Internal Corrosion Assessment of Pipelines – Status and Issues

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Presentation to PHMSA

August 31, 2006

Background and Objectives

- A number of research programs has been funded by PHMSA in cooperation with industry to address internal corrosion
- A comprehensive internal corrosion health management strategy is still needed
- The objective of the presentation is to review the state of internal corrosion research and identify gaps

PHMSA IC Research Efforts

- Location of potential corrosion sites along a pipeline - SwRI, CC Technologies, Electricore
  - Internal corrosion direct assessments (ICDA) for dry gas, wet gas, and liquids –Corrosion rate prediction is not the focus- only locating potential sites of water drop out and relative corrosion severity ranking using subjective weighing factors
- Reassessment interval estimation - SwRI
  - Mostly focused on external corrosion rate modeling
  - Smaller effort on internal corrosion rate modeling – limited because of available resources to CO_2 and O_2 effects
- Corrosion monitoring and sensing – SwRI, CC Technologies
  - Mobile sensors for water detection
  - Multielectrode array sensor for measuring internal corrosion rate in gas and liquids pipeline

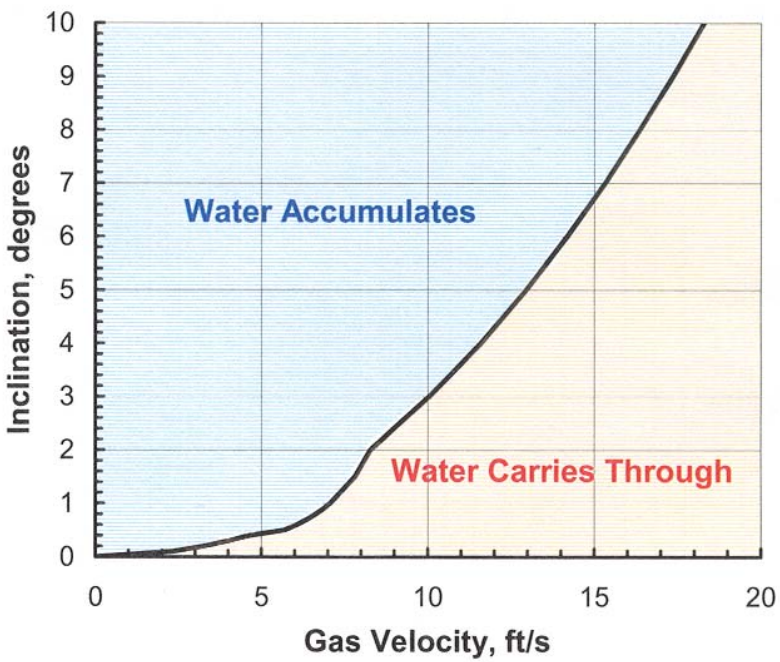
Industry-Funded Research Efforts

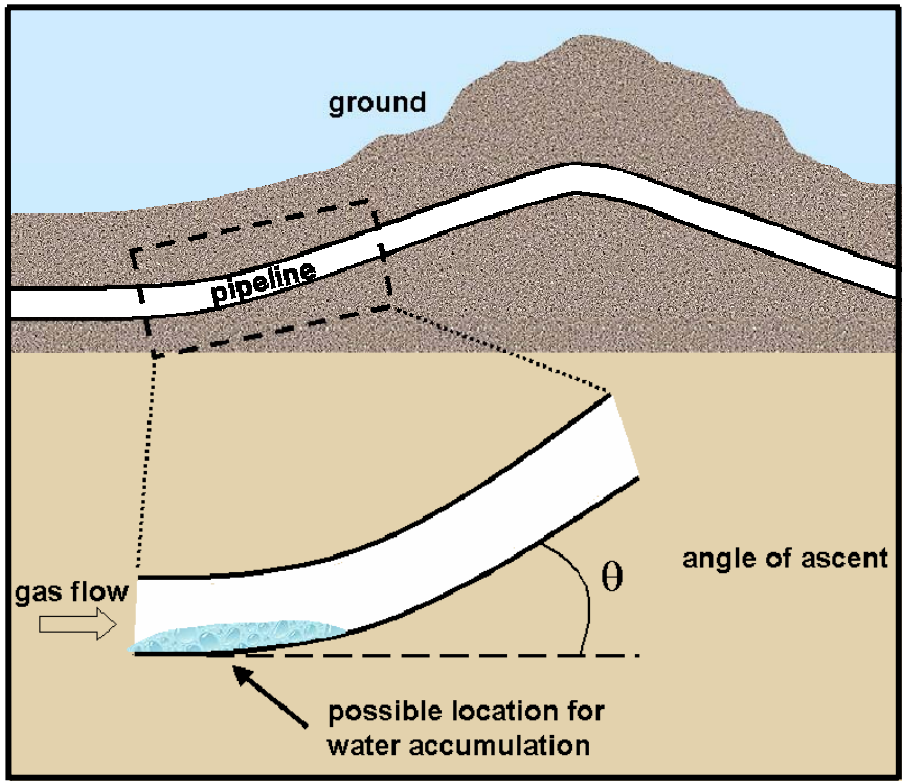
- Effect of gas composition on corrosion in gathering lines (PRCI funding – SwRI)
- Effect of water chemistry on corrosion in gathering lines (PRCI funding – SwRI)
- Effect of bacteria on internal corrosion (PRCI funding – SwRI, Exponent)
- Effect of solids and biofilm on dewpoint corrosion (PRCI funding – SwRI)
- Guidelines/quality standards for transportation of gas (PRCI funding – SwRI)
- Effect of condensate on internal corrosion (PRCI – Canmet)
- Mobile sensors for corrosion detection (SwRI)
- Modeling CO_2 corrosion – Considerable body of work
  - Empirical and mechanistic models (e.g., DeWaard et al., others
  - Often embedded in proprietary software
- Modeling CO_2, H_2S, and O_2 corrosion – more limited research
  - Empirical and mechanistic models
  - Embedded in proprietary software (e.g., OLI Systems Corrosion Analyzer)

Locating Corrosion - ICDA

Dry Gas ICDA Principle

Utilizing a fluid flow model, the critical angle for water holdup is determined as a function of gas velocity.





The actual angle of inclination of pipe with respect to gas flow direction is determined through digital elevation maps and pipe burial depths

Validation of DG-ICDA – Four Pipelines

Example	*Total Number of Sites Examined*	*% of Total Pipe Length Examined*	*Percentage Internal Anomalies Predicted by Dry Gas ICDA **
A	36	<15	85
B	17	<15.6	78.6
C	26	<3.8	15
D	69	<10.7	87**

* Assumes full circumference of pipe examined.
** Anomalies greater than 30% depth, assumes +/- 200 ft (61 m) horizontal uncertainty.

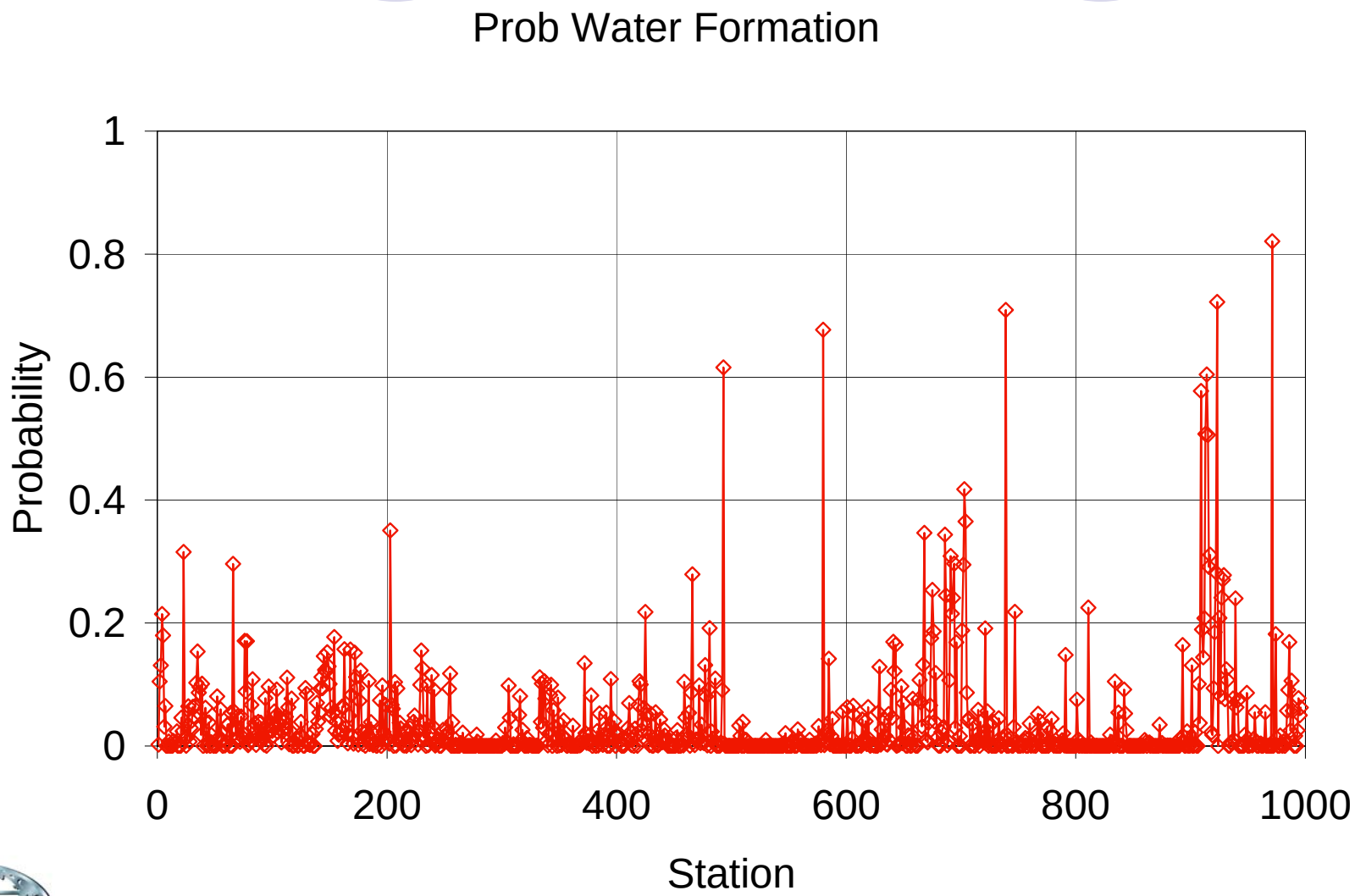
- Mixed success in validation of DG-ICDA
- A NACE TG discusses ICDA implementation issues annually
- Many sources of uncertainties in DG-ICDA implementation

Uncertainties in Current ICDA Procedure

- Pipeline elevation profile
  - USGS map errors
  - Survey uncertainties
  - Features
- Critical angle calculation
  - Flow parameters
  - Flow model (calculation of critical Froude number)
- Operating history
  - ILI or other inspection data

Uncertainties Addressed by a Probabilistic Approach

Probability of Water Holdup



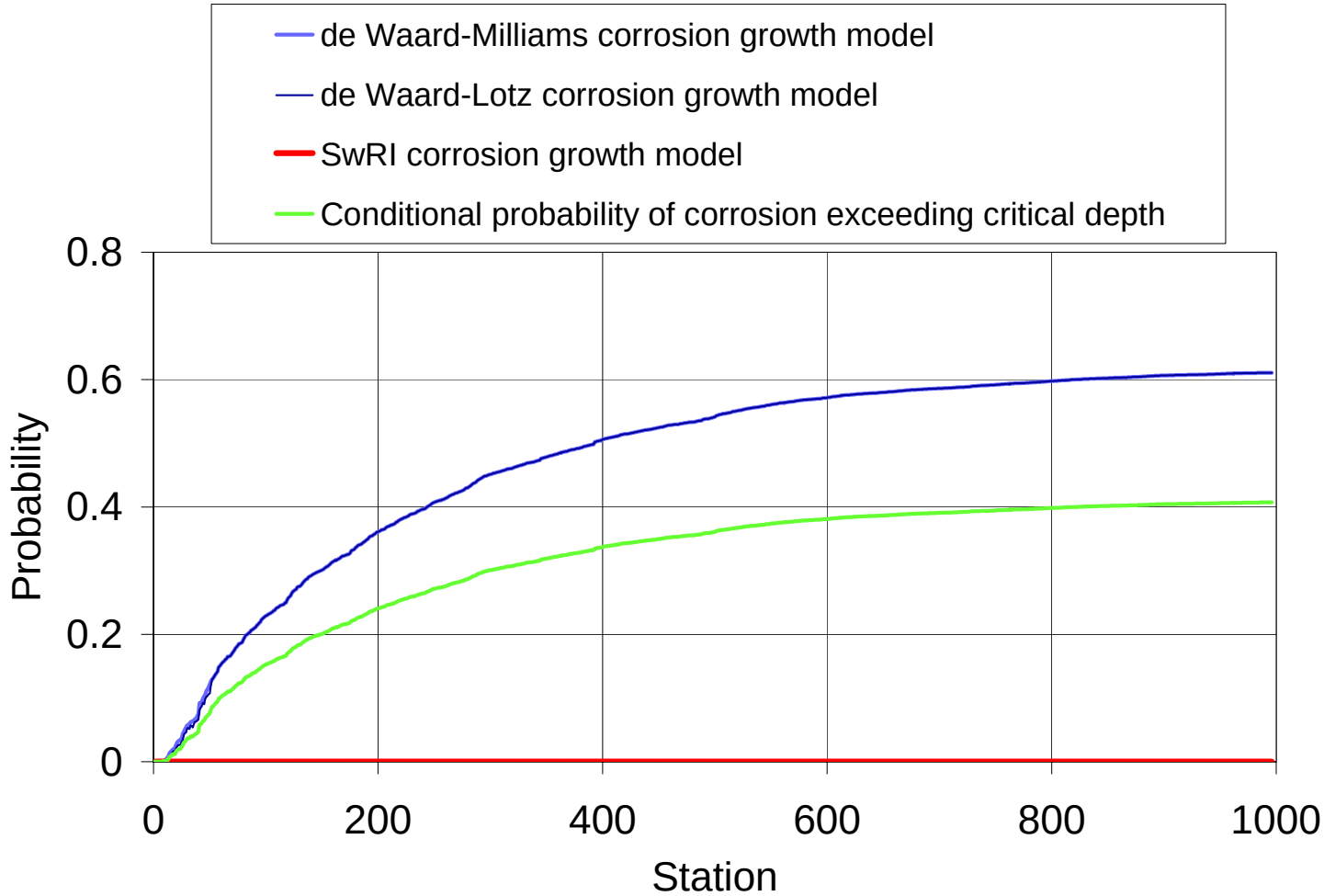
Probability of Corrosion Defect

- Total probability of corrosion exceeding specified limit is given by

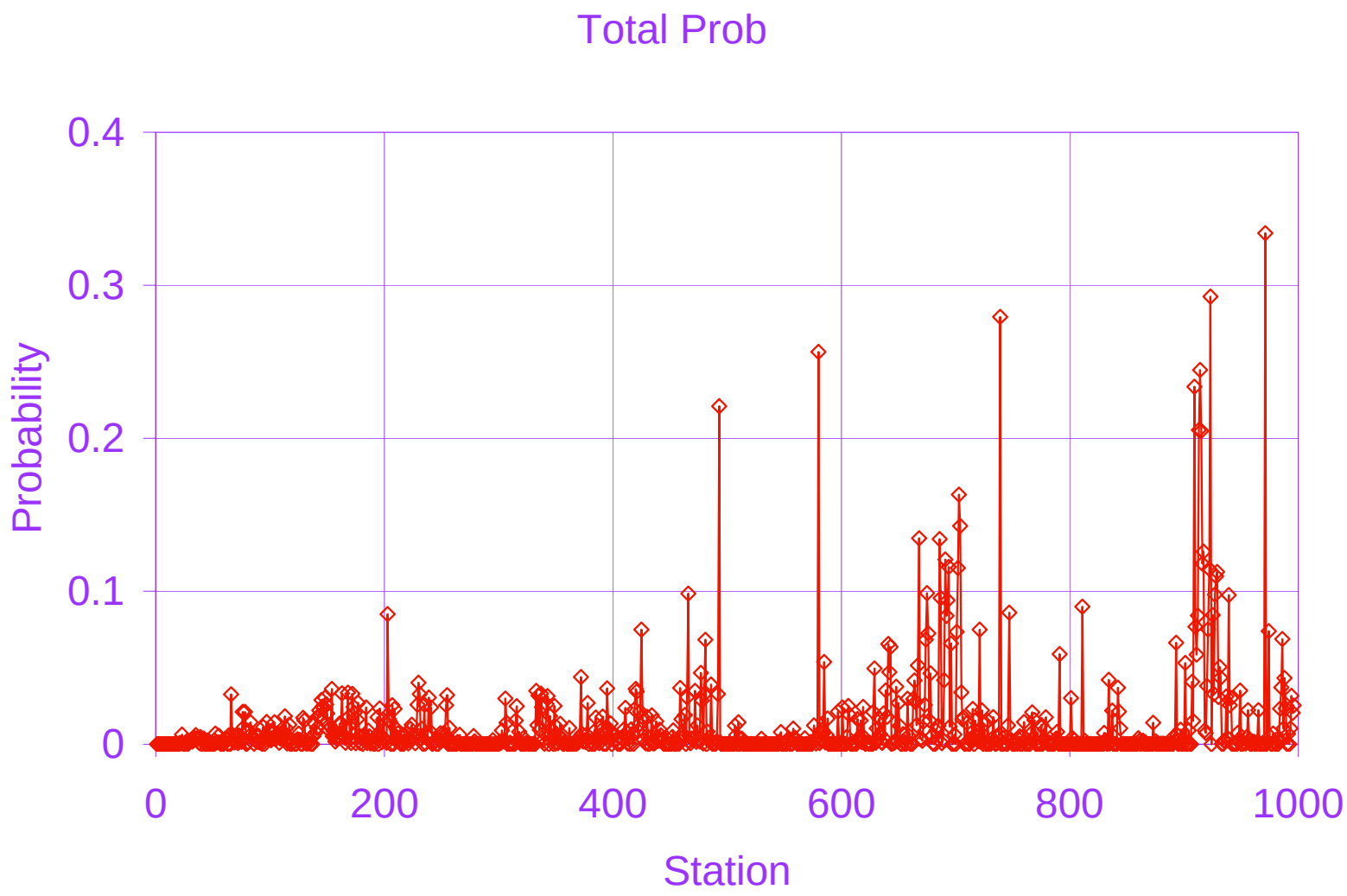
$$P_{total} = P_{water} P_{corr}$$

$$P_{Total} = P_{water} \times P_{corrosion}$$

Probability of Corrosion Penetration



Total Probability



ICDA for Wet Gas Lines

NACE Draft Standard TG 305

Oliver Moghissi (Chair)

Laurie Perry (Vice-Chair)

Draft Standard Preparation

Keith Leewis

Frank Song

Paula Kolb

Nguyen Bich

Carlos Palacios

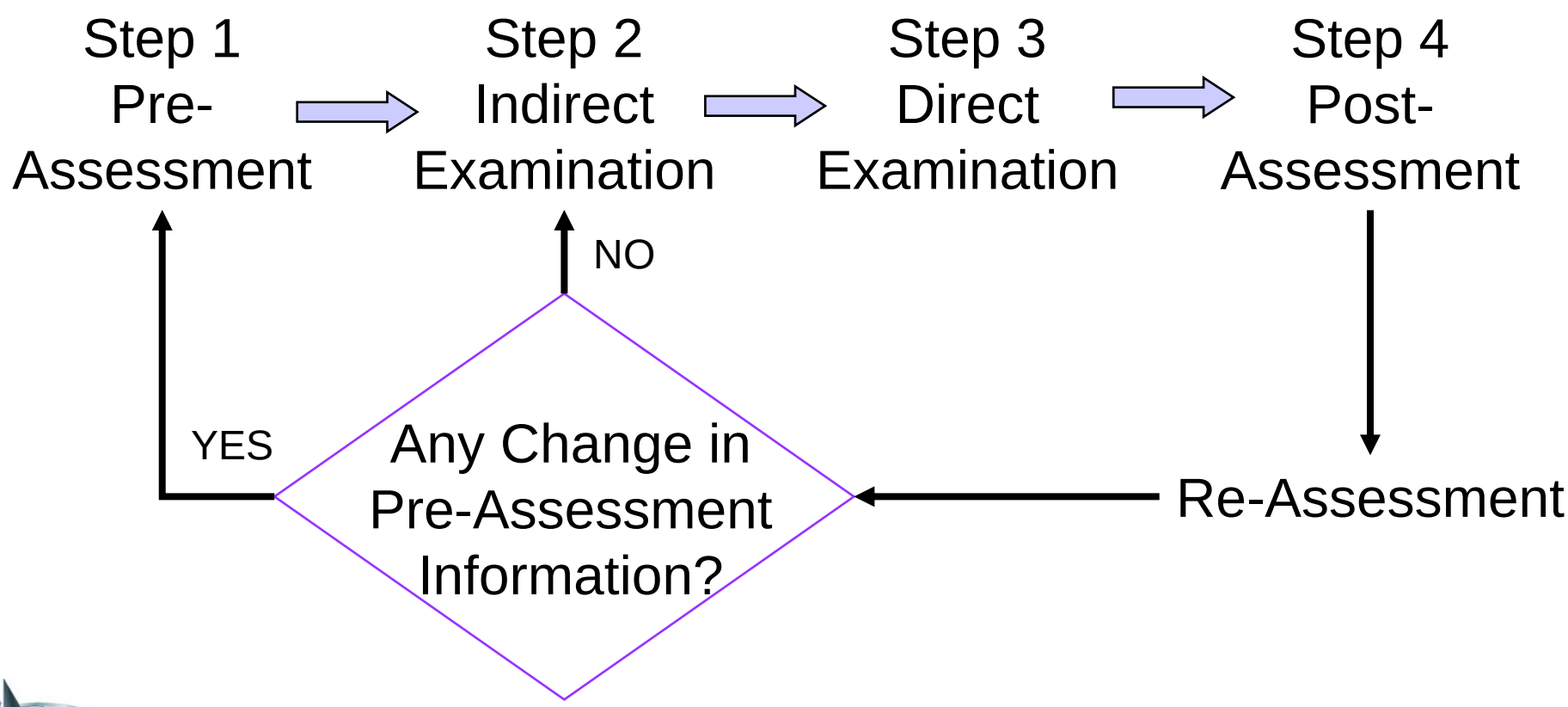
WG-ICDA Addresses….

- Storage systems
- Gathering lines with low liquid fractions
- Chronically water wet transmission pipelines
- Assessment of pipelines for which alternatives (ILI) may be impractical
- Since water may be present anywhere, DG-ICDA method cannot be implemented

Status of Standard

- Draft#3 has been prepared for TG review
- The standard aims to provide a flexible framework
- Many technical issues yet to be addressed

WG-ICDA Approach



Indirect Assessment for WG-ICDA

Selection of Regions

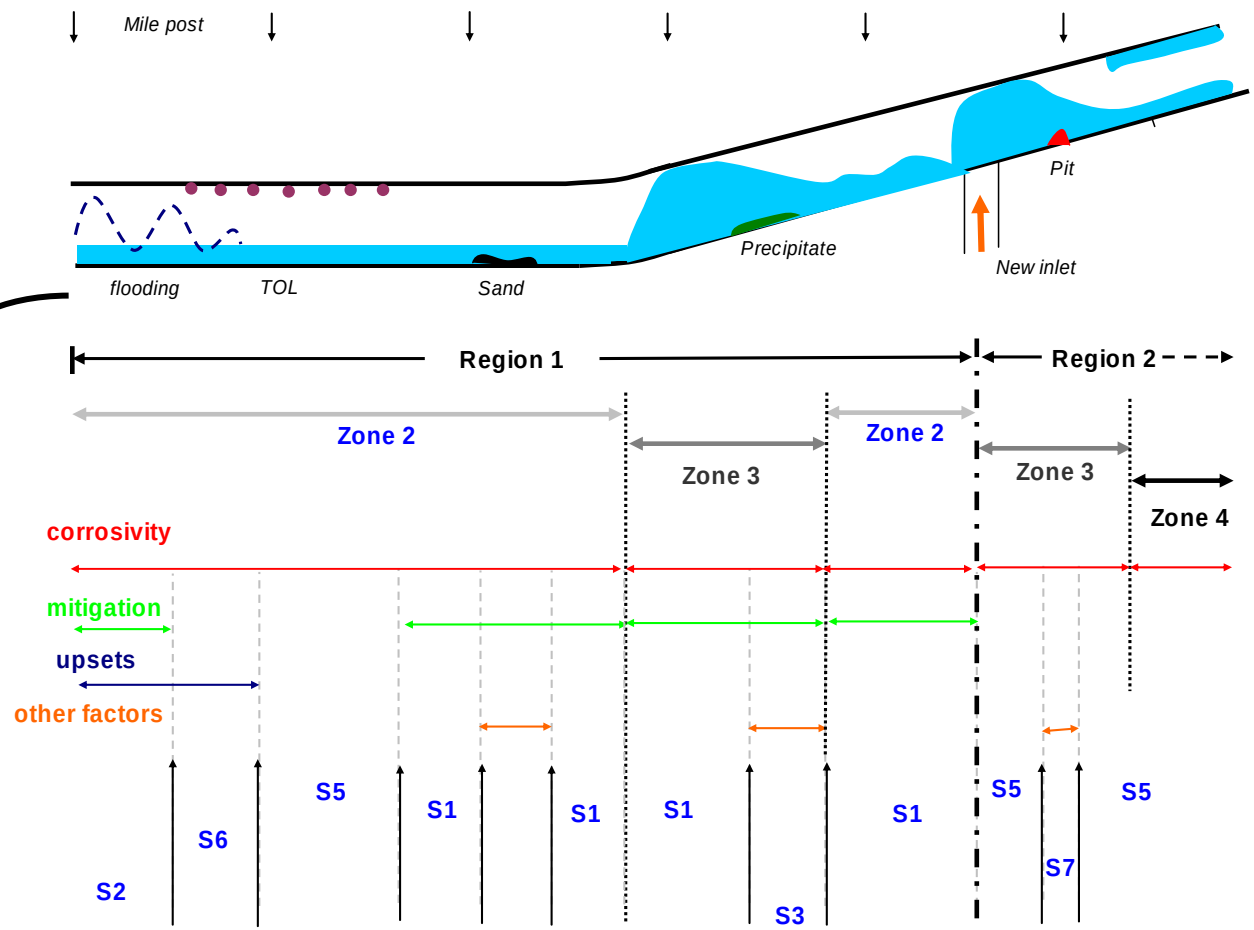
Based on input/output

Selection of Zones

Based on flow regimes

Ranking of Subzones

Based on corrosion



Gaps in WG-ICDA Methodology

- Zone classification depends on multiphase flow calculations
  - The software are complex and not available to everyone
  - Some aspects of flow calculations have not been verified
- The sub-zone classification method is subjective
  - The scoring factors assigned need to be strengthened by additional modeling/data on corrosion rates
  - The method used to combine the scores needs justification (e.g., synergies between factors are ignored)
  - Sensitivity/importance analyses may need to be done to define the most important factors

Predicting Corrosion Rate

SwRI Project Objectives and Vision

- Develop methods to estimate external corrosion rate under disbonded coating/shielded areas
- Develop methods to estimate internal corrosion rate
- Validate the methods using laboratory and field data

A very important aspect is to find simple equations or look-up table that can represent a complex corrosion process so that field engineers can easily implement corrosion rate estimation.

A step-by-step simplification of the model and validation of each simplification is important in achieving reliable rate estimation

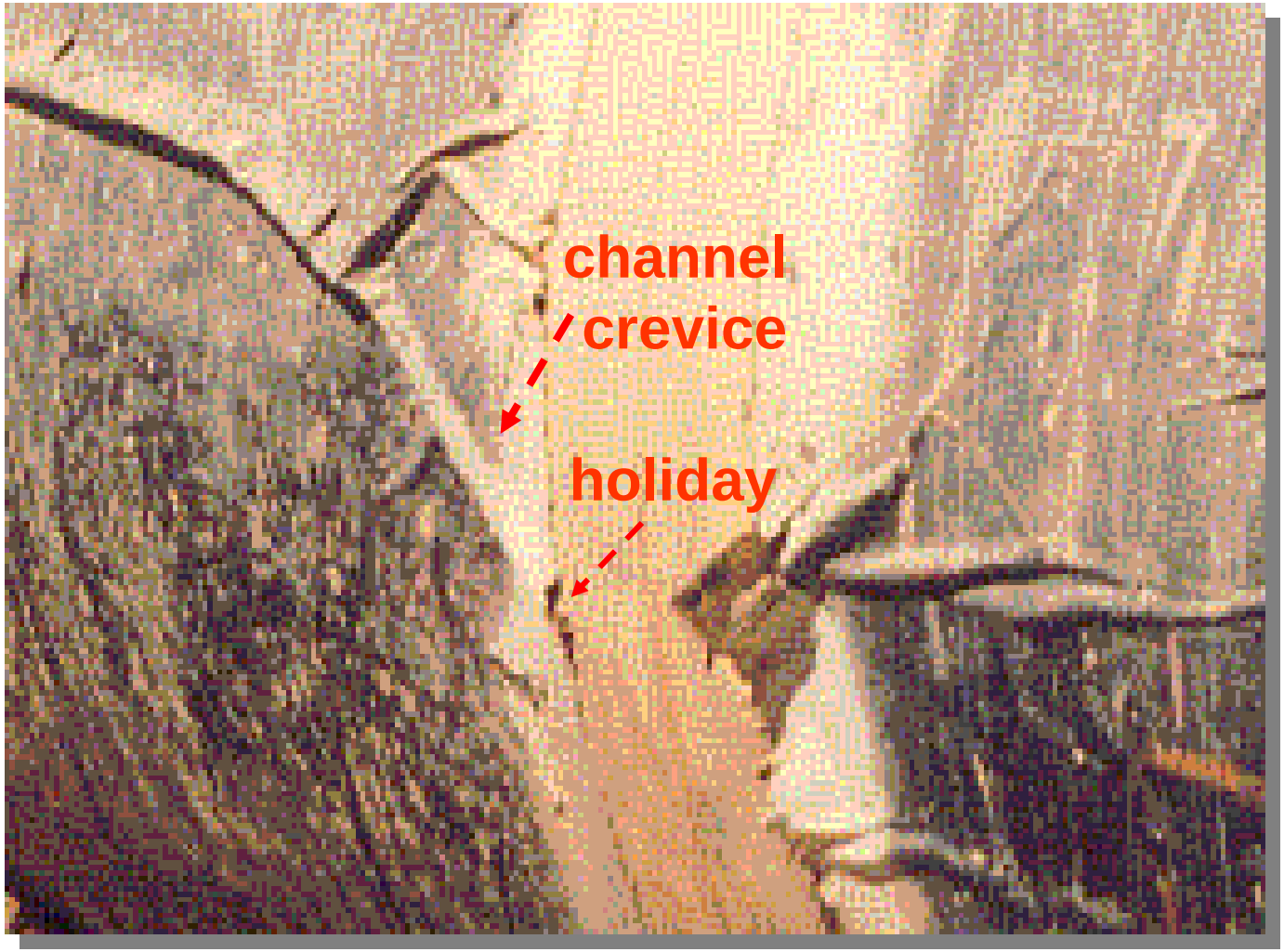
Project Partners

- GDF – External corrosion under disbonded coating and field data
- Valero – Internal corrosion monitoring in liquid lines
- SoCal – Internal corrosion field data
- Funded by PHMSA

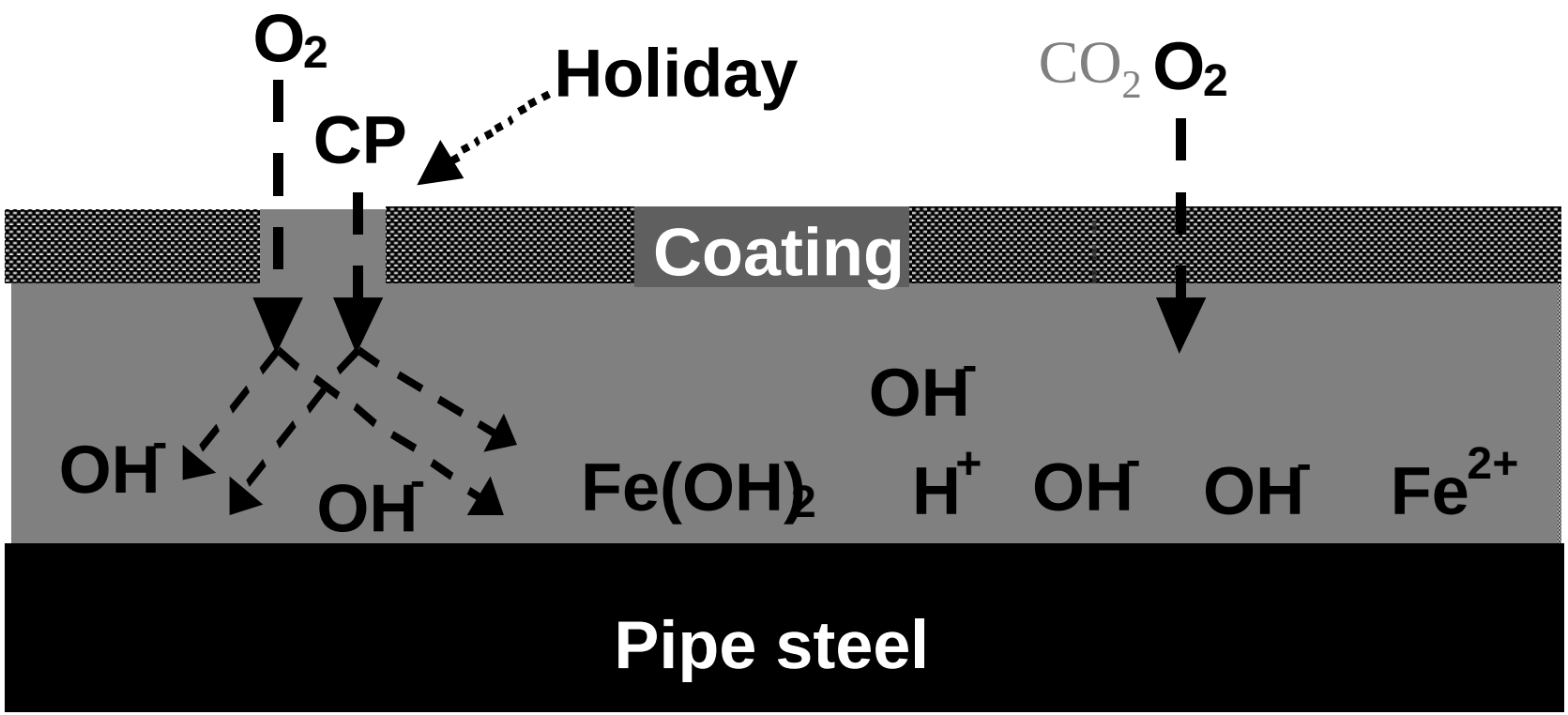
External Corrosion Rate Estimation

- Current rules of reassessment interval
  - A default corrosion rate of 0.4 mm/y is used unless justification of other rates can be made.
- Corrosion modeling showed that
  - Without flow corrosion rate of 0.4 mm/y is conservative
  - A simple algorithm was developed to estimate corrosion rate
- Corrosion under disbonded region with internal flow is a concern

Channel Crevices

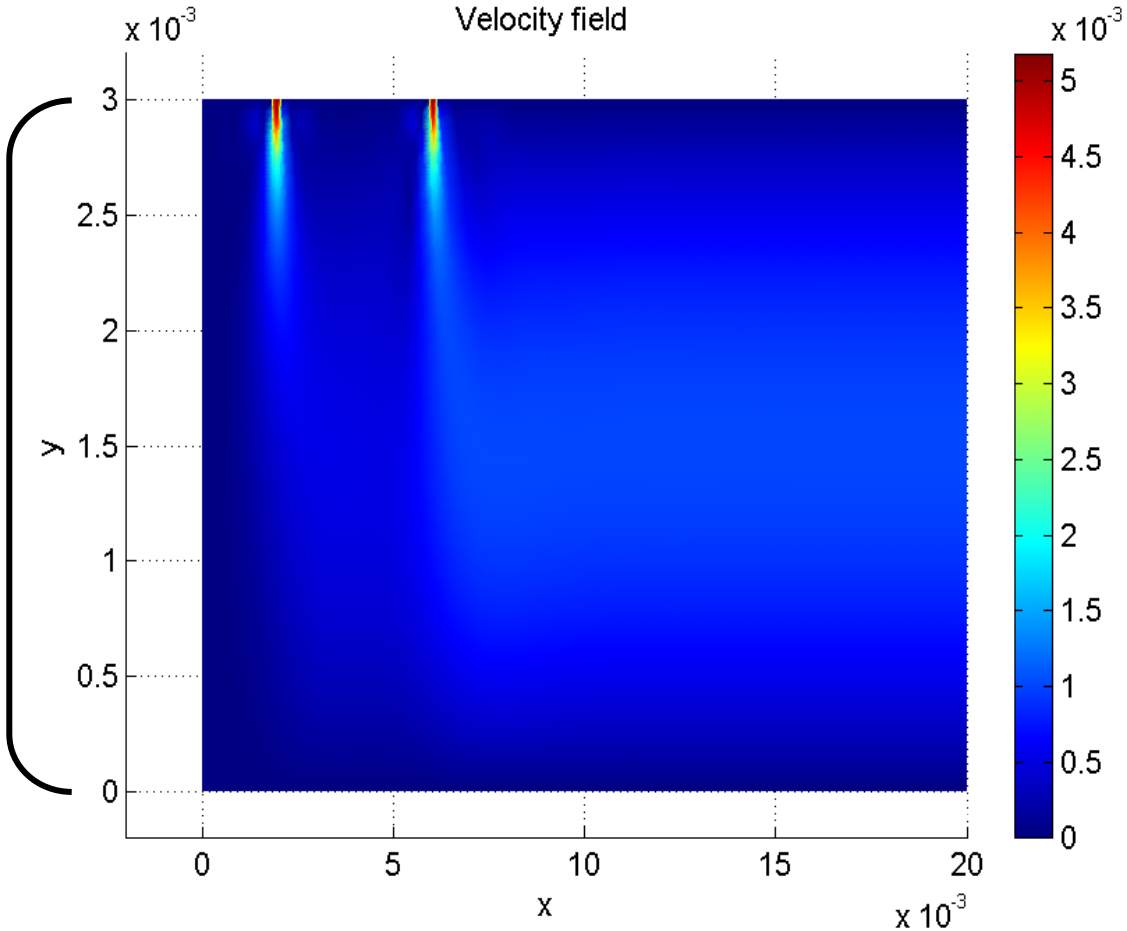


Example Calculation for Flow Conditions



Velocity Profile

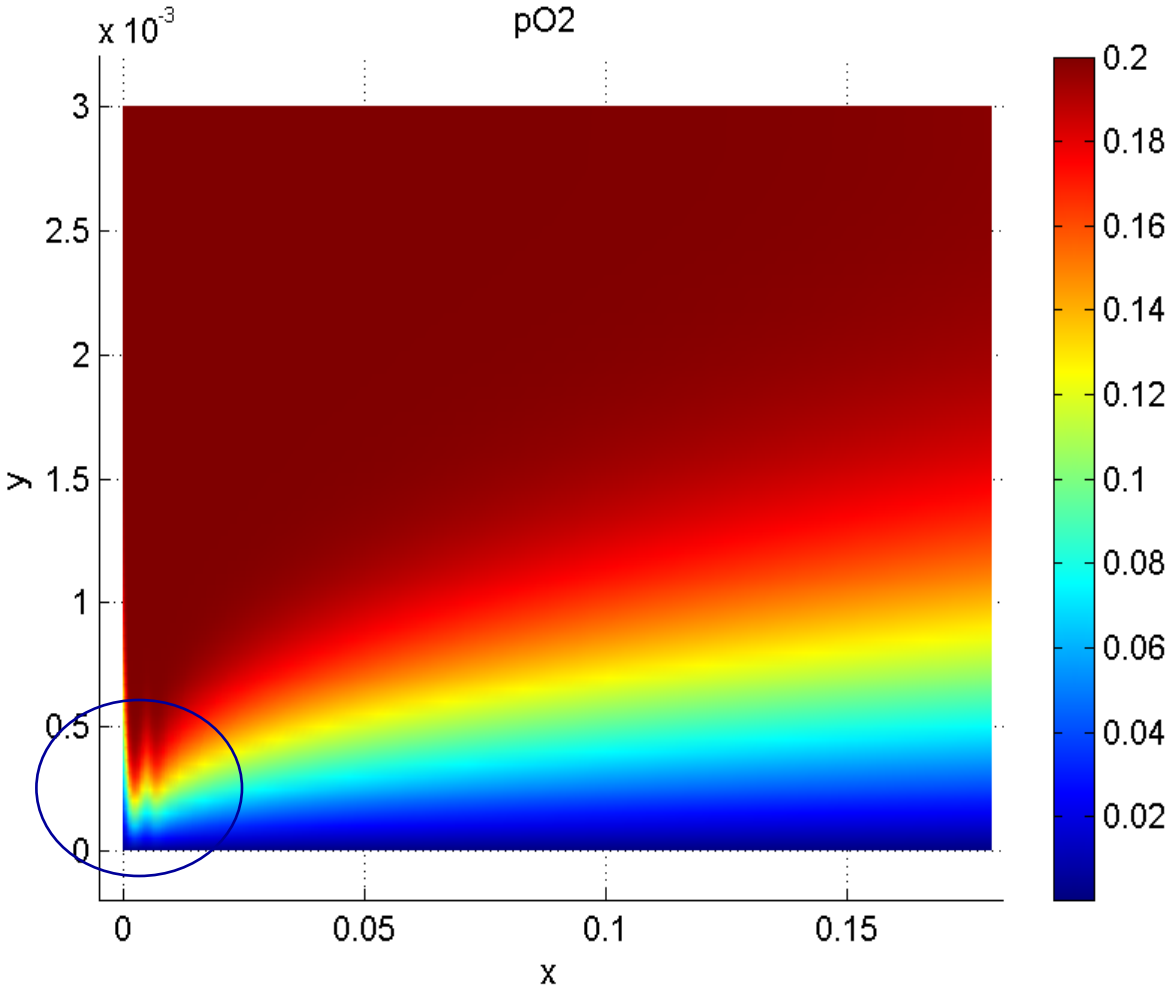
Disbondment Gap



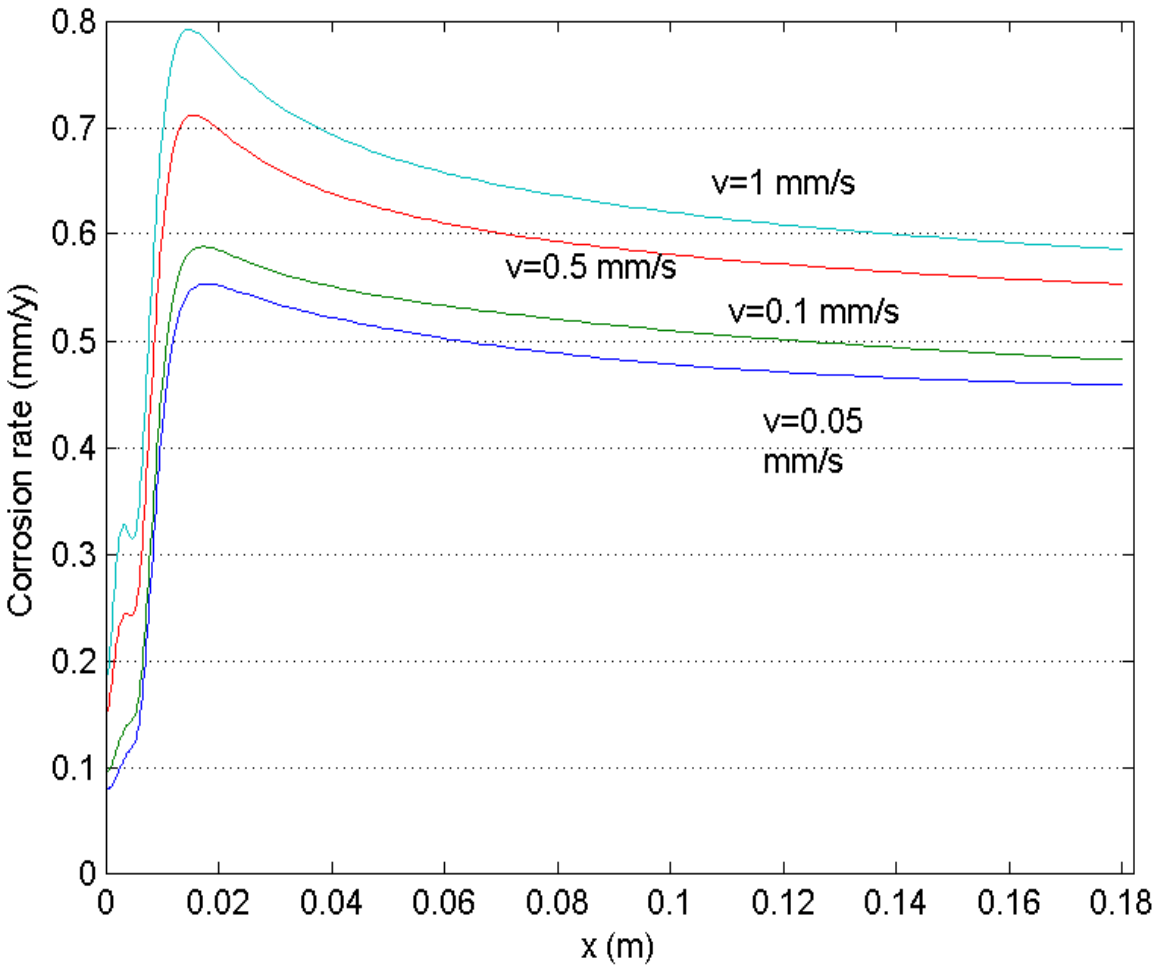
V=1 mm/s; Length =0.18 m

LaplaceFlow> Report velocity -- 3mm gap_Fec+i0_iH_resisti_new.fl

O_2 Partial Pressure Profile



Corrosion Rate vs. Velocity



Internal Corrosion Rate Prediction

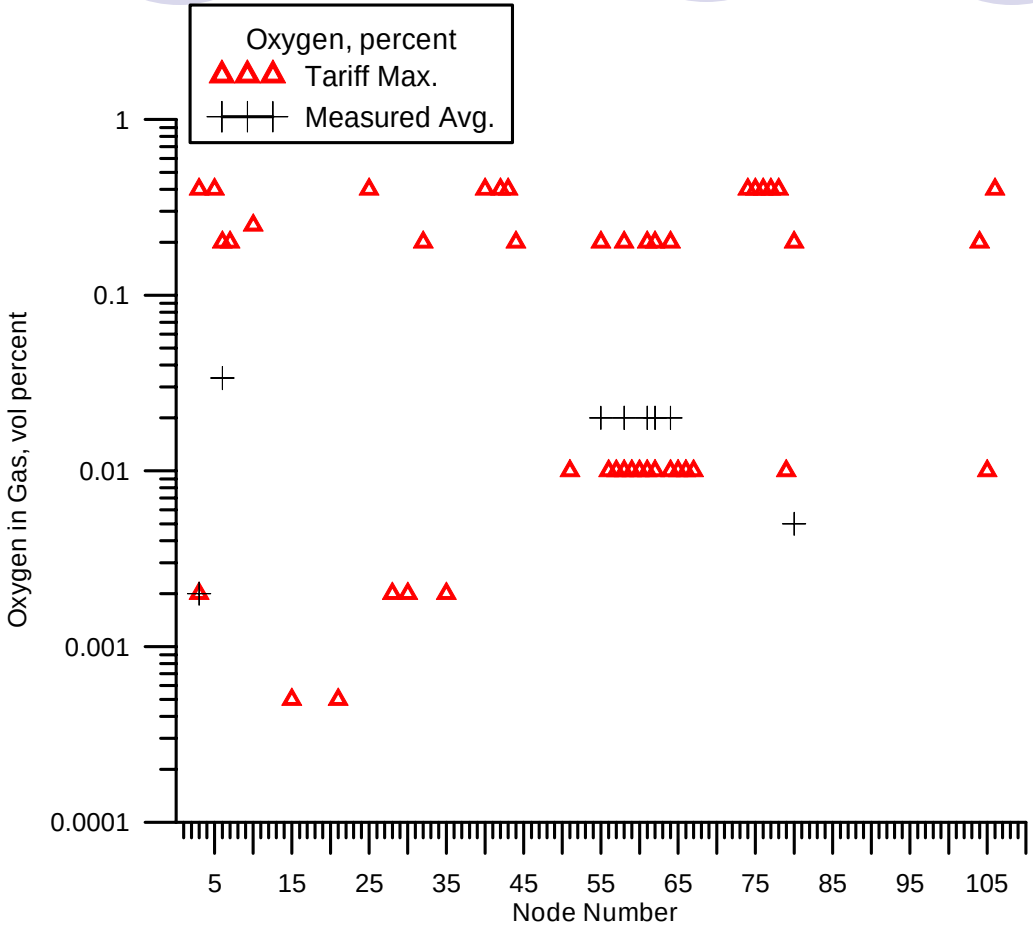
- DeWaard-Milliams model is typically used
  - Does not consider the effects of gas quality completely
  - Does not consider effect of water composition or microbial activity
- Many other models exist – most are embedded in proprietary software
- Empirical models (e.g., SwRI model) are limited by the range of variables examined
- No accepted corrosion model for liquids pipelines

Corrosion Rate Predicted by Three Models

total P, bar	mole% CO2	Mol% H2S	T,C	O2, ppmv	Corrosion rates Using Three Models		
					D-M, mm/y	SwRI, mm/y	OLI, mm/y
296	5.74	0.015	32	0	10.42	0.41	1.2
124	5.74	0.015	4	0	1.58	0.25	0.57
124	5.74	0.015	32	0	5.81	0.25	0.97
296	2.2	0.015	32	0	5.48	0.29	0.45
124	2.2	0.015	4	0	0.83	0.23	0.17
124	2.2	0.015	32	0	3.06	0.23	0.35

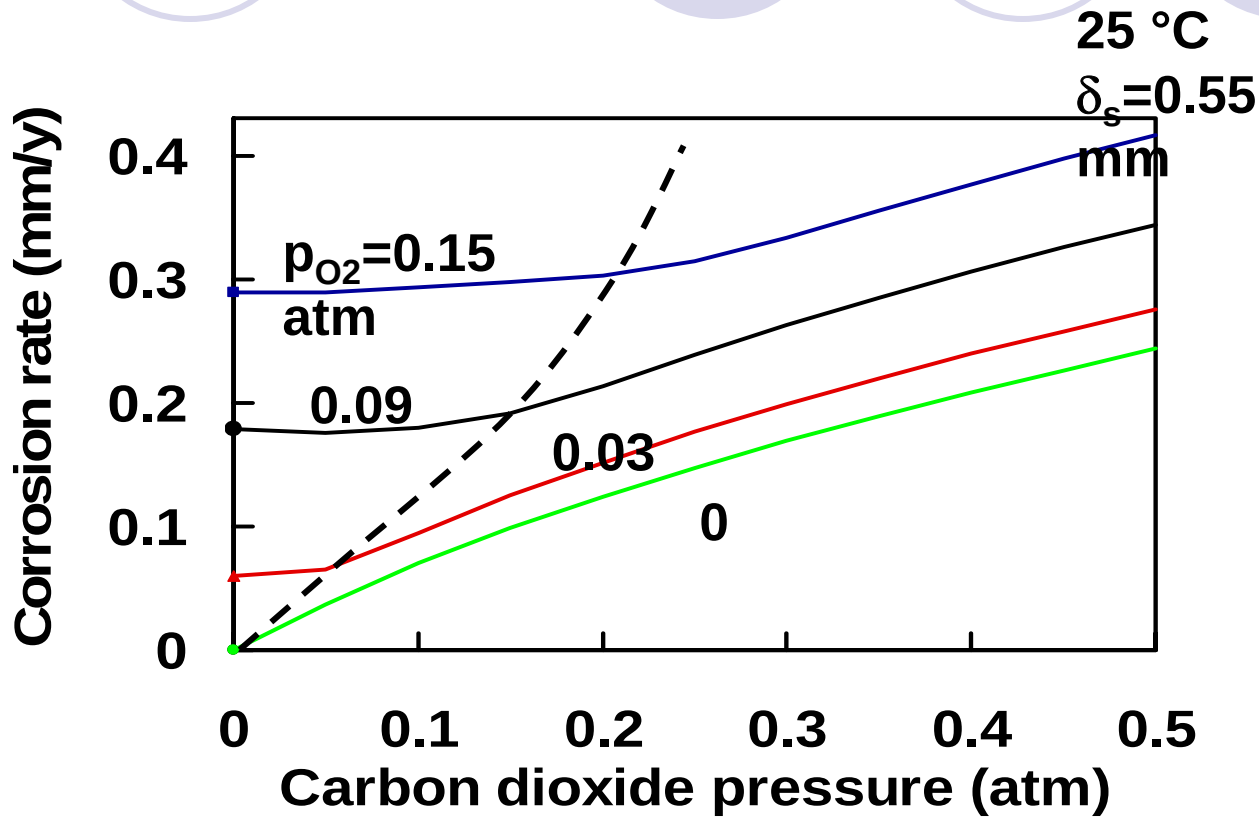
Does Not consider H_2S

Oxygen Variations



- Specifications are very broad
- Average oxygen content is somewhat high

Internal Corrosion Model – Developed under PHMSA Funding



Experimental data show significant localized corrosion in CO_2+H_2S+O_2 environment

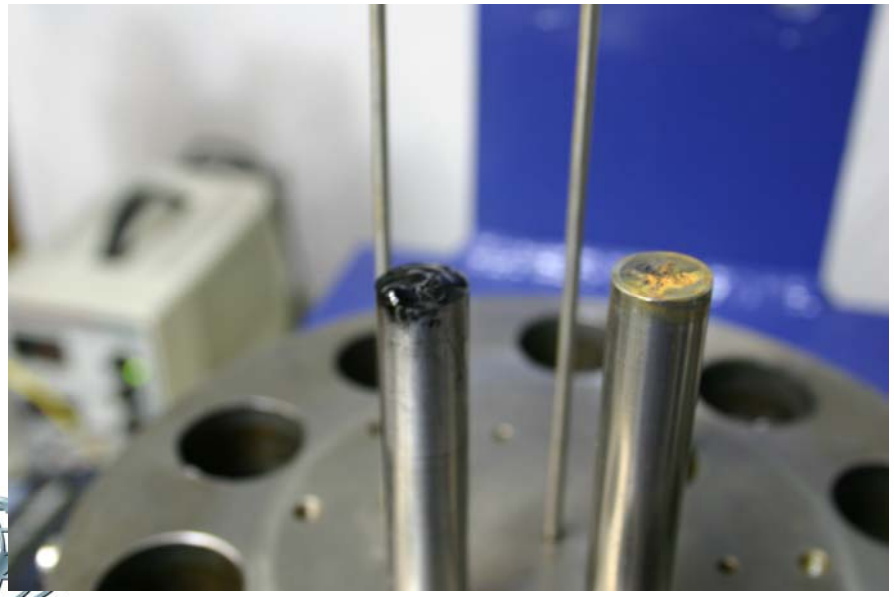
Corrosion Monitoring

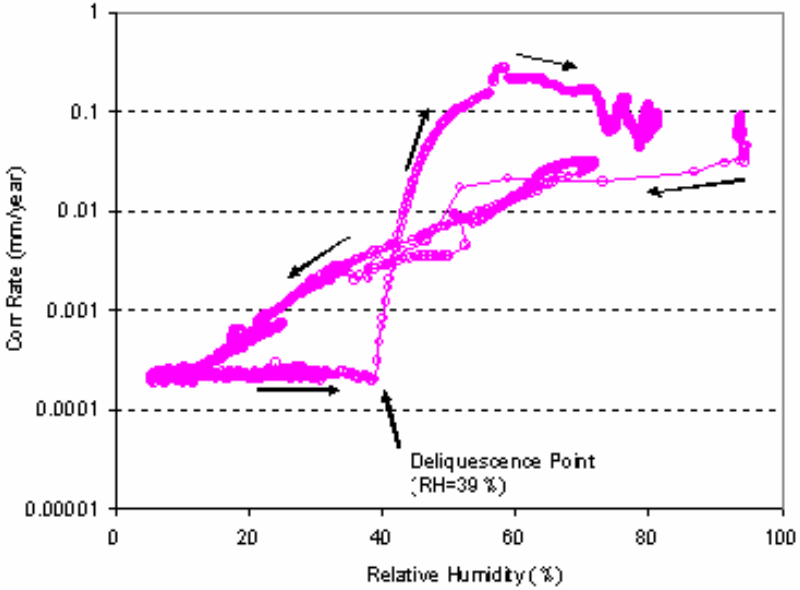
Internal Corrosion Monitoring

- Under a PHMSA-PRCI-GRI project, a multielectrode array sensor (MAS) has been developed to measure internal corrosion rates
- The probes have tested with different gas compositions (500 psi pressure), stagnant conditions, and under bacterial biofilm

Summary of MAS Results

- MAS probes are sensitive to changes in gas composition and consistent with previous results
- Testing in high pressure systems and under bacterial biofilm showed biofilm did not change RH at which corrosion occurred, but dry-out took longer time

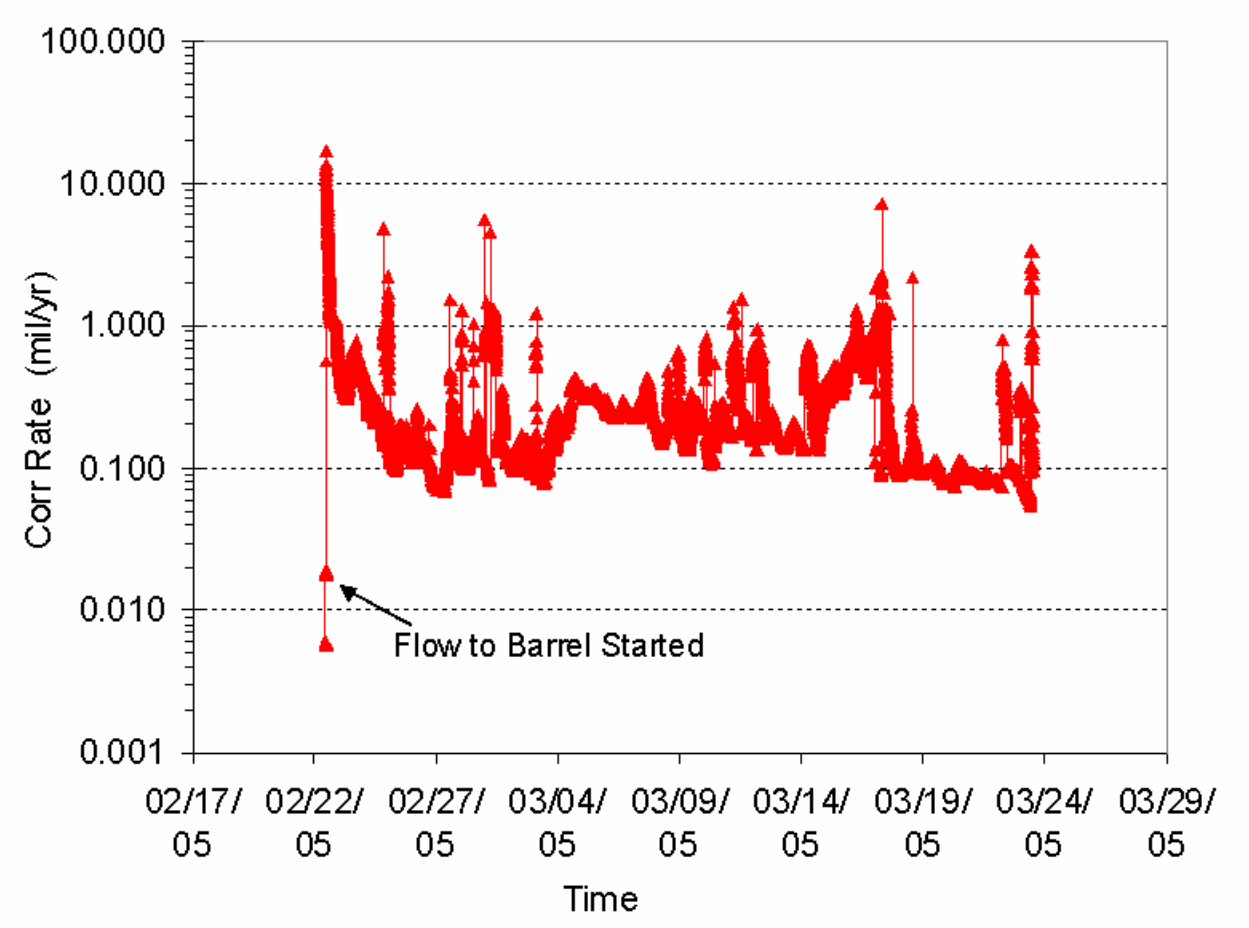




MAS Probe in Liquids Pipeline System

- Installation in a side-loop of a liquids pipeline
- MAS probe emplaced along with coupon
- Ability to extract liquids for analysis

Preliminary Data



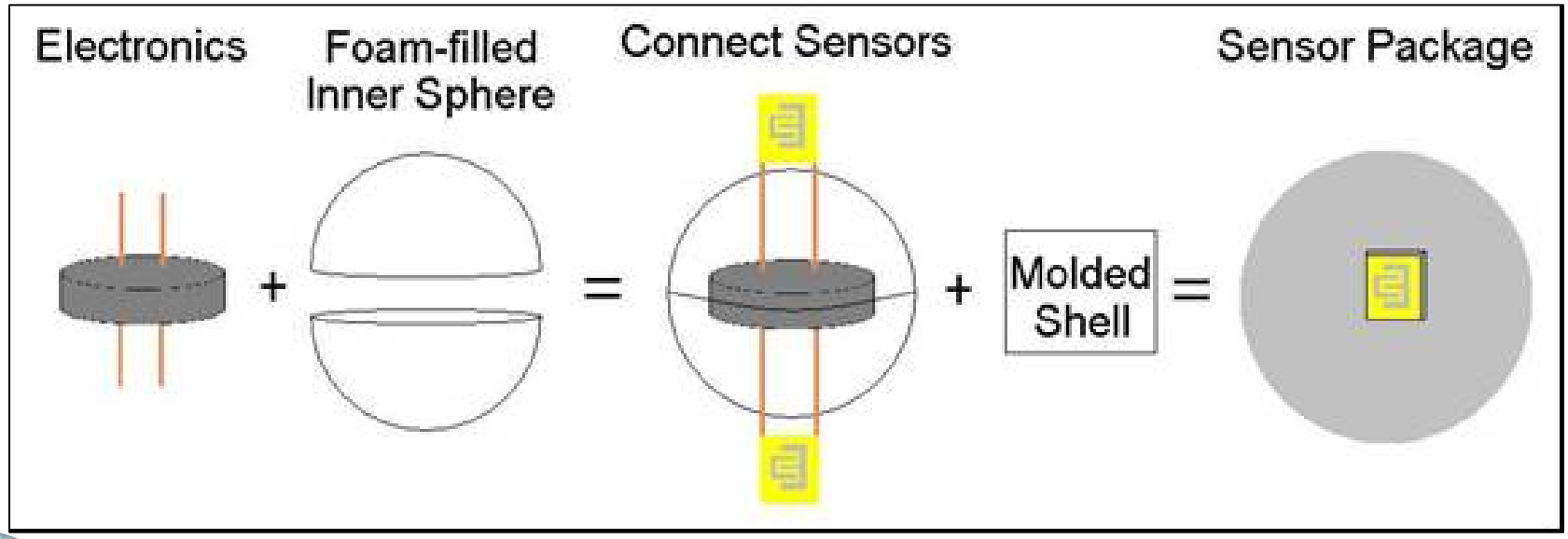
Note: rates are in mils per year. 1 mm/y = 40 mils per year

Mobile Sensors

- Monitoring probes are limited
  - Only certain locations monitored
  - Difficult to install – penetration of pressure boundary, hard to reach areas
- Inspection also have limitations
  - Average wall loss over time, incipient corrosion impossible to detect
  - Not all lines can be inspected
- Fluidized (mobile) sensors
- Sensors on cleaning pigs

Overall Approach – Mobile Sensors (Funded by PHMSA and GTI-OTD)

- Develop sensors and delivery package that can be introduced into the gas stream and identify likely locations of internal corrosion as they flow through the pipeline. This would reduce the total number of required excavations for internal corrosion assessment



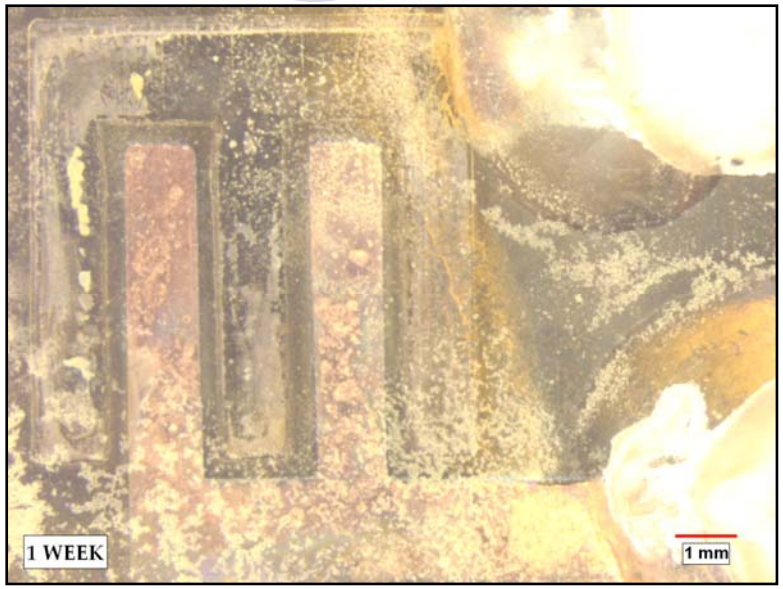
Issues To Be Addressed

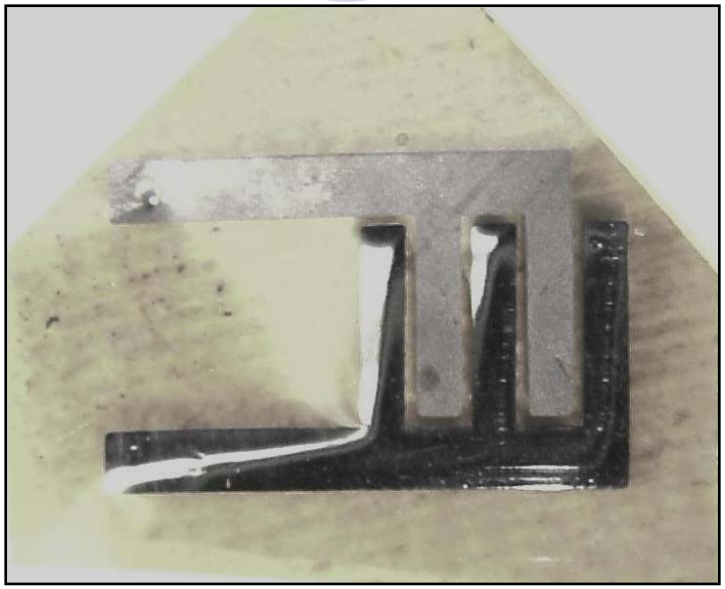
- Sensor life
- Sensor calibration and reproducibility
- Ability to read location or distance along pipe
- Sensor packaging and flow
- Safety/operations

Status

- Optimization of electrode composition
- Electrode corrosion and sensitivity test
- Mechanical integrity/durability test
- Packaging/exterior shell molding
- Initial sensor location studies

Cu-Fe vs. Fe/Cr-Fe in CO_2/H_2S

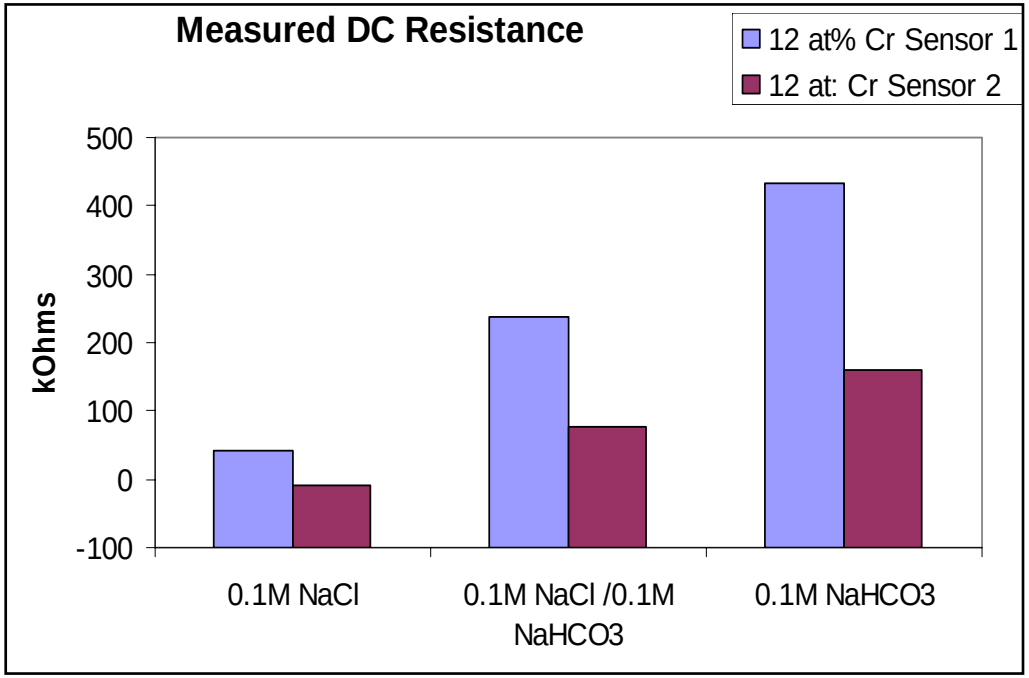




- **Cu-Fe sensor corroded within a week upon exposure to CO2+H2S mixture**
- **Cr added electrodes untarnished after one week – great improvement**

Cr/Fe Electrode Sensitivity

- 12% Cr maintained sensitivity to corrosivity
- 16% Cr not sensitive to corrosivity
- Still have 'offset' between sensors
  - Will overcome with calibration, and
  - Eliminate with streamlined fabrication



Summary of Sensor Development

- Corrosion sensor has been optimized in terms of sensitivity and degradation resistance
- Location method is the most critical issue that is being addressed
- Sensor packaging concepts are being tested

Research Needs

Research Needs

- A significant percent of pipeline incidents is due to internal corrosion (9% for liquids, 14% transmission)
- Three most visible pipeline events in the last decade are due to internal corrosion (New Mexico explosion, Alaska spill and BP pipe shutdown)
- A more comprehensive and sustained developmental effort is necessary to monitor and predict the rate of growth of IC

Recommended Path Forward

- Improve transfer of knowledge from other oil and gas corrosion expertise to pipelines
  - Assemble a workshop of industry experts in corrosion modeling involved in oil and gas industry (production, gas treatment, refinery, and pipeline industries)
- Improve our ability to predict internal corrosion, especially in wet gas and liquid lines
  - Increase research effort in internal corrosion rate prediction and in developing an openly accessible model
  - Validate such a model with a consistent data set
- Continue to develop and deploy internal corrosion sensing and monitoring technologies