BASIC MECHANISMS OF CORROSION AND CORROSION CONTROL FOR WATER AND WASTEWATER SYSTEMS

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Walking Through the Minefield of Corrosion

Market Driver for Corrosion Control is Entropy

Our "Business" is Guaranteed by a Fundamental Law of Nature:

$$\Delta S_{universe} \geq 0$$



DEFINITION OF CORROSION

Corrosion is the deterioration of a substance or its properties as a result of an undesirable reaction with the environment.

- NACE International

It is irreversible and degenerative and related to the Second Law Thermodynamics

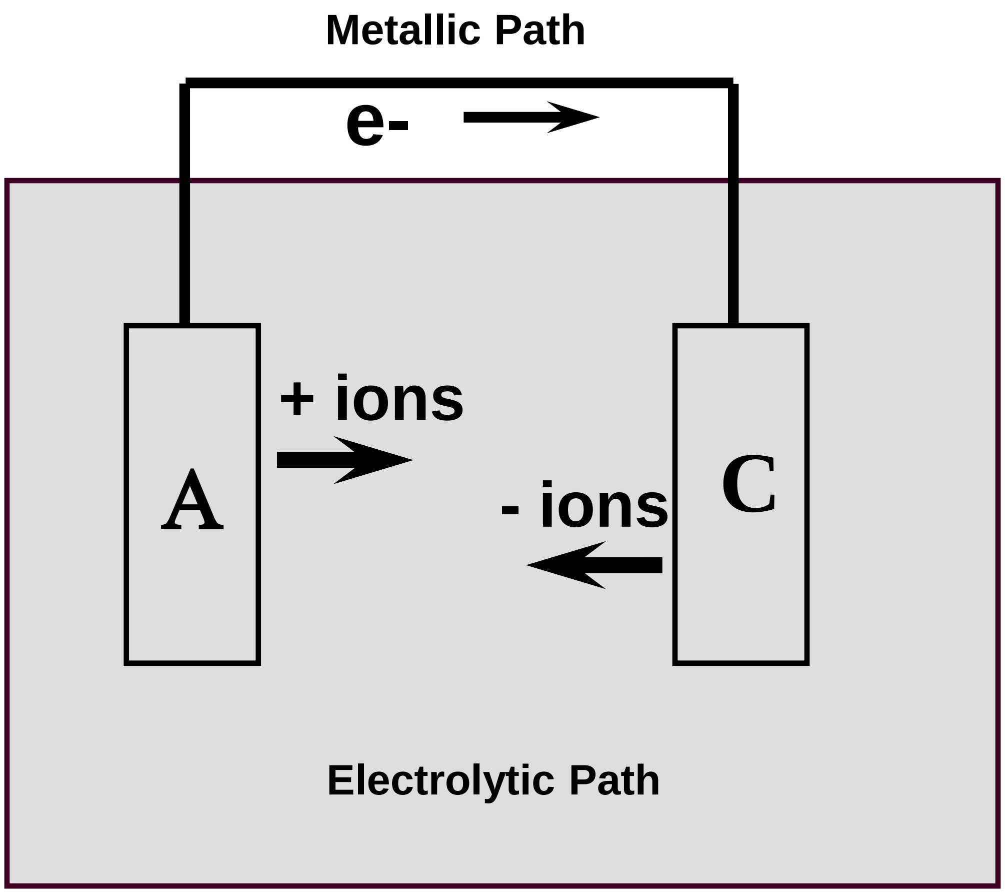
"Energy spontaneously tends to flow only from being concentrated in one place to becoming diffused or dispersed and spread out."

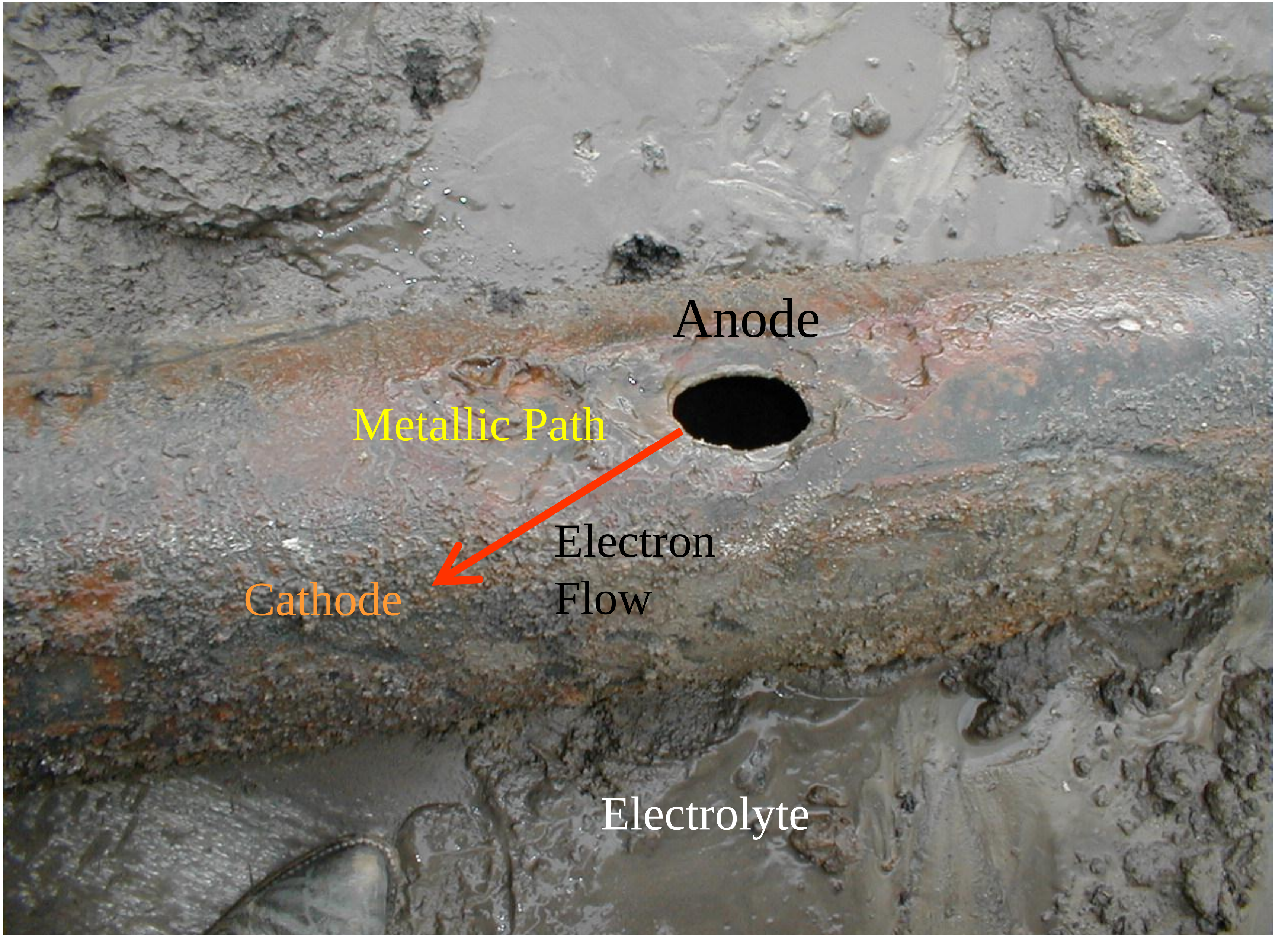
Everything You Need to Know About Corrosion

- 4 Parts of a Corrosion Cell
  - Anode (location where corrosion takes place)
    - Oxidation Half-Reaction
  - Cathode (no corrosion)
    - Reduction Half-Reaction
  - Electrolyte (Soil, Water, Moisture, etc.)
  - Electrical Connection between anode and cathode (wire, metal wall, etc.)

Electrochemical corrosion can be stopped by eliminating any one of the 4 components

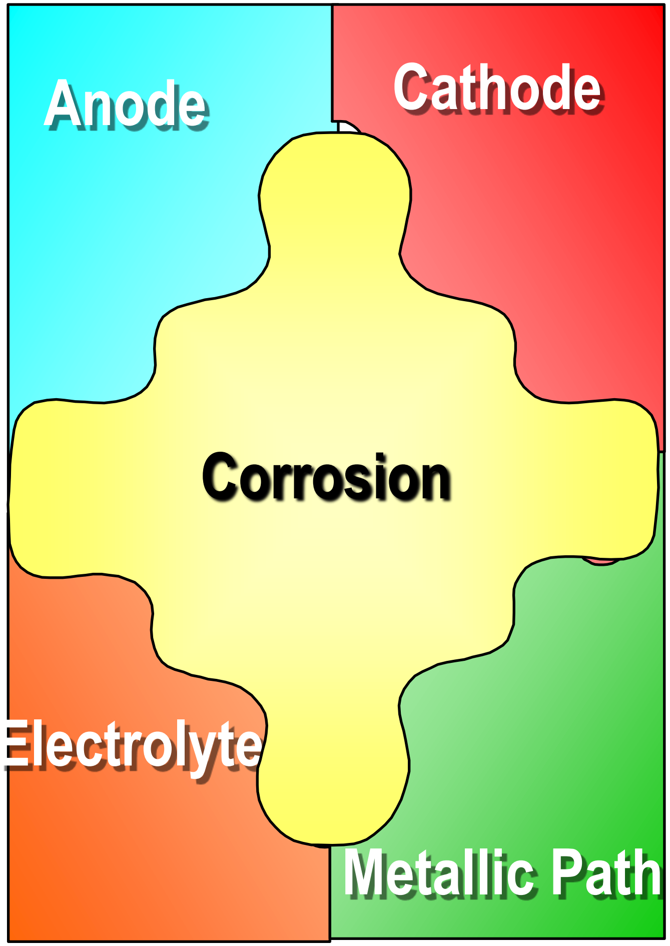
Electrochemical Corrosion Cell



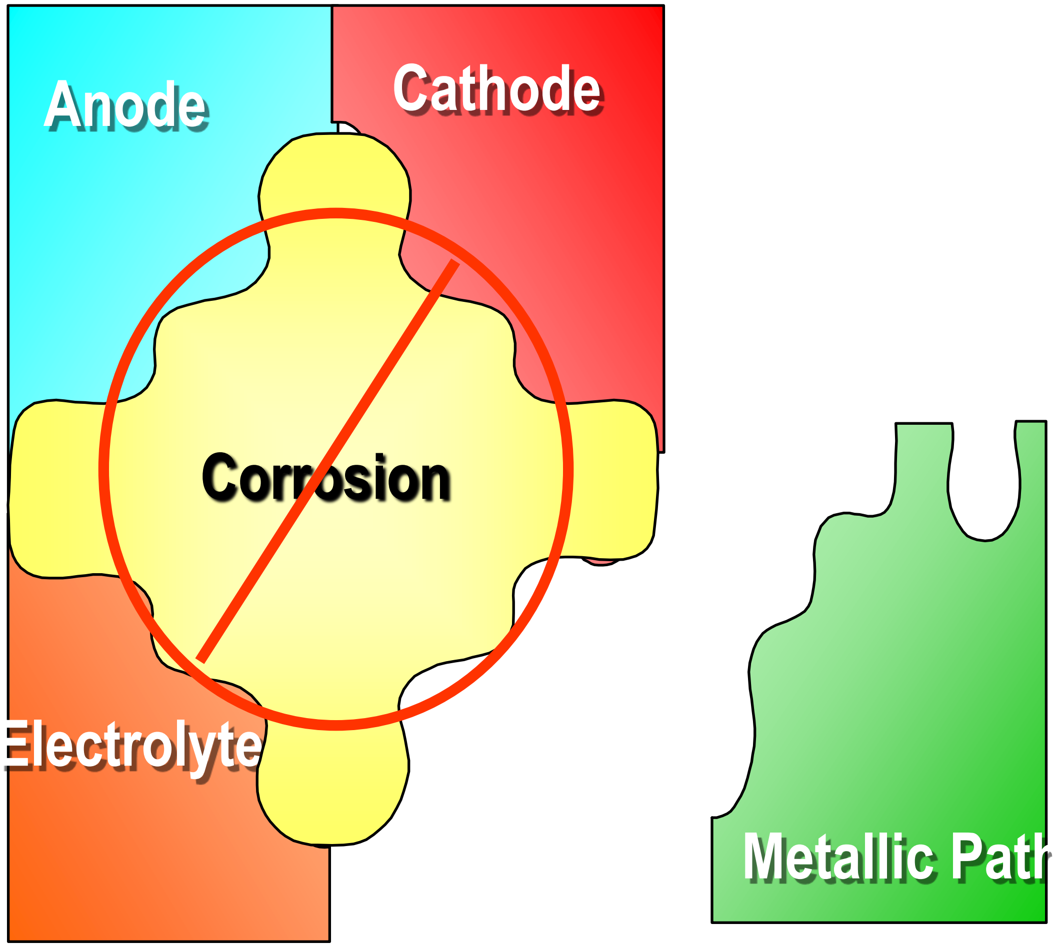

Anode
Metallic Path
Electron
Flow
Cathode
Electrolyte

Can you find the anode?

The Corrosion Puzzle



Remove any piece of the puzzle and corrosion stops!



U.S. Cost of Corrosion is about 3.1% of GDP (50% to 70% Related to Civil Engineering)

2010 US GDP = $14.72 Trillion

U.S. Cost of Corrosion = $460 Billion

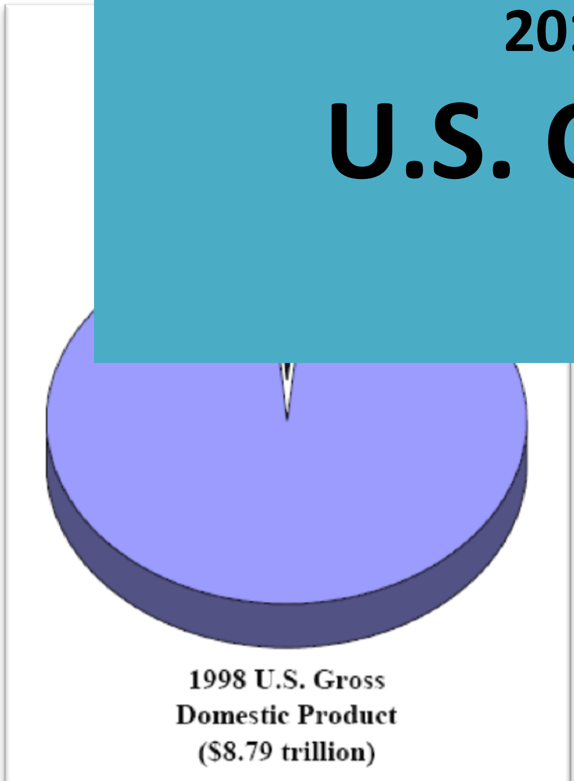


Figure 3. Impact of corrosion on the U.S. economy.

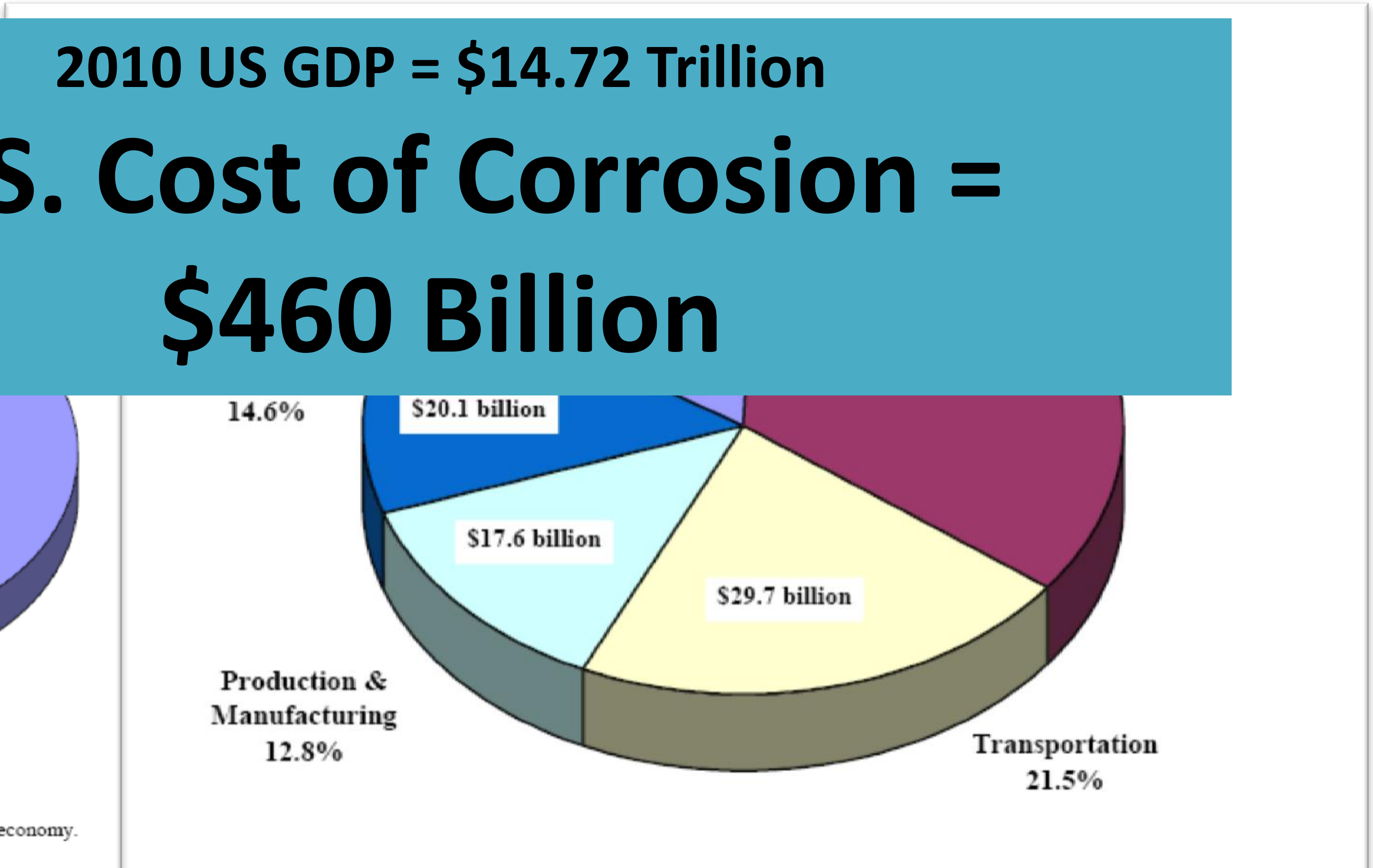
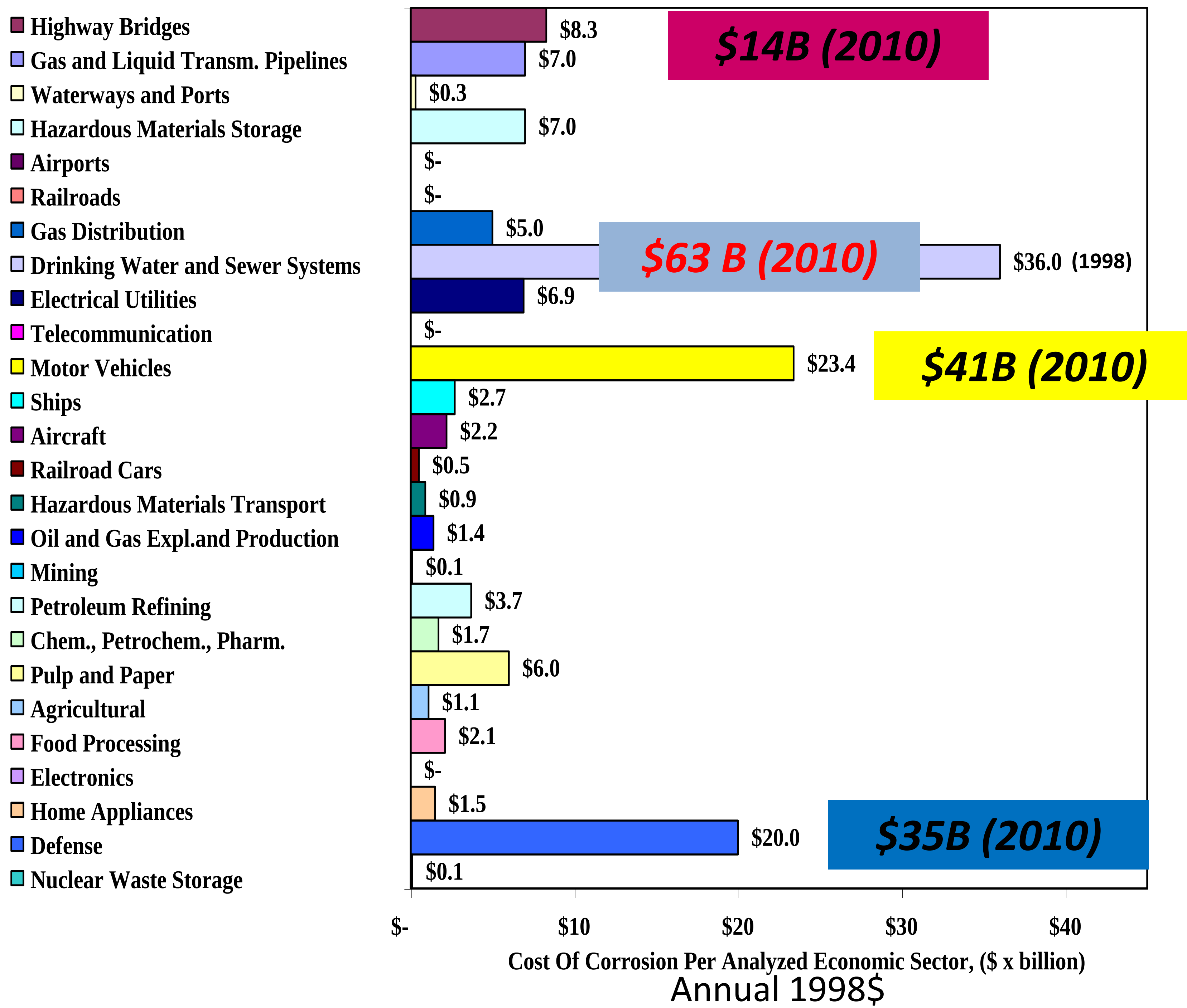


Figure 1. Cost of corrosion in sector categories analyzed in this study (total $137.9 billion/year).



Highway Bridges
Gas and Liquid Transm. Pipelines
Waterways and Ports
Hazardous Materials Storage
Airports
Railroads
Gas Distribution
Drinking Water and Sewer Systems
Electrical Utilities
Telecommunication
Motor Vehicles
Ships
Aircraft
Railroad Cars
Hazardous Materials Transport
Oil and Gas Expl.and Production
Mining
Petroleum Refining
Chem., Petrochem., Pharm.
Pulp and Paper
Agricultural
Food Processing
Electronics
Home Appliances
Defense
Nuclear Waste Storage
$8.3
$7.0
$0.3
$7.0
$-
$-
$5.0
$36.0 (1998)
$6.9
$-
$23.4
$2.7
$2.2
$0.5
$0.9
$1.4
$0.1
$3.7
$1.7
$6.0
$1.1
$2.1
$-
$1.5
$20.0
$0.1
$14B (2010)
$63 B (2010)
$41B (2010)
$35B (2010)
$-
$10
$20
$30
$40
Cost Of Corrosion Per Analyzed Economic Sector, ($ x billion)
Annual 1998$

Objectives of the Most Infrastructure Projects

- Provide a 50 + Year Useful Life
- Useful life means:
  - Functionality Assured
  - Structural Integrity Maintained
  - Operating Costs Controlled
- How do we do this?
  - Control the two time dependent degradation mechanisms
    - Corrosion
    - Fatigue
    - Creep (Generally Not Applicable)

Two distinct and different types of Situations:

- New Pipe (Lot of Options)
  - Chance to Do it Right
  - Right of Way Study through Construction
- Existing Pipe (Limited Options)
  - "Sins of the father"
  - Condition Assessment
- For both, Corrosion Control is a Process, not a Project.

Concepts of the Four Basic Methods Corrosion Control

- Material Selection/Design Details
  - Choose materials compatible with environment.
  - Do not create corrosion cell through design/construction details.
- Corrosion Inhibitors
  - Alter the environment adjacent to metal to passivate and protect metal.
  - Concrete or mortar on steel are inhibitors

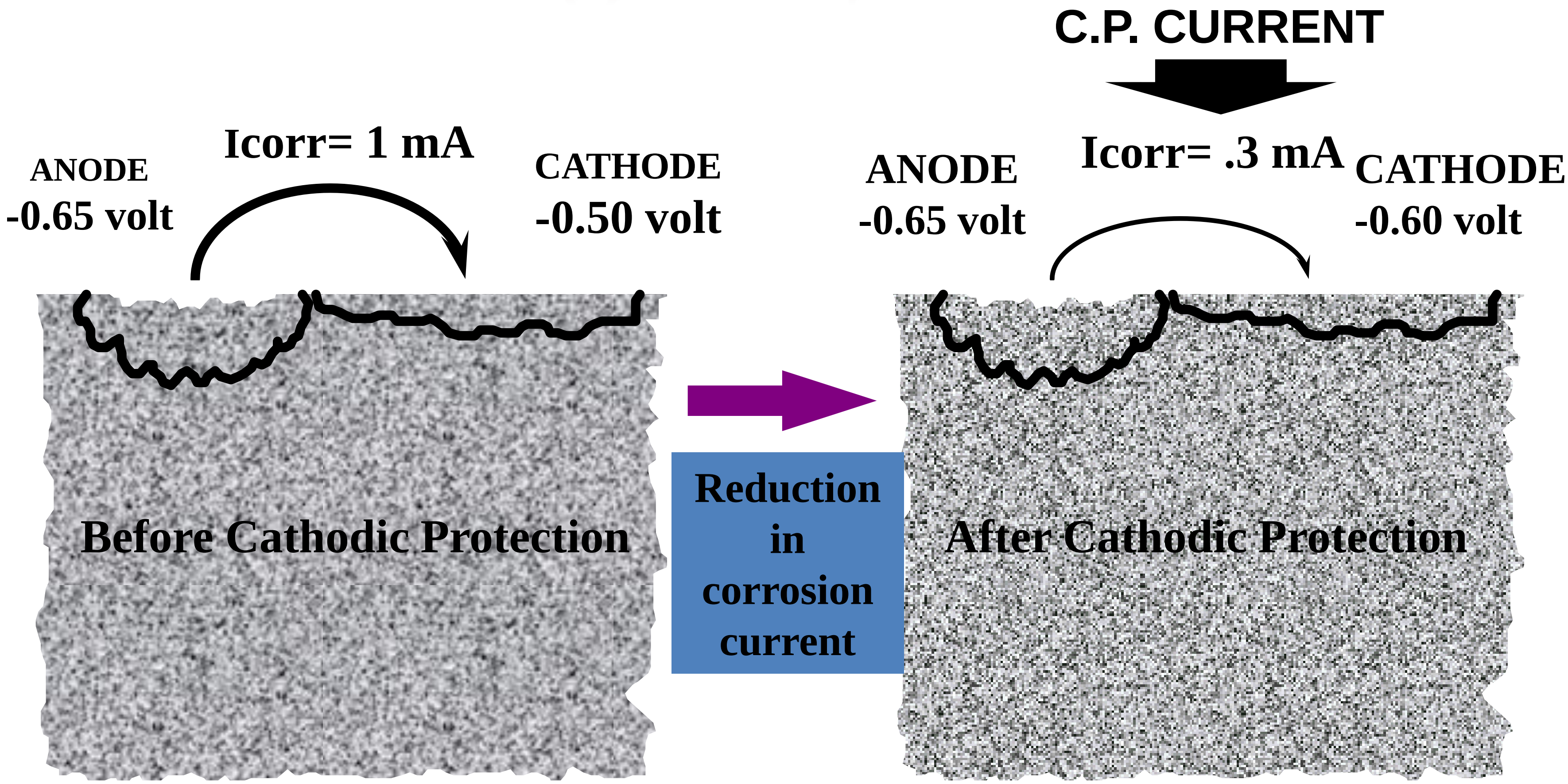
Concepts of the Four Basic Methods Corrosion Control (continued)

- Cathodic Protection
  - Electrochemically alter the surface condition of the metal to move the anodic reactions elsewhere.
- Coatings (exterior) and Linings (interior)
  - Provide a barrier to the electrolyte and protect the metal. Usually dielectric material that prevents electron and ionic current flow.

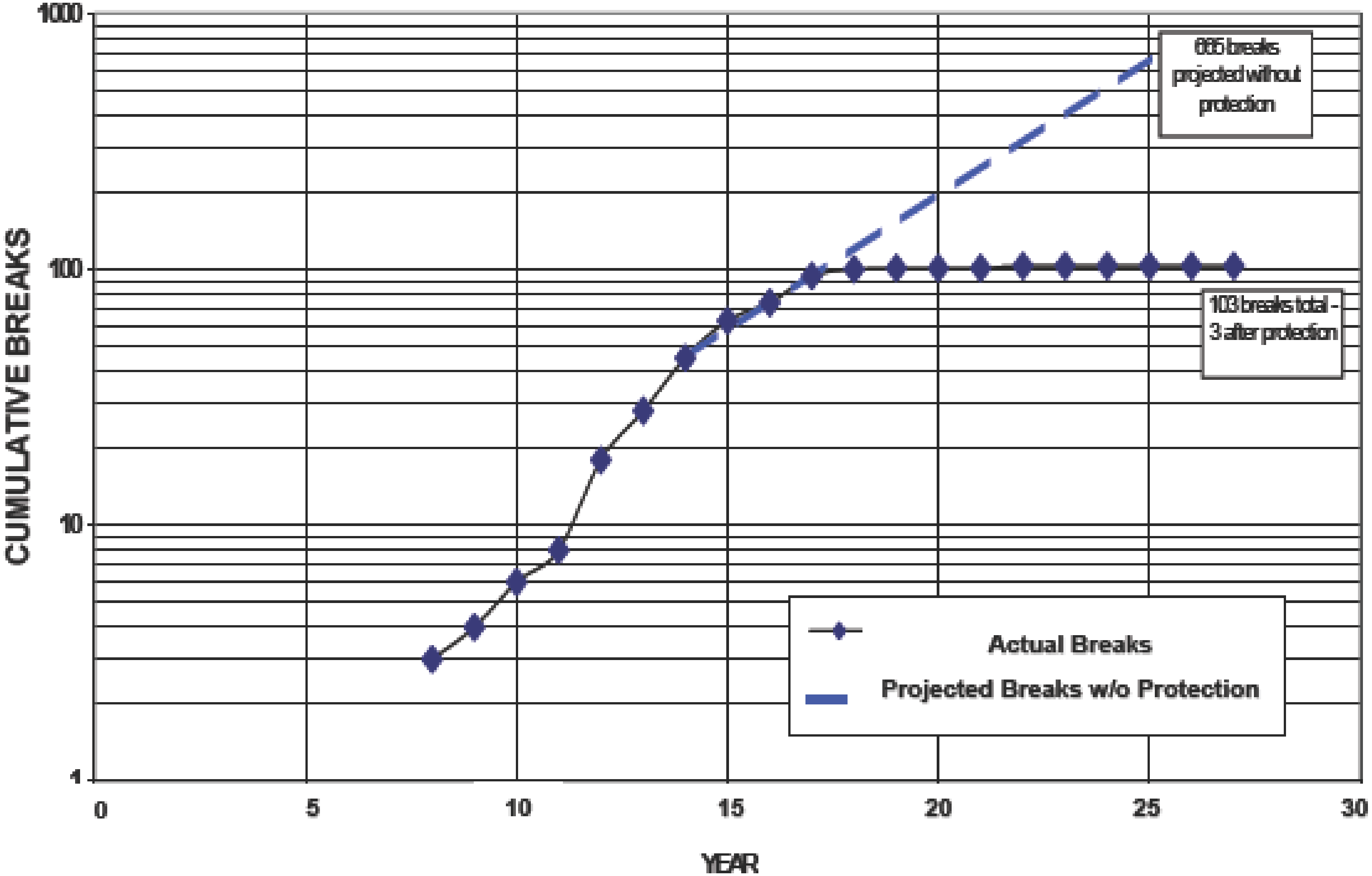
Coatings and Cathodic Protection Work Together

- Cathodic protection can be applied with out coatings.
- Coatings should not be used with out cathodic protection.
- Cathodic protection effectively protects defects in the coating.
  - In many environments actually repairs the coating locally by depositing minerals that plug the holes in the coating

Effect of Cathodic Protection Current



Cathodic Protection Stops Leaks



$$ are Directly Proportional to Current Capacity (Amps)

- Life Cycle Costs = Construction + Operating Costs
- Initial/Construction costs ~ Amps
- Operating/Maintenance Costs ~ Amps
- Anything and everything you do to reduce current requirement saves $$$.

CP Current Requirements for Water Industry Piping

Pipe Material	*Coating System*	*Current Requirement (ma/sf)*
Steel/Iron	***None***	***1 to 3***
Steel	***AWWA C205***	***0.1 to 0.5***
Steel/Iron	***Dielectric Coating AWWA C214, 217, 222***	***0.0006 to 0.020***
Ductile Iron with PE	***AWWA C105***	***0.020 to 0.040***

Water vs. Wastewater: External Corrosion

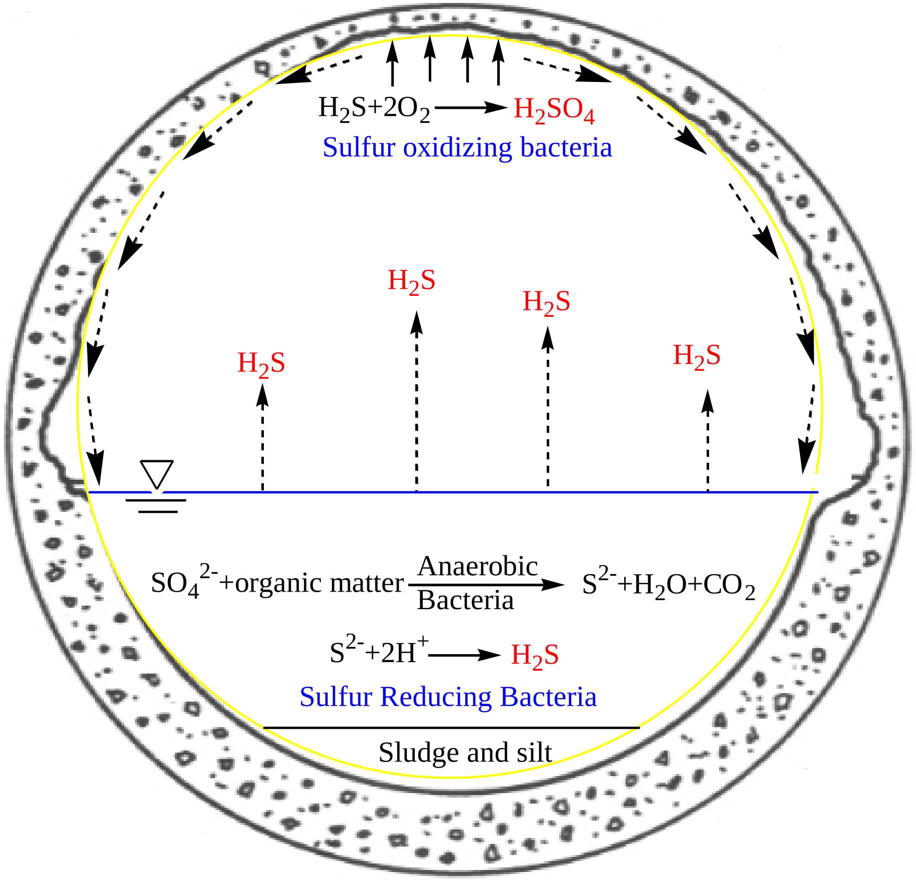
- Mechanisms are identical
- Corrosion Control for Exterior is Identical
- Materials, Design and Construction Practices
  - Similar.....
  - But Wastewater construction does not typically account for the eventual need for cathodic protection
    - Electrical Continuity of Pipelines and Structures
    - Electrical Isolation for Appurtenances

Water vs. Wastewater: Internal Corrosion

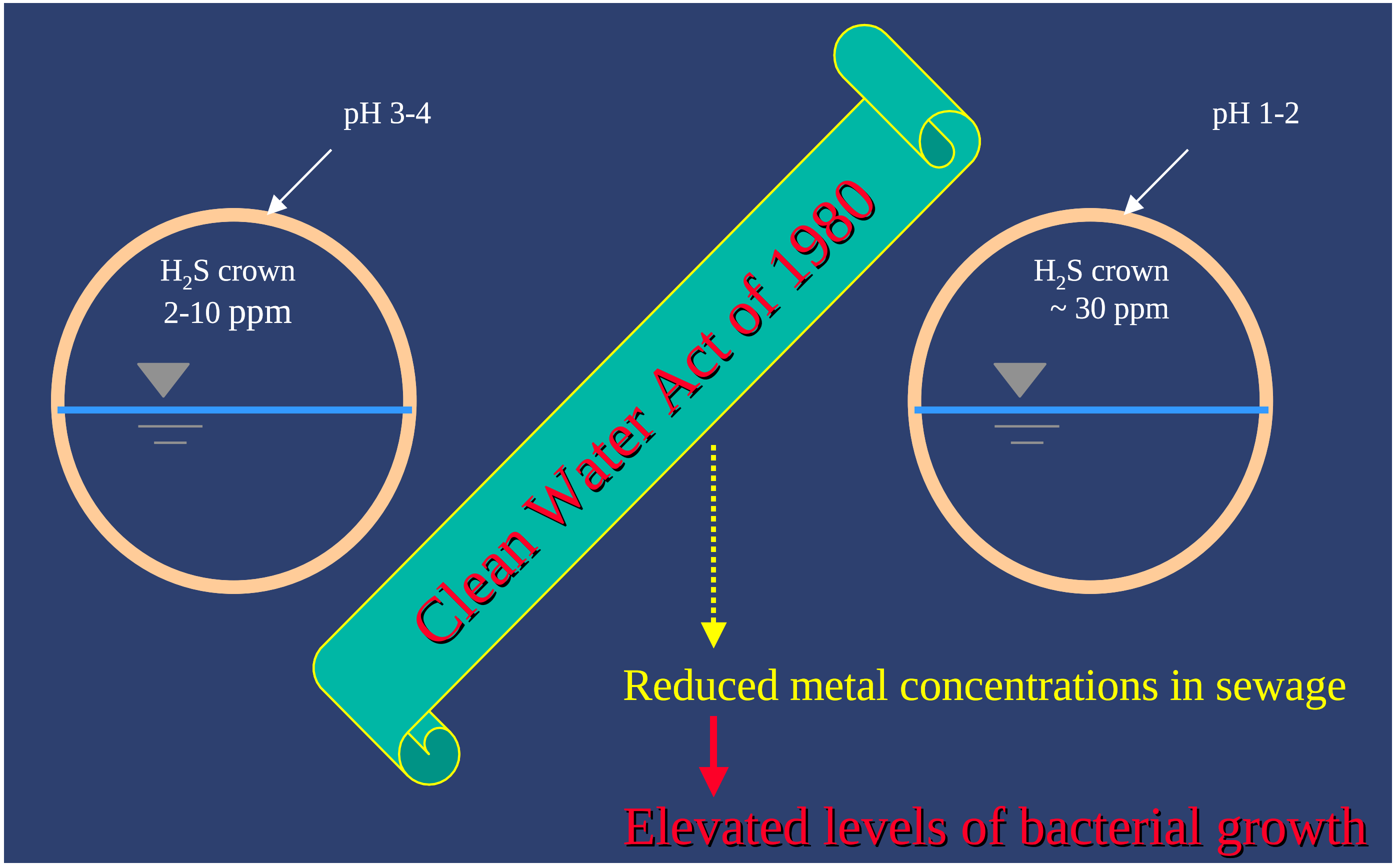
- Not the Same At All.
- Corrosion Rates for wastewater can be extremely high.
- More often internal corrosion leads to problems
- This is one reason why external corrosion is ignored.

Internal Corrosion of Wastewater Systems

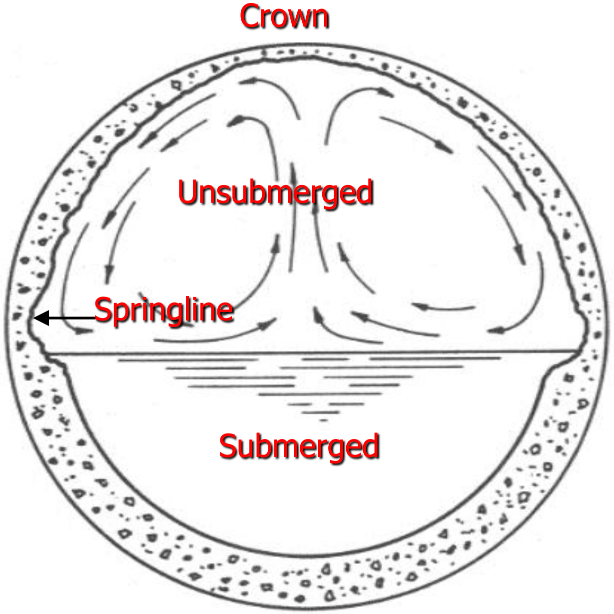
- Dominated by Formation of Sulfuric Acid



"Indirect" Impact of Regulations on Corrosion



Water Line Corrosion

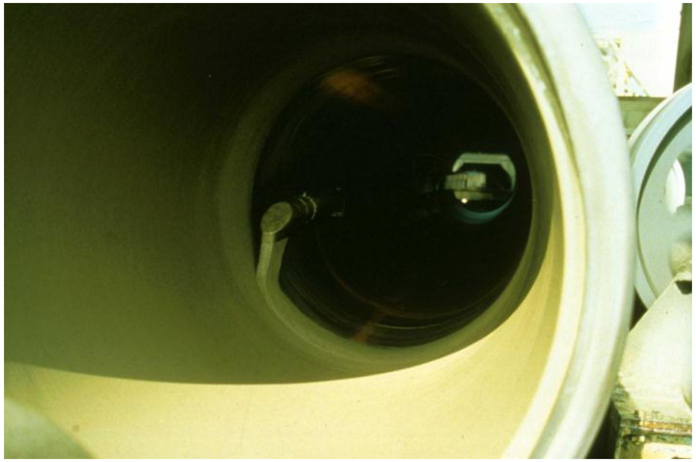


Internal Corrosion

DIP for Force Main
Gas Pocket Corrosion

Corrosion Control for the Outside of CMC or Concrete Water Pipes

- AWWA C205, C300, C301, or C303
- Corrosivity of alignment must be determined
    - Saturated ASTM G57 Soil Resistivity > 1500 Ω-cm
        - Chlorides < 350 ppm in soil
        - Sulfates < 2,000 ppm in soil
        - No fluctuating groundwater in pipe zone.
    - pH > 5.0

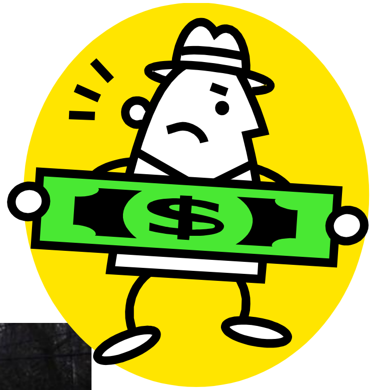


References

- AWWA Manual M27 – External Corrosion
- AWWA Manual M28 – Rehabilitation of Water Mains
- AWWARF Report 90987 – External Corrosion and Corrosion Control of Buried Water Mains
- NACE International Standards SP0169; SP0207; Peabody Control of Pipeline Corrosion

Things we try to avoid…

Condition Assessment is Part of the Asset Preservation



- Financial Motivation
  - Shrinking Budgets
  - GASB 34

- Political Motivation
  - Career Limiting Events
- Regulatory Motivation
  - Jail – Oil and Gas Model

Selection of Condition Assessment Technology Depends on Several Factors

- Budget

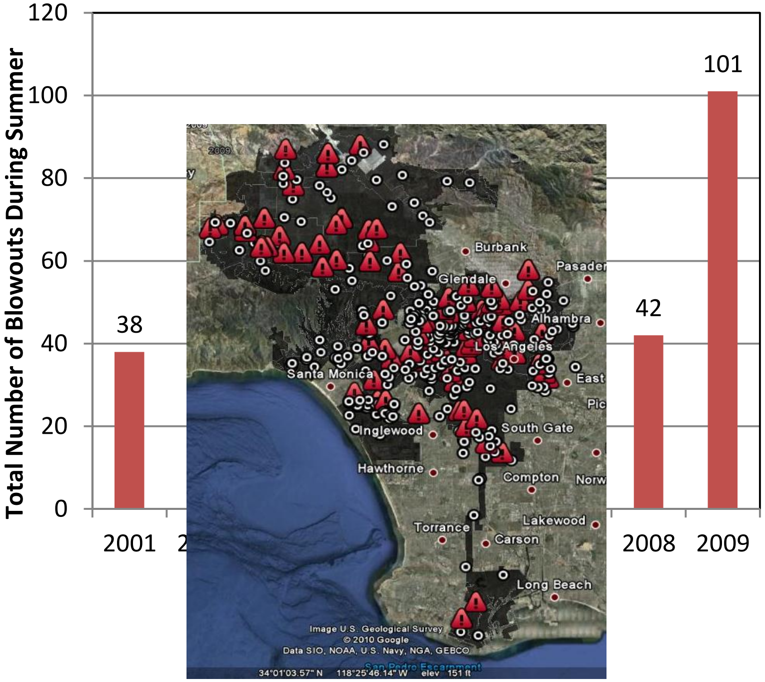
- Accessibility/Availability of Asset

- Risk Tolerance

- Best Practice is to use multiple methods

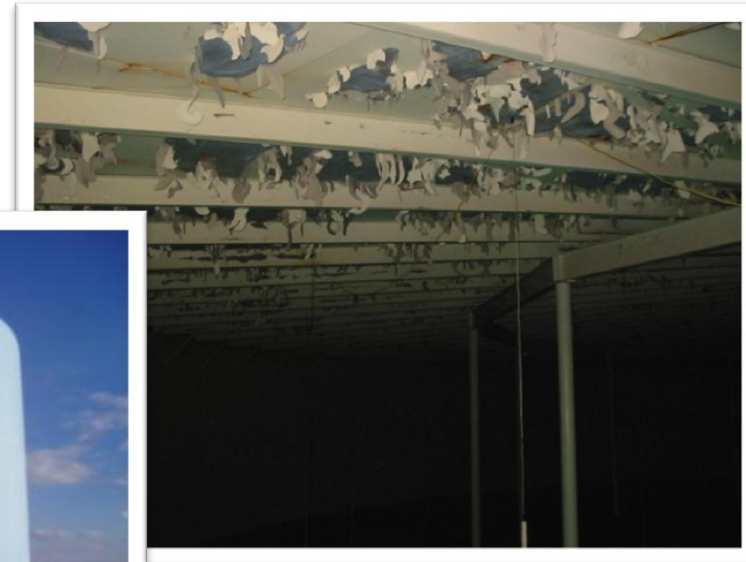
You can do something without Technology!

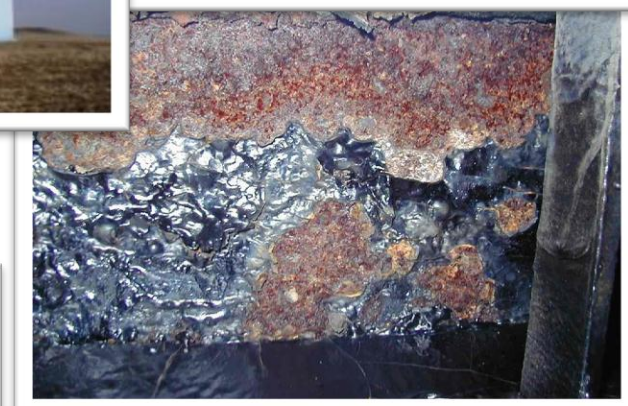
- Historical Information
  - Design Information
  - Leak and Break Rates
- Geographical Information
  - Where should I look?
- Industry Metrics
- Use your brain….

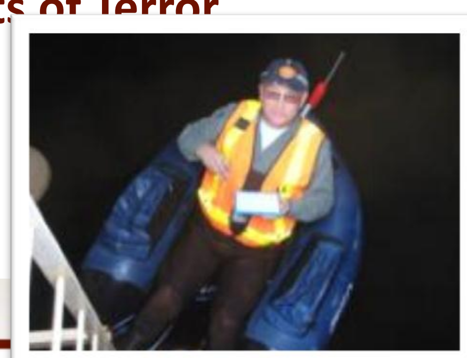


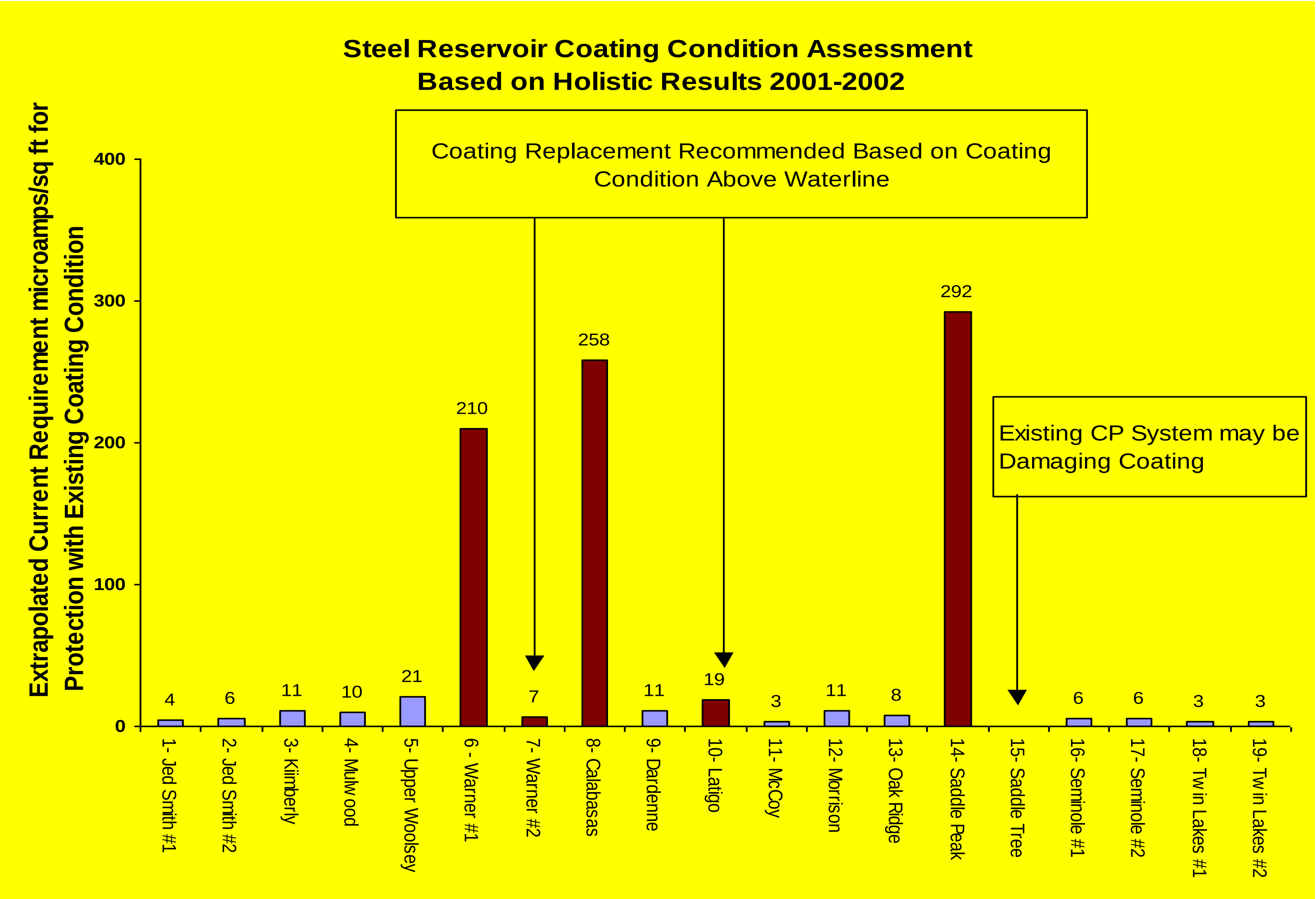
Steel Reservoir Condition Assessments

- Raft Inspection
  - Confined Space
  - Limited View
- Dry Inspections
  - Unpopular to WD's
  - Limits Defects and access
- Hatch Inspection
  - Limited View
  - Confined Space
- Dive Inspections
  - Hours of Boredom, Punctuated by Moments of Terror
  - Clarity of View







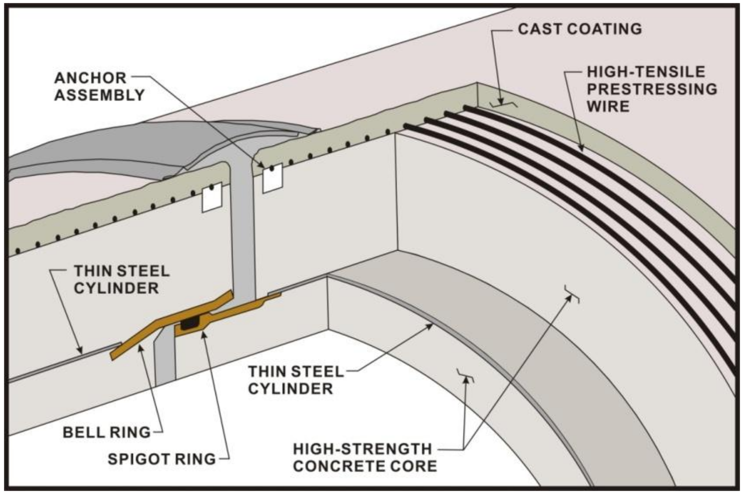


Steel Reservoir Coating Condition Assessment
Based on Holistic Results 2001-2002
Coating Replacement Recommended Based on Coating Condition Above Waterline
Existing CP System may be Damaging Coating
Extrapolated Current Requirement microamps/sq ft for Protection with Existing Coating Condition
400
300
200
100
0
4
6
11
10
21
210
7
258
11
19
3
11
8
292
6
6
3
3
1- Jed Smith #1
2- Jed Smith #2
3- Kiimberly
4- Mulw ood
5- Upper Woolsey
6 - Warner #1
7- Warner #2
8- Calabasas
9- Dardenne
10- Latigo
11- McCoy
12- Morrison
13- Oak Ridge
14- Saddle Peak
15- Saddle Tree
16- Seminole #1
17- Seminole #2
18- Tw in Lakes #1
19- Tw in Lakes #2

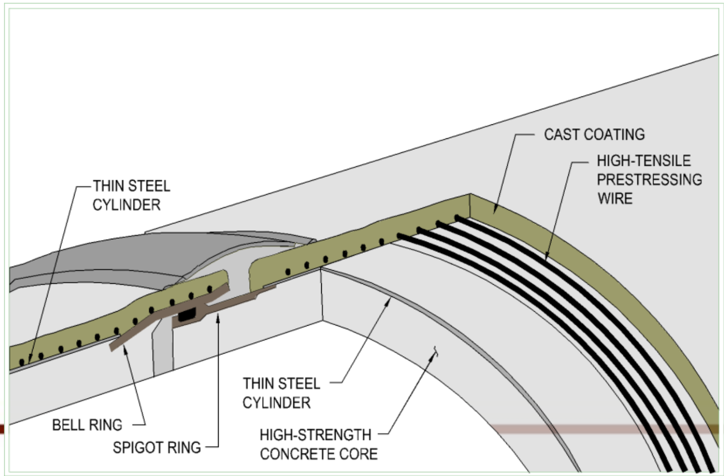
PCCP is a Complex Pipe Material.

- Composite pipe product
  - Internal mortar or concrete lining
  - Steel Cylinder
  - Concrete Core(s)
  - High Strength Prestressed Wires
  - Exterior Mortar Coating
- 1942 "War Pipe" substitute high strength steel annd concrete for steel
- 18 to 250-inch diameter
- Up to 350 psi Pressures

Early EC-PCCP Section
1.5 m to 6.5 m diameter



Early LC-PCCP Section
0.5 to 1.3 m diameter



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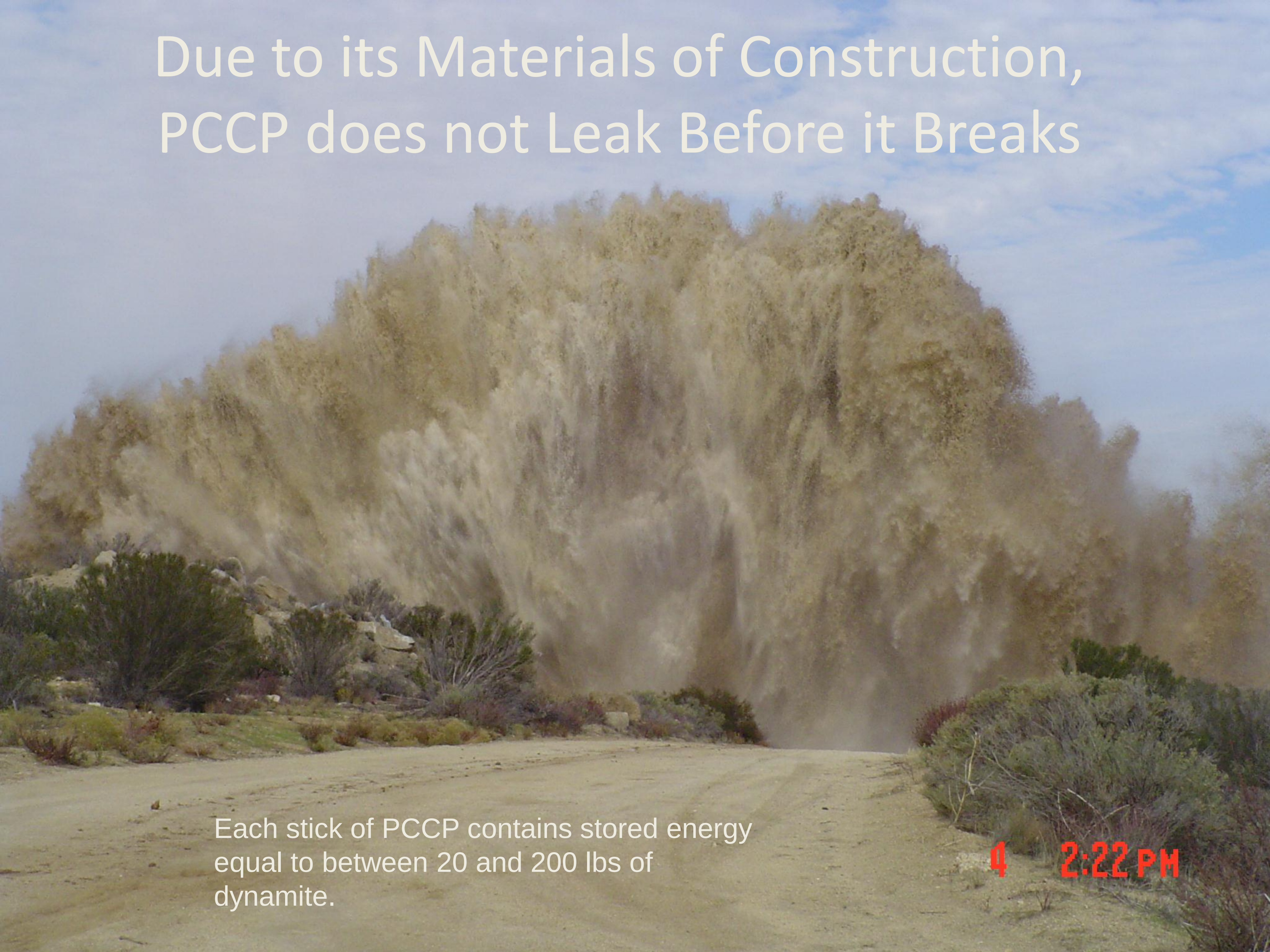
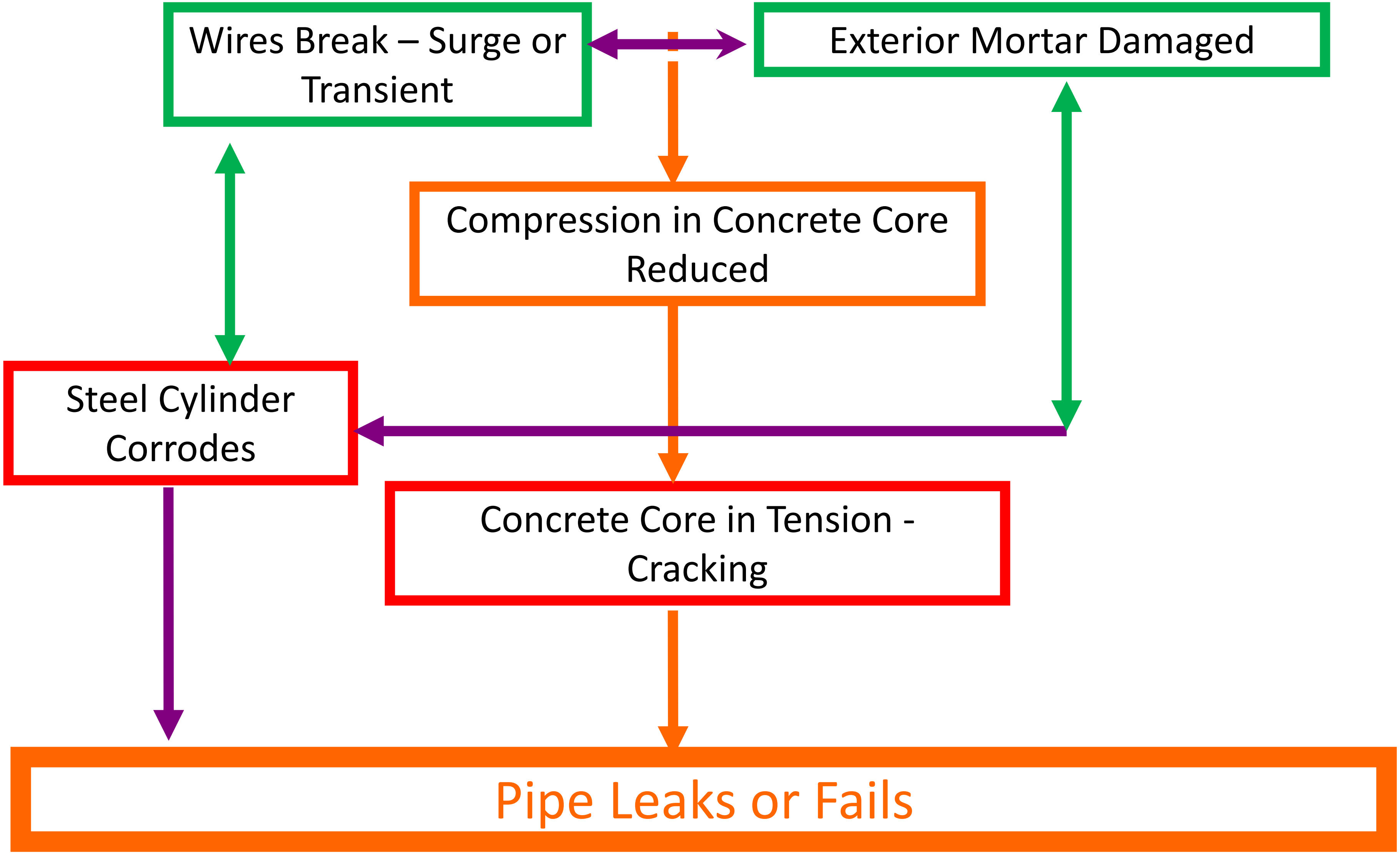
Due to its Materials of Construction, PCCP does not Leak Before it Breaks

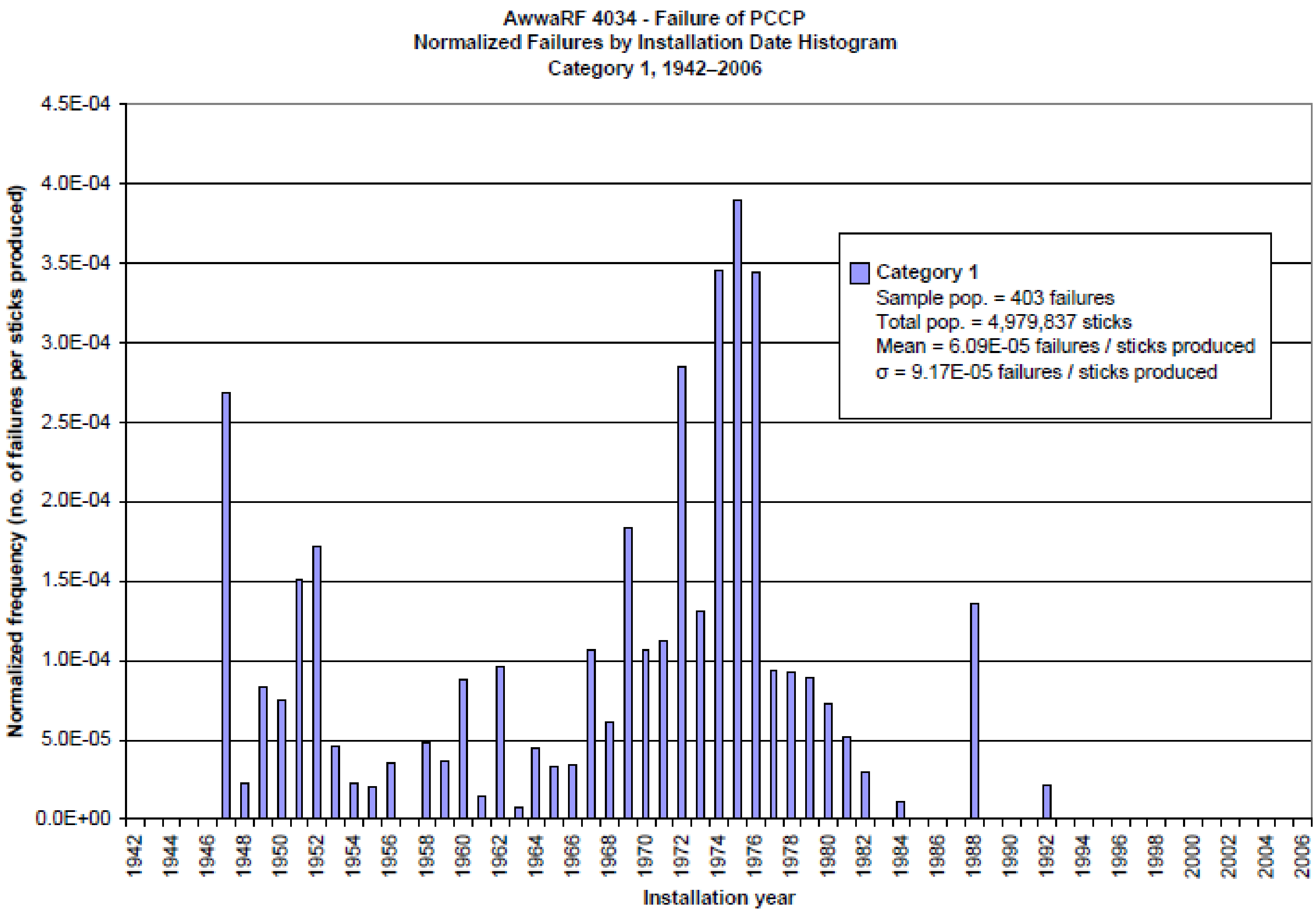


Each stick of PCCP contains stored energy equal to between 20 and 200 lbs of dynamite.

The Integrity of PCCP is Directly Related to The Integrity of the Wires



For PCCP, Based on its Era of Design Initial Estimate of Risk Can Be Made



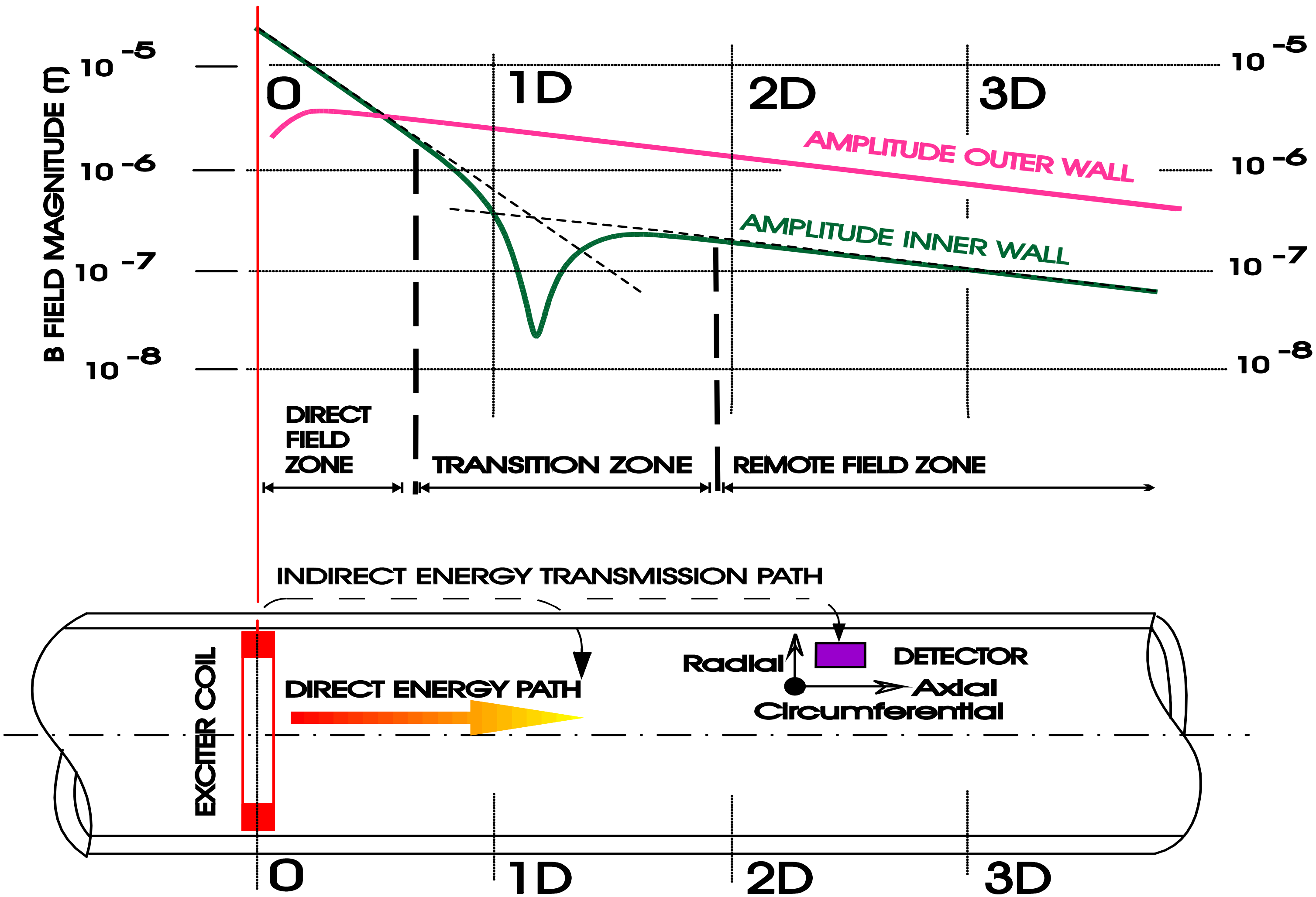
Old School
Condition Assessment
Internal Inspections

- Pre-1992, the only way to inspect PCCP was to dewater the pipeline and perform internal inspections.
- Visual inspection identified unusual cracking or poorly detailed joints.
- Sounding techniques located hollows or delaminations resulting from a loss of prestress.
- Human ear, 20 to 20k Hz
- After age 40, 20 to 16k Hz

Electromagnetic Inspection: "New" Assessment Technology

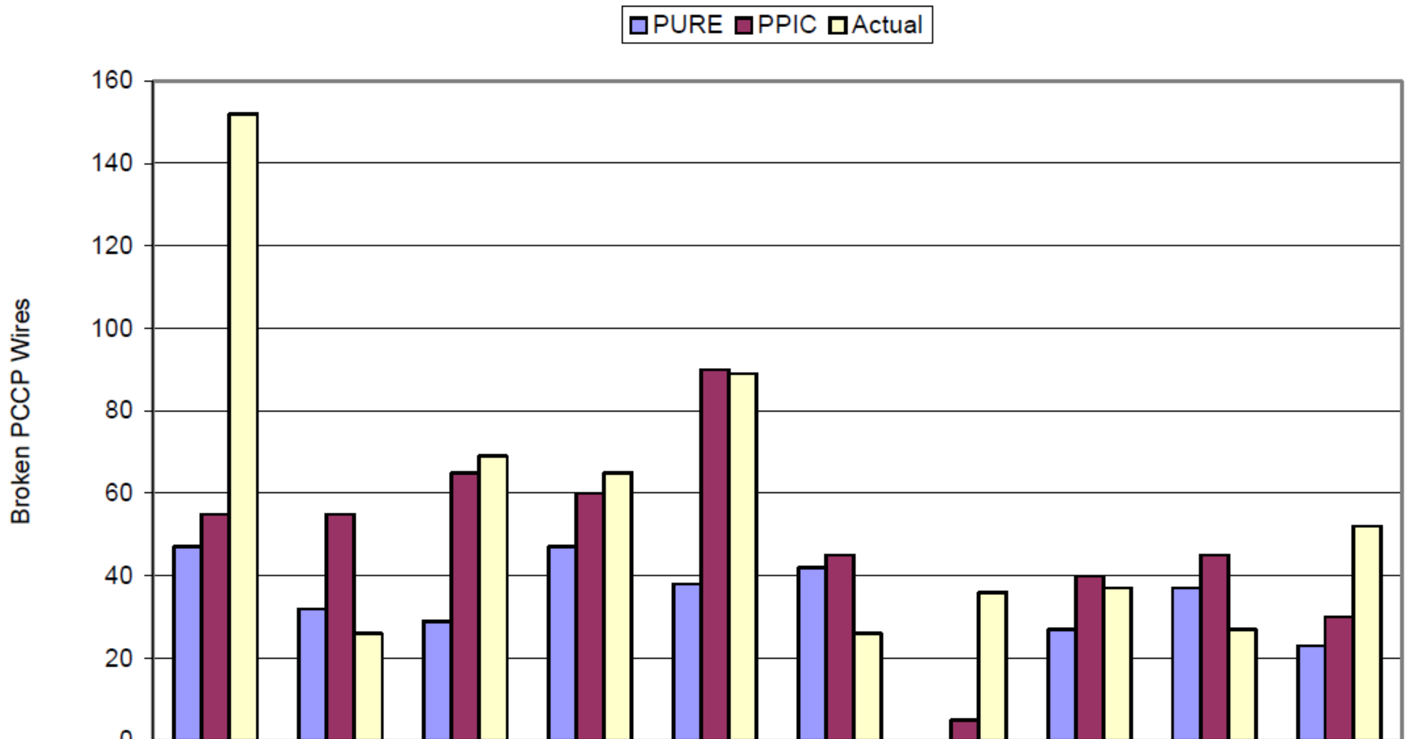
- In 1999 & 2001, supplemented the internal "sounding" procedures with Remote Field Eddy Current/Transformer Coupling measurements (RFEC/TC).
  - "A simple analogy: think of RFEC/TC system as a radio receiver
  - The prestressing wire behaves like the radio antenna
  - With no breaks in the continuity of the prestressing wire, the radio receives a clear signal from the transmitting station
  - If the continuity of the prestressing wire is broken, the clarity of the signal received is also reduced."

Remote Field Eddy Current



Not all damage will be found by technology

False Positive and Negatives are Possible with All Techniques



	MK 1430	MK 913	MK 914	MK 729	MK 725	MK 720	MK 719	MK 718	MK 715	MK 714
PURE	47	32	29	47	38	42	0	27	37	23
PPIC	55	55	65	60	90	45	5	40	45	30
Actual	152	26	69	65	89	26	36	37	27	52

Pipe Number

Technology is only one club in the Condition Assessment Golf Bag

- Imagine trying to play an entire round of golf with a 7-iron.
  - You can do it but you don't score well.
  - Generally, you need a driver and a putter…at least I do.
- Technology provides data, not information.

Closing Shots and Thoughts

- There are four ways to control corrosion
  - Material Selection and Design
  - Corrosion Inhibitors and Monitoring
  - Coatings and Linings
  - Cathodic Protection
- Technology is a powerful and expensive tool that needs to be used wisely
- There is no substitute for laying eyes and hands on the structure.