Catasrophic Failure of Aging Underground Pipelines Is Inevitable Under Certain Corrosion Conditions

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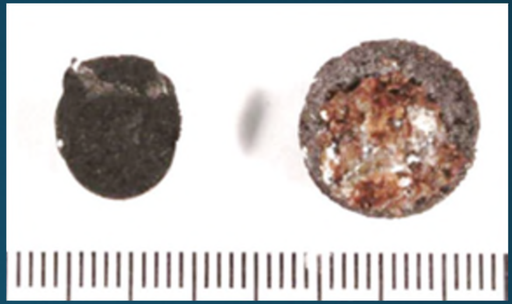
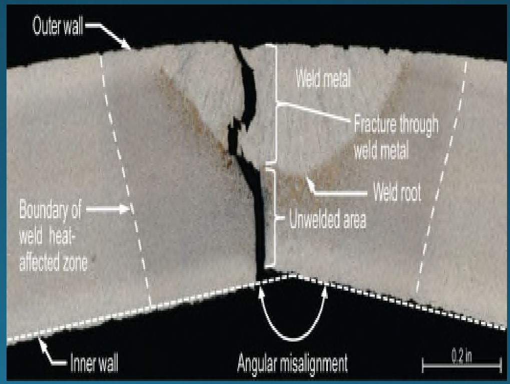
NACE CERTIFIED CORROSION / MATERIALS SELECTION / DESIGN / COATING / CP SPECIALIST
NACE Approved Instructor

Exova Pittsburgh

- Materials Testing and Failure Analysis
- Pipeline Corrosion Assessment
- Root Cause Failure Analysis
- Materials Testing
- Metallurgical Evaluation
- Accelerated Corrosion Testing
- Tier Testing for Coating Selection
- Concrete Petrographic Analysis
- QA/QC Inspection and Technical Audit
- Corrosion Monitoring





Dr. Zee,
Fellow of NACE, Fellow of ASM

NACE Certified Corrosion Specialist
NACE Certified Coating Specialist
NACE Certified Materials Selection/Design Specialist
NACE Certified Cathodic Protection Specialist

25 patents on coatings, corrosion sensors and CP

60 plus publications in Technical Journals

Instructor for three NACE Courses
(corrosion, CP and Condition Assessment)

Recipient for ASM, NACE Awards

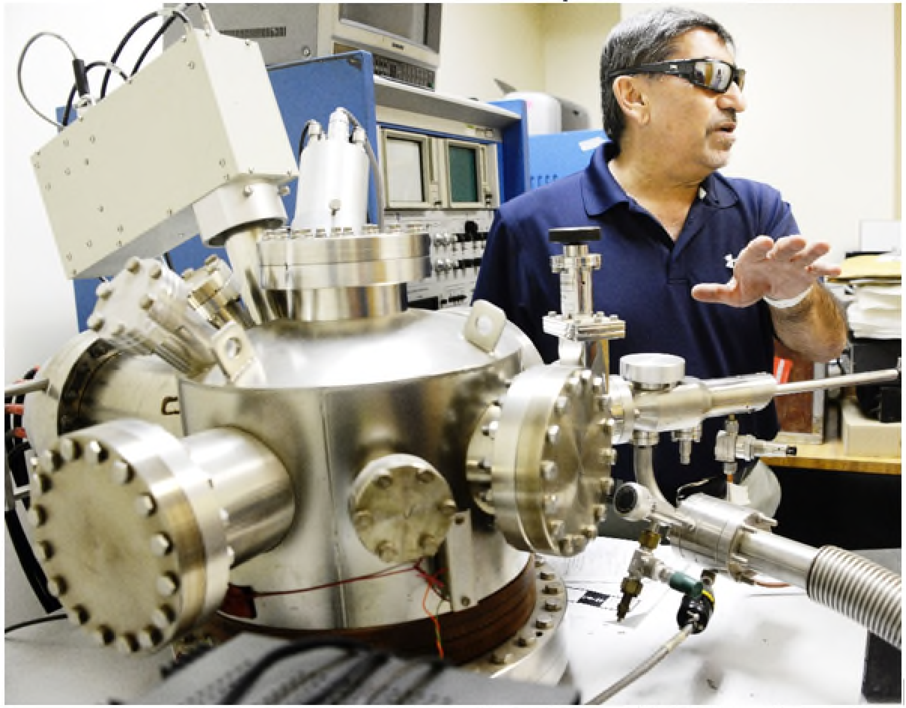
Six Months Life of A Failure Analyst

- Failure Analysis of a ruptured pipeline due to SCC in North East
- Corrosion Assessment of CP Protected Above 500,000 Failure Ground Tank
- AC Interference Assessment in Nevada and British Columbia
- Stress Corrosion Cracking investigation of 1000 SS transformers
- Underground Cathodic Protection Design and Installation for Exxon Tank/Pipes
- St. Croix Federal Court House Water Line Problems and Recommending Solutions
- Cayman Island: 500,000 Gallon Storage Tank Leak Failure Analysis
- Corrosion Mapping of City of San Diego for SGD&E
- Paint Failure on 7075 Aluminum Alloy in Major Commercial Airline
- Four papers for Publication in NACE Corrosion Conference 2016
- Pittsburgh: Jet Fuel Investigation - Plugging Filters and Biofilm
- Published “Fatigue Failure Analysis Case History” in Failure Analysis Journal
- NACE Course Teaching Pa and California
- Four Short Courses for Engineers including NACE courses for CP and corrosion design
- Last year frequent flyer: 195,000 miles
- No complaints except airports: **House of Pain**

Pittsburgh Post-Gazette
ONE OF AMERICA'S GREAT NEWSPAPERS

As Pa. pipelines age, role of corrosion in accidents examined

July 17, 2016 12:00 AM



Darrell Sapp/Post-Gazette

Mehrooz Zamanzadeh, or "Dr. Zee," says many pipeline companies don't know what materials were laid underground decades ago. This Auger electron microscope at Exova in Robinson helps decode the mystery.

Catasrophic Corrosion Failures in Aging Pipelines Are Inevitable Under These Conditions

- Graphitization in Cast Iron Aging Gas Lines in corrosive soils
- Coating Disbondment and Cathodic Protection Shielding
- Irregularities in CP systems with variation (300-400mV) in corrosive soils and seasonal change
- DCand AC stray current and Interference
- Stress Corrosion Cracking(SCC)
- Fatigue or CF

Exploded Pipe

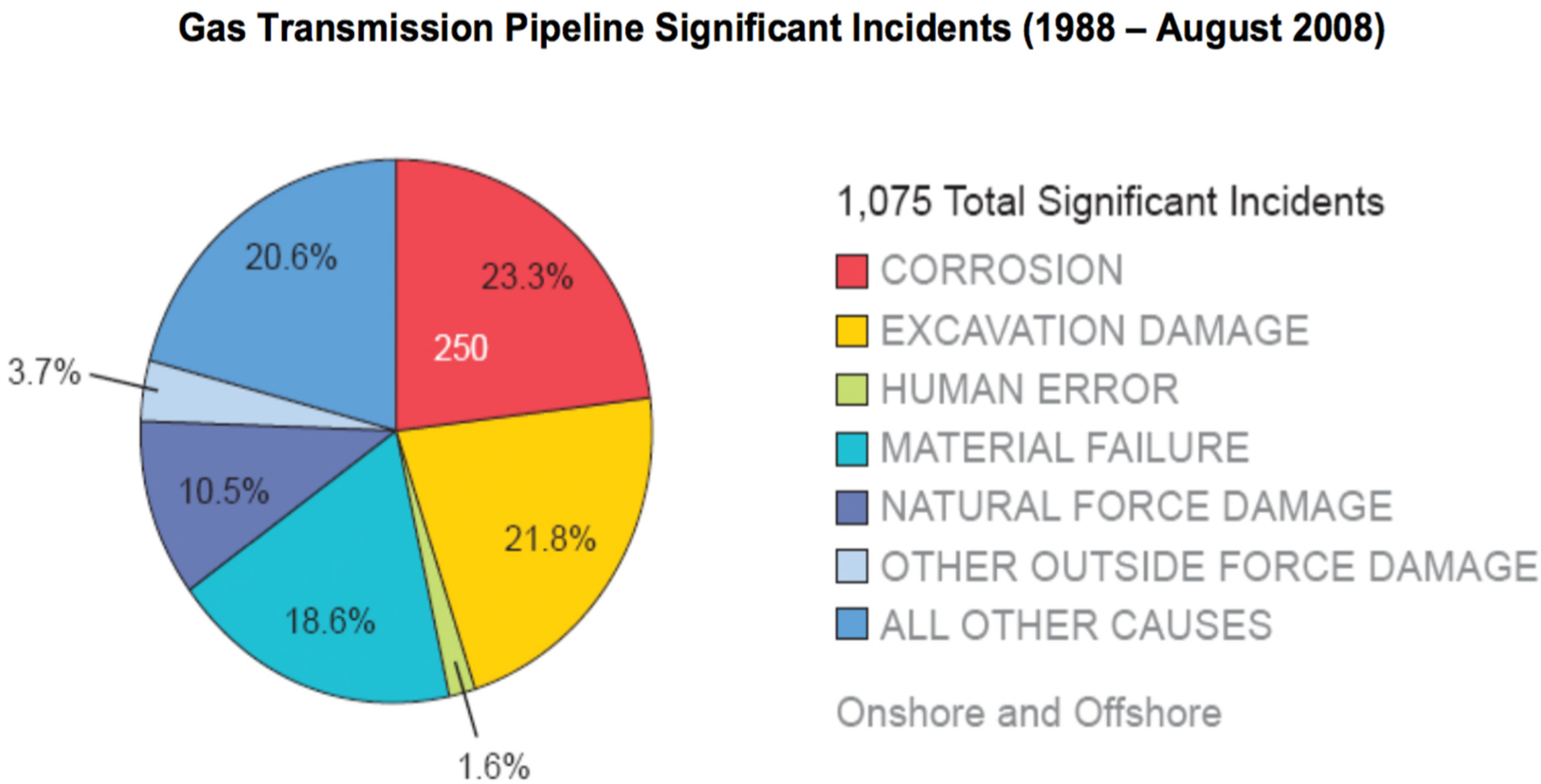


***Figure 1.4** – Causes of significant incidents in onshore and offshore natural gas transmission pipelines (Source: PHMSA Filtered Incident Files)*

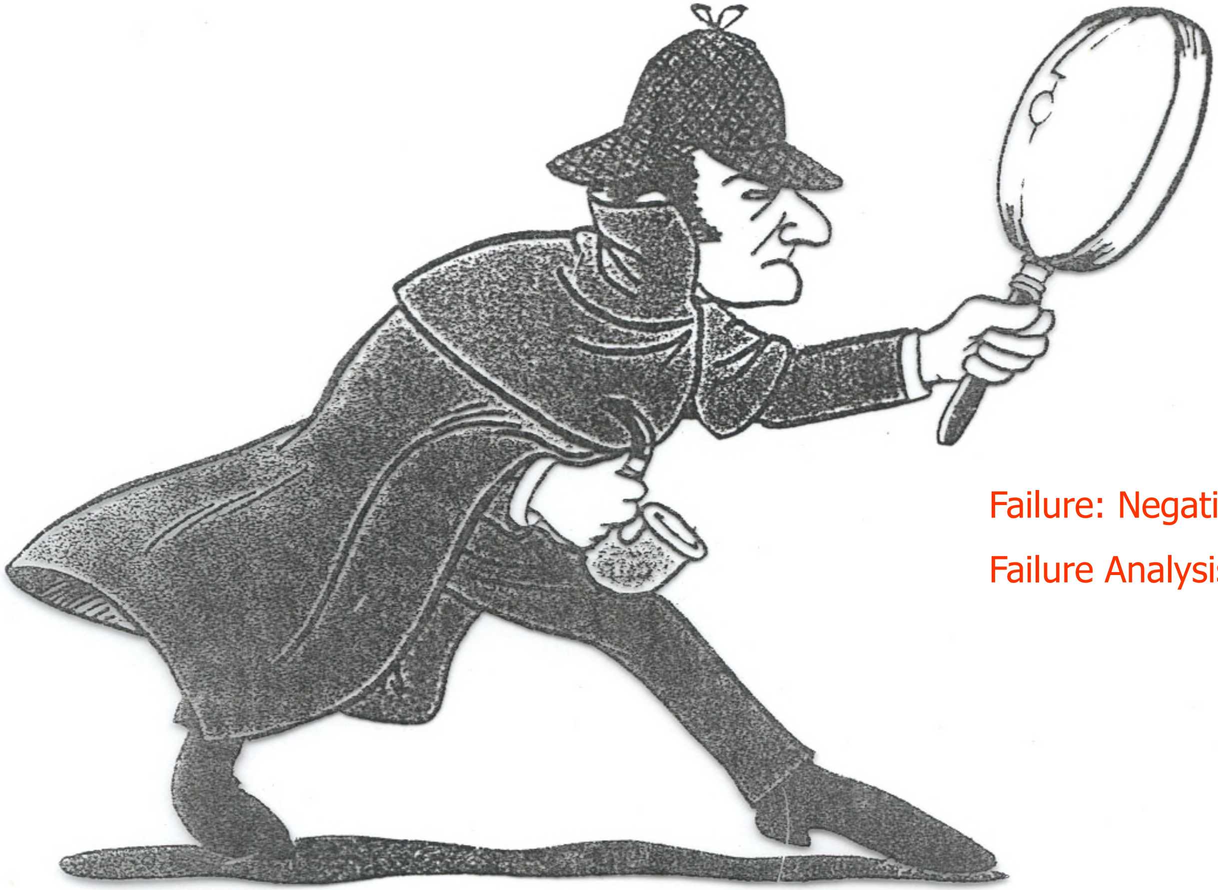
Causes of Significant Incidents during 1988 to 2008

Costs Due to Corrosion for Transmission Pipelines

Table 1.1 – Cost of Corrosion in U. S. Transmission Onshore Pipelines

	Low Estimate (Millions of US $)	High Estimate (Millions of US $)	Average	
			(Millions of US $)	Percent
Cost of Capital	2,500	2,840	2,670	38
Operations and Maintenance (O&M)	2,420	4,840	3,630	52
Cost of Failures (Non-Related O&M)	471	875	673	10
Total Cost Due To Corrosion	5,391	8,555	6,973	100

(Source: http://www.corrosioncost.com/pdf/gasliquid.pdf) FHWA-RD-01-156, March 2002.



Failure Analysis

Failure: Negative Term

Failure Analysis: Very Positive

Just the facts...

- ✓What happened? How did it fail? Mode of failure...
- ✓Why did it happen? Root Cause Analysis
- ✓Who was responsible? Designers, Contractors, Inspectors...
- ✓Who should have done what? Codes, Standards...
- ✓Reports, Technical Conclusions
- ✓Engineering Solutions: Repair, Replacement, Inspection Frequency
- ✓Legal Issues

Materials Don’t Fail,
People Do!

Materials Follow the Laws of Physics and Chemistry Perfectly

Causes of Failures….

There are three basic types of human errors:

a) Errors of knowledge
b) Errors of performance (negligence)
c) Errors of intent (greed)

Failure Analysis Defined

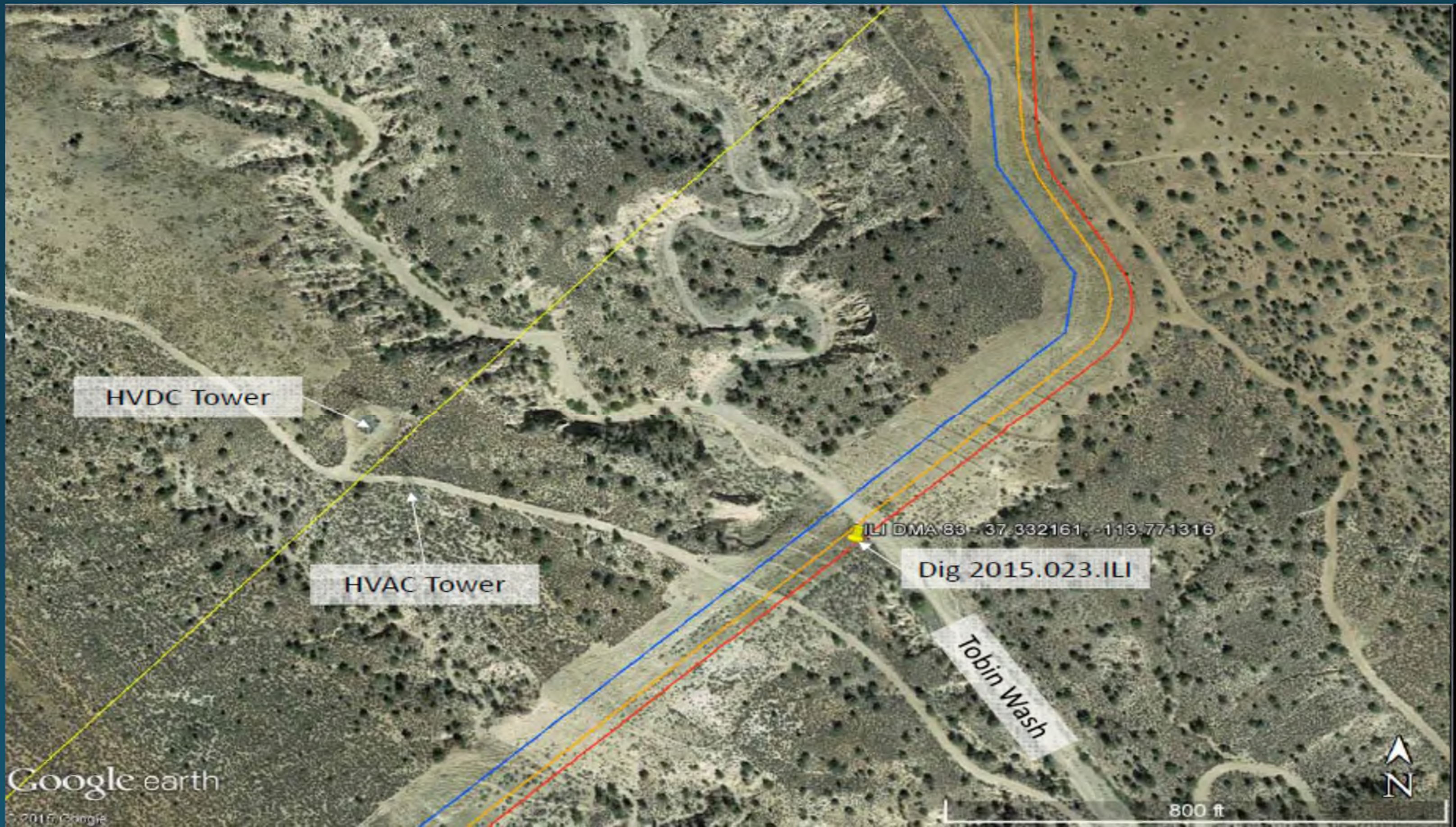
- Root Cause Failure Analysis
  - Identifies the underlying cause or “root” cause of failure.

- Failure Mode and Effects Analysis

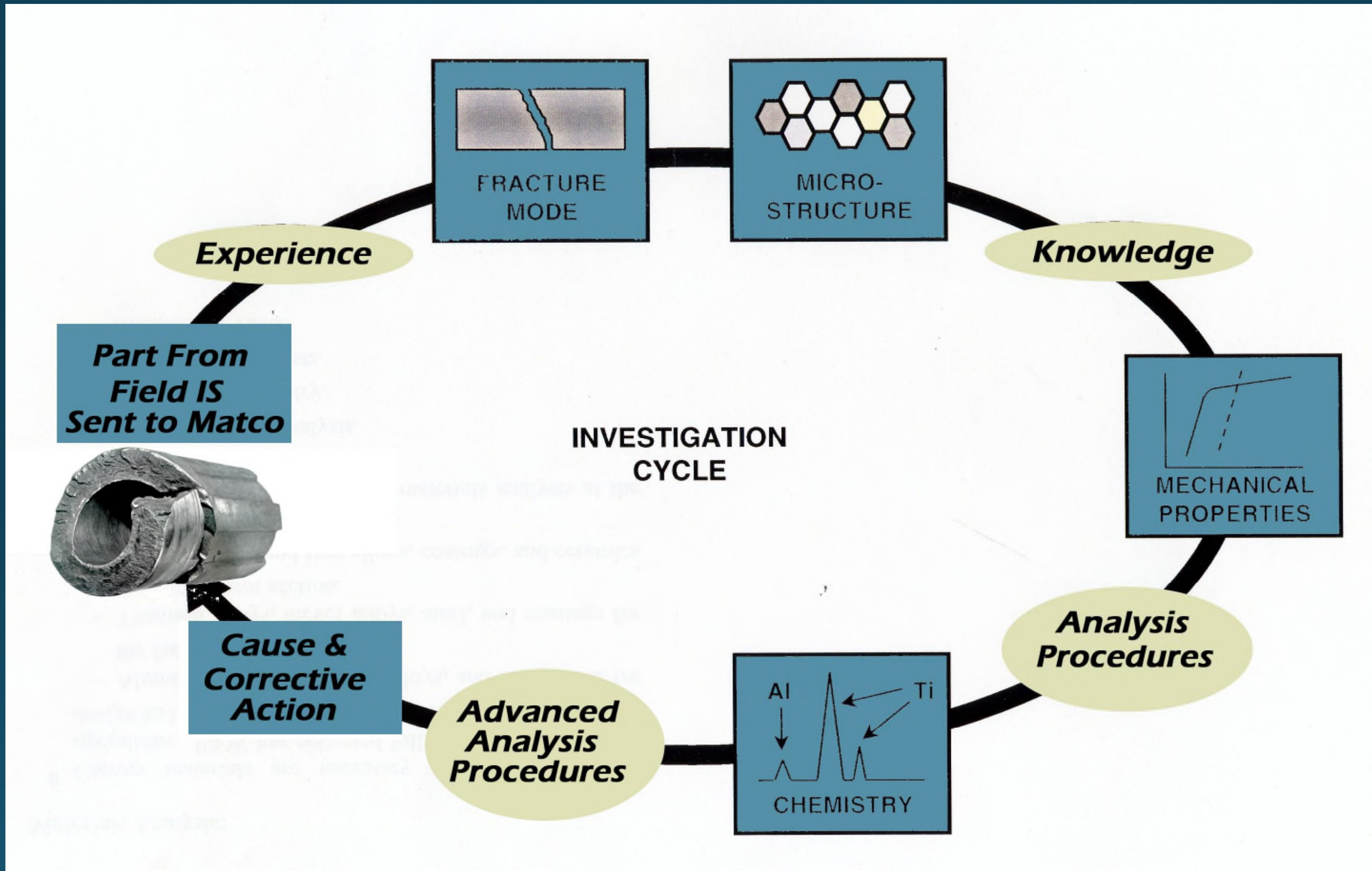
  - potential failure modes within a system consequences of those failures. Sequence of Events Analysis

- Forensic Engineering
  - Science concerned with relations between engineering and the law.

Site Information



Steps In Failure Analysis



Root Cause Found → **Make Corrective Actions**

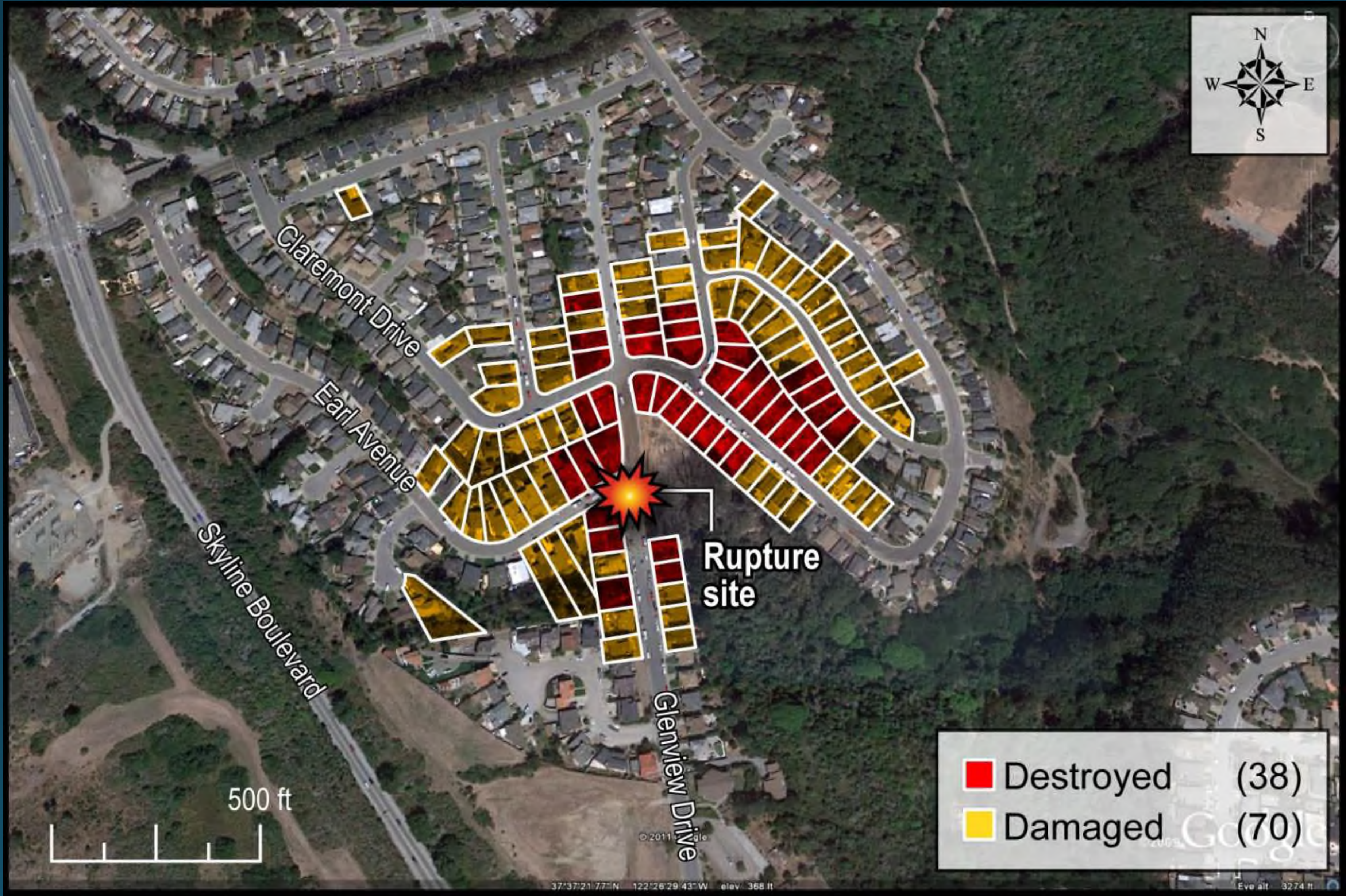
CORRECTIVE ACTIONS

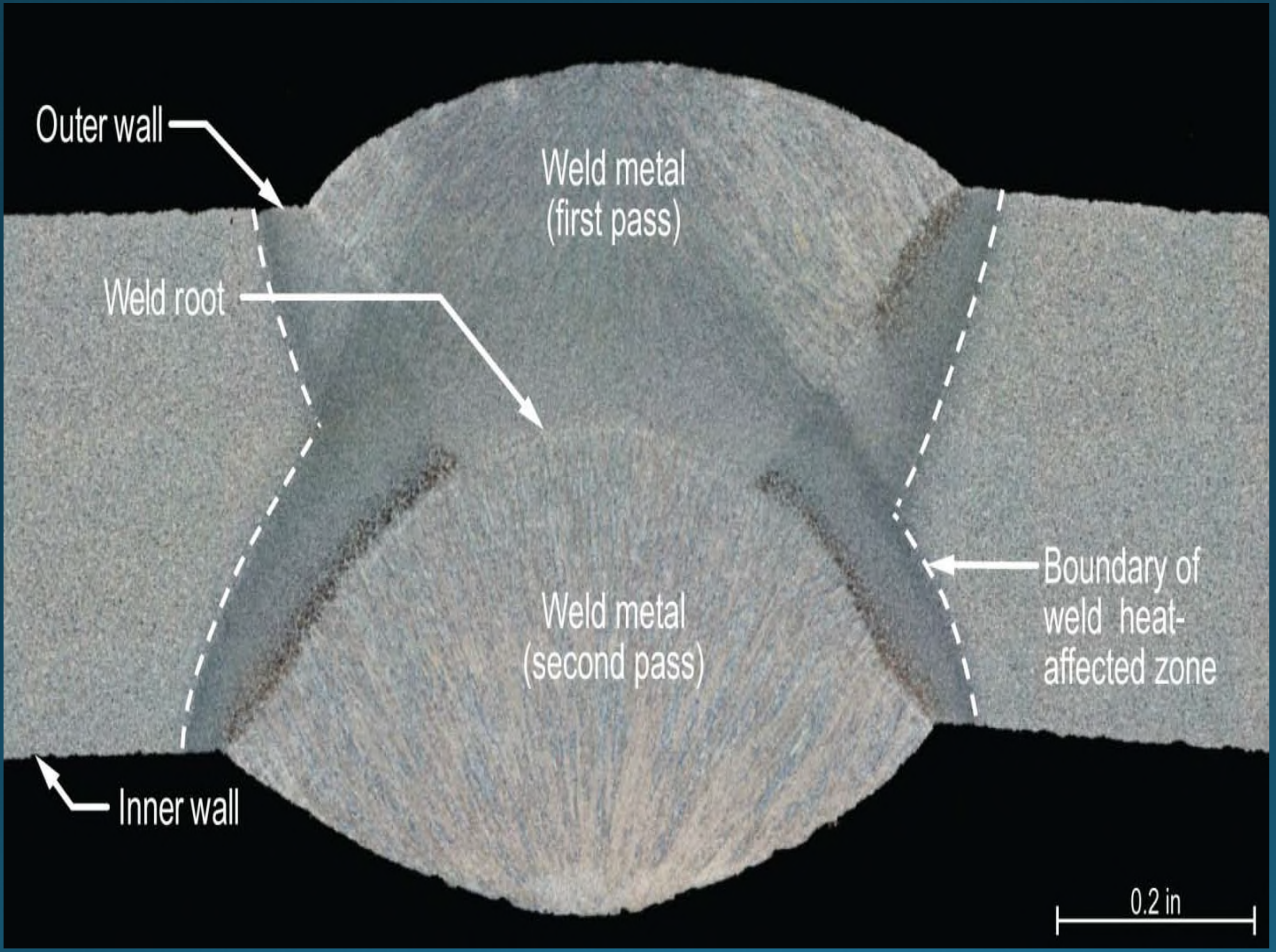
Pipeline Accident

- On September 9, 2010 a 30 inch diameter segment of gas line ruptured in a residential area in San Bruno California. The rupture produced a crater about 72 ft long by 26 ft wide.

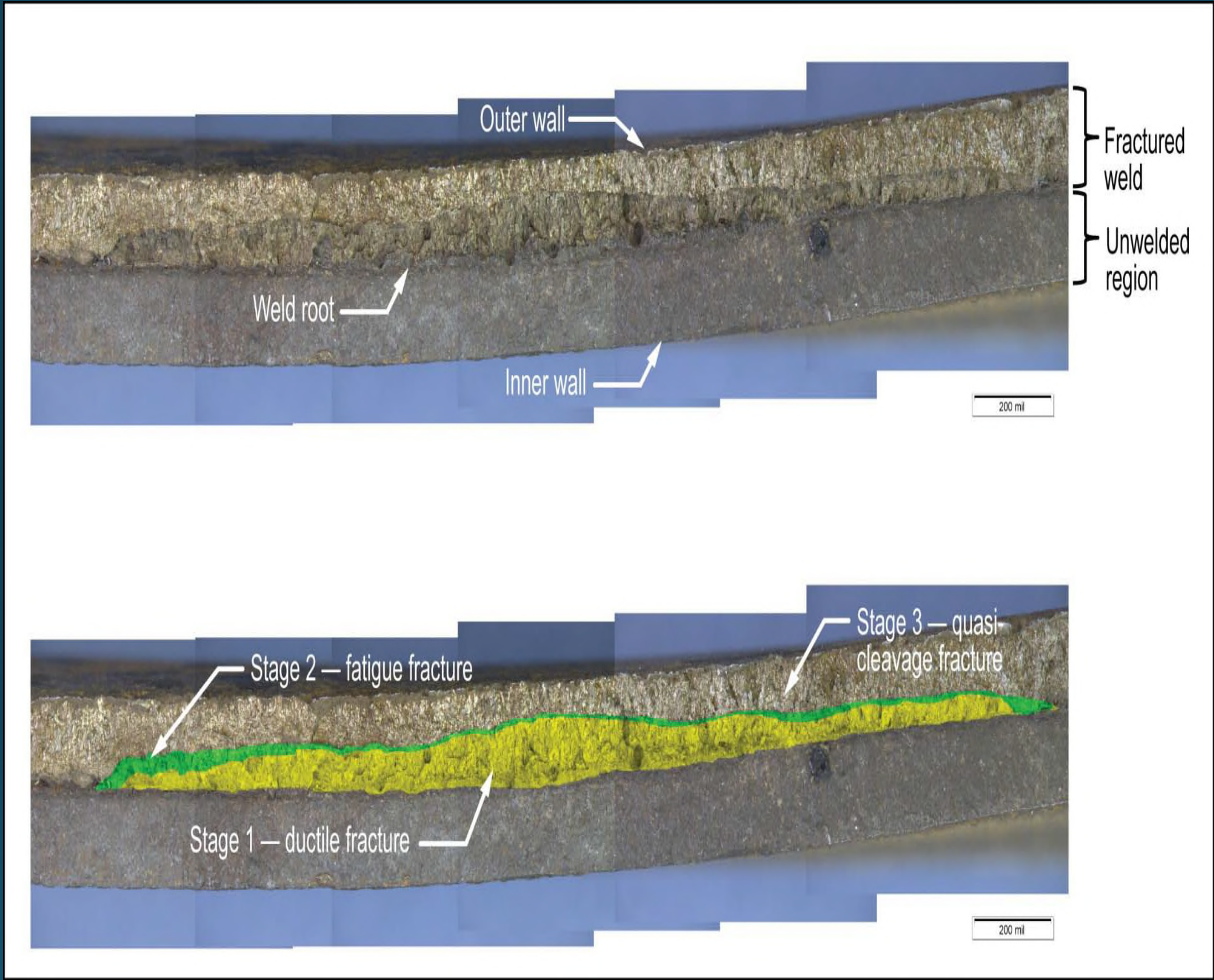
- The natural gas ignited resulting in destruction of 38 homes and damaged 70. Eight people were killed and many were injured.

NTSB Investigation

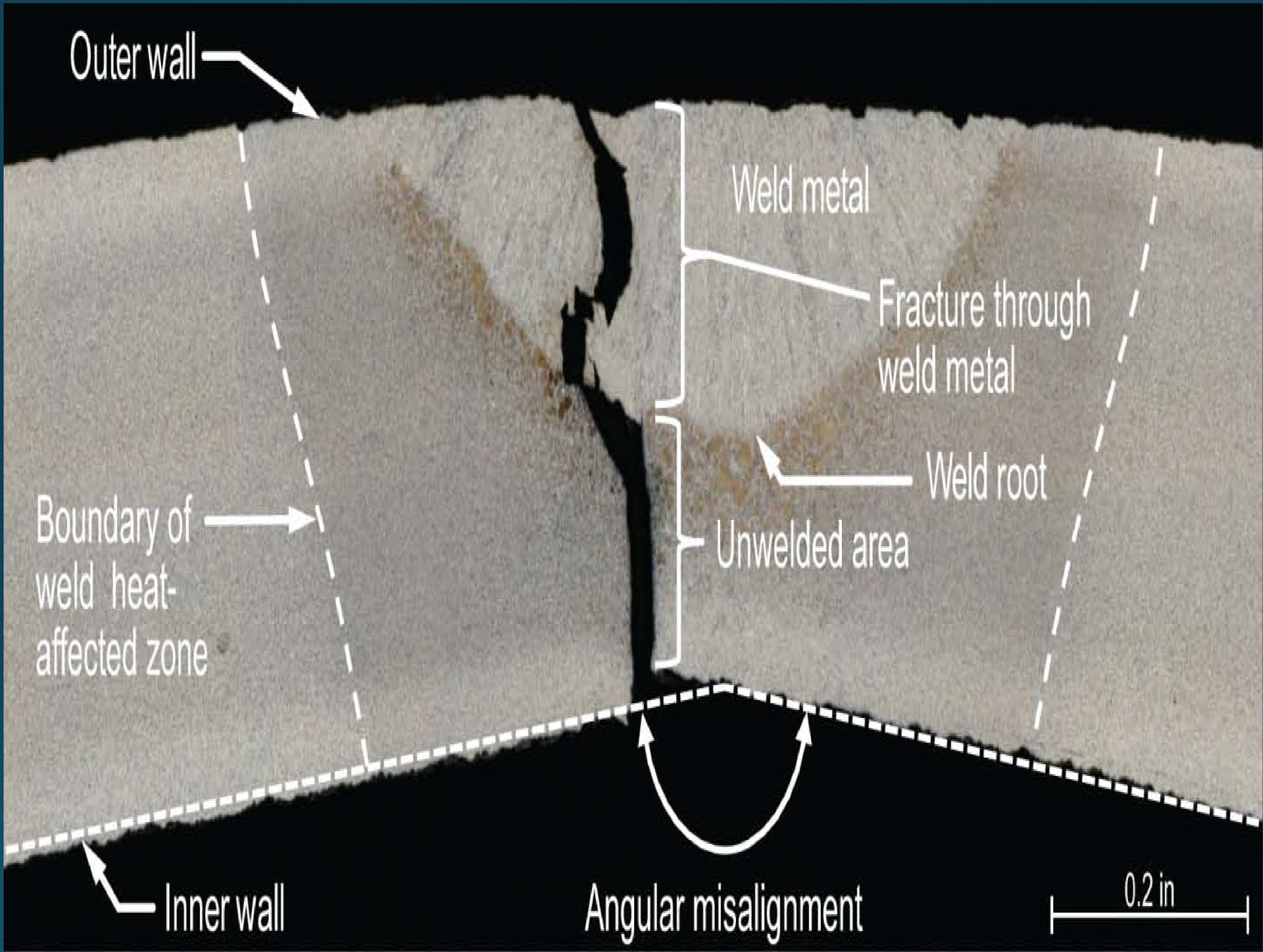

N
W
E
S
Claremont Drive
Earl Avenue
Skyline Boulevard
Glenview Drive
Rupture site
500 ft
Destroyed (38)
Damaged (70)



Full Penetration

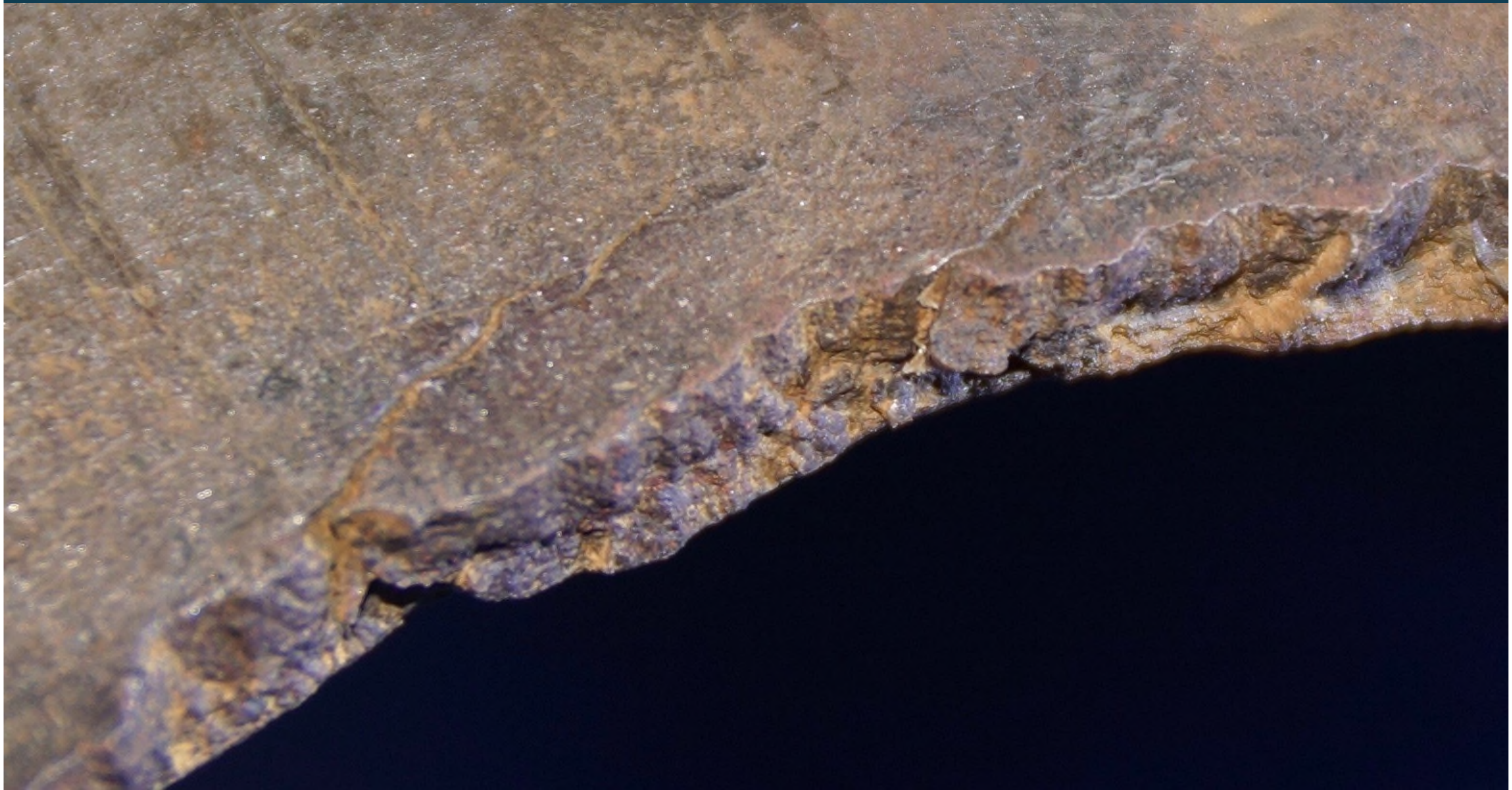


NTSB Investigation



Partial Penetration

Fracture Surface



CP Shielding

Shielding Cathodic Protection

1-External Barriers (river weights, Shields, Rocks…
2-Coating (FBE, Polyurethane, liquid epoxy, wax, and shrink sleeve)

Determine the permeabilty/shielding as function of water, corrosive ions absorption and thickness:

Corroded FBE Pipe

Corrosion & CP Protected Pipe

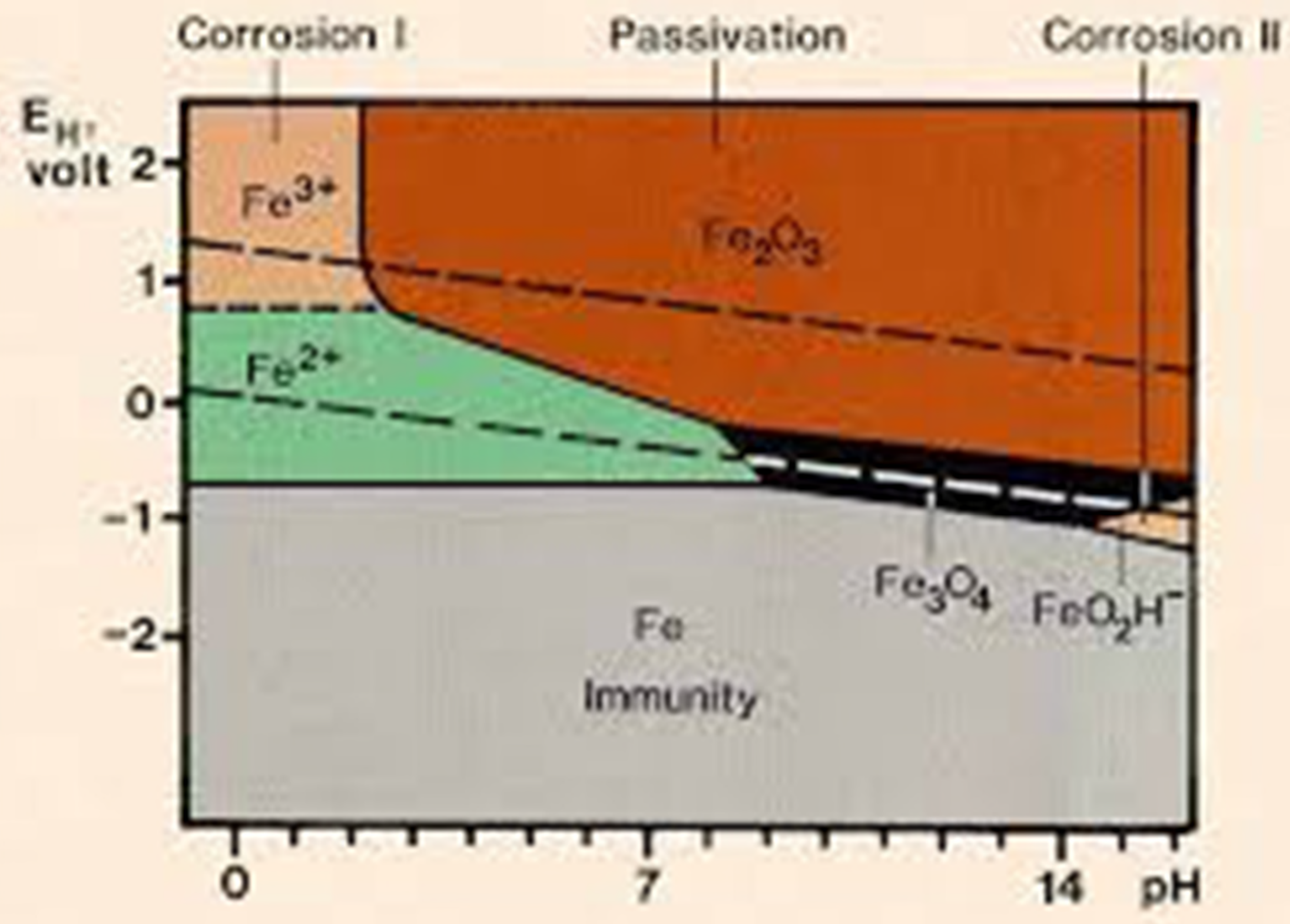


Fig. 110 — Potential-pH diagram for $Fe–H_2O$ at 25°C; 10^{-6} M dissolved Fe

Localized Corrosion and Magnetite

Engineering Tools To Identify Active Corrosion

- Assessment of Leak Records
- In Line Inspection
- Visual Inspection (Direct Examination)
- Soil Corrosivity/Chemistry Assessment
- Wireless Potential and Rectifer Data

Soil Testing

Key Risk Factors in Soil Corrosivity

- Soil chemistry

- Soil resistivity (soil conductivity)

- Chlorides, sulfates, sulfides
- Low soil resistivity (high conductivity)
- Acidity (low pH)
- Wet-dry fluctuations
- Differential aeration

Cast Iron Graphitization

Incident and Consequence Analysis

- **10.2 percent** of the incidents occurring on gas distribution mains involved cast iron mains. However, **only 2.3 percent** of distribution mains are cast iron.
- In proportion to overall cast iron main mileage, the frequency of incidents on mains made of cast iron is more than **four times that of** mains made of other materials.

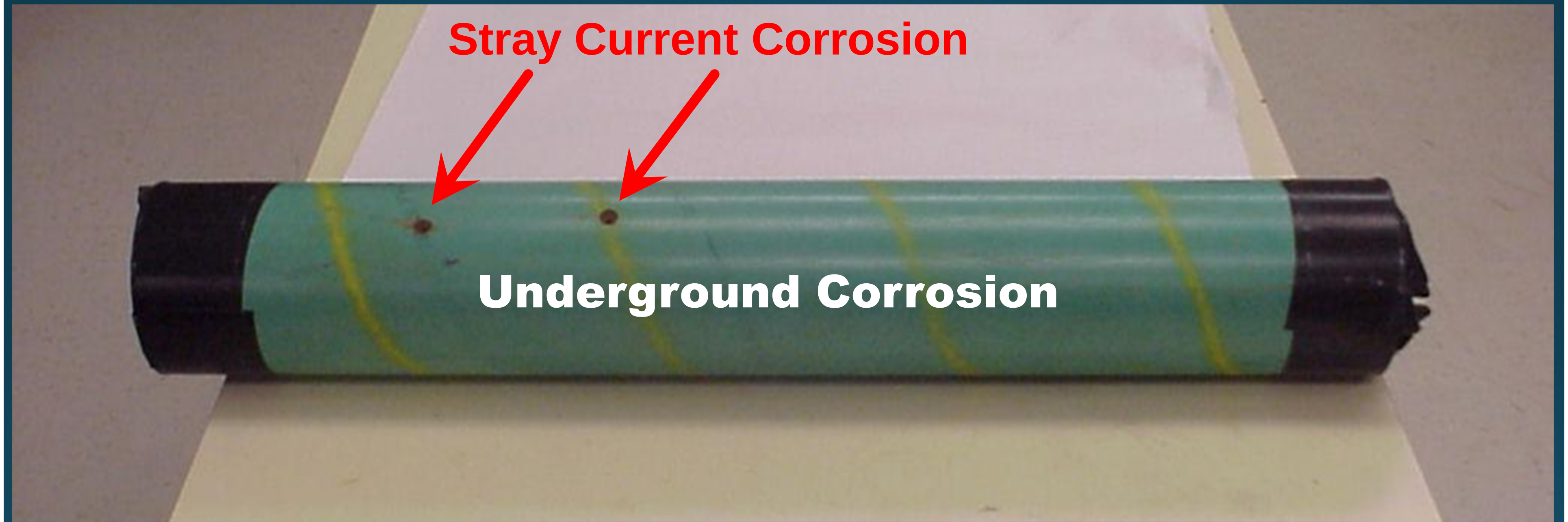
Cast Iron Graphitization

Cast Iron Replacment

- The utilities replaced about 10,000 miles of the most vulnerable cast-iron pipe from 2004 through 2013, leaving 30,000 miles to go. They replaced an additional 17,000 miles of bare-steel mains during the same period, leaving about 56,000 miles still in operation.

- To unearth, remove and replace an old cast-iron gas main can cost more than $1 million a mile. It means cutting into streets, navigating a rat's nest of other pipes and underground infrastructure, shutting down roads and sidewalks. The cost can be several million dollars a mile in major cities, where those disruptions are amplified by the presence of more people, buildings and cars.

Stray Current Corrosion
Unacceptable Risk: Immediate Action



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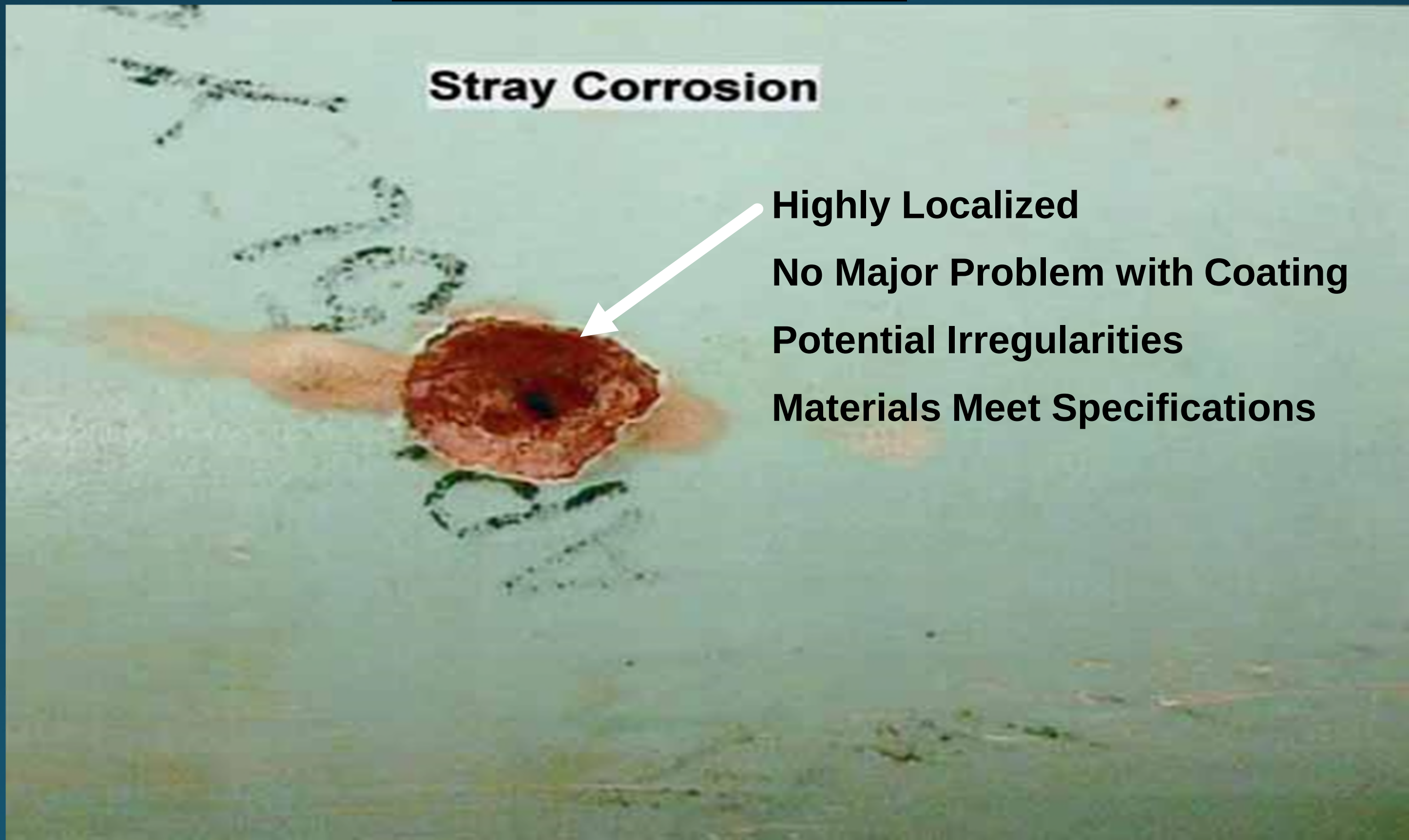
Stray Current Corrosion
Unacceptable Risk: Immediate Action

Stray Current Corrosion
(6 months only)



Stray Current Corrosion

1. Corrosion Potential Measurements

   Noble potential at point of discharge
   Negative potentials at point of entry

2. Current Measurements

AC Interference

The magnetic field generated by the overhead power lines induces an AC voltage onto the pipeline (which creates AC currents). The magnitude of such currents depend on many factors such as coating condition, soil composition, power line voltage, distance, etc.

AC Interference

Fusion bonded epoxy (FBE) coating

AC Interference Characteristics

- AC Interference

  >100A/m2

  >4.8 AC Voltage

  Low soil restivity

  High pH

Smooth round pit?

Hard corrosion product: Magnetite

Likely hood increase with decreasing AC frequency and decreasing holiday surface area.

Stray Current and AC Interference

Important Questions for Blistered FBE Coated Pipe Under CP?

Optimum CP potentials

Shielding

Electrodeposition

- AC Interference and Blistered FBE coated Pipeline

Case History

Failure Analysis of Fusion Bonded Epoxy Pipeline Coating

Disbondment

Blistering

FBE Coated Gas Line Exhibiting Blisters, Adhesion Problems and Delamination

FBE Disbondment

Blister Solution Sample Collection

Root Cause

- Findings and Primary Cause

1-Extensive disbondment after 15 years

2-Corrosive soil

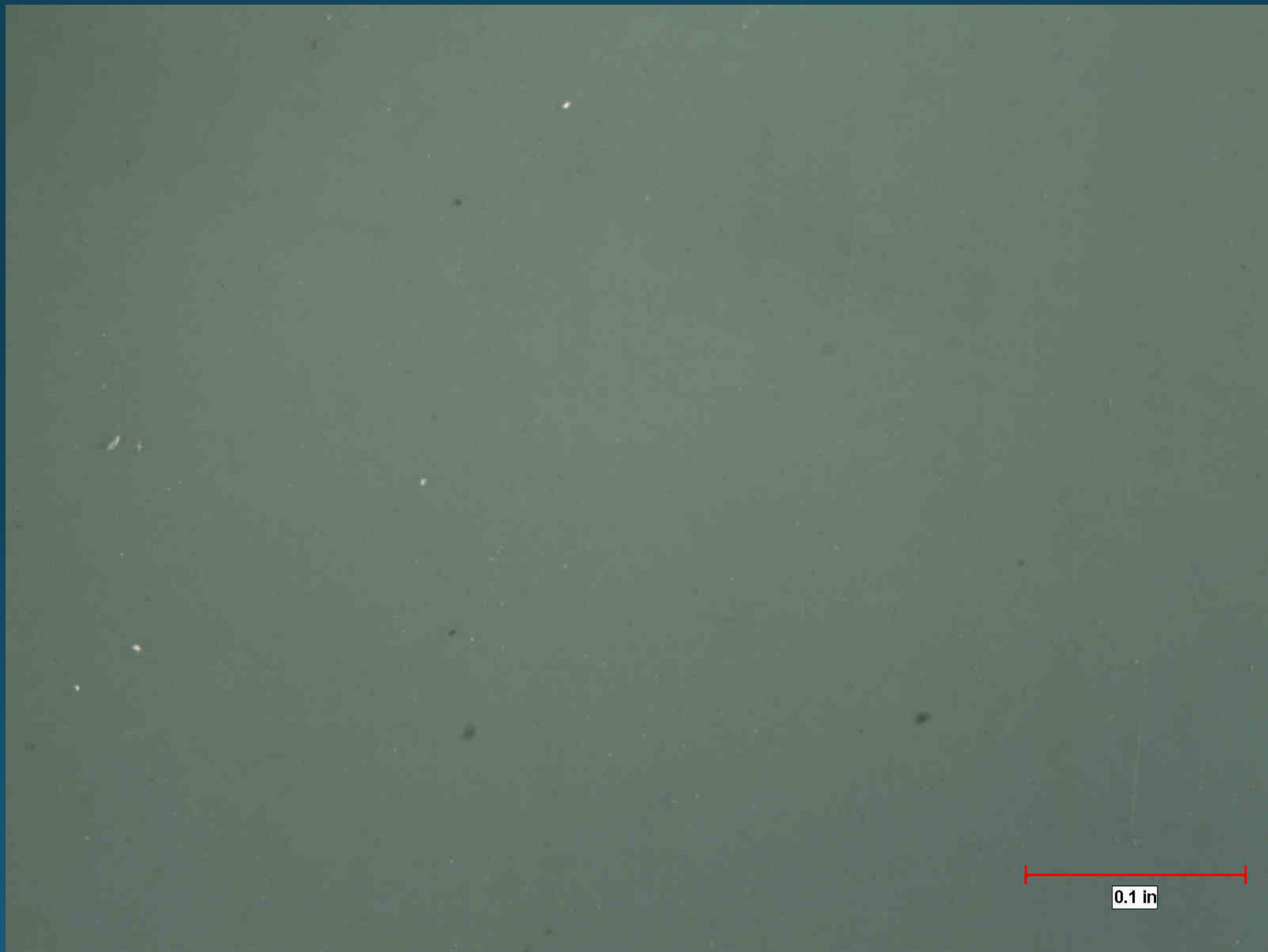
3-Poor cathodic disbondment resistance

4-Presence of high amounts of negativly charged ions, Cl^-, NO_3^-

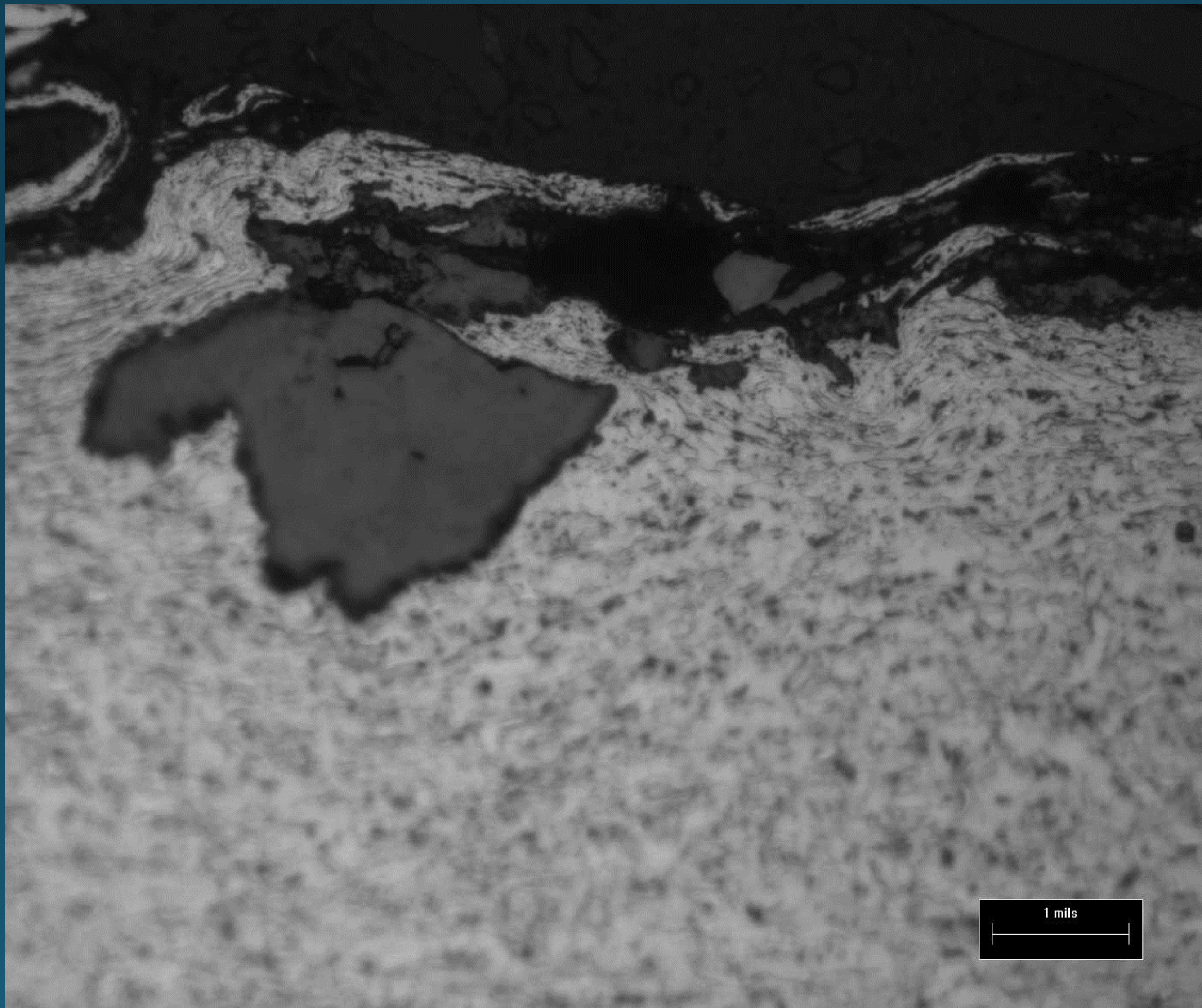
5-Surface contamination prior to coating

6-Root Cause –Inadequate QC/QA prior and during coating process

Coating Looks Good Early On



Under Surface Defect



Important Considerations

- Surface contamination, angularity and peak heights plays a major role in the amount of disbonding that will occur in a given time span.

- Cathodic Protection potentials can effect disbondment and blistering

- Cathodic Protection can mitigate corrosion provided the CP criteria is met at all times and AC interference(if present) is taken into consideration

Conclusion

- Aging pipelines are at risk of corrosion and cracking
- Corrosive Soils and Stray Currents
- A pre-assessment can identify the sites for direct assessment
- Direct assessment should determine the extent of corrosion penetration and rate
- Repair or replacement will be based on remaining strength and corrosion rate
- Cathodic Protection can mitigate corrosion proided Criteria is met
- Remote monitoring is best for assessment of corrosive soils

- WE NEED TO DEVLOPE NDT TECHNIQUES AND PROCEDURES TO DETECT INITIATION OF PITTING AND CRACKING PRIOR TO CATASROPHIC FAILURE

Is this Sun Rise or Sun Set?

The eye can lie.

Check the facts first before forming an opinion or making a decision – because we really don't know!

Do we?

Cathodic Protection at all times
Adhesion during wet and dry periods
AC Interference and DC stray current

Training Seminars are Fantastic!

Question & Answers