Corrosion Growth Rates

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Background: External Corrosion of Pipelines

- On average, pipelines corrosion rates are low
  - Typical soils and effective CP produce rates <1mpy
  - Challenge is to find the exceptions
- Corrosion rates are segment-specific
- Corrosion rates are distributed
  - Environment is heterogeneous
  - Isolated mechanisms (i.e., not O_2)
    - MIC, Stray Current, AC, Crevice, etc.
  - Stochastic component to corrosion
- Leak vs. rupture
  - Depth vs. width
  - Coalescing of damage

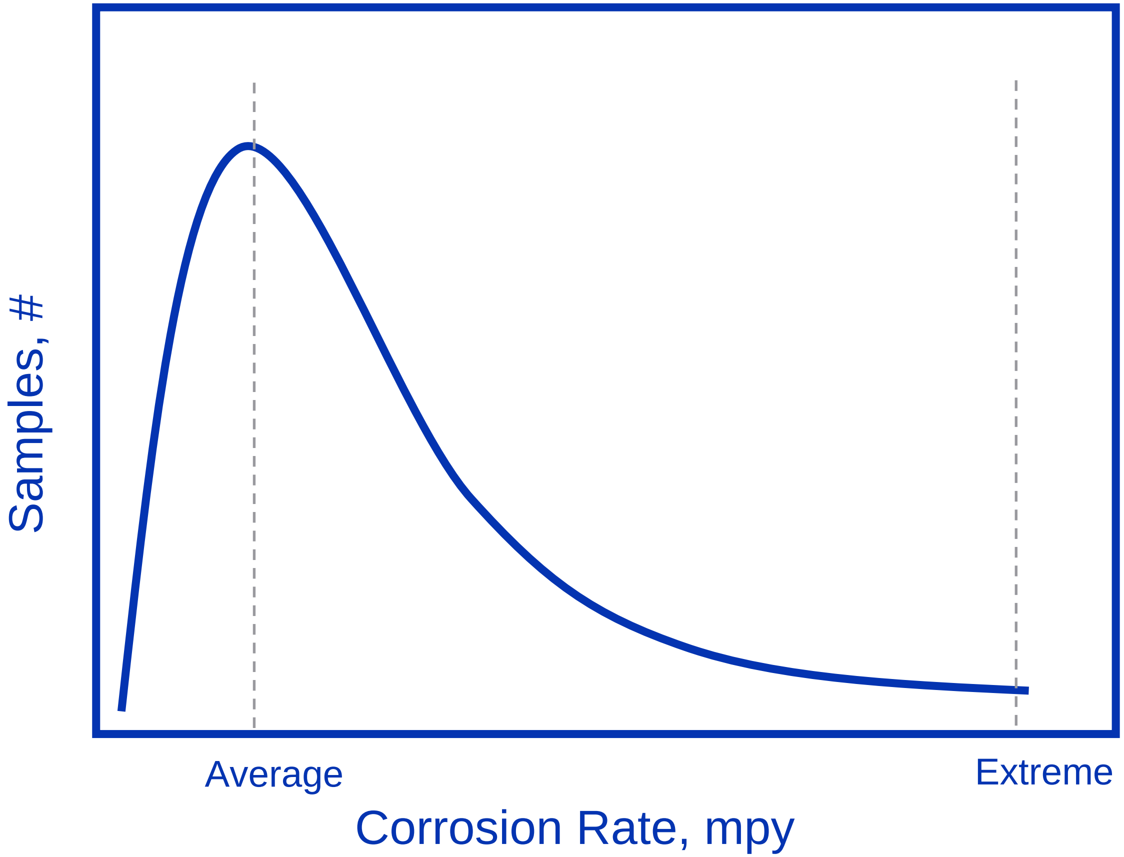
Predicting Corrosion Growth Rates

- Default
  - Value higher than most pipelines experience
- Perform Analogue Tests
  - Expose samples and measure loss
    - Correct mechanism
    - Accurate simulation of environment
    - Sometimes accelerate tests
    - Account for mitigation
- Experience
  - Previously identified damage
  - Single flaw over time
- Develop Model
  - From test results or experience
  - From 1st principles
- Measure at flaw
  - Depth
  - Chemical sampling for model input
  - Electrochemically (e.g., LPR)

Predicted Rate in Context of Average & Distribution

- On average, pipelines do not fail
- Average rate is low, but what is likelihood of extreme value?

All pipelines, segment, or specific site



Use of Single Value for Rate

- Default values (e.g., 4mpy, 7mpy, 12mpy, 16mpy)
  - Unnecessarily conservative most of the time
  - Are not pipeline-specific
  - Do not identify extreme values
- Increasing default values (e.g., as safety factor) does not significantly help identify possible failure locations

Conclusion

- Use a rate reflecting corrosion typical of pipeline segment
  - Default, model, tests, sampling, etc.
- Evaluate likelihood of extreme value at anomaly of interest

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Drew Hevle
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Pipeline and Hazardous Materials Safety Administration
Anomaly Assessment and Repair Workshop

Wednesday, October 22, 2008

Determining corrosion rates

Industry Standards

- NACE SP0502 ECDA Methodology
  - The NACE standard gives several methods for determining external corrosion rates for assessed segments
    - Measuring wall thickness changes over time interval
    - Consideration of corrosion history of segment or like/similar segments
    - Linear Polarization Resistance (LPR) measurements
    - Electrical resistance (ER) probe measurements
    - Gravimetric corrosion coupons
    - Statistically valid methods based on data
    - Estimating corrosion initiation time
    - Consideration of the soil characteristics and environment to determine its corrosiveness
    - Default pitting rate
  - The reassessment interval is based on the half-life of this growth rate

Determining corrosion rates

Industry Standards

- Other NACE standards and reports give procedures for the various methods of field measurement
  - Publication 3T199 Techniques for Monitoring Corrosion and Related Parameters in Field Applications
  - Publication 05107 Report on Corrosion Probes in Soil or Concrete
  - RP0104 The Use of Coupons for Cathodic Protection Monitoring Applications
  - SP0206 Internal Corrosion Direct Assessment Methodology for Pipelines Carrying Normally Dry Natural Gas

Theory versus Practice

In theory, there is no difference
between theory and practice.
But, in practice, there is.

- Jan L.A. Van De Snepscheut.
Or Albert Einstein.
Or, Yogi Berra.

Determining corrosion rates

Industry Standards

- The best method for determining corrosion rates is by directly comparing measured wall thickness changes after a known time interval, such as excavation and examination, or inline inspection
- The next most accurate method for determining corrosion rates is by measuring the corrosion rate of the material in situ (in the environment)
- The next most accurate method is by measuring coupons or corrosion in similar conditions such as statistical data
- The next most accurate method is by estimating the corrosion rate based on corrosion initiation or models
- The least accurate method is by using a default rate

Determining corrosion rates

Industry Standards

- If adequate cathodic protection levels are maintained, under normal conditions the corrosion rate is effectively zero
- Any external corrosion defects discovered either:
  - occurred prior to the application of effective CP, or
  - are experiencing abnormal conditions (corrosion despite meeting CP criteria)
- Many of the methods in SP0502 are not valid for these conditions
- Selecting a 2σ or 3σ pitting rate from bare coupons without CP would be non-conservative in these instances

Determining corrosion rates

Industry Standards

- It is not possible to talk about corrosion growth rates in the real world without considering
  - Corrosion mechanisms
  - Levels of cathodic protection
  - Environmental factors
- It is not possible to talk about the risks of average corrosion growth rates without considering
  - Localized versus general corrosion
  - Size and shape of existing defects
  - Characteristics and operating conditions of the pipe

Theory versus Practice

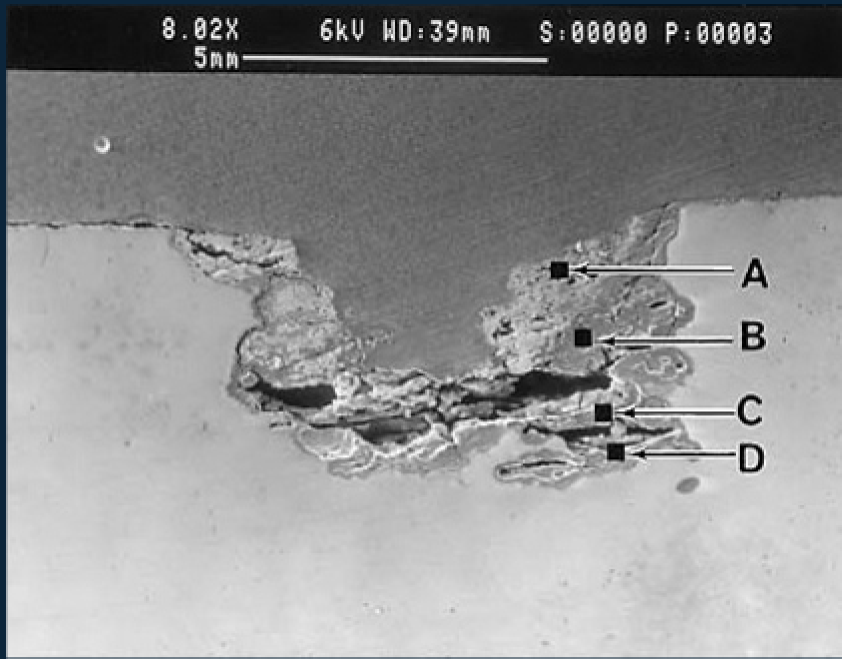
Every experiment destroys some of the knowledge of the system which was obtained by previous experiments.

- Werner Heisenberg

Determining corrosion rates

Industry Standards

- Corrosion defects are not always nice parabolic shapes
- Average corrosion rates can be very misleading, corrosion rates change over time
- Even measuring the corrosion depth of a defect can be difficult
- Torture numbers, and they'll confess to anything
- 98% of all statistics are made up



Determining corrosion rates

Industry Standards

- It is impossible to select a sufficiently high average corrosion rate to meet all possible conditions
  - 10 mpy? 100 mpy? 1000 mpy?
- Selecting a sufficiently high corrosion rate to meet an acceptable level of confidence would require an excessively conservative response for most anomalies
- This would take resources away from other integrity risks

Determining corrosion rates

- A little bit of information many times would allow an operator to rule out conditions that cause the outliers
  - Level of cathodic protection
  - Coating type and condition
  - Operating temperature
  - Past history
- From this information the operator could make a judgment as to the appropriate response to an anomaly

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Corrosion Growth Assessments Using ILI Data

Presenter: Kevin Spencer

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Estimating Corrosion Growth Rates

Internal Corrosion Rates

- Worst case estimates from theoretical models (e.g., deWaard & Milliams, Norsok…)
- Utilise monitoring data, weight loss coupons, probes, FSM...

External Corrosion Rates

- Prediction is complex
- Correlations available between soil corrosivity & corrosion rate
- Single ILI Run
- From deepest corrosion defect present
- Statistical treatment of corrosion dimensions

Repeat ILI Runs

- Monitoring corrosion development in repeat excavations/examinations
- ***Most accurate method available – can provide growth information at every corrosion site***

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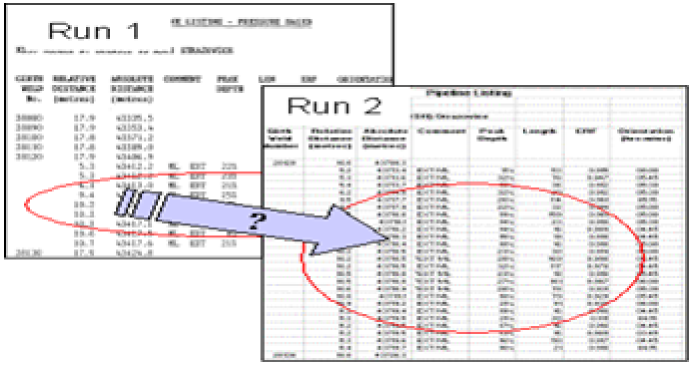
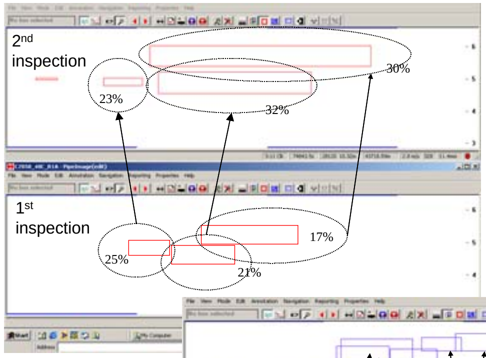
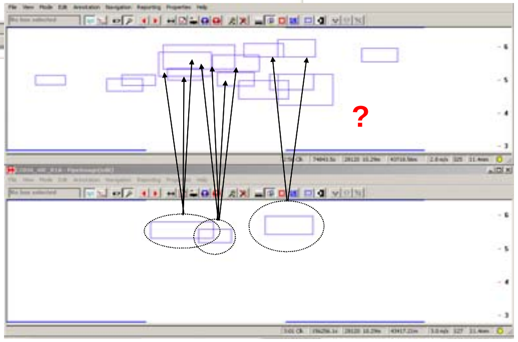
Corrosion Growth Rates from Repeat ILI Data

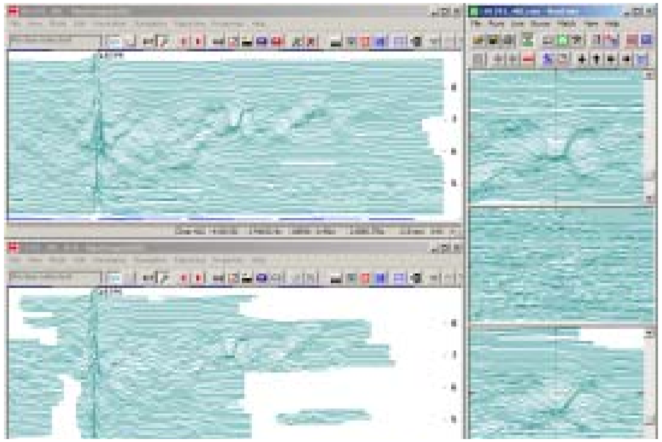


- Feature matching from spreadsheet data
- Feature matching using visual display software
- Box matching
- Signal matching (RunCom™)





Increasing level of accuracy



GE RunCom software

At least 3 times more accurate, >3 if matching difficult

“As reported” FEATURE matching e.g., any vendor data

2001 Report

Upstream Girth Weld	Relative Distance (feet)	Absolute Distance (feet)	Comment	Peak Depth (%wt)	Length (in)	Width (in)	Local Wall Thickness (in)	Steel Grade
	28.5	9019.3	EXT ML	26%	9.7	7.7	0.335	X52

2006 Report

Upstream Girth Weld	Relative Distance (feet)	Absolute Distance (feet)	Comment	Peak Depth (%wt)	Length (in)	Width (in)	Local Wall Thickness (in)	Steel Grade
	28.9	9019.6	EXT ML	29%	10.9	8.0	0.335	X52

Is this feature growing? … **doesn’t appear to be but**

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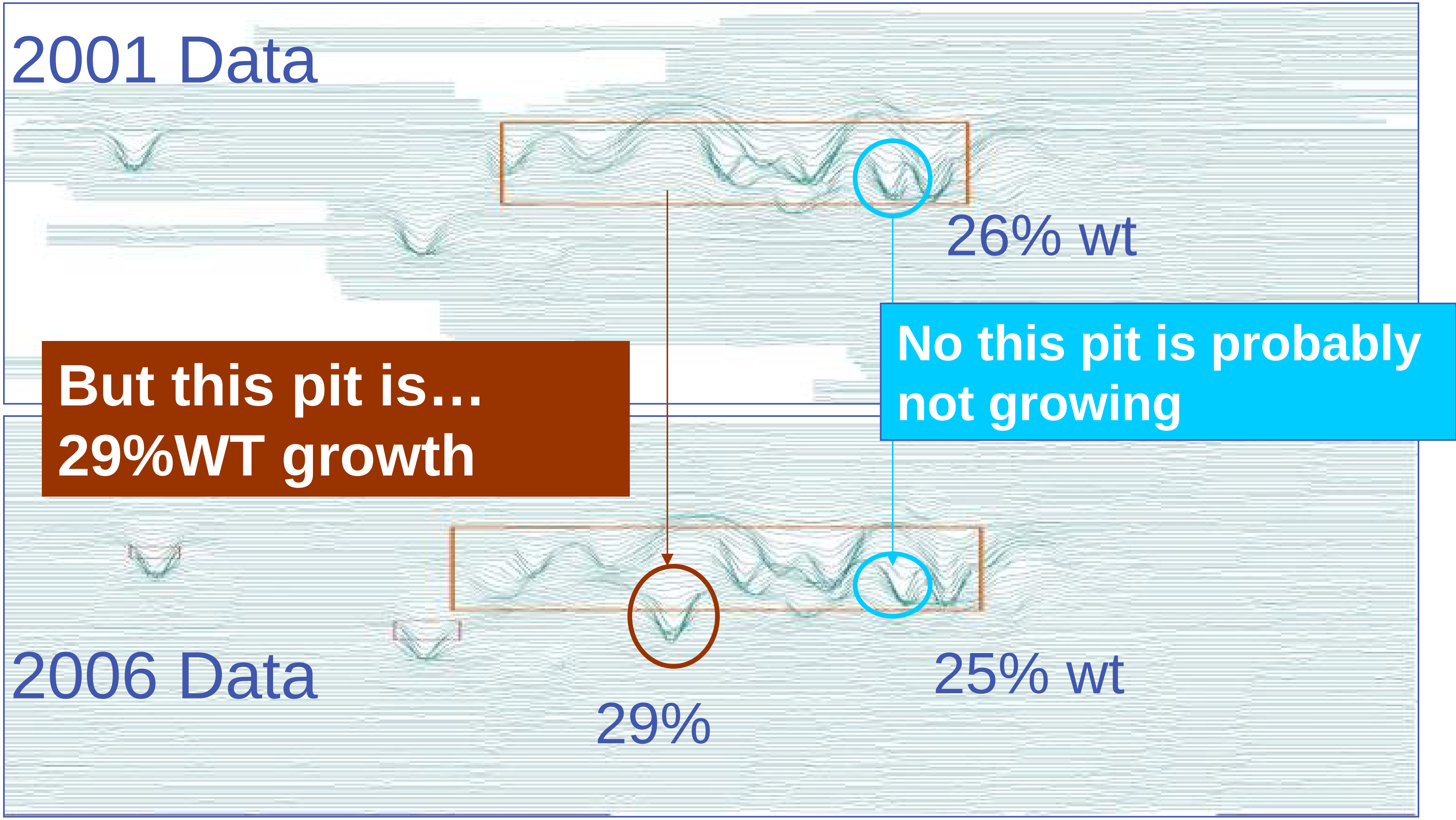
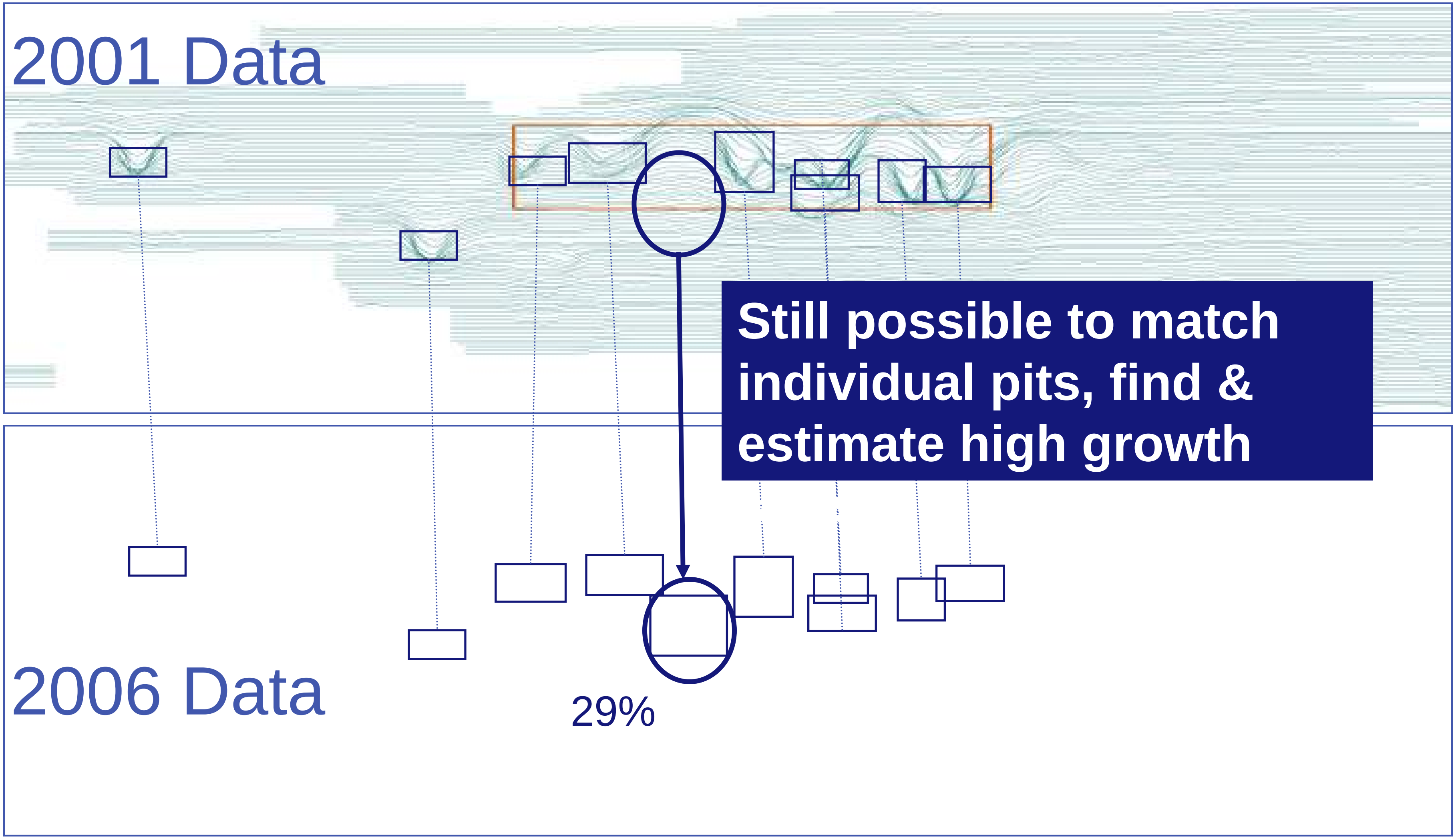
Vs. SIGNAL Matching with same vendor data



Signal matching is the most accurate method

Vs. BOX matching e.g., on different vendor data



Box matching possible even on different vendor data

Sources of Errors in Corrosion Growth Assessment

- Data matching errors effect
  - Feature matching as can’t access detailed pit information
  - Box matching to lesser extent due to differences in reporting between vendors
  - Can effect signal matching but usually only in poor quality or heavily thresholded data sets & can be manually adjusted

Least accurate

Most accurate

- Tool measurement tolerances, bias & repeatability error effect
  - Feature & box matching on different vendor data
  - Feature & box matching on same vendor data to a lesser extent as repeatability error is smaller
  - Signal matching on same vendor data – bias is minimized & repeatability error is much smaller than measurement tolerance

Least accurate

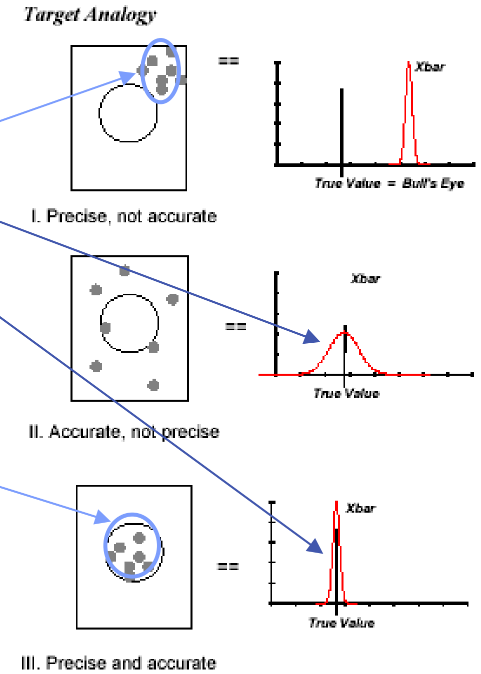
Most accurate

1st choice is signal matching, 2nd choice is box matching

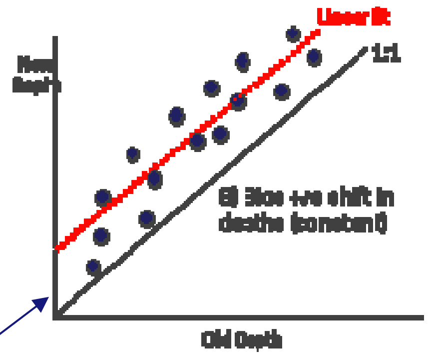
What do we mean by measurement tolerances, bias & repeatability?

Measurement tolerance is the difference between the predicted depth & actual defect depth, e.g., +/-10%wt 80% of the time

Repeatability is the ability to repeat a measurement with precision. This can be determined from either pull-test information or by comparing “static” defects in the line.

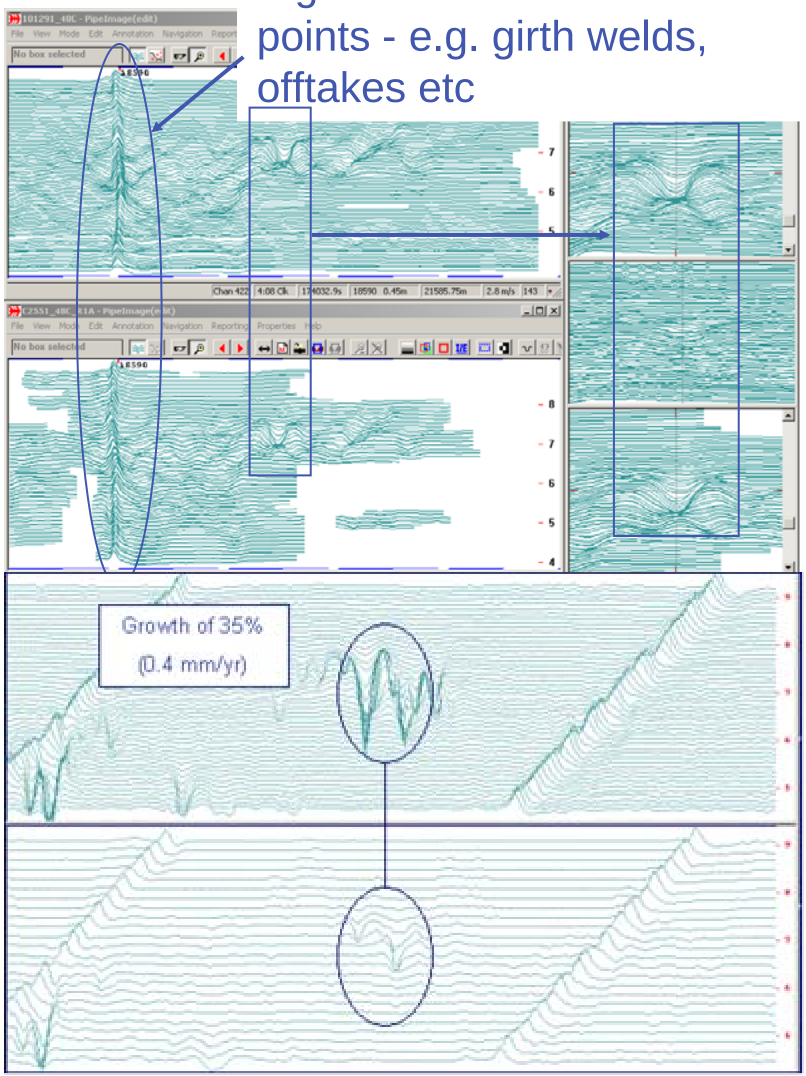


Bias is a systemic difference in the prediction of feature depth that is NOT associated with growth. This can be identified by comparing “static” defects (e.g., mill faults) & checking for deviations from 1:1 line e.g., as illustrated here.

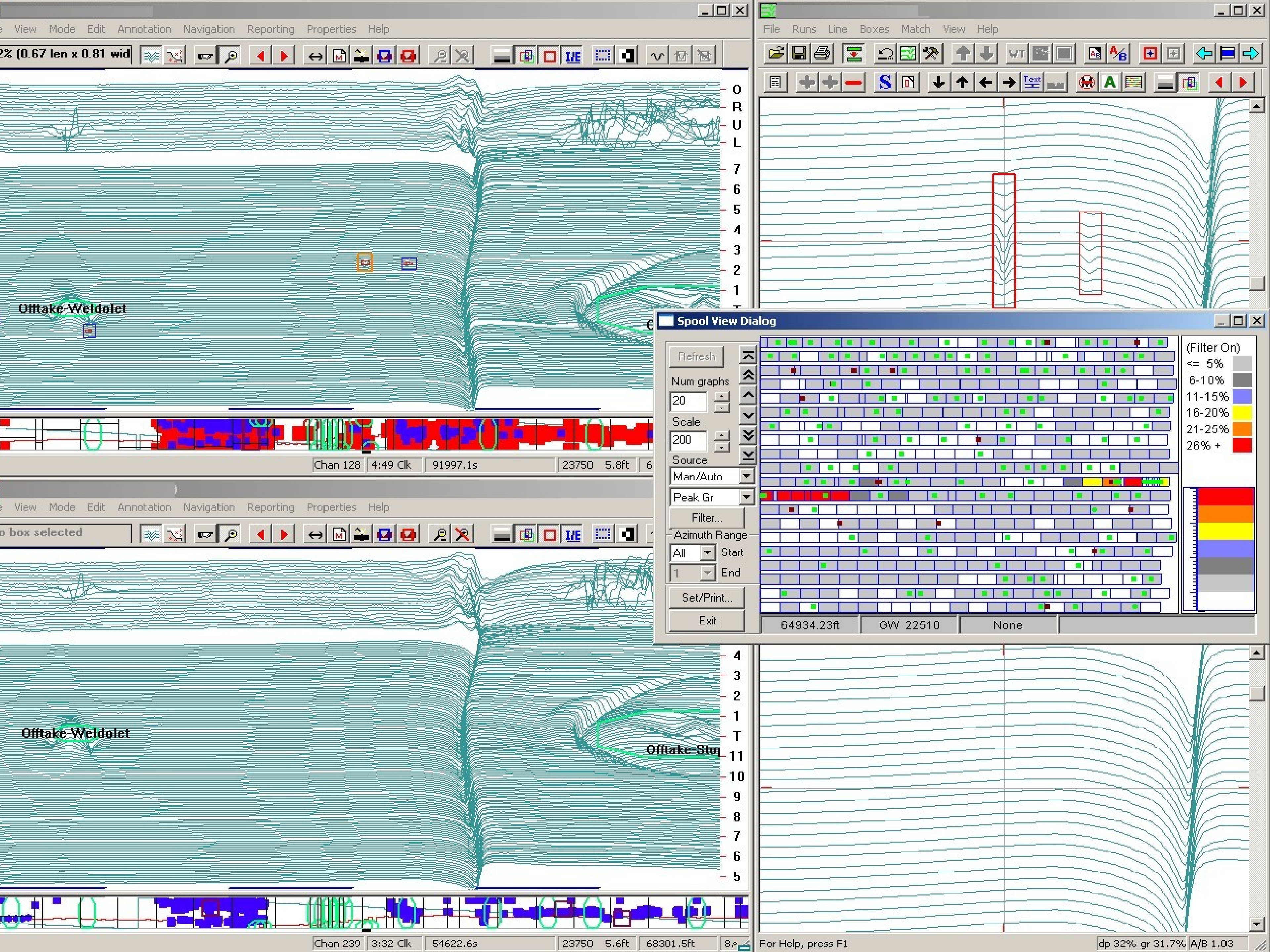


Repeatability & bias errors have biggest effect on ability to predict rates

MFL RunCom signal matching



- Automatic signal matching algorithm provides matches throughout entire pipeline.
- Signal scaling normalizes the data to minimize measurement and bias tolerances.
- Pull testing shows a 95% probability of success of correctly identifying growth above 5%wt change.



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Project Overview

Objective

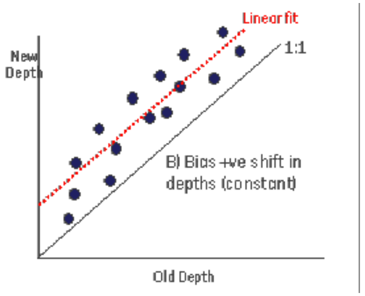
Develop a "user's guide" to assist operating companies in successfully **select, implement and validate a pipeline data-specific method** for determining corrosion growth rates using successive in-line inspection runs

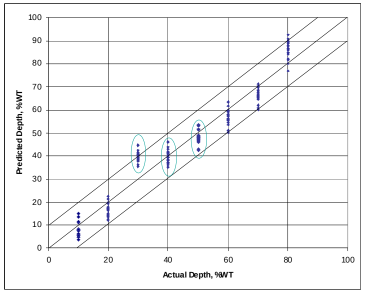
3 Step Process

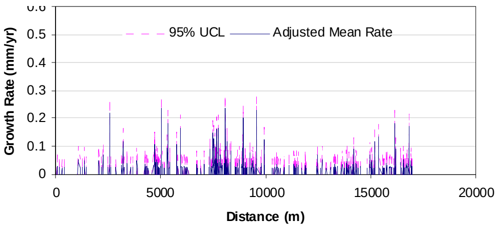
- Task 1 – Research Corrosion Growth Rate methodologies
- Task 2 – Develop User Guide
- Task 3 – Review, Testing & Validation

Key Project Highlights

- Effect of measurement uncertainty on growth rates addressed
- Uncertainty affected by measurement tolerance, repeatability and bias errors
- Process defined for determining uncertainties, to adjust observed rates & provision of confidence intervals
- Local growth methods particularly signal matching have much greater precision (important when looking for worst case rates & making individual repair decisions)
- Segment method is less precise & does not give individual defect rates but does “average out” uncertainty over the segment







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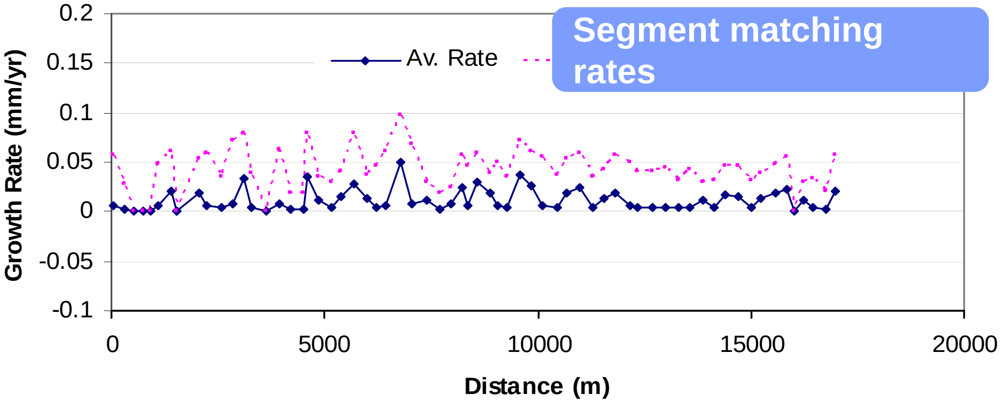
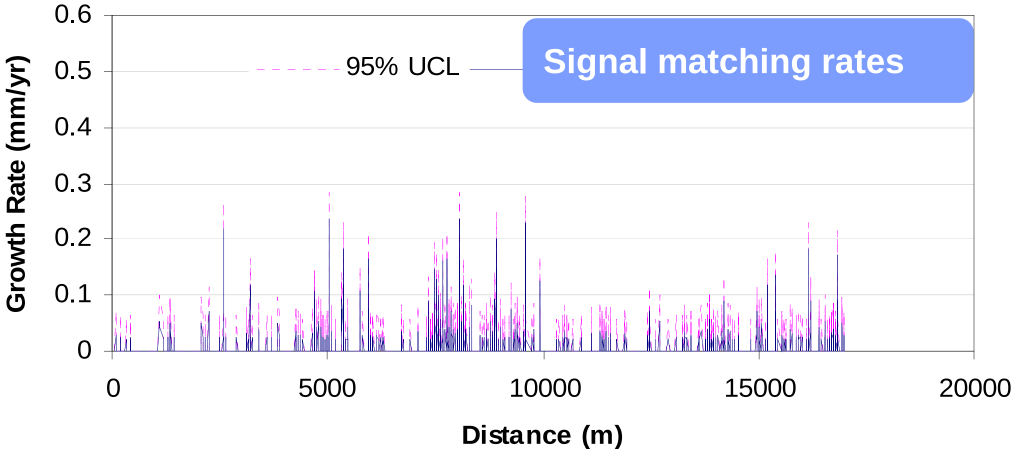
Segment vs Local Rates





- Peak growth rates 3 times less – segment method misses high localized rates
- Segment method is less precise & it does not give individual defect rates
- Local growth (signal & defect matching) methods have greater precision
- Important when looking for worst case rates & making individual repair decisions
- Segment method has advantage of “averaging out” errors & causing effect to diminish as no. of defects in segment increases

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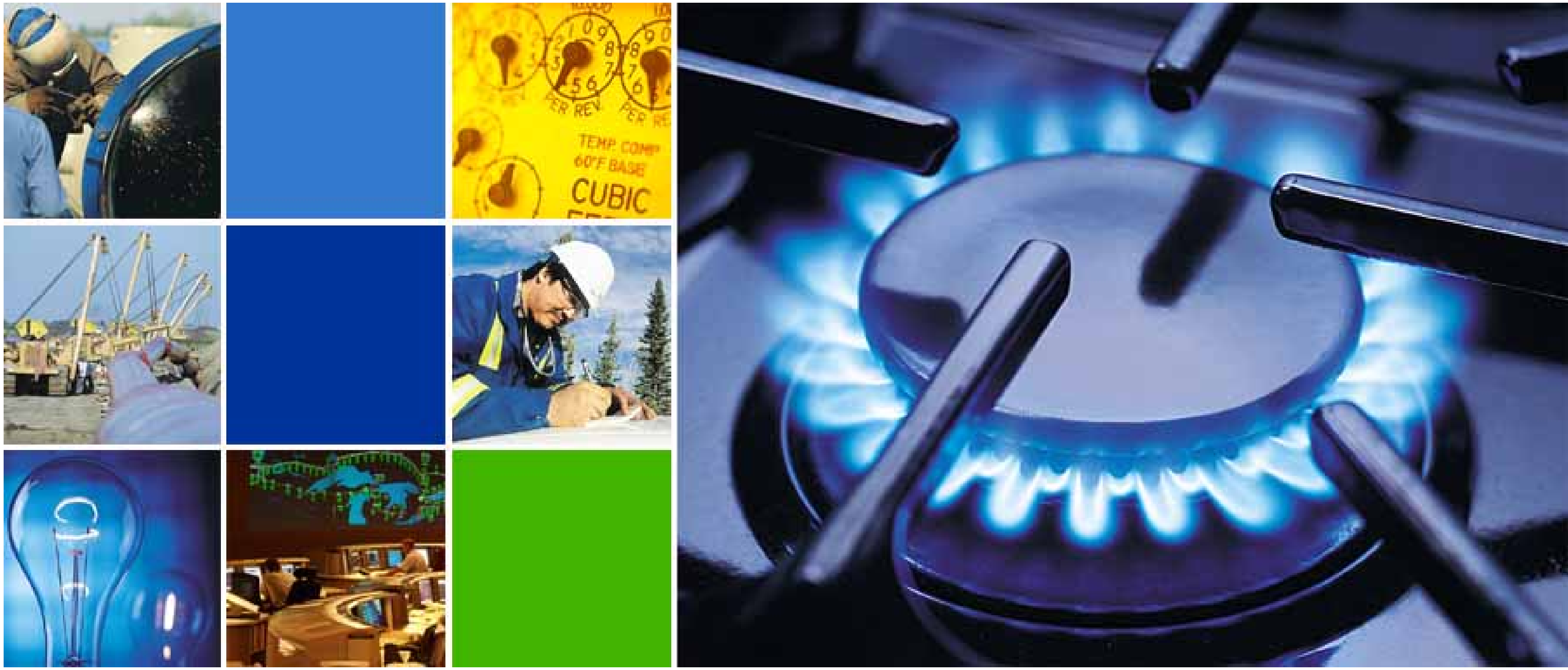
Conclusions

- ILI data can be used to accurately quantify corrosion growth rates along a pipeline.
- ILI data gives more accurate and relevant corrosion growth rates along a pipeline
- Hotspot areas of corrosion growth can be easily highlighted for mitigation activities.
- Local growth methods, particularly signal matching, have greater precision (compared to segment) as measurement errors are minimized.
- PRCI Project EC 1-2 provides detailed information and user guidelines for best practices for application of approach.



Accounting for Corrosion Growth Rates TransCanada Experience

Shahani Kariyawasam

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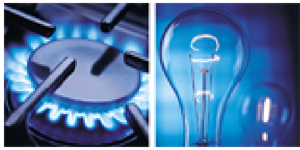
Understand the Threat and Technology Needs



- Corrosion growth (esp. extremes) is **complex** process
  - General nature understood
  - High variability in location specific severity & growth

- Measure growth - Require **defect sizes**, their locations, and **growth rates**
  - **ILI based assessment**
  - Threat Management; preventative maintenance

- Estimate growth - Predict ranges, **segment specific values**
  - **Mechanistic methods** can **predict** based on operating conditions
  - Risk ranking, DA

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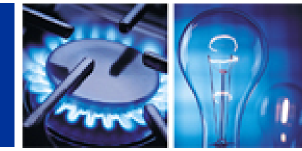
Estimating Corrosion Growth Rates

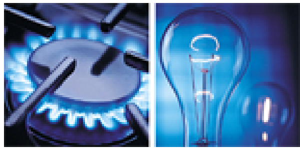


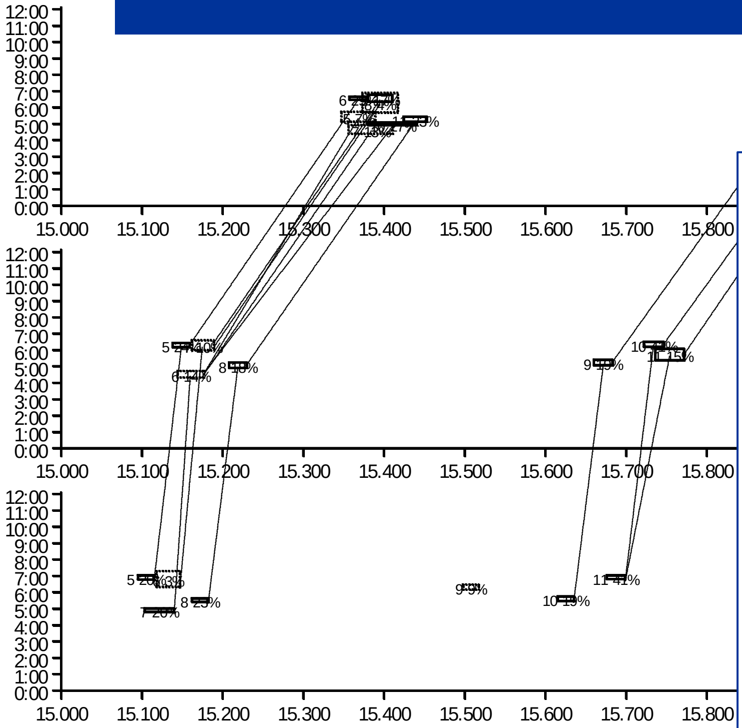
More accurate

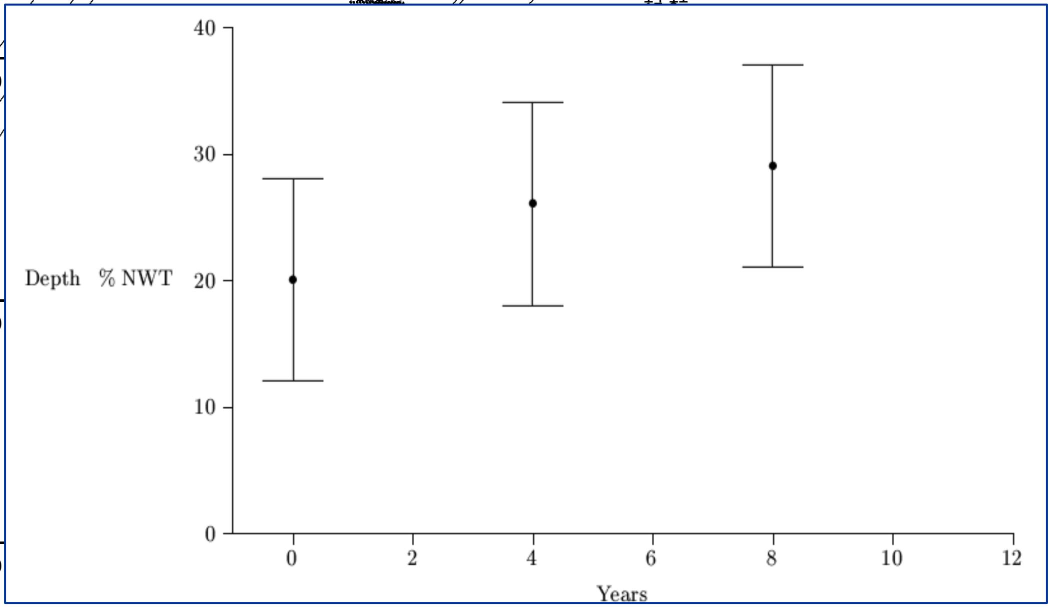
- Methods to assess corrosion growth rate
  - **Multiple ILI runs** – Run comparison (Signal or Box matching)
  - **Single ILI runs** – initiation time estimates and learning from multiple runs
  - **No run** – Mechanistic methods, rates from similar pipelines

- **Understand technology** – strengths & limits of applicability
  - **Growth is extrapolating past rates to future**, similar to predicting weather further out you predict the higher the uncertainty.

Triple Run ILI







- Multiple runs can be used to determine non linear growth behavior
- However in this case the triple run is with box data
- Error too large to confirm non-linear growth

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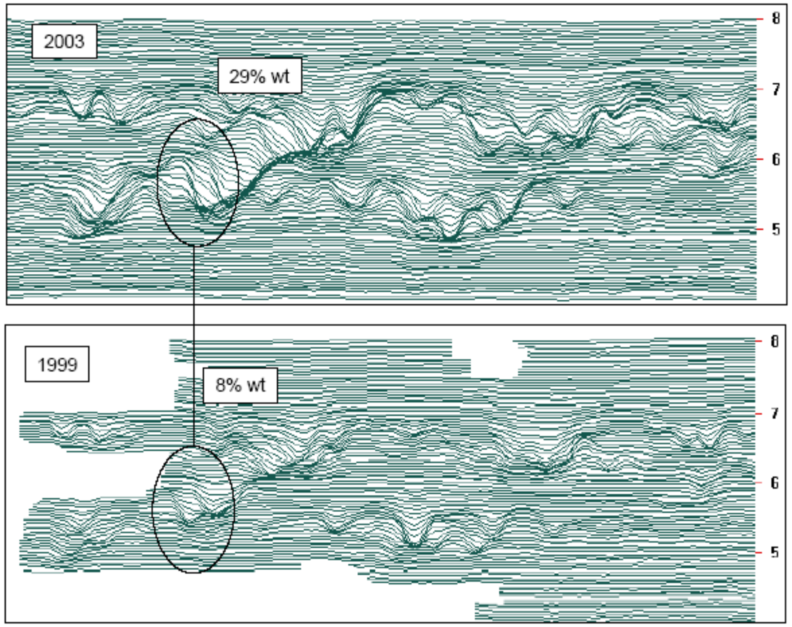
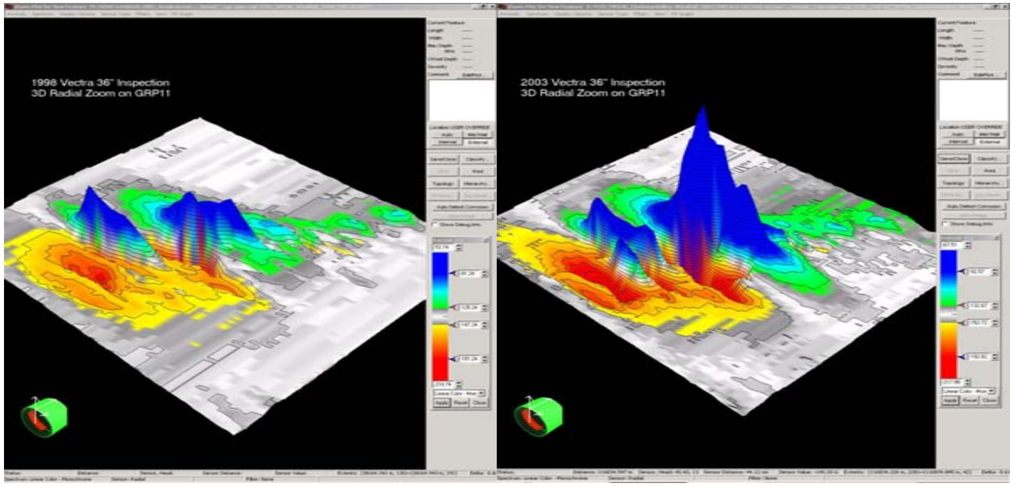
Two run - signal matching





- Can obtain **defect specific growth rates**
- Errors ~ 5% WT
- Highly accurate defect growth rates to apply to rupture and leak criteria
- Assumes linear growth

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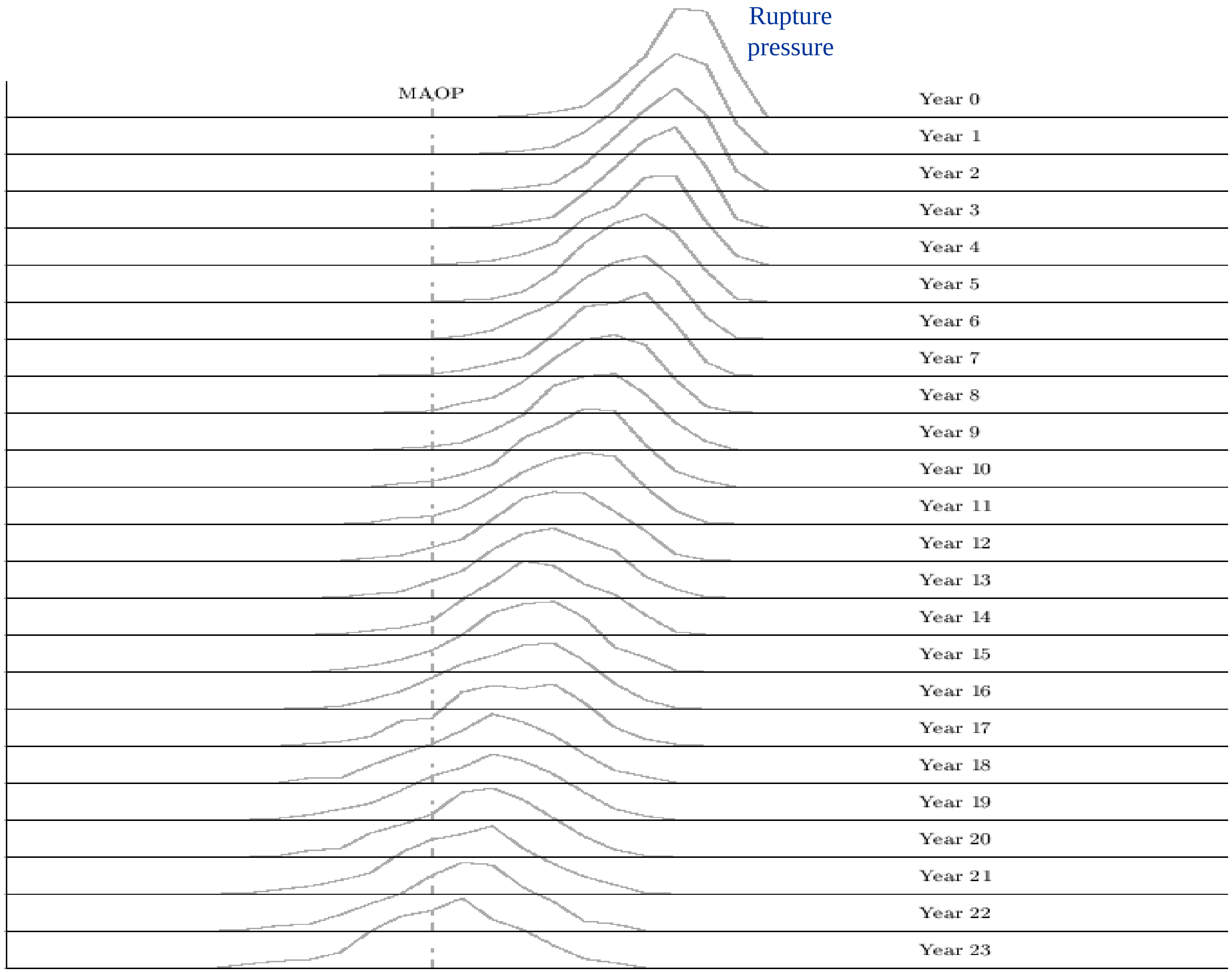
Effect of corrosion growth on Prob. of Rupture



- With time, rupture pressure decreases and uncertainty increases
- Similar assessment for Prob. of leak with wall thickness and max defect depth

Learning from multiple runs apply to single runs

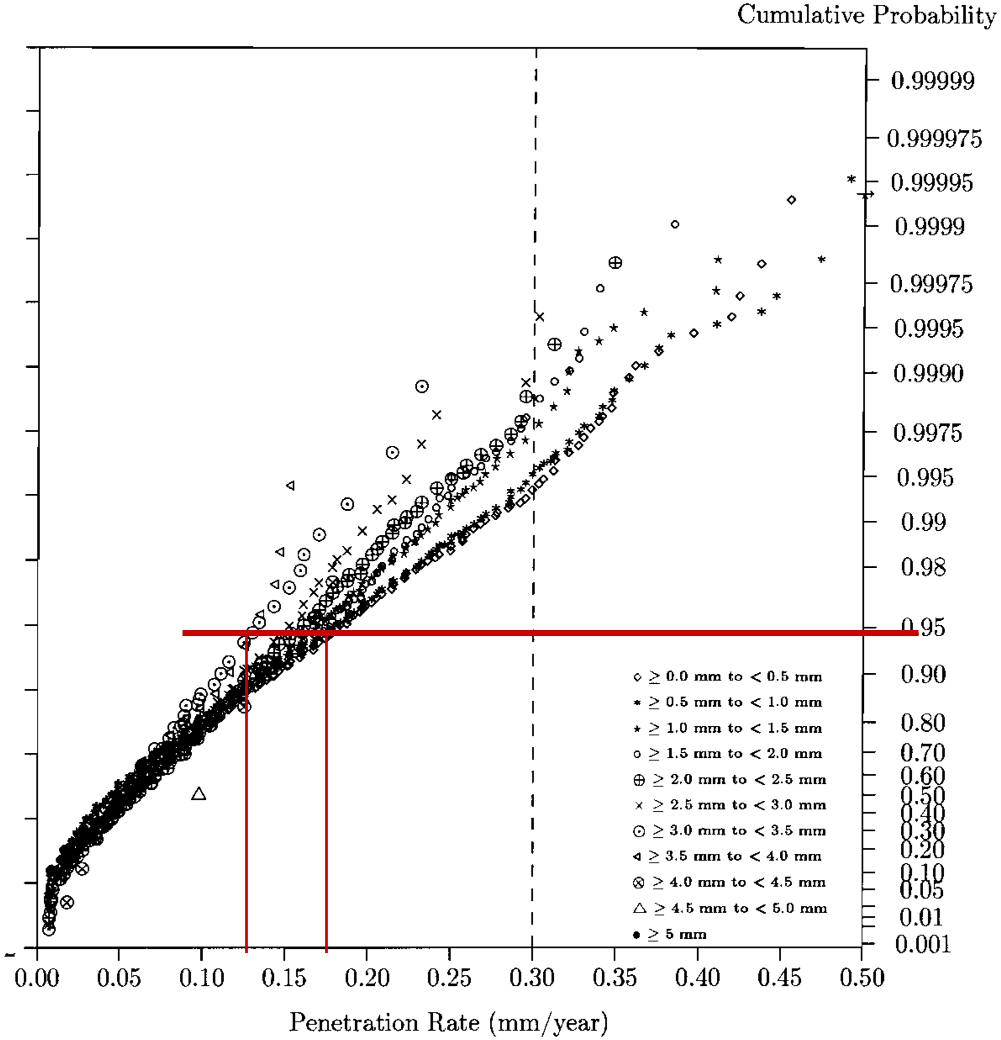
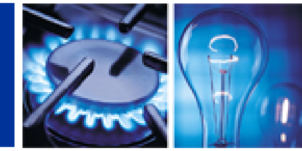


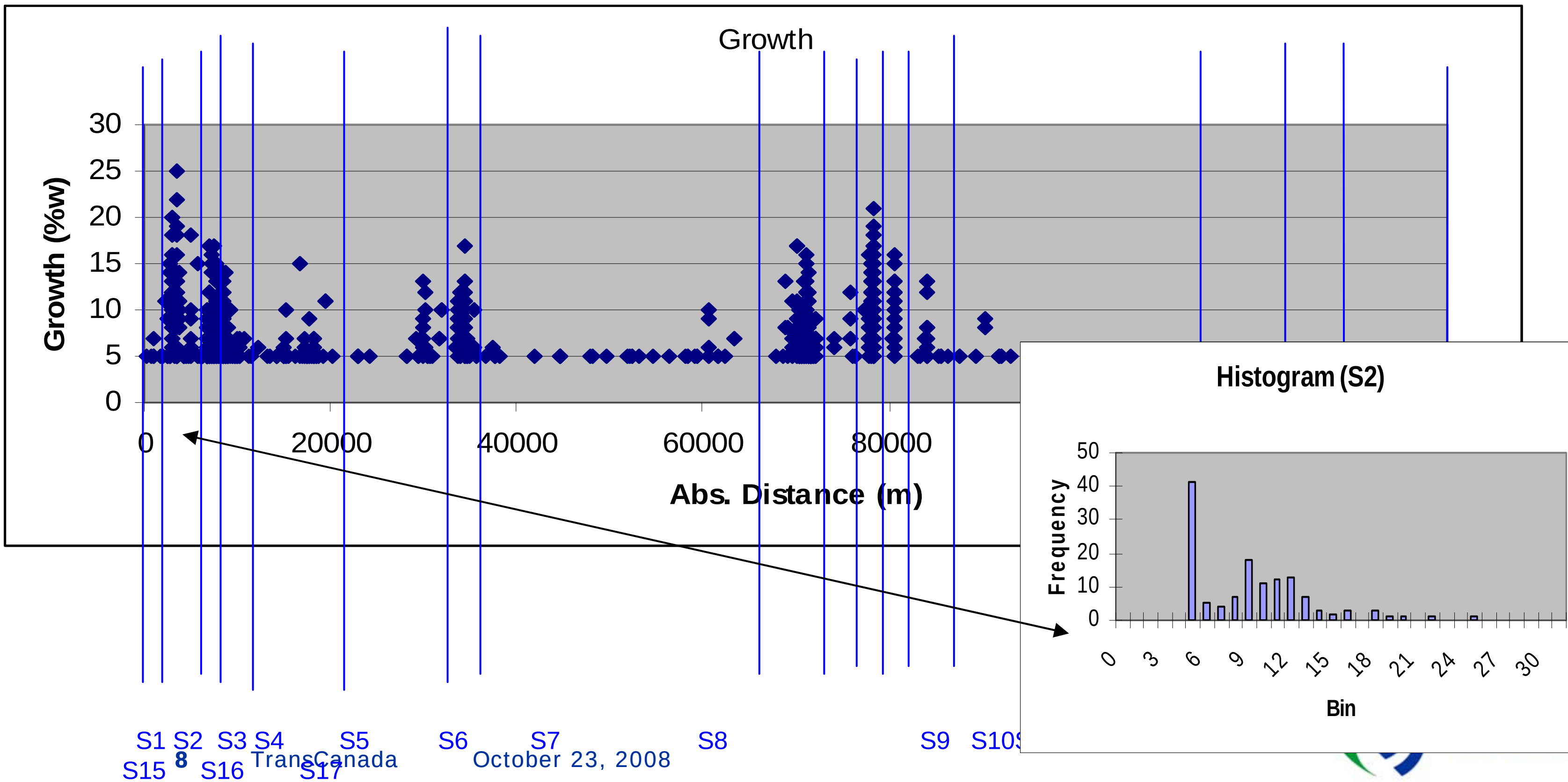
Figure 2.2: Growth Rates for Triplets on All PRML—Grouping Based on 1986 Penetrations

- Growth rates for different size categories
- Smaller defects grow faster

Learning from multiple runs apply to single runs

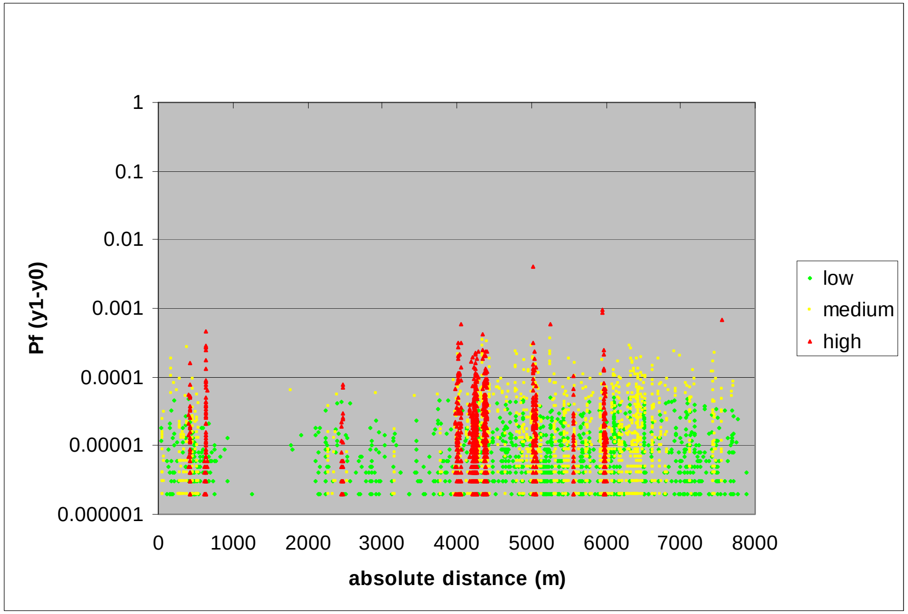


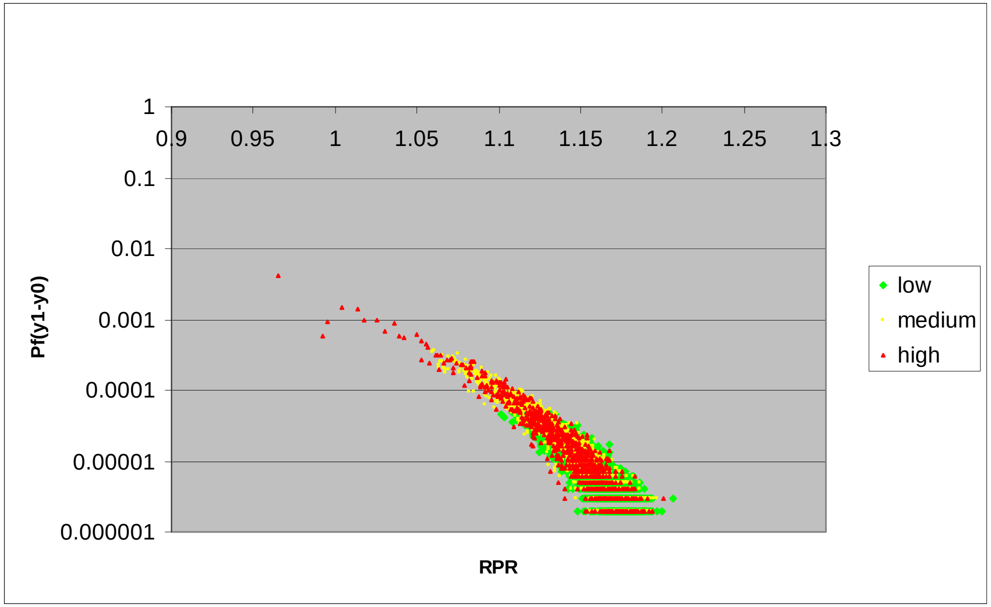
- Growth distributions by segments – aggressive to mild segments
- Correlation of quantitative growth rates with operating conditions



Single Run Growth Rates

- Not all defects are growing aggressively
- Identify “bad neighborhoods” – aggressive to mild
- Base also on similar segments
- Use conservative **segment specific growth** rate distributions



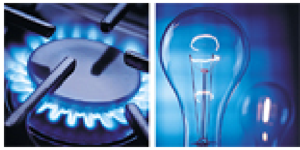


No Run Growth Rates – For Hydro and DA

- Identify and manage unusual conditions – MIC, CP interference, conditions that affect coating
- **Mechanistic methods and indirect surveys** can **predict** based on operating conditions
- Utilize learning from multiple runs –similar pipelines
- Used for **prioritizing or ranking, Hydro tests, DA**
- Predict approx. ranges, pipeline or **segment specific values**



In Conclusion



- Pipeline industry understands
  - Corrosion mechanisms and its variability
  - Available technologies and processes to detect and estimate corrosion growth
  - Strengths of each technology and process
  - Limitations of technology and appropriate response
- Continue to research and improve understanding

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Thank you

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