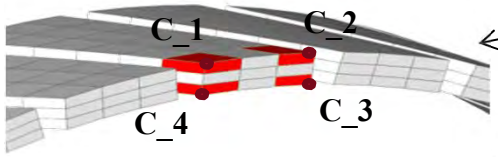
- **Reduced Order Models**
  - Numerical methods for efficiently solving high fidelity FEM
- **Nonlinear Dynamic Substructuring (NDS)**
  - Systems of reduced order models and associated algorithms to enforce the nonlinear interactions

NDS – Solver Advantages

- Orders of magnitude reduction in size of the simulation, while retaining accuracy
- Efficient solver algorithms update only nonlinear substructures undergoing a “state” change
- Handling of “specialized” nonlinearities at local nonlinear substructure level without impacting overall model solution procedures
- Fully IMPLICIT solution

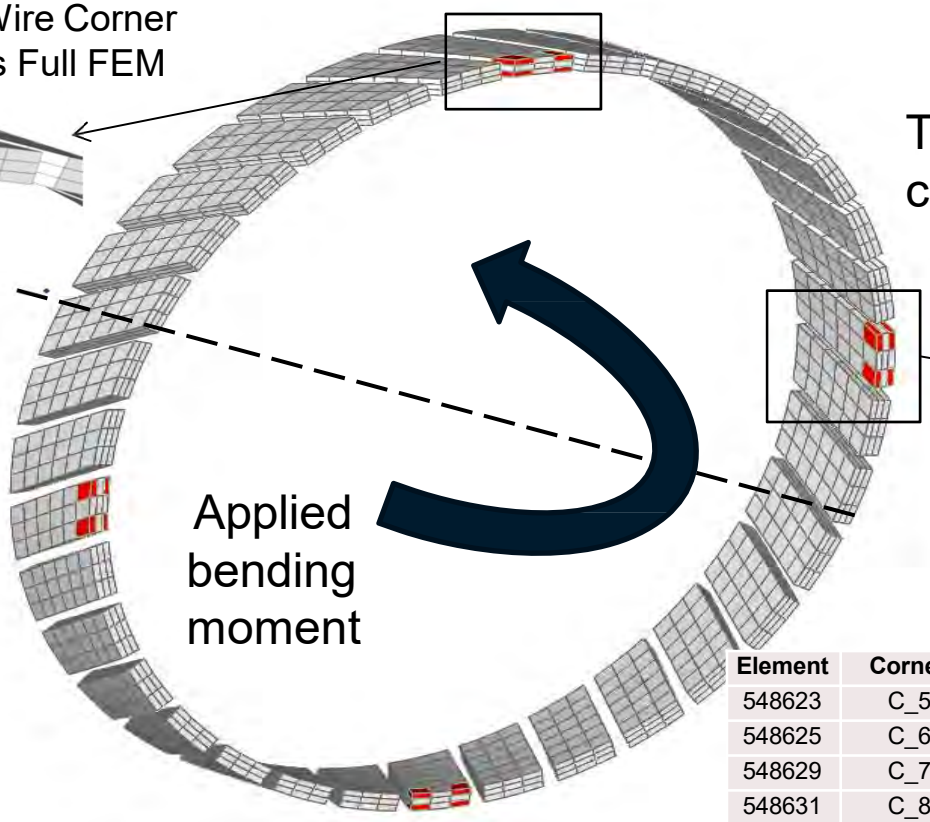
NDS – Flexibles Verification and Validation

Sample Verification Case: Armor Wire Corner Stresses Due to Bending - NDS vs Full FEM

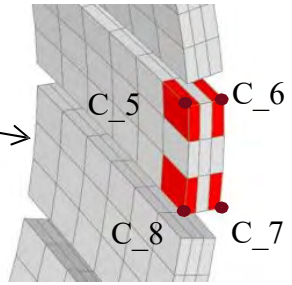


Element	Corner	Wire Stress NDS /FEM
567631	C_1	0.9999999471393
567633	C_2	0.9999999810539
567637	C_3	1.0000000266467
567639	C_4	1.0000000377601

Excellent comparisons between NDS and FE solver for wire corner stresses in bending



Transverse local curvature



Element	Corner	Wire Stress NDS/FEM
548623	C_5	1.0000000444484
548625	C_6	1.0000000000000
548629	C_7	0.9999999691231
548631	C_8	1.0000000000000

NDS – Flexibles Verification and Validation

- **Numerical Benchmarking:**
  - 1200+ stresses at armor wire locations were compared for axis-symmetric and bending cases with errors within “numerical noise”
- **Experimental Benchmarking:**
  - 236 computed armor strains were compared against strain gage measurements for axis-symmetric and bending cases resulting in very good agreement

NDS – Flexibles Verification and Validation

Joint Publications

ExxonMobil and INTECSEA (ISOPE 2016)

Majed, A. (INTECSEA), Rombado, G. (ExxonMobil), Chinello, L. (INTECSEA), Cooke, N. (INTECSEA), and Kan, W. (ExxonMobil), "*Computationally Efficient Simulation of Flexible Risers via Nonlinear Dynamic Substructures: Numerical and Experimental Validation*", ISOPE 2016, Rhodes, Greece, June 2016.

Chevron, Anadarko, DeepStar, and INTECSEA (OTC 2017)

Majed, A. (INTECSEA), Yiu, F. (Anadarko), Cooke, N., (INTECSEA), Chinello, L. (INTECSEA), Gomes, J. (Chevron/DeepStar), and Kusinski, G. (Chevron), "*New Generation Computational Capabilities in Nonlinear Dynamic Simulations of Flexible Riser Systems*", OTC 2017, Houston, Texas, May 2017.

NDS – Flexibles

Other Joint Publications

ExxonMobil and INTECSEA (OMAE 2018)

Rombado, G. (ExxonMobil), Cooke, N. (INTECSEA), Pasala, D. (INTECSEA), Ni, X. (INTECSEA), Low, A. (INTECSEA), Majed, A. (INTECSEA), "*Efficient Computation of Irregular Wave Wire Stresses in Flexible Risers*", OMAE 2018, Madrid, Spain, June 2018.

ExxonMobil and INTECSEA (OMAE2019)

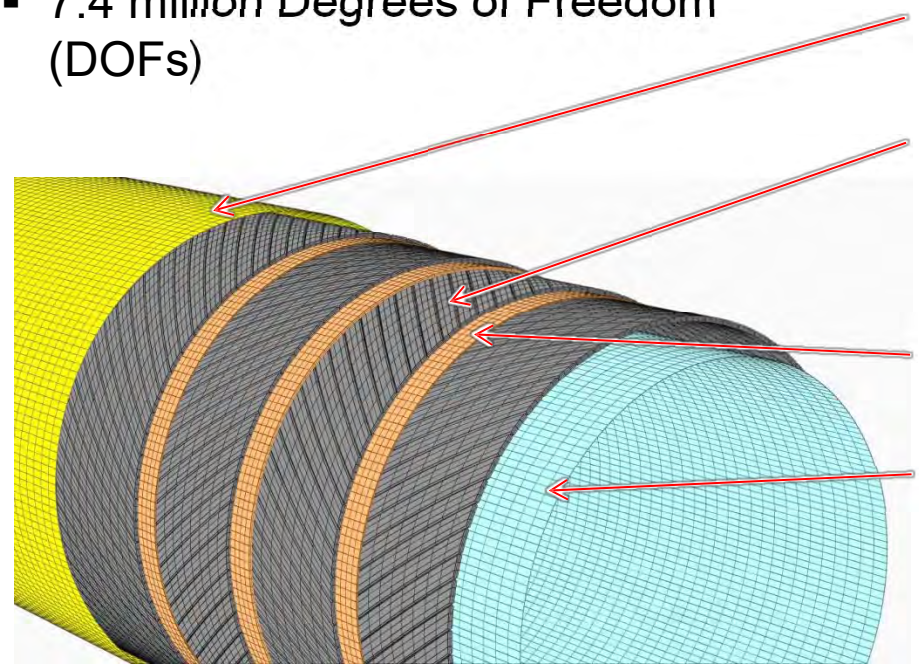
Rombado, G. (ExxonMobil), Doynov, K. (ExxonMobil), Cooke, N. (INTECSEA), Majed, A. (INTECSEA), "*Effect of Local Model Dynamics on Flexible Riser Tensile Armor Wire Stress Predictions*", OMAE 2019, Glasgow, Scotland, June 2019.

Overviews

- NDS Process
- FlexIQ
- Case History: Shell Bonga Flexible Riser Life Extension

NDS Process – Local Finite Element Model

- 14 inch ID
- 2.04 meter Pitch Length
- 7.4 million Degrees of Freedom (DOFs)

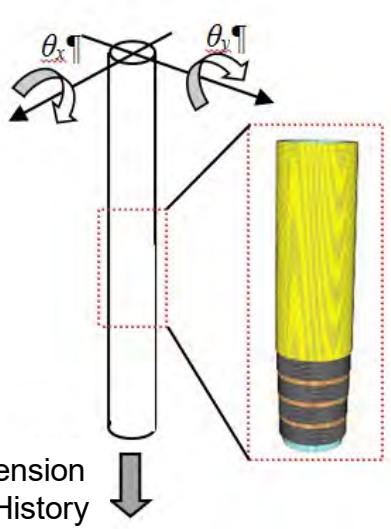


- **External sheath & Fabric Tapes**
  - Isotropic shells
- **Tensile Armor Layers**
  - 4x at +/- 35 degree lay angle
  - 70, 71, 74, 75 wires from inner to outer
  - Isotropic hexahedral bricks
- **Intermediate Antiwear Layers**
  - Isotropic hexahedral bricks
- **Carcass / Pressure Sheath / Antiwear**
  - Orthotropic composite shells

NDS Process – Local Model Configuration / Inputs

Local analysis assumes that the local model (at hang-off) is driven by rotation time-histories (2-planes) and tension as inputs

Enforced Hangoff Rotation Time-History Θ_x and Θ_y



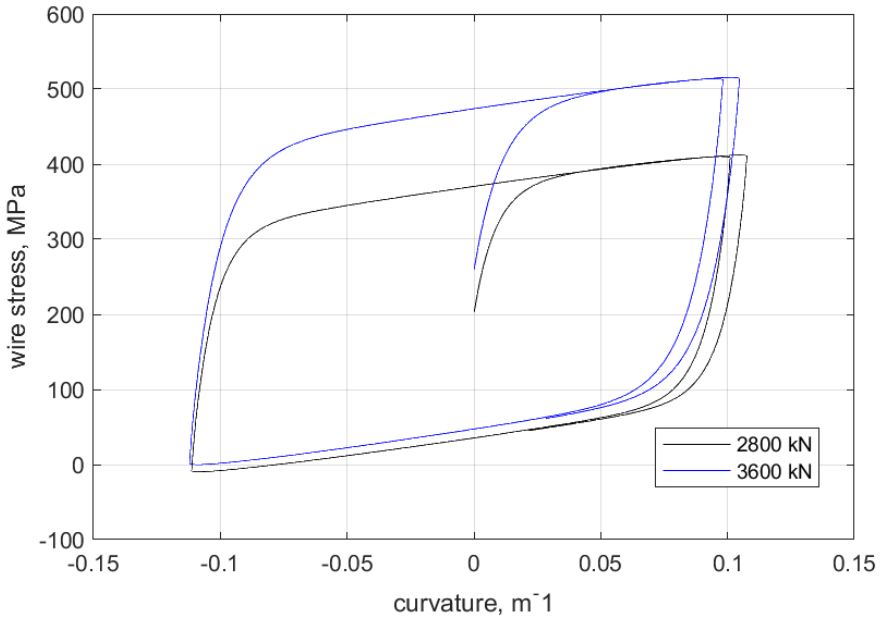
NDS of local FEM replicated into desired local model length

Axial Tension Time-History

Stress recovery locations at corners of inner-most and outer-most tensile armor layers

NDS Process – Local Model Checks (1/2)

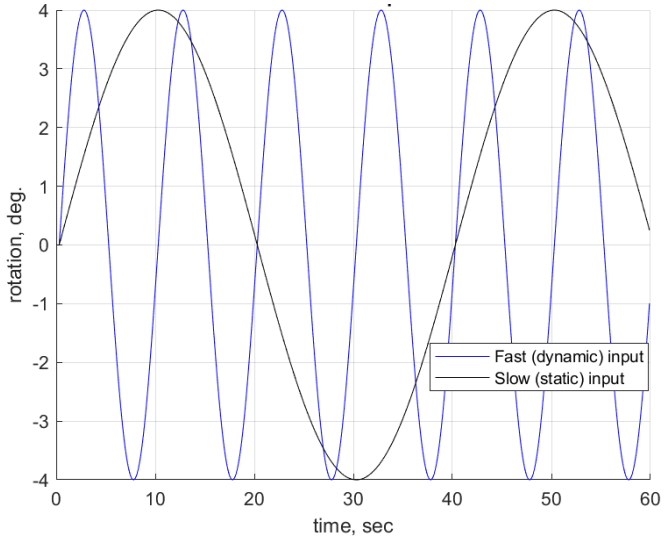
- Regular cyclic rotation input
- Stress-curvature response
- Effect of tension at same operating pressure



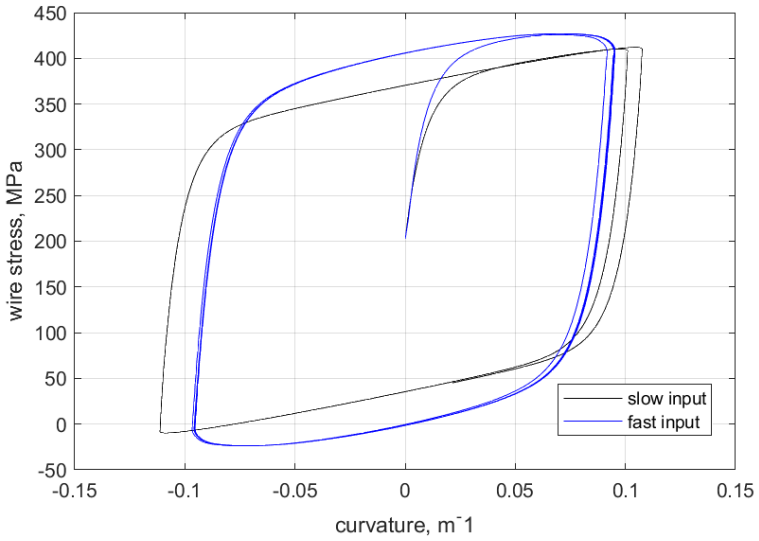
Effect of tension on wire stress hysteresis

NDS Process – Local Model Checks (2/2)

- Regular cyclic rotation inputs at different periods
- Local model inertia resists rotation increasing wire stress (for the same curvature) while decreasing overall curvature; increase energy dissipation



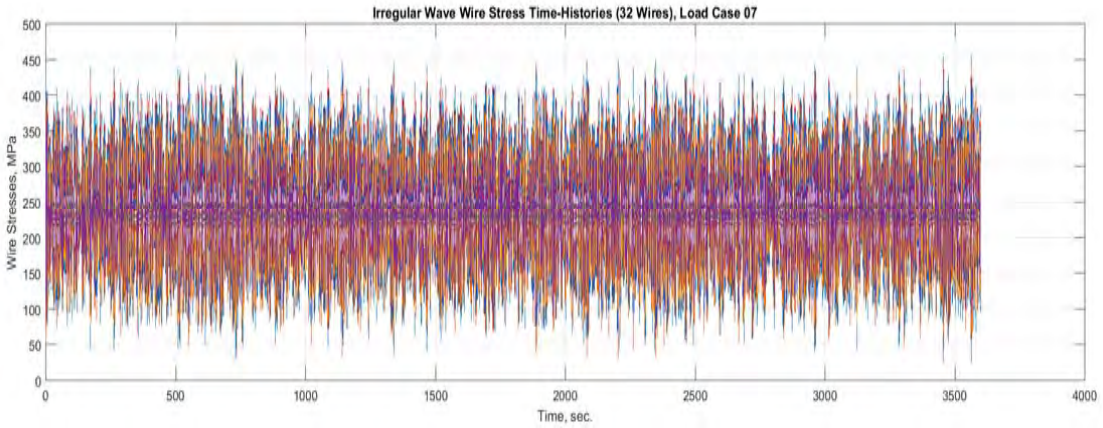
Slow vs Fast Rotation Inputs (40 second and 10 second periods, respectively)



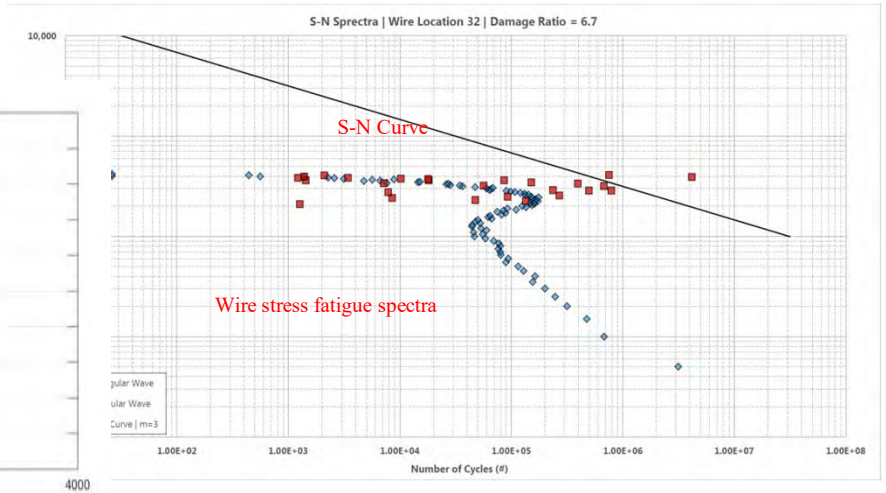
Regular Wave Wire Hysteresis Due to Slow and Fast Inputs (2800 kN Tension Case)

NDS Process – Irregular Wave Fatigue Simulations

1-hr long fatigue simulations of the local model with NDS computation speed = 1.2x wall clock



Wire Corner Stresses (32 locations) from Irregular Wave Fatigue Simulations



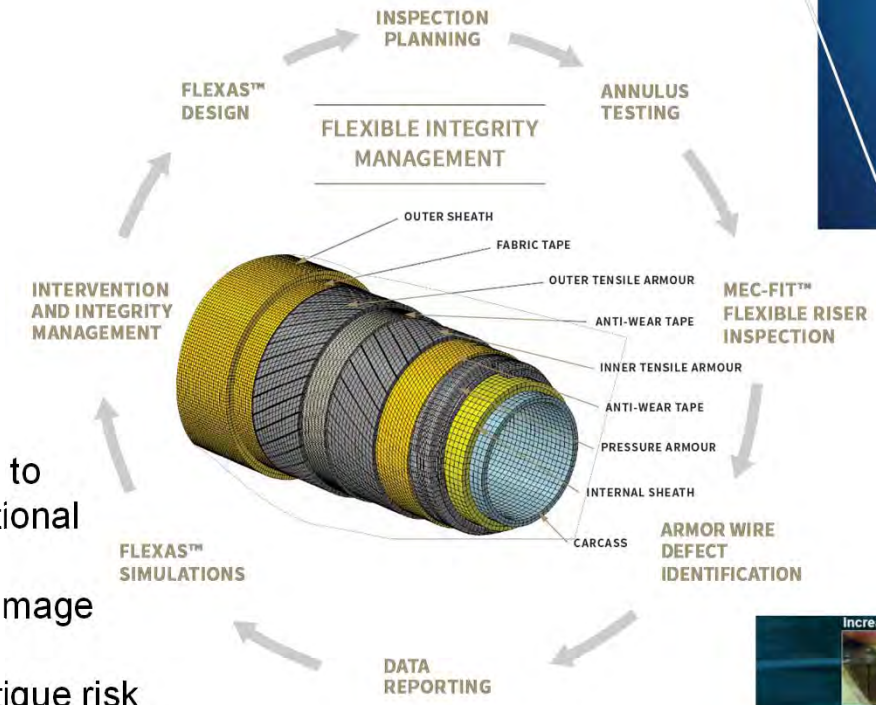
Fatigue Spectra (1 location)
Note: predicted damage from regular wave approach (red squares) is ~7x greater than irregular wave approach for this case

FlexIQ – Flexible Riser Inspections + Simulations

FlexIQ

INTECSEA WorleyParsons Group

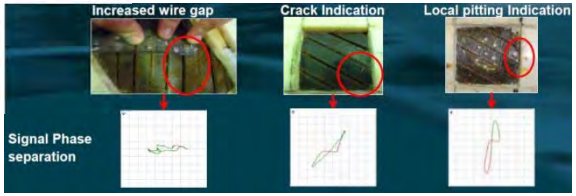
innospection



MEC-FIT™ Crawler

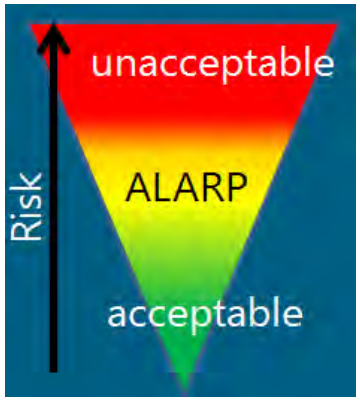
- MEC-FIT™ Inspection data for integrity assessment
- Simulation of high fidelity FEM to eliminate inaccuracies of traditional analyses
- Meaningful incorporation of damage data
- Improving understanding of fatigue risk
- Embedded into Integrity Management

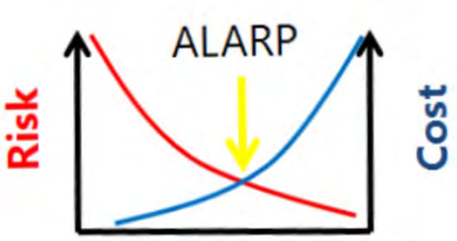
MEC Eddy Current Signal Analysis



FlexIQ – Integrity Assessment

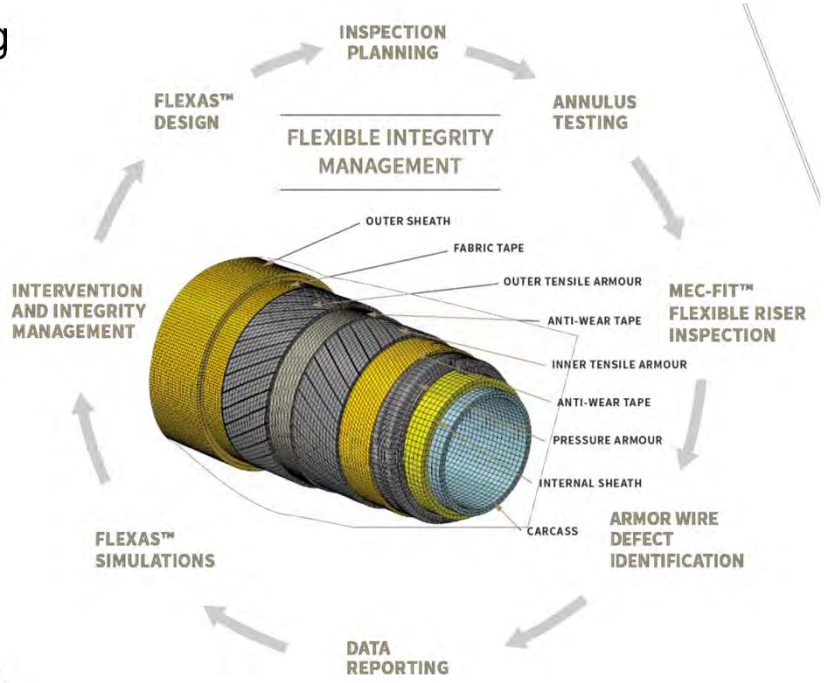
- **Layer by layer Risk Based Assessment (RBA)**
  - Embedding the fatigue analysis into a risk assessment study to assess qualitatively the risk of failure of each layer of the flexible risers and its ancillary equipment.
- **The benefit of RBA**
  - It enabled the likely degradation threats to be identified and assessed in a logical manner for each layer of the flexible. All the credible degradation mechanism form API 17 N have been considered.
  - Provides an assessment of "non-inspectable" layers (such as carcass, internal plastic sheaths) which are important to the integrity of the flexible.
  - Allows specific mitigation actions to be defined (inspection, test, monitoring, additional assessment) to keep the risk level to ALARP (As Low As Reasonable Practicable).





FlexIQ – A Novel Approach

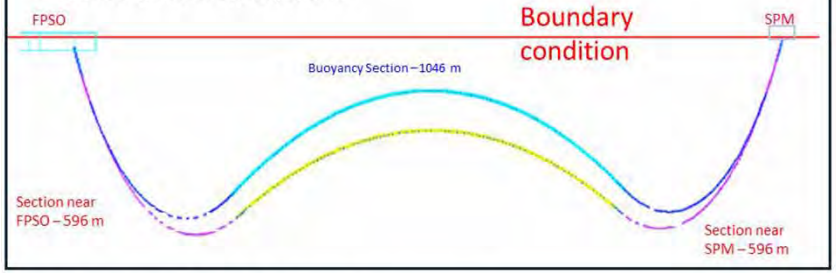
- The FlexIQ approach demonstrates that combining methods of advanced inspection and analysis as part of an integrity assessment is a valid solution for increased understanding of flexible riser condition in a life extension program.
- Life extension of flexibles beyond design life depends primarily upon the flexible pipe condition, rather than it's age.
- For the following case study, the FlexIQ approach has demonstrated that life extension can be achieved by implementing a comprehensive risk based integrity plan that includes routine inspections, monitoring and maintenance activities.



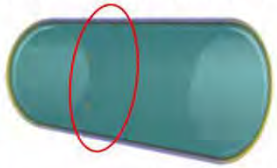
Case History: Shell Bonga – Flexible Riser Fatigue Simulations

Global Model and Simulations

- 111 (37 H_s/T_p, 3 vessel heading directions) swell seastates, 10 local windsea bins
- Marine growth at the hangoff (100 m on both ends of flexible)
- Mid-life contents density
- Simulation time is 1 hour per case

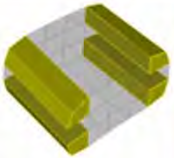


Local Model & Wire Stress Locations

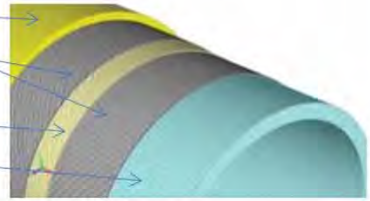


- Pitch Length: 1.192m
- FEM Size: 4.8M DOF
- Discretized into 2x half-pitch NDS (2.4M DOF)
- 8 hoop locations x 2 layers x 4 corners

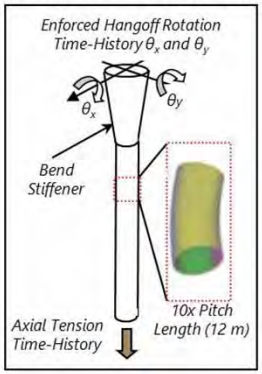
64 stress time-history tensors recovered per NDS (3 normal + 3 shear)

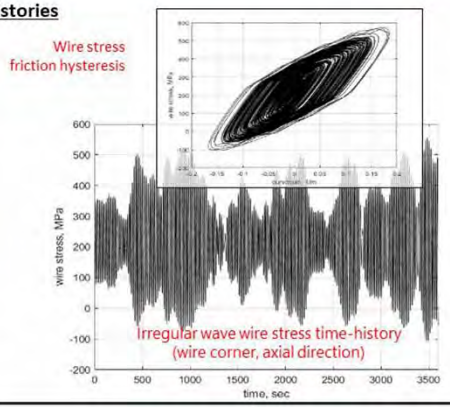


- External Sheath and Fabric Tapes: Isotropic Shells
- Inner (78) / Outer (80) Tensile Armors: Isotropic Hexahedral Bricks (3 through thickness, 5 across width)
- Intermediate Antiwear: Isotropic Hexahedral Bricks
- Carcass / Pressure Sheath: Orthotropic / Isotropic Shells

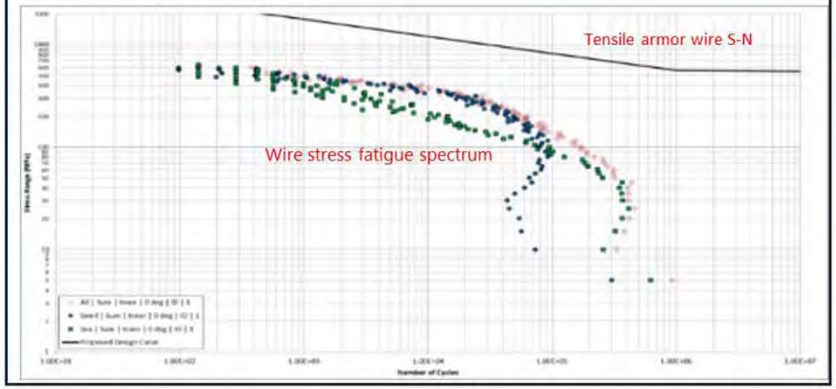


Fatigue Simulation / Stress Time-Histories



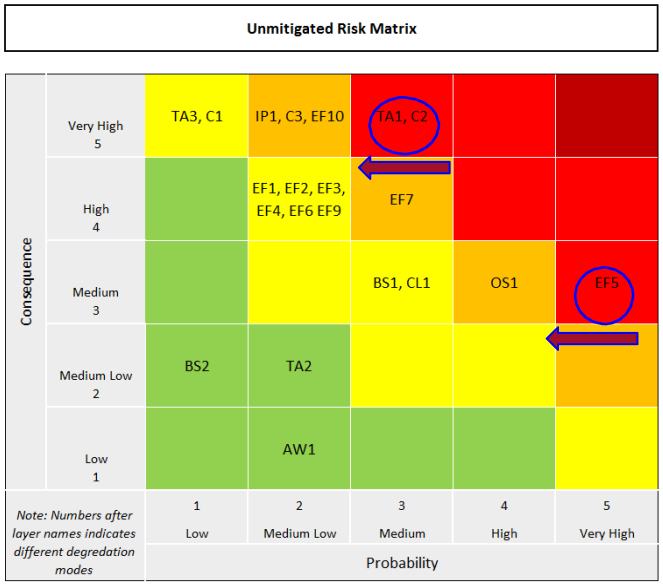


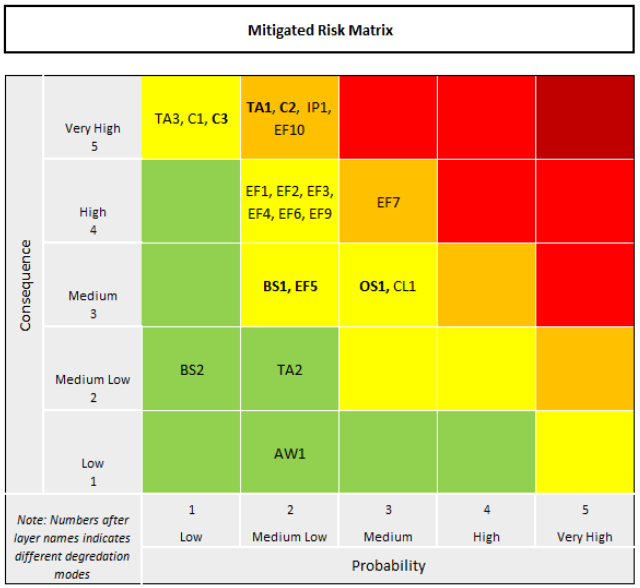
Rainflow & Damage Summation



Case History: Shell Bonga – Layer by Layer RBA

The RBA has revealed three high-risk elements (related to the tensile armour layer, the carcass and the end fittings). However, it is possible to reduce these risks to an acceptable (ALARP) level, with the implementation of specific mitigation actions that have been defined as part of the future integrity management plan.





Concluding Remarks (1/2)

- High fidelity 3D FEM is the most accurate means of capturing the flexible riser kinematics and stresses.
- Direct computation of high fidelity 3D FEM by the FE solver is extremely time consuming, even for a single bending cycle. This makes fatigue simulations utilizing high fidelity 3D FEM infeasible.
- Reduced order models/algorithms are numerical methods for efficiently and accurately solving high fidelity 3D FEM. These methods/tools are referred to as Nonlinear Dynamic Substructuring, or NDS.
- The applications of NDS to flexible riser tensile armor wire stress predictions has been numerically verified and experimentally validated by the oil and gas industry.

Concluding Remarks (2/2)

- The following overviews were presented:
  - The NDS flexible riser simulation process, including reduced order model generation, model checks, and irregular wave fatigue simulations and wire stresses
  - The FlexIQ offering, which provides flexible riser inspection to detect armor wire damage and high fidelity simulations to predict impact of the damage on remnant life
  - The application of FlexIQ to the Shell Bonga flexibles life extension project

Pipeline Research Council International, Inc.

PRCI Project MATS-1-1 Phase 3

CRA Weld Overlay Pipes for Subsea Application – Ultrasonic Inspection

Channa Nageswaran
TWI Ltd

PRCI 2019 Research Exchange Meeting
Houston, Texas
Date March 5 - 6, 2019

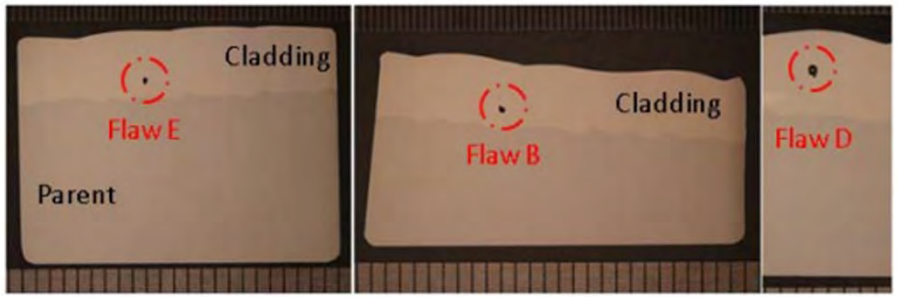
Overview of MATS-1-1

- **Delivered in three phases:**
  - 1: state-of-the-art
  - 2: fatigue performance
  - 3: inspection validation
- **Review of state-of-the-art for pipe fabrication and inspection**
- **Assessment of bond interface and characterisation**
- **Selection of optimal weld overlay deposition method**
- **Development of optimal inspection method for fabrication quality assurance**

Inspection development in Phase 1

- Review of codes and state-of-the-art for surface and subsurface inspection technology
- Assessment on plate samples used also for welding and characterisation studies
- Dye penetrant, eddy current and ultrasonic methods investigated
- Flaws of concern were determined, establishing detection requirements
- Six (6) ultrasonic techniques were assessed using a set containing 14 flaws

	Technique					
	1	2	3	4	5	6
Flaw A	×	✓ (L)	×	✓ (L)	✓ (M)	×
Flaw B	✓ (H)	✓ (L)	✓ (M)	✓ (H)	✓ (M)	✓ (M)
Flaw C	✓ (H)	×	×	×	✓ (M)	✓ (H)
Flaw D	×	×	×	×	✓ (L)	×
Flaw E	✓ (H)	✓ (L)	✓ (M)	✓ (H)	✓ (L)	✓ (M)
Flaw F	✓ (H)	✓ (M)	✓ (M)	✓ (H)	✓ (M)	✓ (M)
Flaw G	✓ (H)	×	×	×	✓ (L)	×
Flaw H	×	✓ (L)	×	×	×	×
Flaw I	✓ (H)	✓ (M)	✓ (L)	×	×	✓ (L)
Flaw J	✓ (H)	✓ (L)	✓ (H)	✓ (M)	✓ (M)	✓ (H)
Flaw K	✓ (H)	✓ (L)	✓ (L)	✓ (M)	✓ (L)	✓ (L)
Flaw L	×	✓ (H)	✓ (H)	✓ (H)	✓ (L)	×
Flaw N	×	×	×	✓ (H)	**	**
Flaw P	×	✓ (H)	✓ (H)	✓ (H)	**	**



PRCI Report Catalogue No. ***PR164-114512-R01***

Inspection development in Phase 2

- Based on findings of Phase 1, a tool developed in a TWI JIP for inspection of mechanically lined pipe was assessed
- The tool was evaluated on a representative pipe with a flaw set determined by PRCI project team
- Tool was used to screen pipes used in resonance fatigue test

PRCI Report Catalogue No. ***PR164-114512-R02***

Work done in Phase 3

- Objective was to establish the performance of the tool evaluated in Phase 2
- This was done using a very large flaw set to create probability of detection (PoD) curves, which is an established way to establish performance
- Implanted flaws and unintentional flaws found during baseline scanning numbered 120+
- Inspections were conducted blind by two trained independent operators
- All flaws were salami-sectioned to complete the assessment

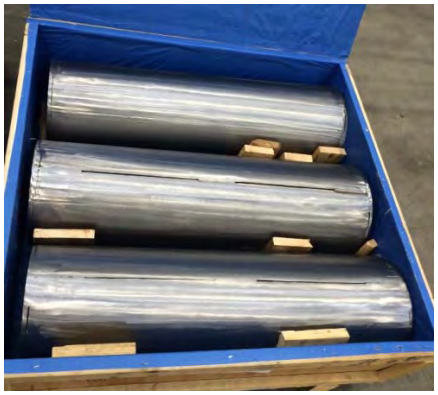
What is the problem and what is the tool?

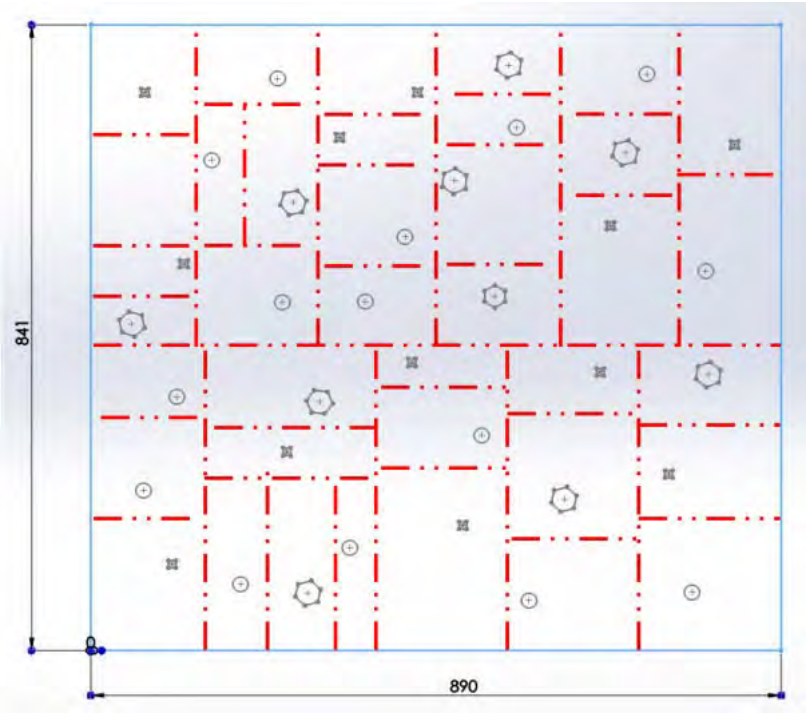
- **Why is inspecting weld overlay cladding an issue?**
  - Typical corrosion resistant alloys (CRAs) used for cladding such as 316L stainless steel and nickel-based Alloy 625 are austenitic
  - The weld deposited cladding is composed of coarse textured grains which grow along the thermal gradients during solidifications
  - When a sound wave propagates through such material it distorts the wave and gives rise to noise in the received signal, as well as potential errors in positioning of indications
  - Due to noise, interpreting signals from the cladding can be difficult
  - The distortion and high attenuation can potentially lead to flaws being missed during inspection, allowing potential failure points during fatigue service to be introduced into assets

- **What does the tool offer?**
  - Implements three techniques simultaneously over the same region of the cladding (termed Shear, Normal and TRL)
  - The data from the techniques (referred to as channels in the report) is visualised and analysed simultaneously by the operator
  - This improves:
    - ***Detection***
    - ***Confidence in the interpretation***
    - ***Characterisation***
  - Circumferential length sizing is possible, but through-wall length sizing is not yet possible
  - Nominal flaw sizes introduced into the specimens were <0.8mm in through-wall size
  - Techniques are broadly compliant with governing existing codes

Specimens

- Three suppliers from the UK, India and USA were approached to create the specimens with implanted flaws
- Based on price, lead times and quality assessed on trial specimens, the UK supplier was selected
- Specimens were scanned to verify implantation and to create a baseline map

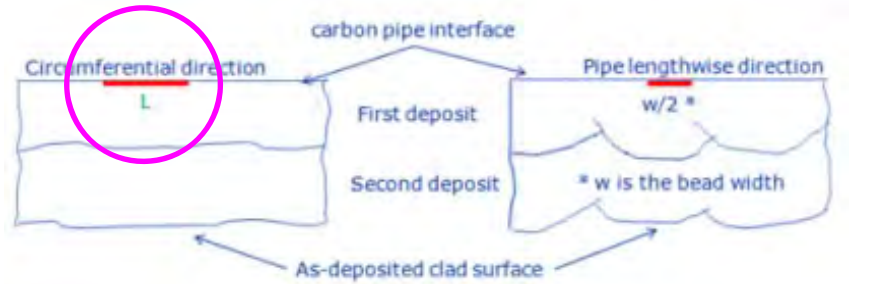


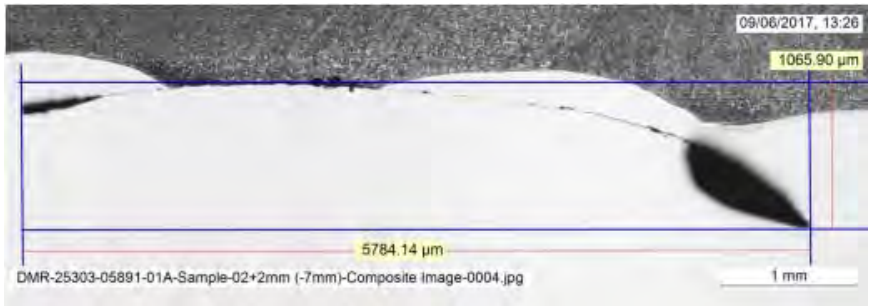


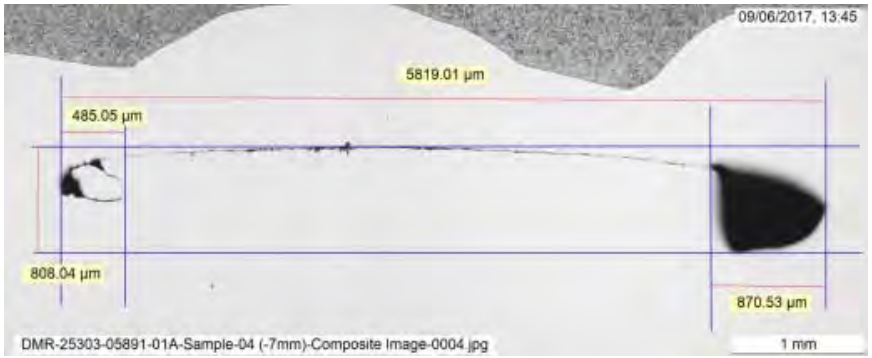
Flaw Type 1

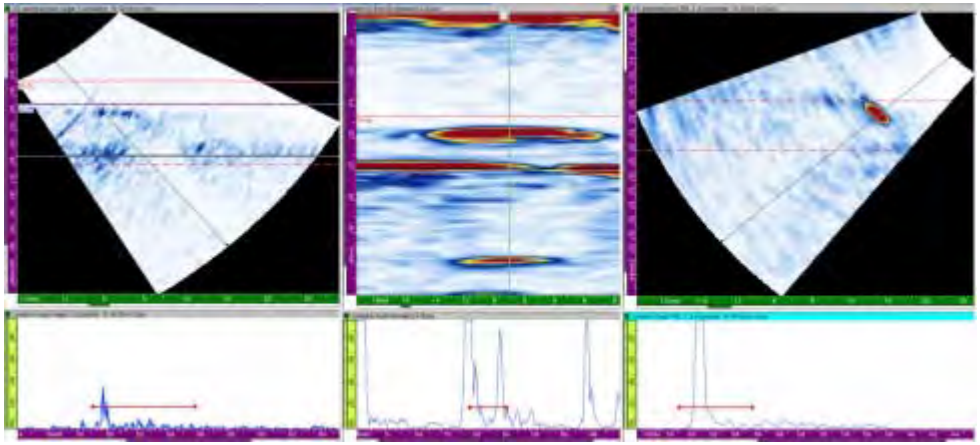
Outside surface

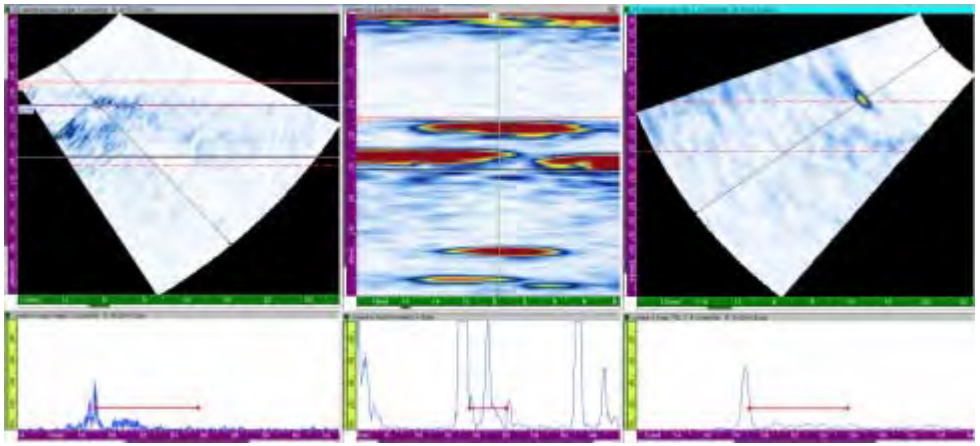
Outside surface





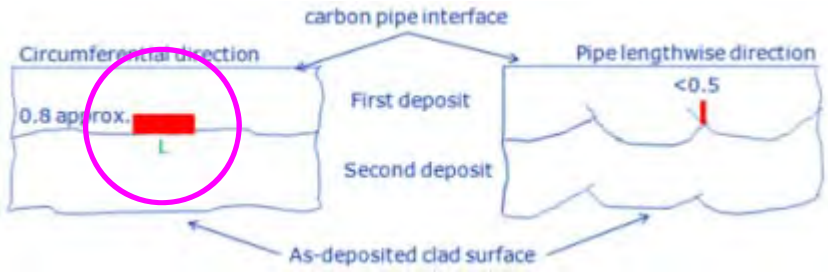




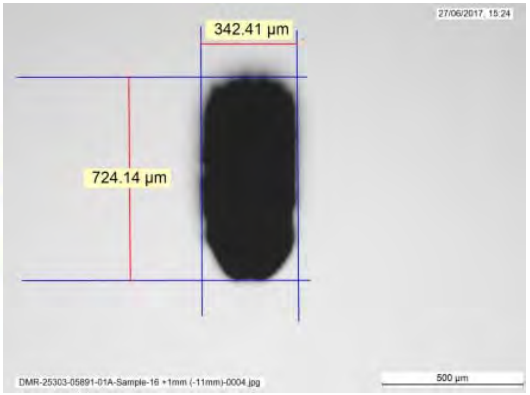


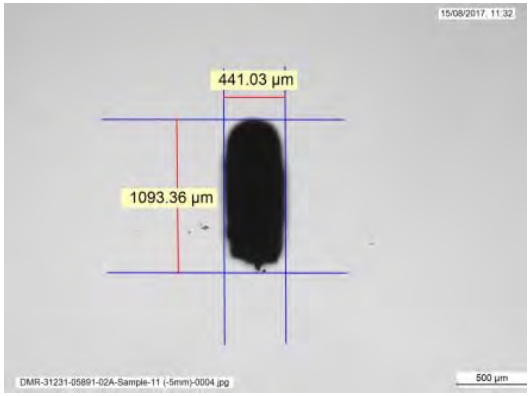
Flaw Type 2

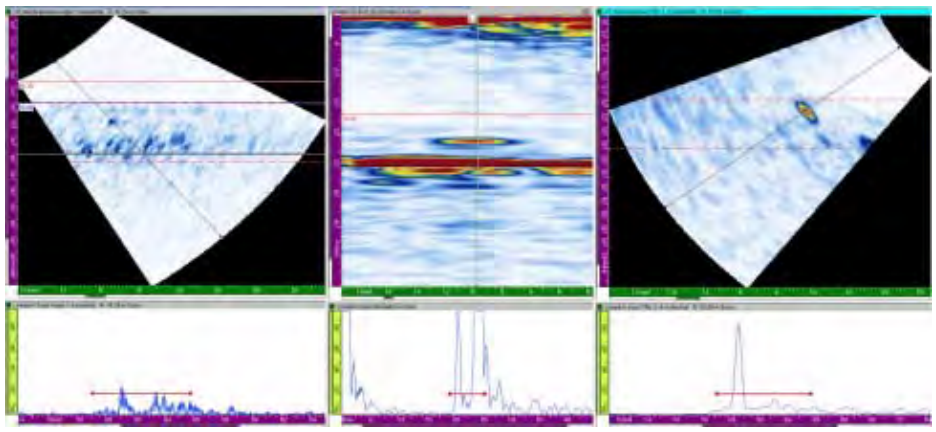
Outside surface

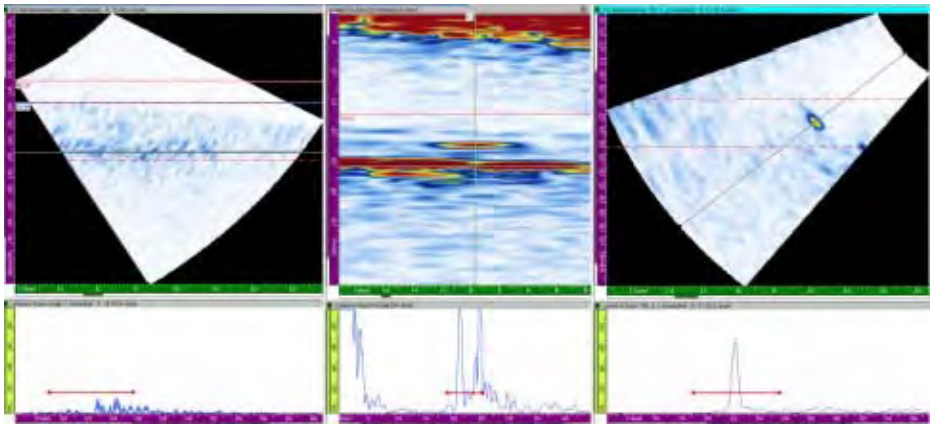


Outside surface



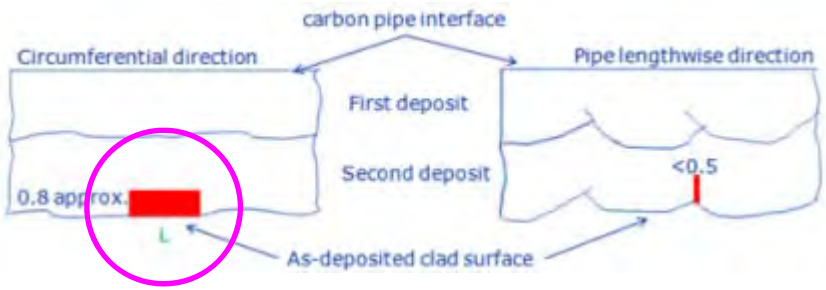




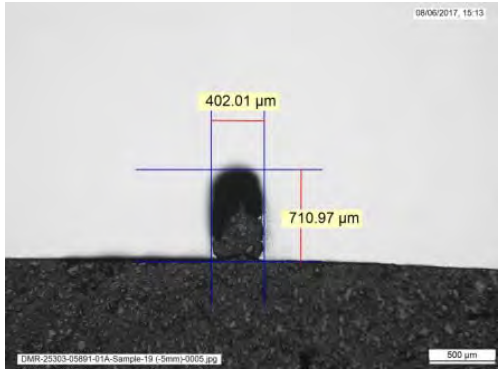


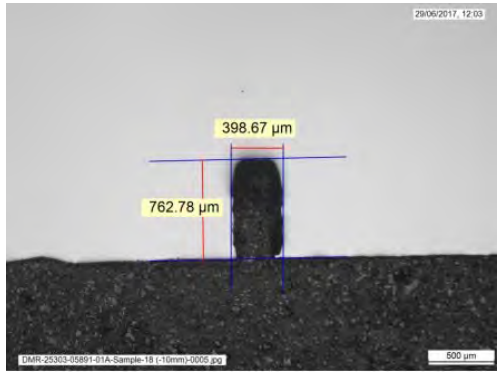
Flaw Type 3

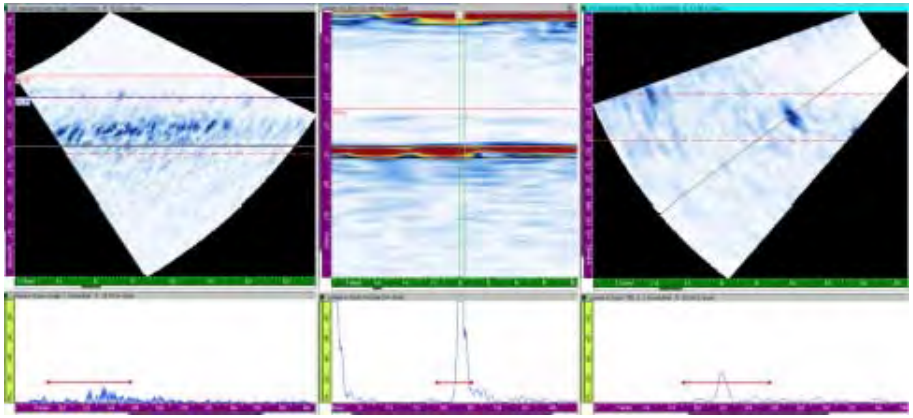
Outside surface

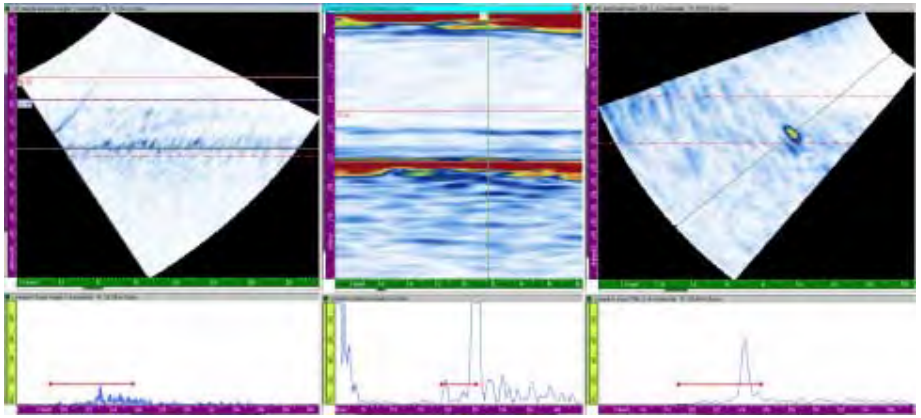


Outside surface

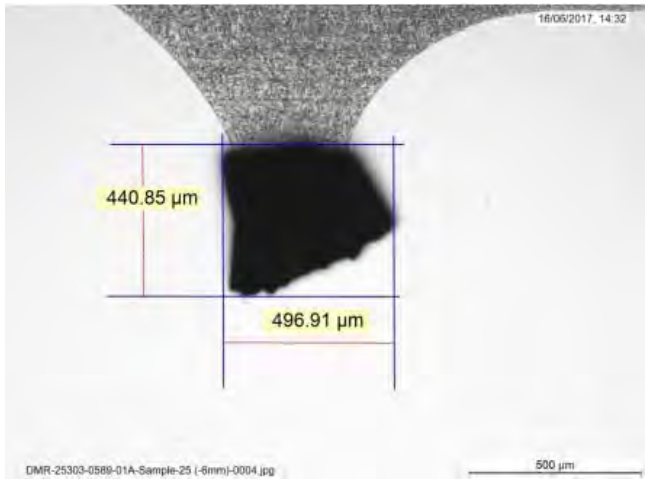


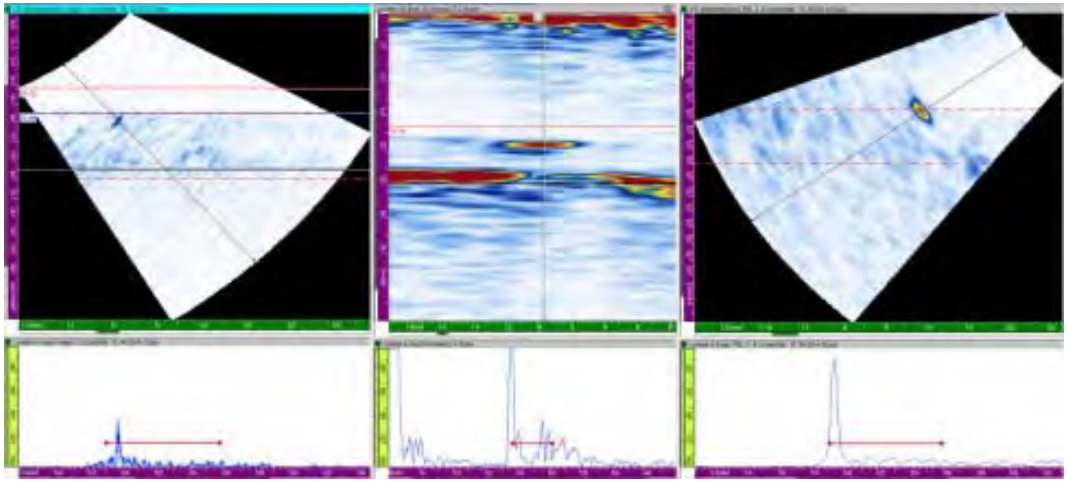


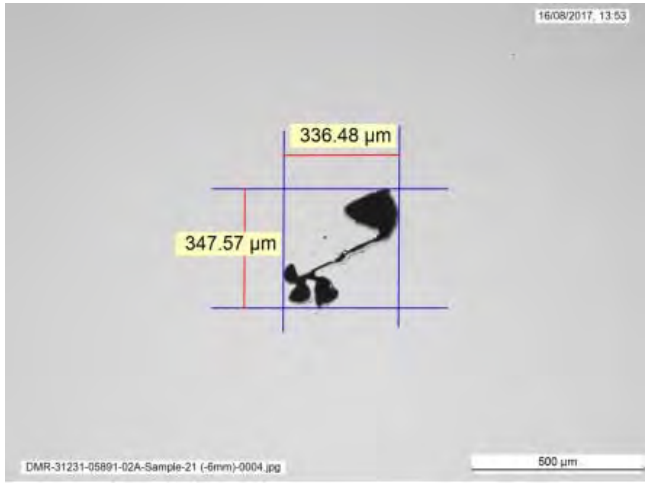


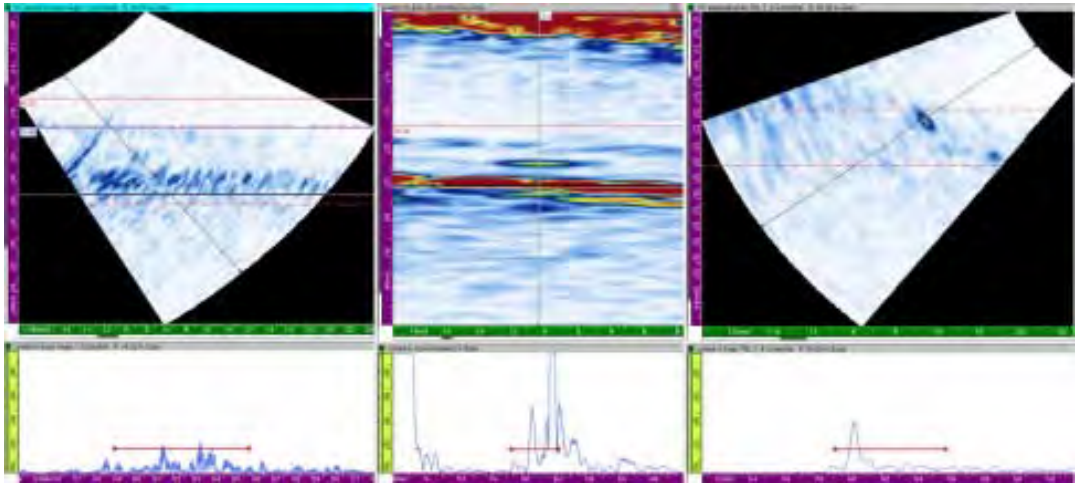


Unintentional flaws





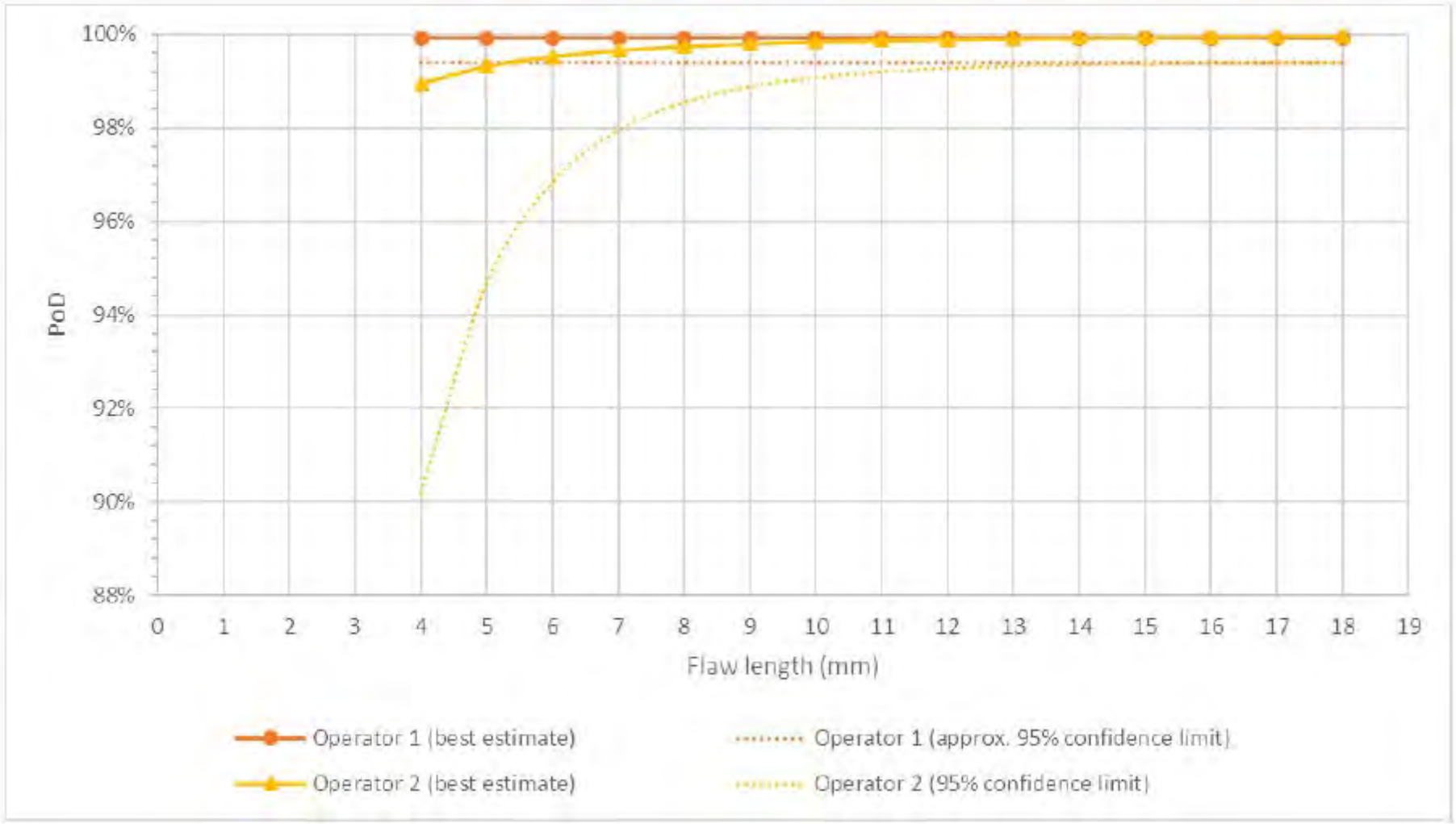




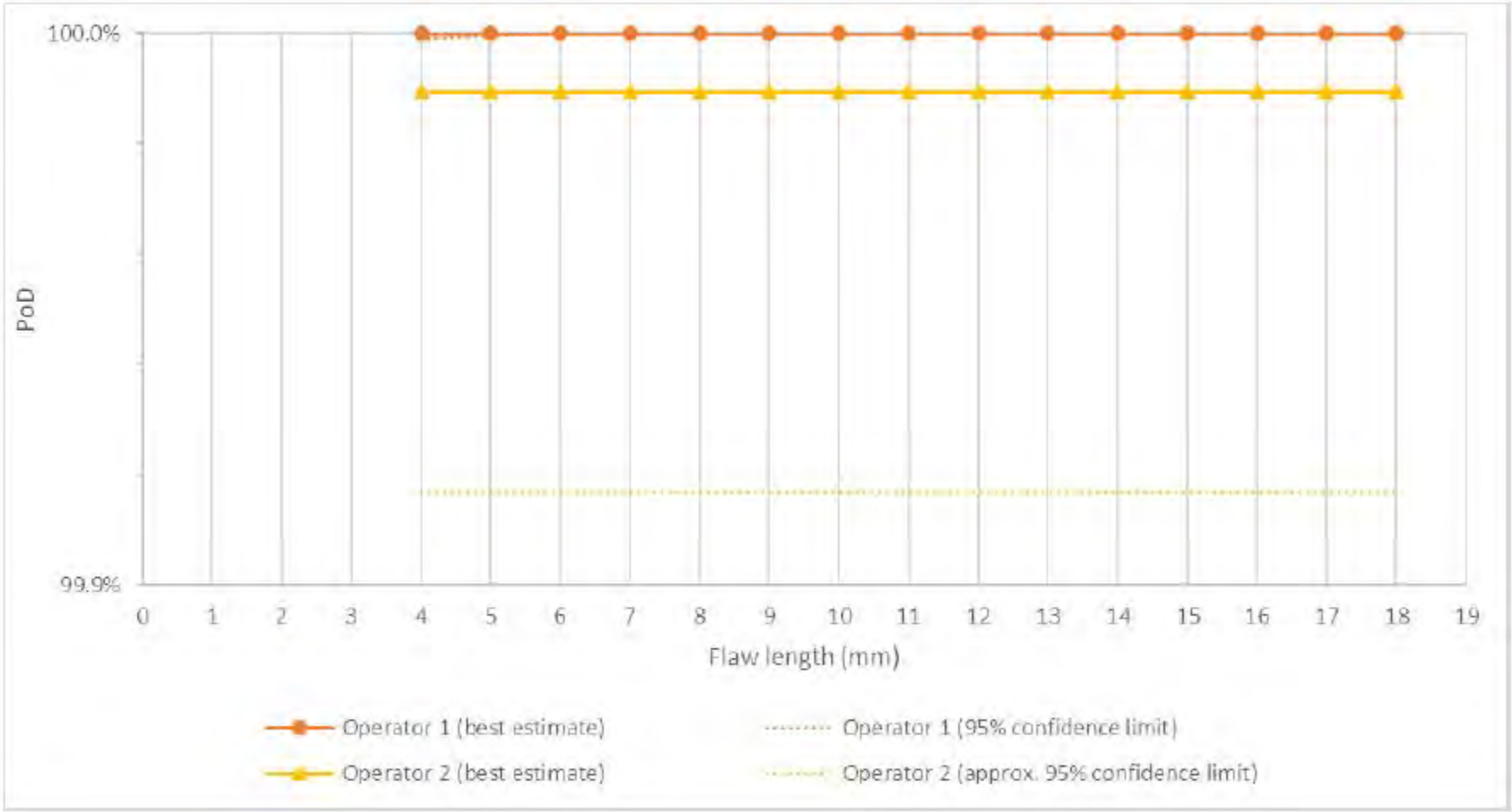
Approach to the PoD analysis

- **Estimated using deliberately induced flaws only**
  - Inclusion of unintentional flaws found by the tool would have added bias
- **PoD model was based on the recorded peak amplitude**
  - Relative to a threshold of -12dB from the signal from the reference target
  - The reference target was a 1mm notch on the ID of a reference pipe
  - The reference pipe was of identical geometry with identical cladding
- **18 data sets were recorded corresponding to combinations of:**
  - Channel (Shear, Normal, TRL)
  - Flaw type (1-3)
  - Operator (1 & 2)
- **PoD curves were fitted to each of the 18 data sets as the different combinations were assessed to be distinct from each other**
- **A linear regression fit assumed for a response vs size approach**

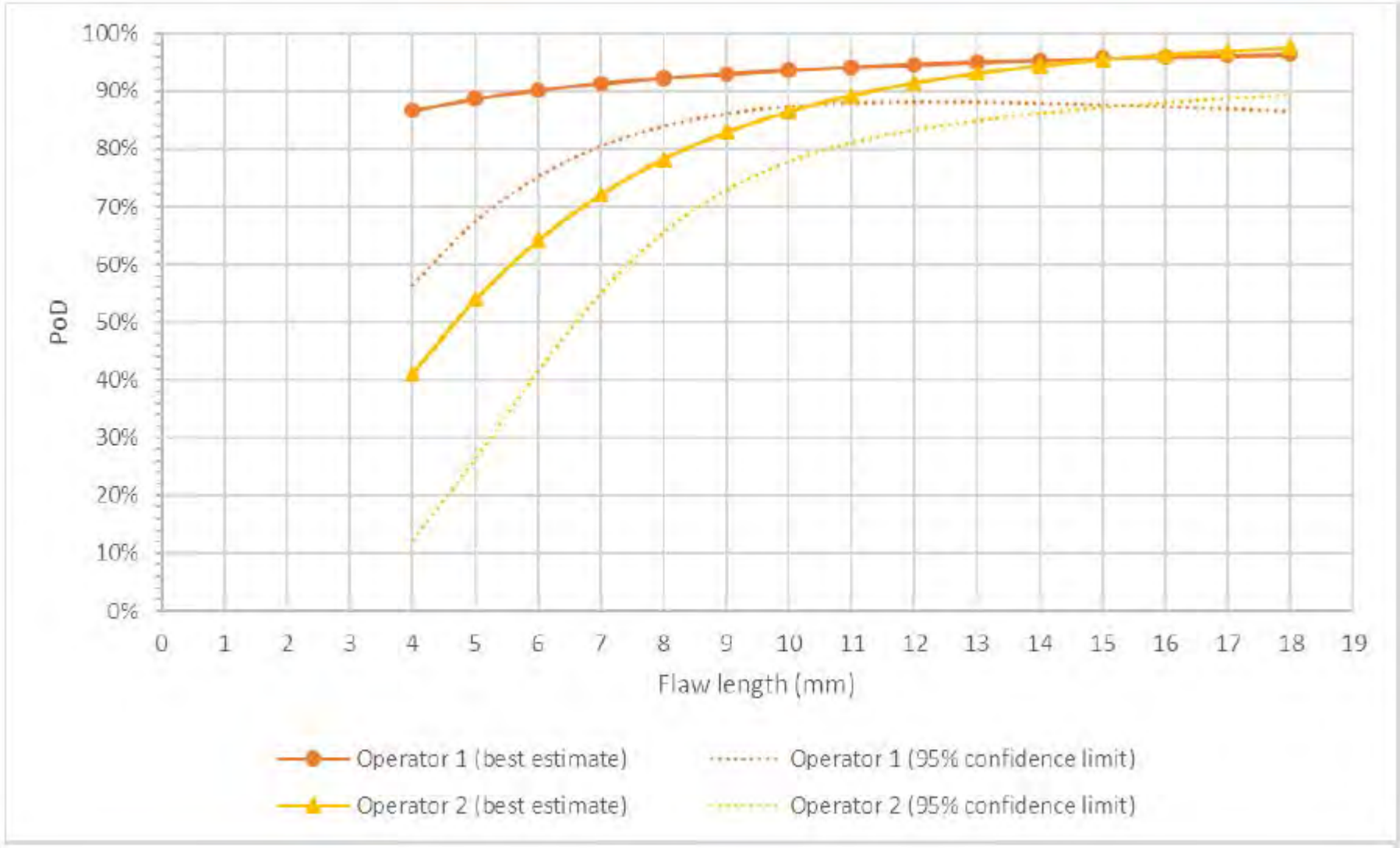
Predicted PoD curves for Type 1 flaws using the Shear channel



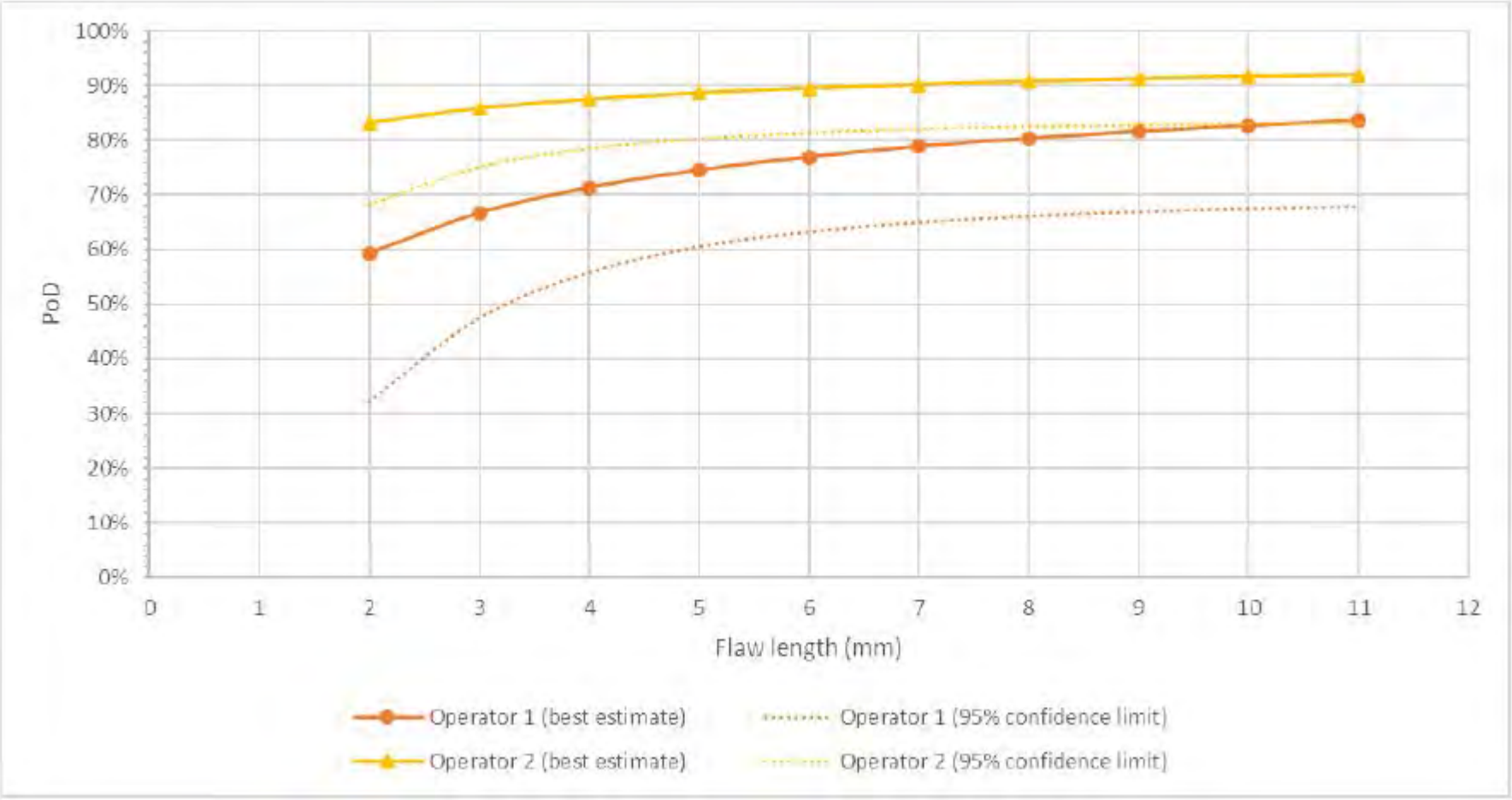
Predicted PoD curves for Type 1 flaws using the Normal channel



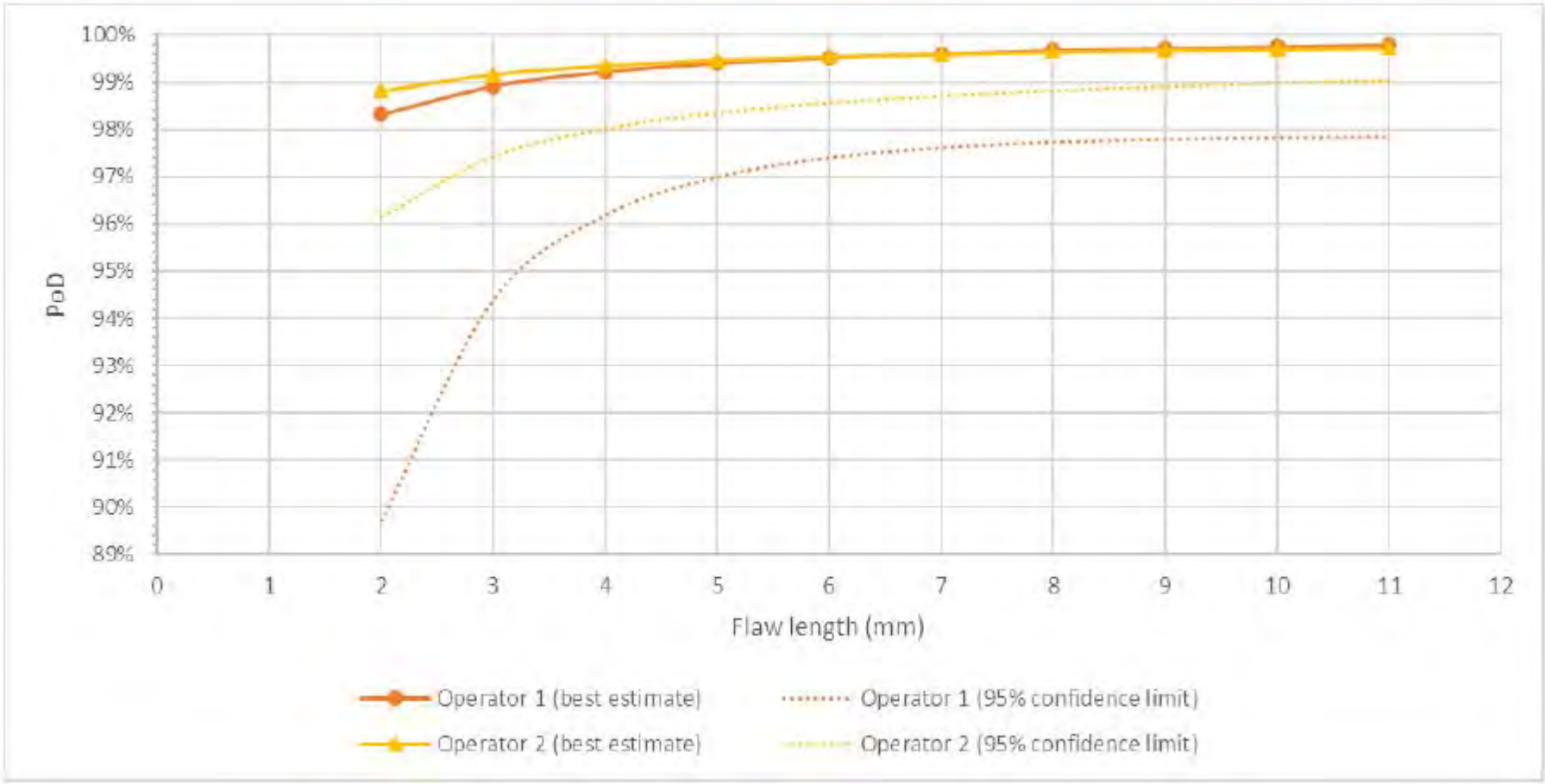
Predicted PoD curves for Type 1 flaws using the TRL channel



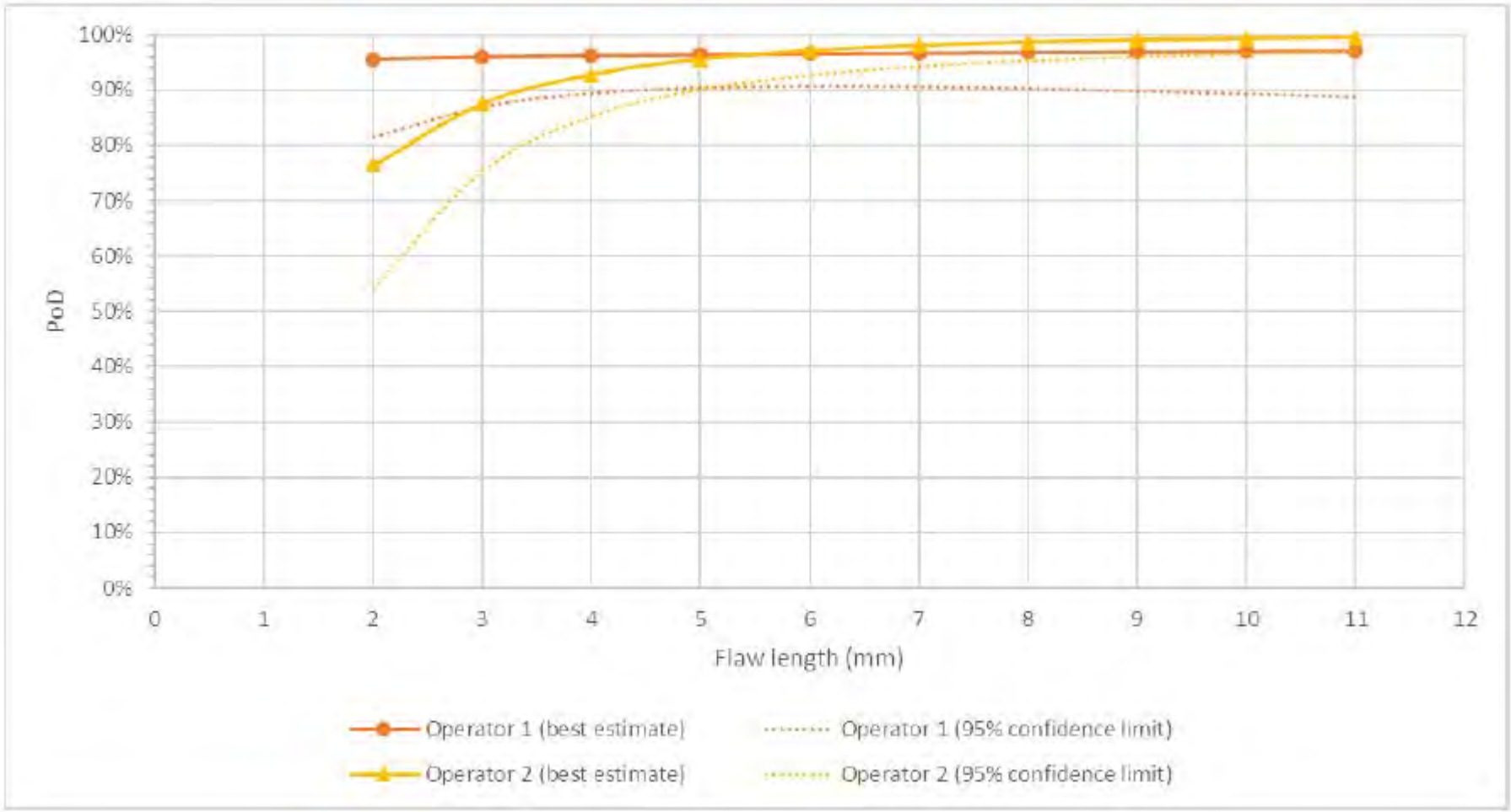
Predicted PoD curves for Type 2 flaws using the Shear channel



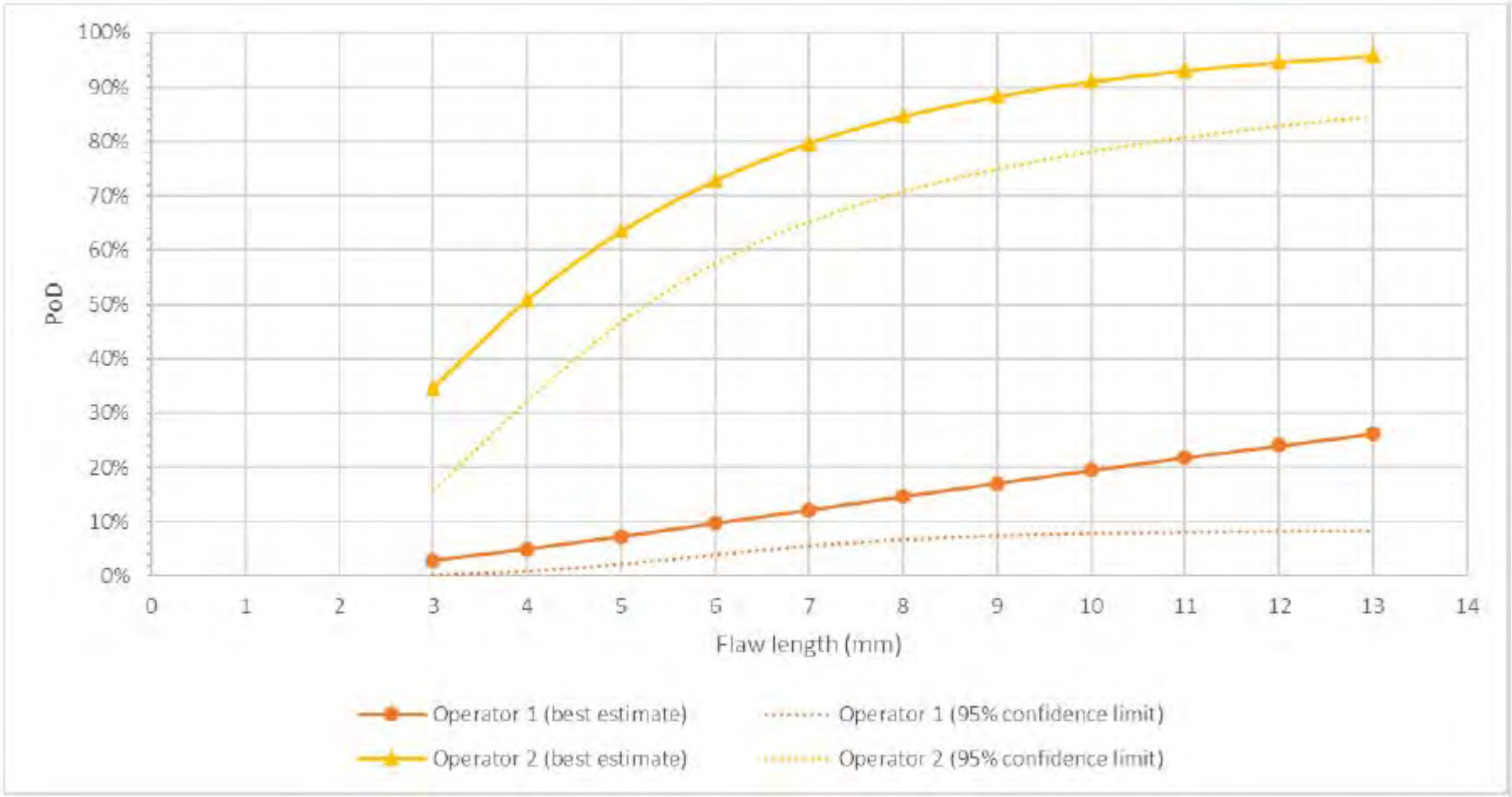
Predicted PoD curves for Type 2 flaws using the Normal channel



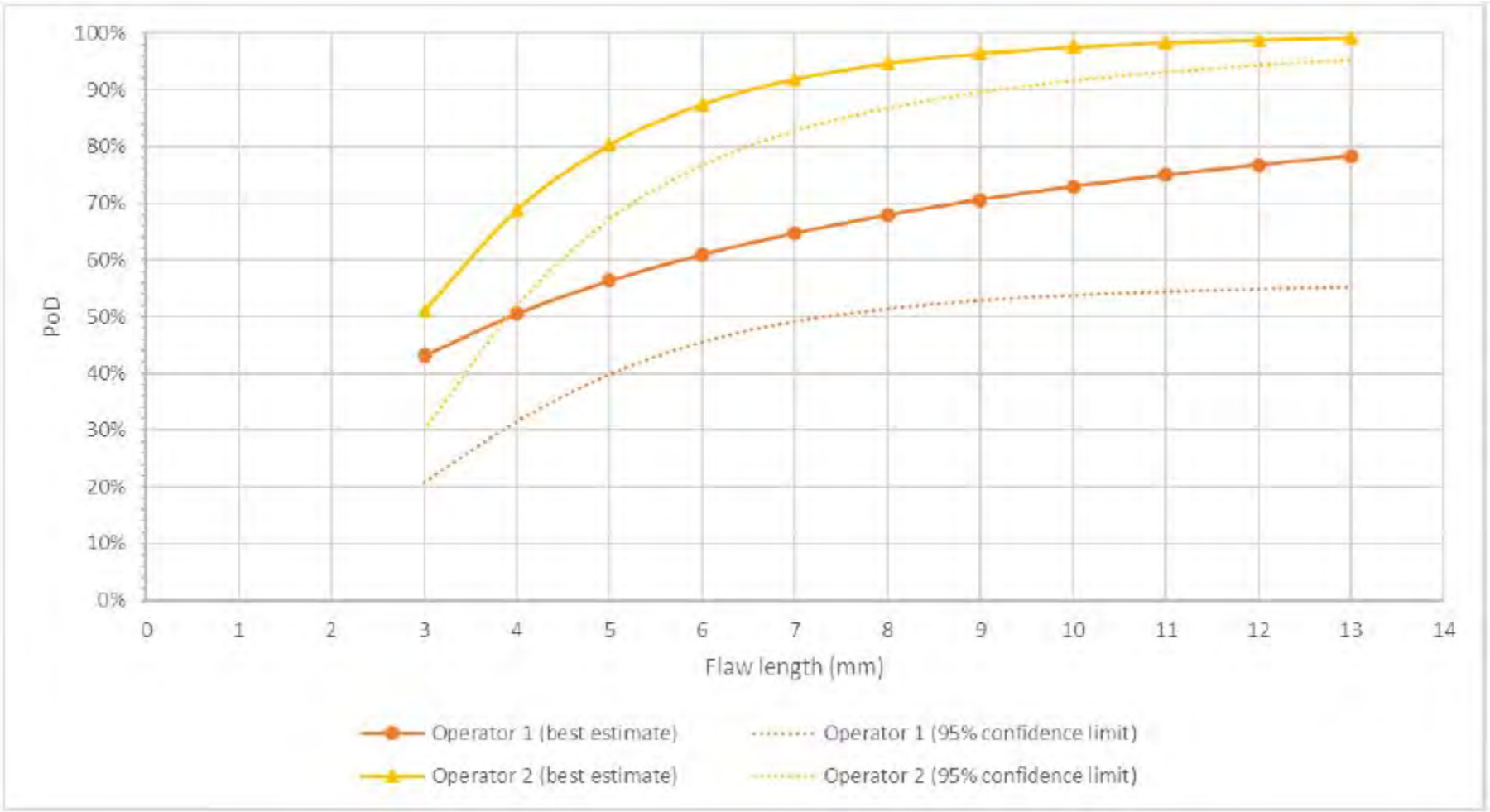
Predicted PoD curves for Type 2 flaws using the TRL channel



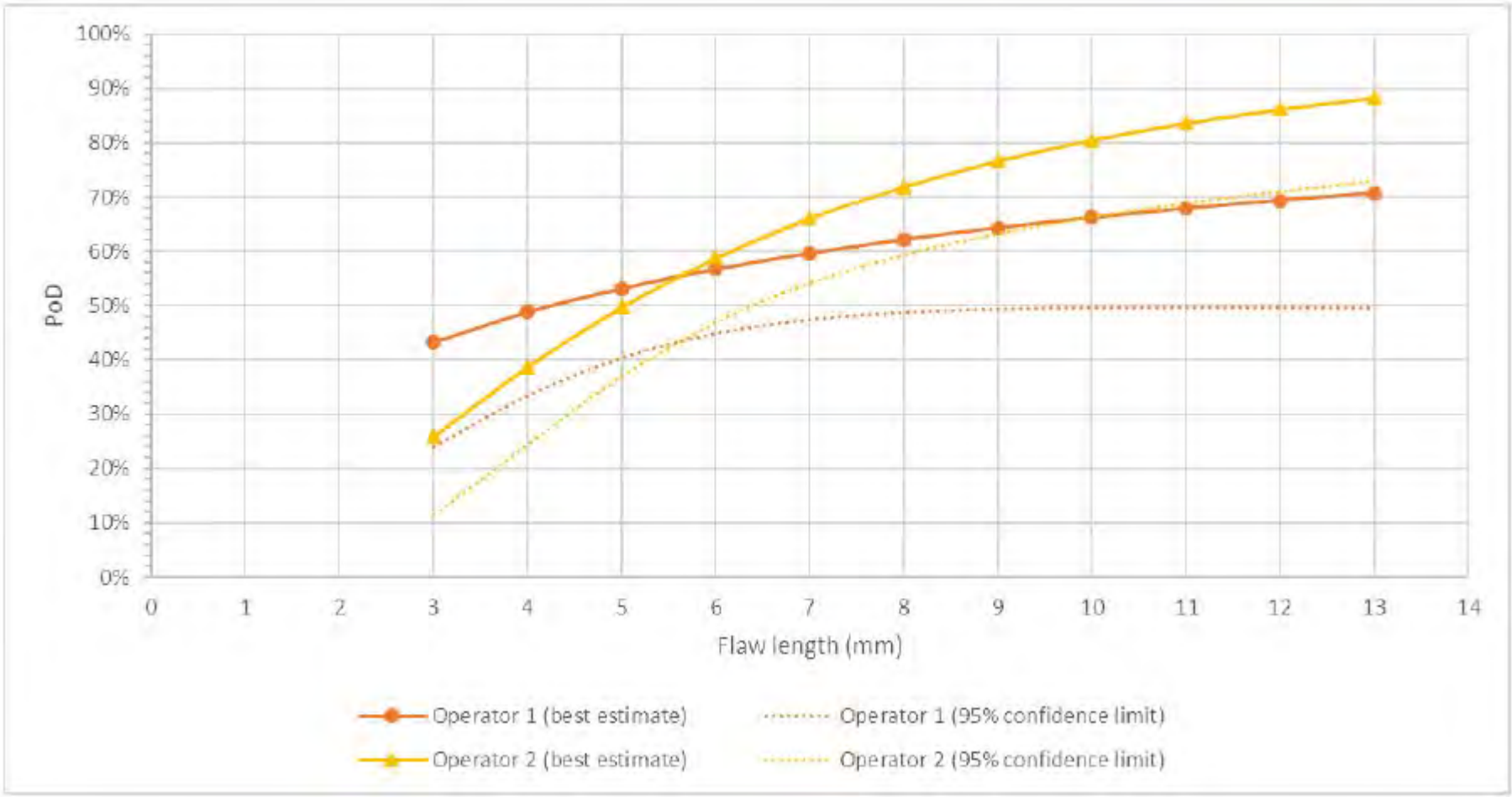
Predicted PoD curves for Type 3 flaws using the Shear channel



Predicted PoD curves for Type 3 flaws using the Normal channel



Predicted PoD curves for Type 3 flaws using the TRL channel



Summary of performance and sizing errors

- **For a mean flaw length of 7mm:**

Flaw type	Channel	PoD (best estimate)		95% lower confidence limit	
		Operator 1	Operator 2	Operator 1	Operator 2
1	Normal	>99%	>99%	>99%	>99%
	TRL	91%	72%	81%	55%
	Shear	>99%	>99%	99%	98%
2	Normal	>99%	>99%	98%	99%
	TRL	97%	98%	91%	94%
	Shear	79%	90%	65%	82%
3	Normal	65%	92%	49%	83%
	TRL	60%	66%	47%	54%
	Shear	12%	80%	6%	65%

- **Estimated sizing errors for a flaw length of 10mm:**

Flaw types	Mean error (mm)		Standard deviation S (mm)		2-sided 90% prediction interval (mm)	
	Operator 1	Operator 2	Operator 1	Operator 2	Operator 1	Operator 2
1	−2.1	−0.7	3.0	1.7	−2.1 ± 5.1	−0.7 ± 2.8
2 & 3	−0.9	−0.4	1.7	1.8	−0.9 ± 2.9	−0.4 ± 3.1

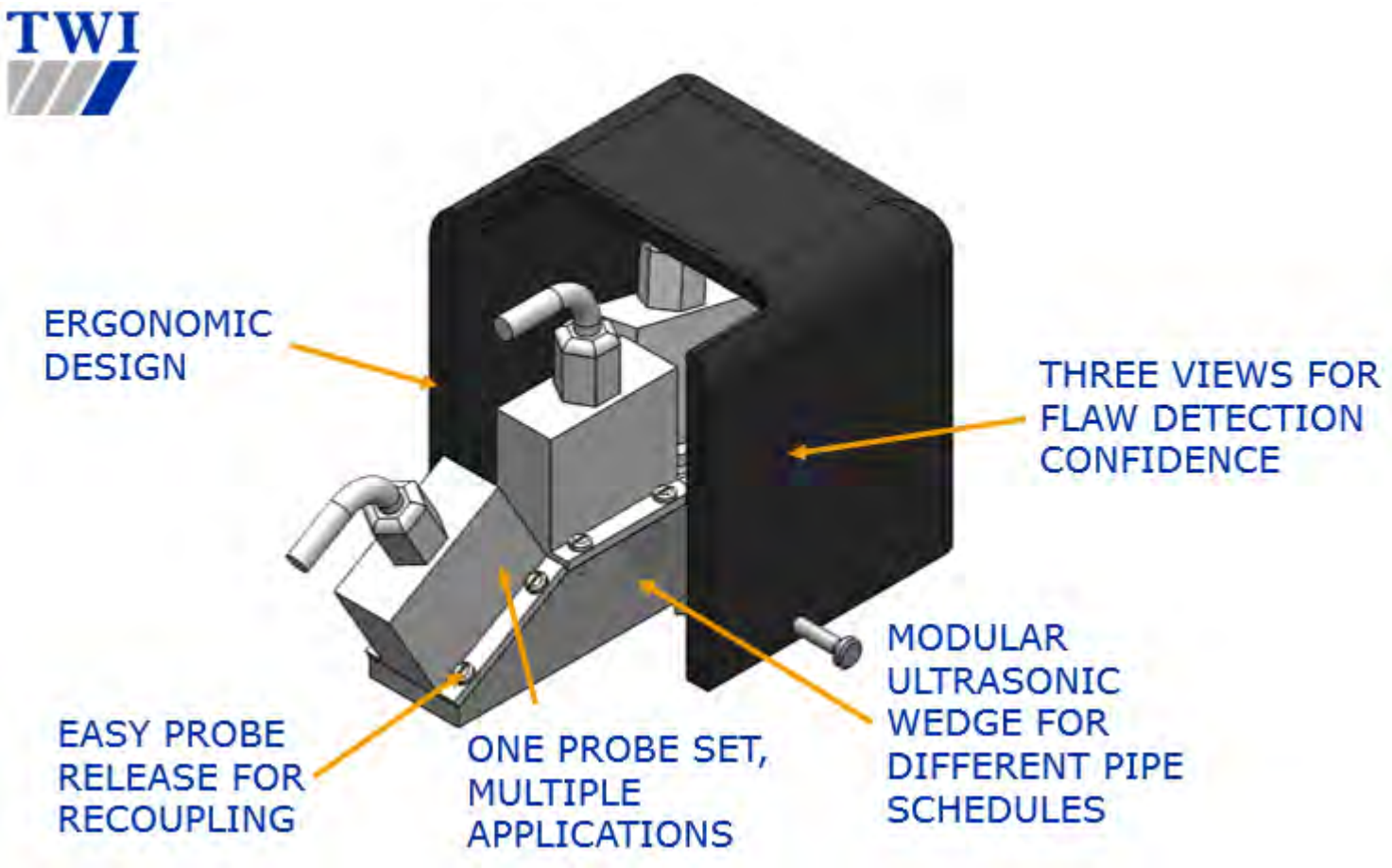
Outcomes of Phase 3 - General

- The tool was successfully validated using a statistical approach providing probability of detection (PoD) curves
- An inspection procedure for manual implementation by trained operators was created and validated in this project
- Ability to implant representative critical flaws in weld overlay cladding was demonstrated successfully by industry supplier
- The blind inspections by two independent operators showed that the tool can be used by industry certified personnel
- The specimens were made available to third-parties selected by the project team for additional technology development
- All flaws used for the statistical study (>120) were salami-sectioned to characterise their morphology and establish their true length for the statistical performance analysis

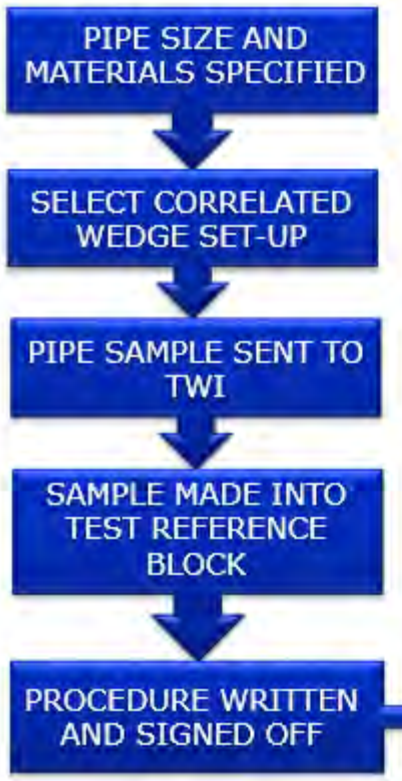
Outcomes of Phase 3 – Tool performance

- **Limitations:**
  - Type 1 flaws had satellite indications at edges
  - Type 2 and 3 flaws were notches with between 0.3 and 0.5mm gape
- **Type 1 flaws were detected with high reliability**
  - Both operators achieved over 90% PoD with a confidence of 95%
  - Shear and Normal were the primary detection channels
- **Type 2 flaws were detected with good reliability for lengths >5mm**
  - Both operators achieved over 90% PoD with a confidence of 95%
  - Normal and TRL were the primary detection channels
- **Type 3 flaws were less readily detected**
  - For 5mm long flaw both operators achieved 50% PoD using TRL channel
  - For 5mm long flaw one operator achieved 60% PoD but the other only 7% PoD using Shear channel
- **The length of a 10mm long flaw could be undersized with a mean error up to 2.1mm with a standard deviation of up to 3mm**

CladView™ – Clad and Lined Pipe Inspection



CladView™ – Modular approach to pipe schedule

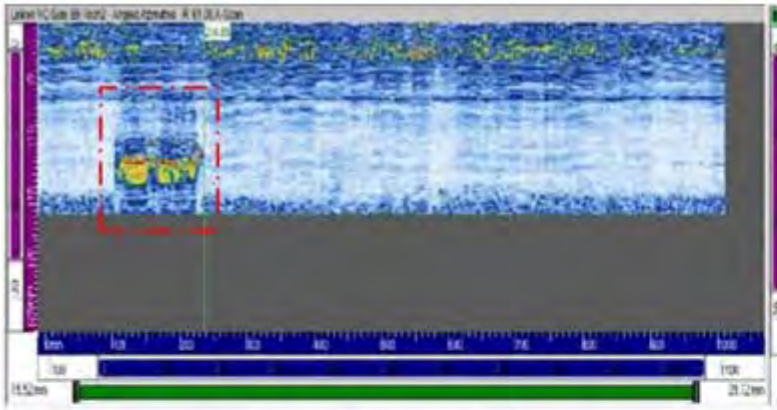


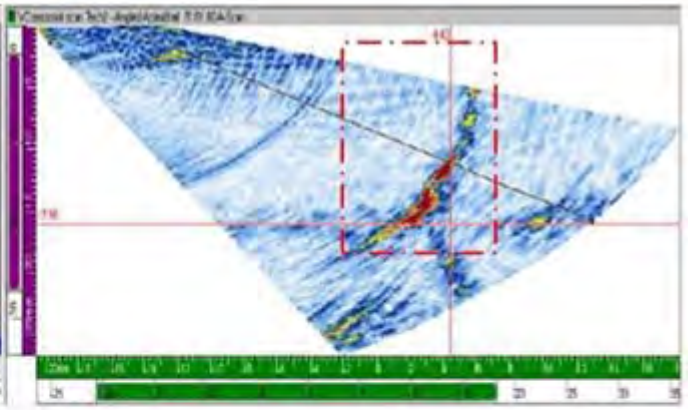
OUTER DIAMETER		WALL THICKNESS EXCLUDING CLADDING (mm)														
INCHES	mm	7.0	8.5	10.0	12.0	14.0	15.0	16.0	17.0	18.5	20.0	22.0	23.5	25.0	27.0	30.0
6.625	168	1-A	1-A	1-A	1-A	1-A	1-A	1-A	1-B	1-B	1-C	1-C	1-C	1-C		
7.800	198	1-A	1-A	1-A	1-A	1-A	1-A	1-A	1-B	1-B	1-C	1-C	1-C	1-C		
8.000	203	2-A	2-A	2-A	2-A	2-A	2-A	2-A	2-B	2-C	2-C	2-C	2-C	2-C		
8.375	213	2-A	2-A	2-A	2-A	2-A	2-A	2-A	2-B	2-C	2-C	2-C	2-C	2-C		
8.625	219	2-A	2-A	2-A	2-A	2-A	2-A	2-A	2-B	2-C	2-C	2-C	2-C	2-C		
9.300	236			2-A	2-A	2-A	2-A	2-A	2-B	2-C	2-C	2-C	2-C	2-C		
9.700	246			2-A	2-A	2-A	2-A	2-A	2-B	2-B	2-B	2-B	2-B	2-B		
10.000	254			2-A	2-A	2-A	2-A	2-A	2-B	2-B	2-B	2-B	2-B	2-B	2-D	2-D
10.300	262			2-A	2-A	2-A	2-A	2-A	2-B	2-B	2-B	2-B	2-B	2-B	2-D	2-D
10.500	267			2-A	2-A	2-A	2-A	2-A	2-B	2-B	2-B	2-B	2-B	2-B	2-D	2-D
10.750	273			3-A	3-A	3-A	3-A	3-A	3-B	3-B	3-B	3-B	3-B	3-B	3-D	3-D
12.500	317			3-A	3-A	3-A	3-A	3-A	3-B	3-B	3-B	3-B	3-B	3-B	3-D	3-D
12.750	324			3-A	3-A	3-A	3-A	3-A	3-B	3-B	3-B	3-B	3-B	3-B	3-D	3-D
13.500	343			3-A	3-A	3-A	3-A	3-A	3-B	3-B	3-B	3-B	3-B	3-B	3-D	3-D
14.000	356								4-B	4-B	4-B	4-B	4-B	4-B	4-D	4-D
15.000	381								4-B	4-B	4-B	4-B	4-D	4-D	4-D	4-E
16.000	406								4-B	4-B	4-B	4-B	4-D	4-D	4-D	4-E
17.750	451								4-B	4-B	4-B	4-B	4-D	4-D	4-D	4-E
18.000	457								4-B	4-B	4-B	4-B	4-D	4-D	4-D	4-E

Table 1: Pipe dimensions to wedge configuration

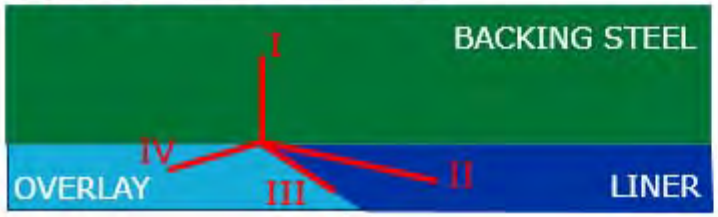
DELIVERY OF TOOL, PROCEDURE, REFERENCE BLOCK AND OPERATOR TRAINING

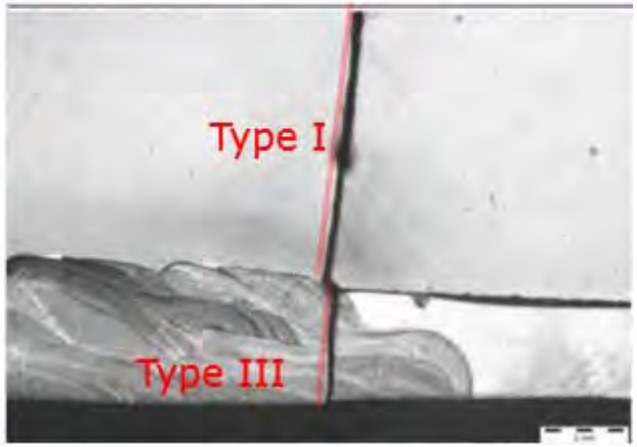
CladView™ – Lined Pipe Inspection





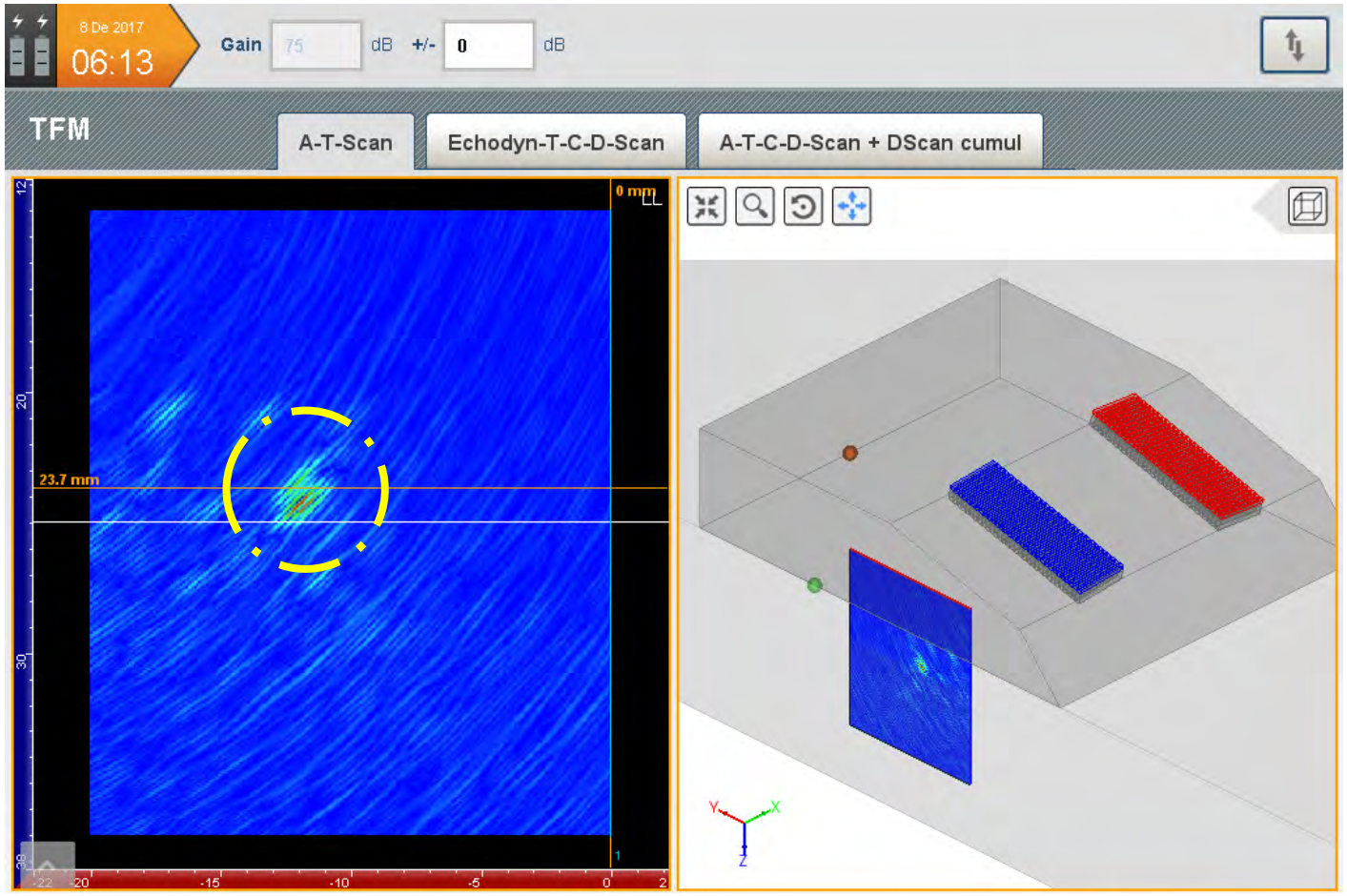
Type I – Into backing steel
Type II – Into liner
Type III – Along overlay to liner interface
Type IV – Into overlay





Johnston C, Nageswaran C and London T, '***Investigations into the Fatigue Strength of CRA Lined Pipe***', Offshore Technology Conference, OTC-27141-MS, 2016.

CladView™ – Multiple techniques in one tool - PAUT & FMC/TFM



SHEAR

NORMAL

TRL

Alloy 625 Weld Overlay Cladding in FMC/TFM

Phase 4?

- **Fabrication:**
  - Automate the inspection in pipe mills
  - Inspect online while cladding is being deposited
  - Test and implement automated defect recognition (ADR) algorithms
- **In-service:**
  - Inspection through coatings
  - Deployment on remotely operated vehicles (ROVs)

Questions?

- **TWI Project Team – Phase 3**
  - Harendra Kumar
    - *Experimental programme*
  - Charles Schneider
    - *Statistical analysis*
  - Ashley Spencer
    - *Validation programme*
  - Diane Shaw
    - *Validation programme*
  - Channa Nageswaran
    - *Project management*

- **PRCI Project Team - Phase 3**
  - Rafael Wagner F. dos Santos
    - *Petrobras, Team Lead*
  - Michael Grimes
    - *Exxon Mobil*
  - Mario Macia
    - *Exxon Mobil*
  - Robert Rettew
    - *Chevron*