Chapman Engineering

# Rocky Mountain, WELCOME TO CORROSION – OR, REALLY, CONTROL OF!

# Electrochemistry and Corrosion Protection/ Corrosion Control

## (or, How Do We Keep Metal Being Good Metal Over Time?)

Add SP0169, CP measurements, graph, etc.

**By Cal Chapman, P. E.**
NACE-Certified Cathodic Protection Specialist #23357
NCEES Model Law Engineer #35248, Boerne, TX USA

# Corrosion Cell Defined

Corrosion of a metal WILL OCCUR if you have four elements present:

- Cathode
- Anode
- Metallic Path Connecting the Cathode and the Anode
- Electrolyte Contacting Both Cathode and Anode (completing the electrical circuit)

# By the Way, Terms I Despise

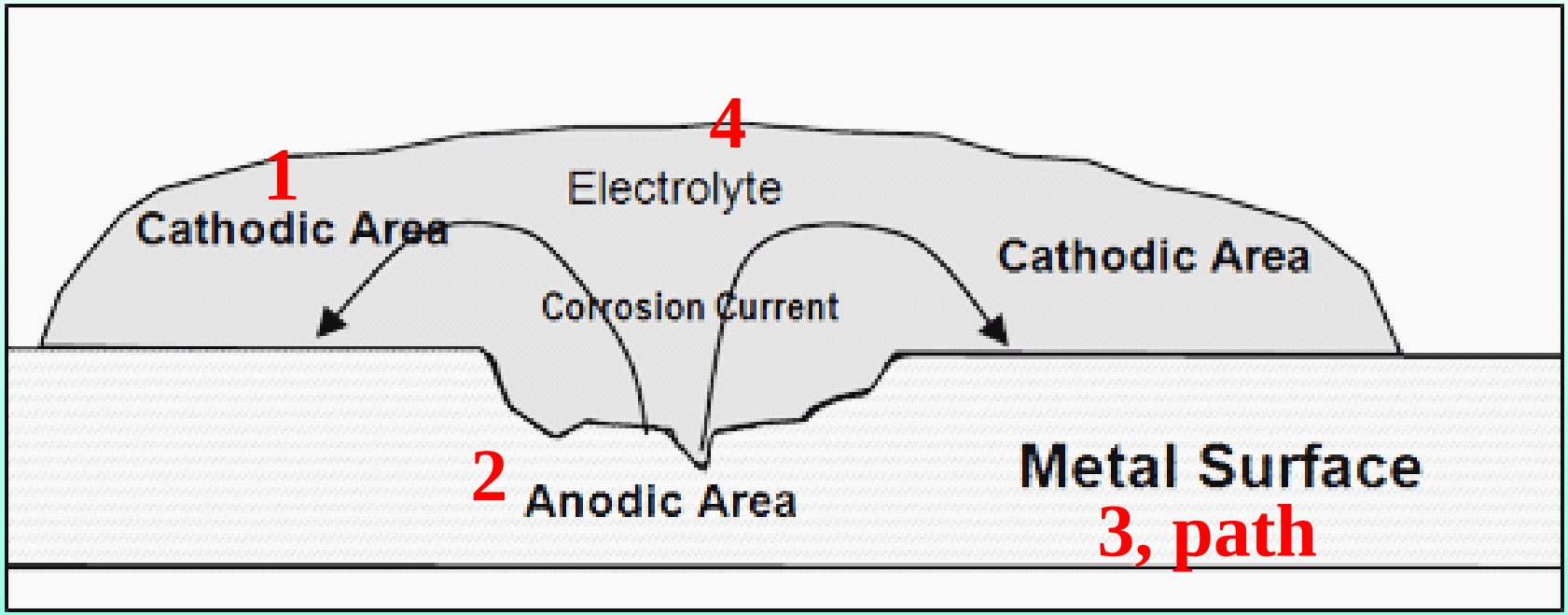
Corrosion prevention – nope, we're not that good. We minimize corrosion rates, or temporarily stop them.

Ground bed, or Anode ground bed – what is a ground in electricity? The earth, the negative of DC circuit, and the CATHODE! (Just call it an anode bed.)

**Potential – nope, you almost certainly mean Structure-to-Electrolyte Voltage.**

- The pipe-to-soil number is depressed, or too low – nope, you actually mean it's not negative enough. It's not getting enough spare electrons supplied. It's too high, too positive. Frame of reference is IMPORTANT FOR THE PEOPLE WHO DON'T KNOW WHAT WE DO!

# Basic DC Electrochemistry, Metal Pipe in Electrolyte




**Why does current flow? A difference in electrochemical potential energy (voltage) between two points – yes, chemical and electrical properties** of the metal(s).

This single steel bar has cathodic areas (stable metal) and anodic areas (higher-energy metal). Positive DC current flows from anodes to cathodes until/unless equilibrium is established. If reaction products go into solution, new metal is continuously exposed, and no equilibrium reached.

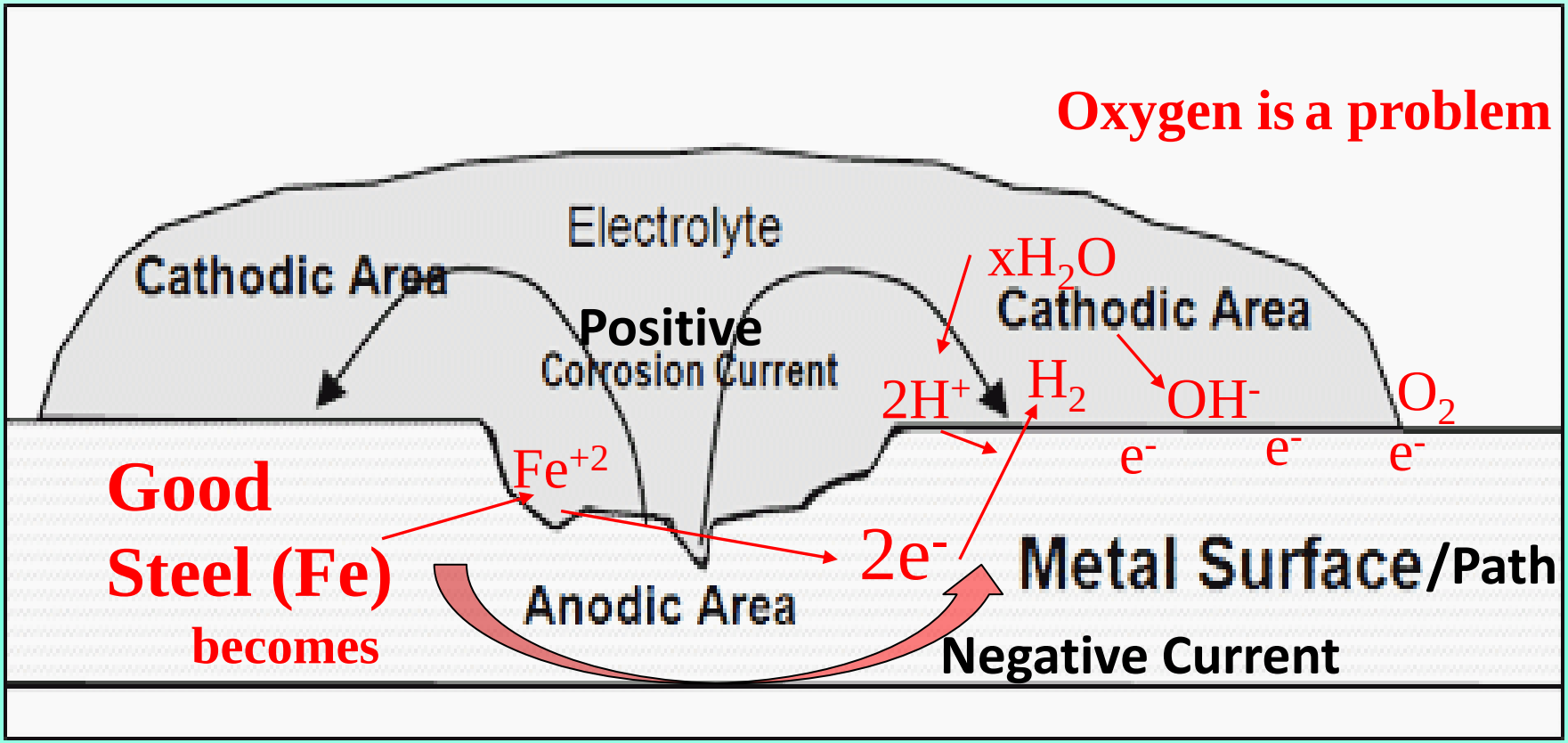
# One Steel Pipe in an Electrolyte,

# A Complete Corrosion Circuit

**Water = $H_2O$** **Oxygen = $O_2$** **Atomic Hydrogen = H**

**Molecular Hydrogen = $H_2$** **Hydrogen Ion = $H^+$**

**Hydroxyl Ion = $OH^-$**



# Chemical Reaction To Manufacture Iron and Steel:

**Iron has two electrons in the outer-most orbital shell, and when they are shared or removed, it is in lowest stable energy state (FeO, $Fe_2O_3$ and $Fe_3O_4$ are very stable).**

**Once refined into usable metal, those added electrons are easily lost through corrosion current flow, and rust is formed again.**

**Cathodic protection supplies excess electrons, to offset the corrosion current/electron loss. This drives metal more electrically negative.**

$$2FeO + 4\ e^- \rightarrow 2\ Fe + O_2$$

**Adding lots of energy to iron ore**

# Energy Management – Yes, It's About Energy.

**Where does mild steel come from? Mine the iron ore, combine with some carbon, other alloying additives, and add lots of heat – ENERGY.**

**That added energy is not permanently "locked in place," once it is put into the new steel. In Mother Nature's math and science, since it has been artificially added – manufactured – then that energy can/will be taken away again.**

**Most metals we rely on are also refined ores, and become susceptible to corrosion, depending on what their lowest stable energy states are.**

# Corrosion Control & Basic DC Electricity

- **Ohm's Law (ALWAYS true for DC):**
- **Voltage (Volts, V) = Current (I, amperes, A) x Resistance (R, ohms or Ω)**
- **or V = I x R**

**(V is also called "E" for electromotive force)**

If we can measure voltage and current, we can determine resistance of one electrical circuit by "doing the math."

Or measure voltage and resistance – then you determine the current flowing.

# Corrosion Protection for Metal – Two Complimenting Methods

**First level of corrosion protection is Coatings** – DON'T expose metal surface to **electrolyte** – really, to the environment. Electrolytes are everywhere! (Soils, water, other electrically conducting liquids, etc.)

**Second level of corrosion protection is Cathodic Protection** – using ANODES to produce protective current and apply it to the metal you ARE RELYING ON!

**IF METAL IS IN THE ATMOSPHERE, AIR DOES NOT CONDUCT ELECTRICITY, SO CATHODIC PROTECTION CANNOT WORK.**

# Atmospheric corrosion (technically). Three years of exposure. Six inches above ground surface.

4-inch Load pipeline into a 400-bbl API-12F crude oil tank.

**Coat the metal!**

**Pipe threads & ions in dust wetted just by dewfalls overnight.**

**Temporary moisture was the electrolyte!**

**Where was 6 o'clock on pipe?**

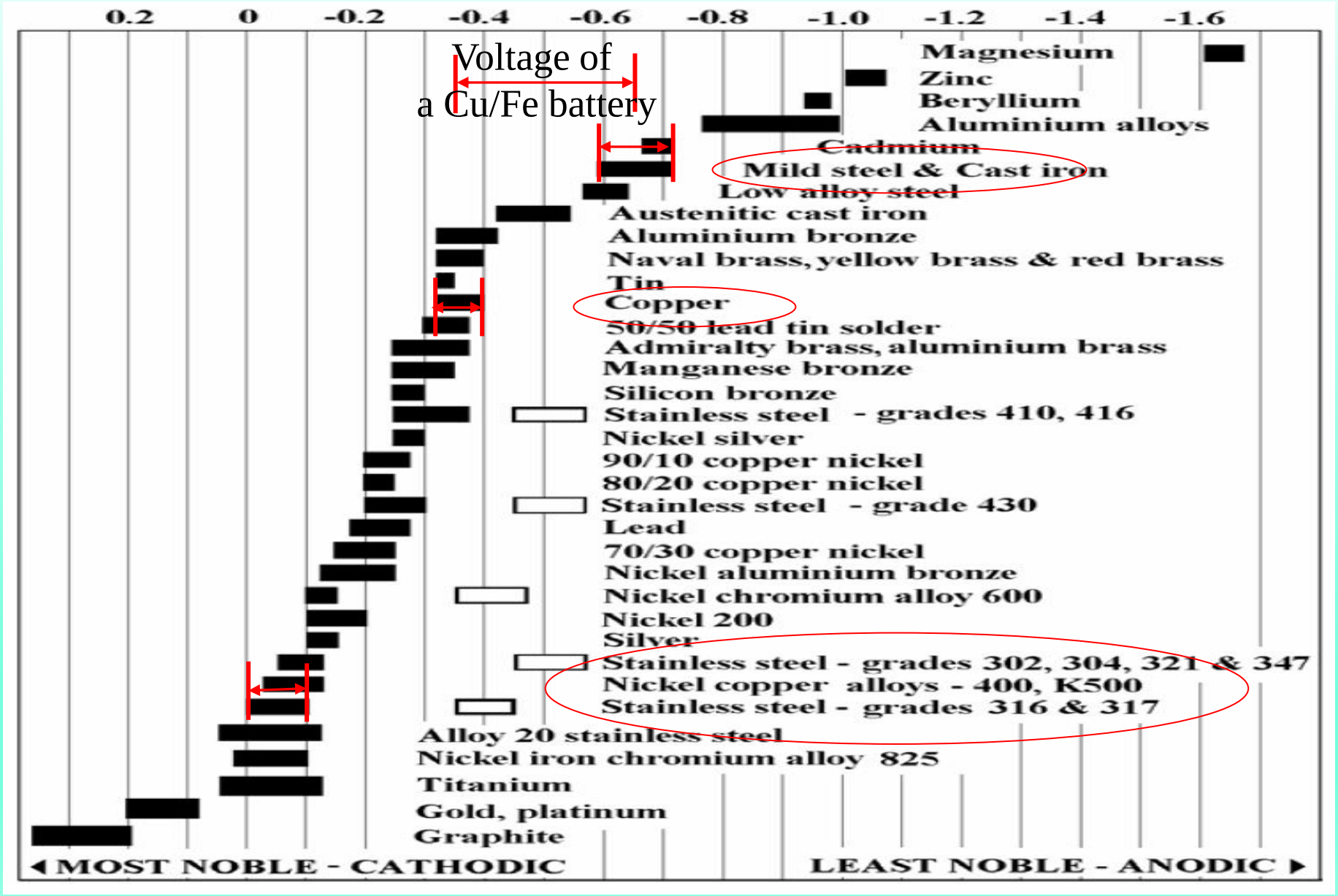
# Some Types of Carbon Steel Corrosion (External or Internal)

- **Uniform or General Corrosion**
- **Dissimilar-Metal Corrosion (heard of the "Galvanic Series of Metals?") Aluminum, steel, copper . . .**
- **Pitting Corrosion**
- **Erosion Corrosion**
- **Atmospheric Corrosion**
- **Concentration Cell Corrosion**
- **Differential Aeration Corrosion**
- **Microbially-Influenced Corrosion (MIC)**
- **Crevice Corrosion (Weld bead edges? Mechanical joint surfaces? Cut threads left exposed?)**
- **What about types of interference?**

# 87,000-Barrel Crude Oil Tank with Crevice Corrosion at Chime/Plate Welds, West Texas

**Two Years of Service, poor sealing and coating work.**

# The Galvanic Series of Metals




From Atlas Specialty, tech note #7; voltage compared to Cu-CuSO4 half-cell. Unshaded boxes are metals in acidic water.

# Corrosion Control for Carbon Steel
# Basic DC Electrochemistry

Voltage in volts (V); current measured in amperes (amps or A); resistance measured in ohms (Ω).

If one amp of DC current flows through and off of a steel or ductile iron (DI) structure **for one year,** how much metal loss occurs in that year?

A) 21 ounces

B) 21 grams

C) 21 pounds

What's your pick? Keep in mind that one amp is equal to the flow of $6.24151 \times 10^{18}$ electrons in one second, past a certain point!

# A Dissimilar-Metal Story

416 Stainless Steel Pipe String showed aggressive external corrosion after three years in use.  Artesian water flow, no pumping.

# No outside DC or AC power sources identified.

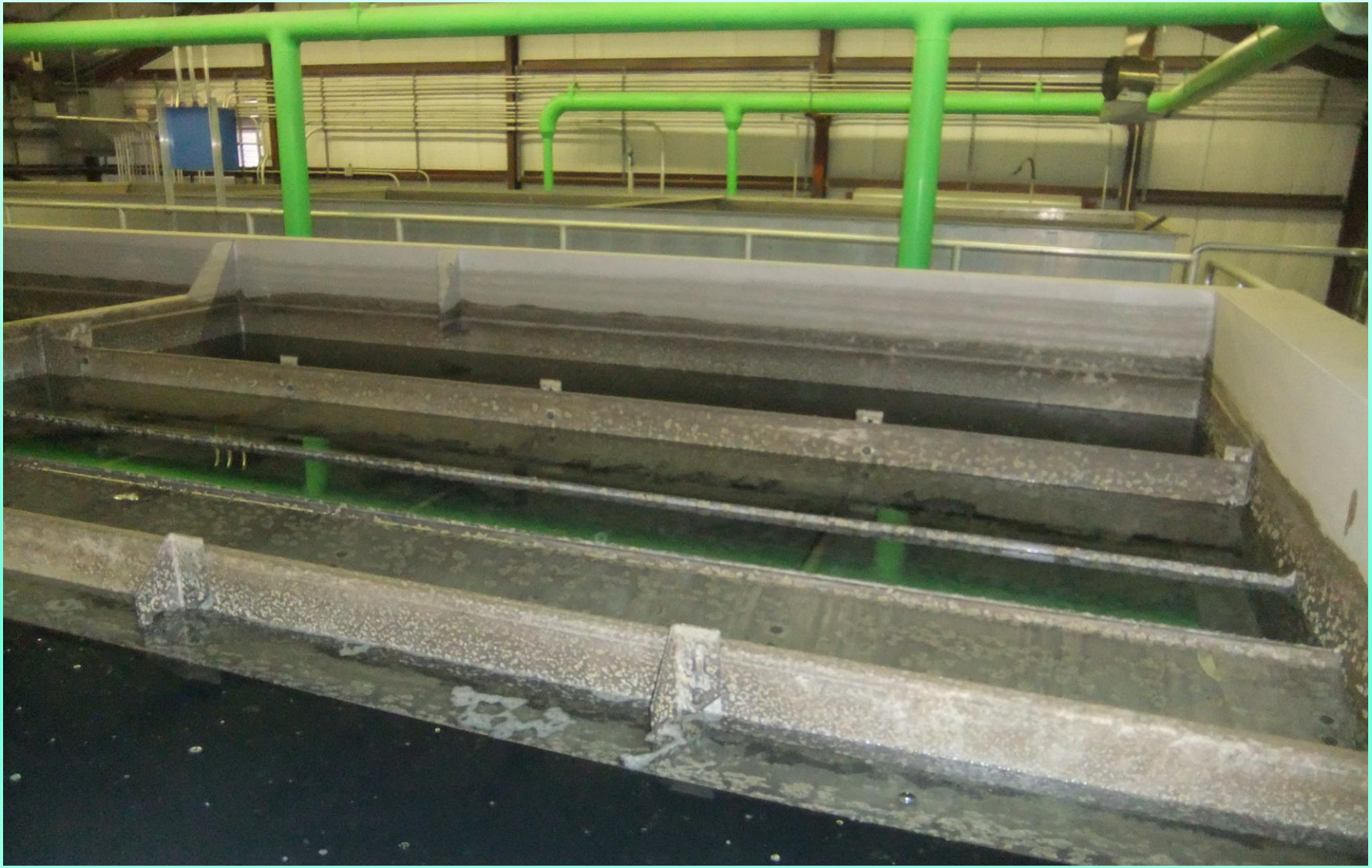
## Copper Ground Conductors on Enclosure Racks Tied to Dedicated Copper Ground Ring Around Wellhead

| Test | Current Flow from Ground to Pipe thru Cu (A DC) | Potential at Well Piping (V DC) | Remarks |
|---|---|---|---|
| 1 | 1.70 | -0.167 | Southern Ground Disconnected |
| 2 | 0.91 | -0.237 | South Central Ground Disconnected |
| 3 | 0.46 | -0.335 | North Central Ground Disconnected |
| 4 | 0.04 | -0.670 | Northern Ground Disconnected |

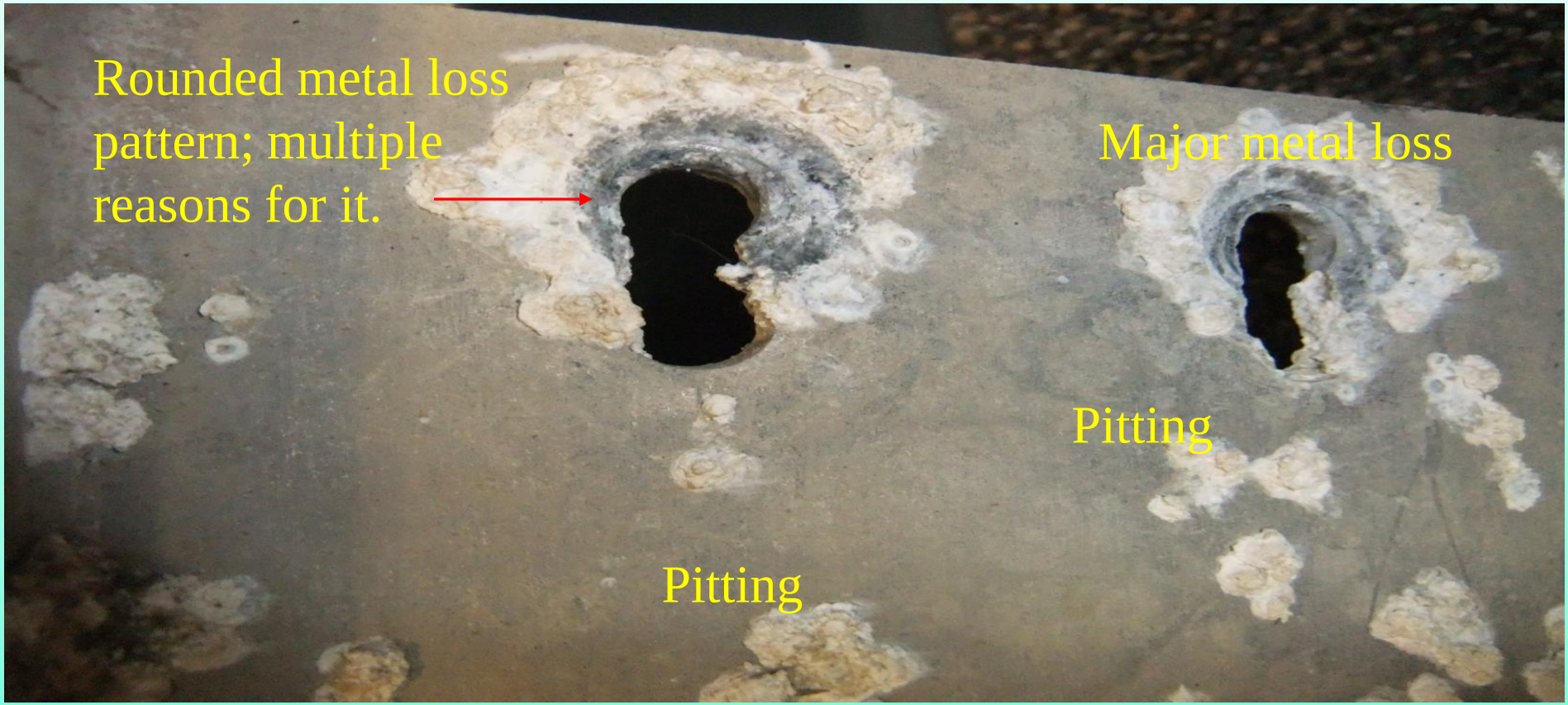
**Copper system bonded to exposed steel. (How extensive a system?)**

**Electrochemical battery of 0.2 volt DC. Current flow of 1.7 A DC. Resistance of about 0.11 ohm. Corrosion would continue for how long?**

# Water Filtration/Settling Tanks at Surface Water Treatment Plant (no coated surfaces)



# How Many Kinds of Corrosion Here?




## An aluminum weir plate in settling tank.

(1) Steel washers, bolts/nut assemblies used to join aluminum plates with no isolation spacers. (2) DI & steel pipes tied to aluminum chamber body become cathodes. (3) Water oxygenation by aeration/moving alum and debris flocs, and with technicians jetting the chamber walls frequently. Aluminum surfaces get chemically **depolarized** outside of pH 4 to about 8.5 range. pH more alkaline with alum additions.

# See any corrosion?


Some concentrated corrosion is taking place. Why?

# Corrosion Concerns?


Welded Steel Fire Water Pipeline System Across This Site.
(Leaking Water Lines Don’t Help Fight Fires.)

# Corrosion Protection

## (External and Internal Possible)

**What is a Coating?** – A material used on metal surface to retard an electrical current's flow – it must be a good electrical insulator. Concrete and mortar mix are not considered great-quality "coatings," though they are often used on water pipelines. (And they're better than leaving metal bare.)

- **Coatings** may be as simple as paint, or a tape wrap, or a combination of a primer coat followed by a tape wrap.
- The coating might be a mastic material smeared onto all the exposed metal surface.
- The best-quality pipeline coating available is called "fusion-bonded epoxy" (FBE) – a mix of two resins that, when combined, form a very strongly adhered layer, extremely hard to chip or break. This FBE is also slightly water-permeable, meaning CP current can pass through it when needed.

# Corrosion Protection

**Applying Coatings** – Putting a coating on pipe or a fitting – When does it happen? Where does it happen? How does it get done?

- **Preparation for coating – you need clean, prepared surfaces, the right environment for the coating application, and qualified people applying the coating.**
- **Coatings don't go on in rainy weather or high-humidity conditions (true for almost all coatings).**
- **They don't go on in really cold weather. And they may not transport or handle well ONCE APPLIED. How much cure time is needed for each coating? How many coats needed?**
- **If coating work is done poorly, what next? You need larger and stronger cathodic protection system(s).**

# Water Ground Storage Tank Internals

# Water Tank Internals, As Found

Raw Water Tank #1 had not been cleaned in many years. Water supply from well into local aquifer.

# Water Tank Internals, As Exposed (No coatings)

Severe Corrosion Attack under Anoxic Mud Layer, Microbes, Etc.

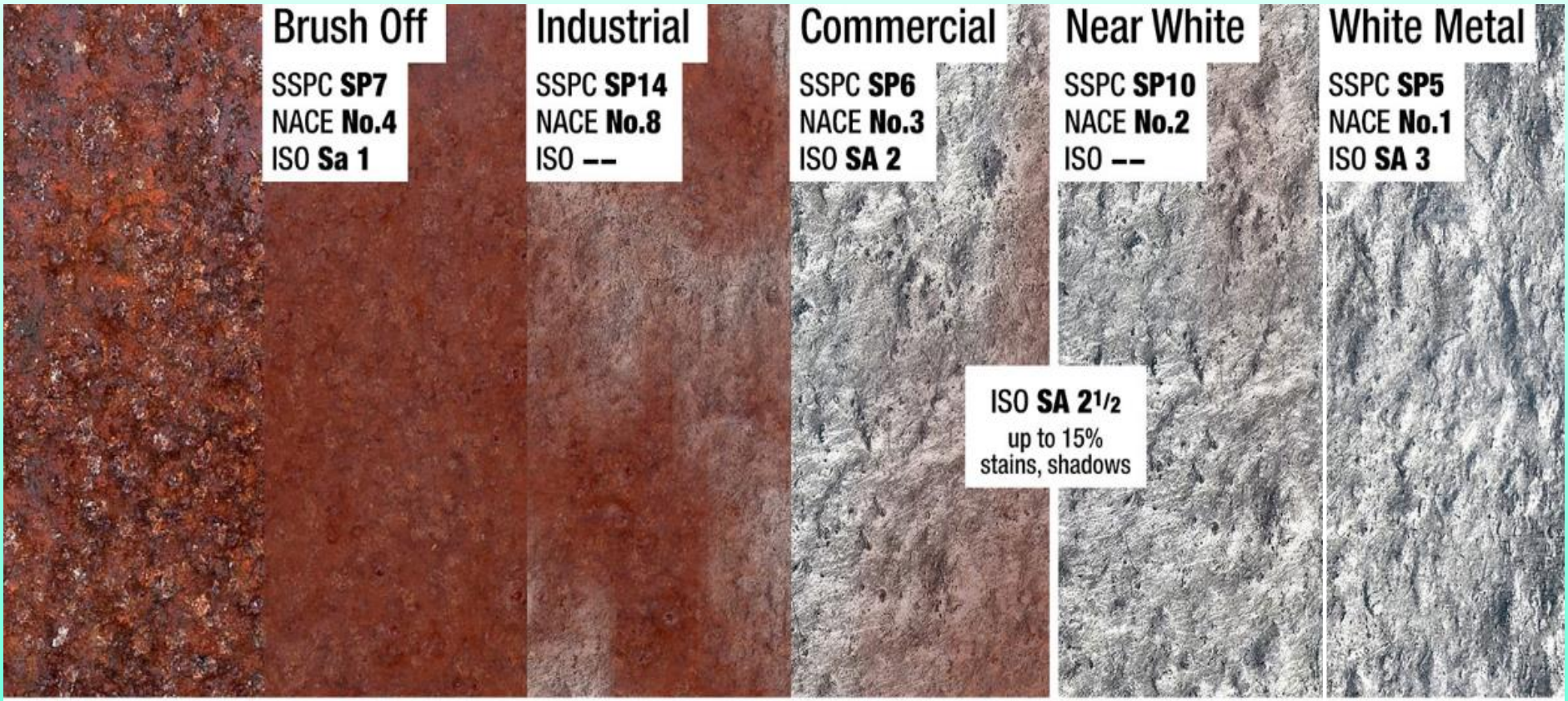
# Opportunities to Recoat?

**For above-grade structures, coating inspections are vital over time. Coating damage can be identified, and remedy/re-coat plans put together and executed.**

**For below-grade assets (pipelines, usually), the chance to recoat is almost never available. Some survey types are available to evaluate below-grade coatings. But repair or replacement of coating is very costly in these situations.**

**What about corrosion under insulation? Many industrial facilities insulate hot vessels and pipes.**

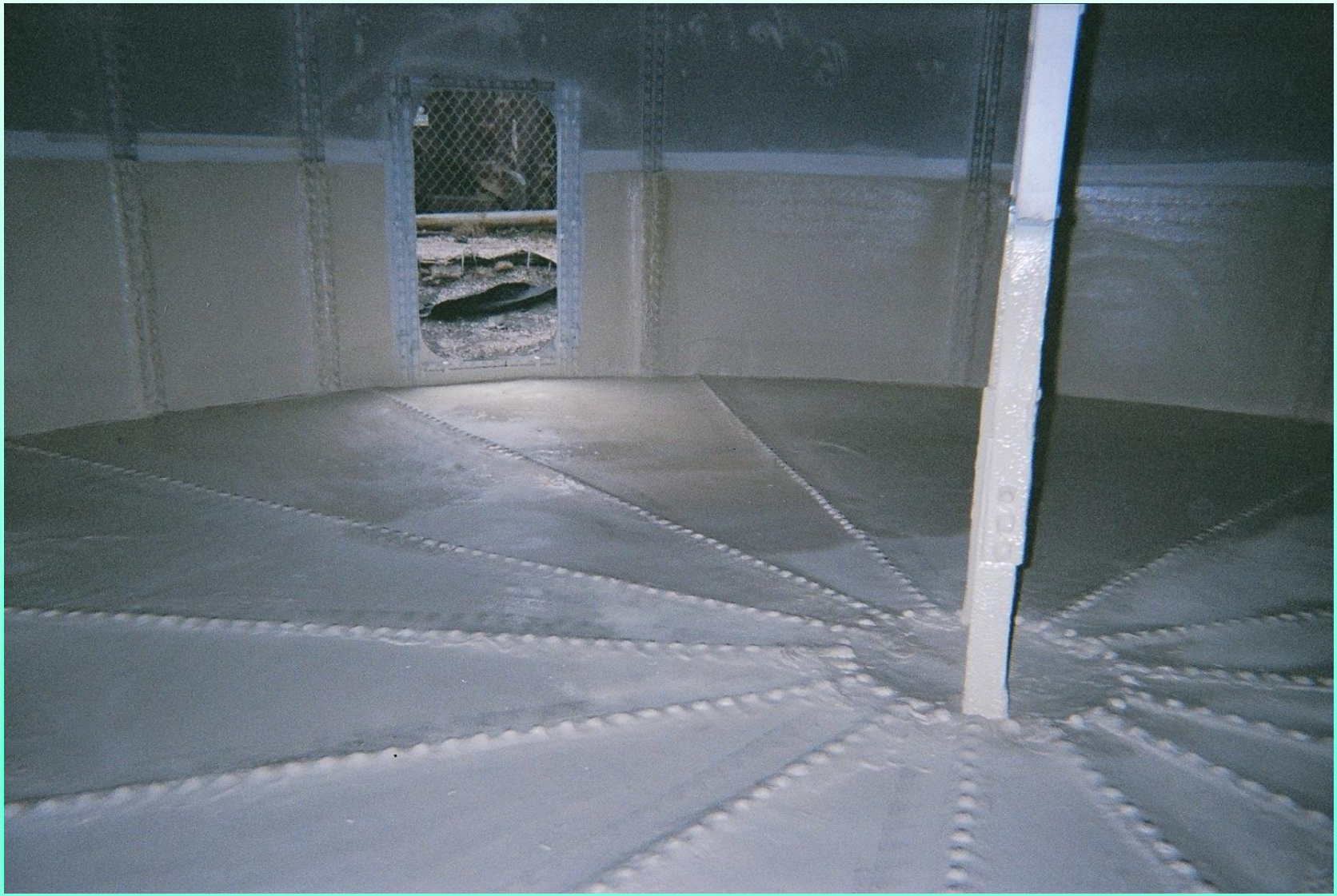
# Steel Surface Preparation for Coating Work




| | | | | | |
|---|---|---|---|---|---|
| Loose Material | None | None | None | None | None |
| Tight Material | 100% | up to 10% | None | None | None |
| Stains, Shadows | 100% | 100% | up to 33% | up to 5% | None |

**SSPC & NACE Carbon Steel Surface Cleanliness Chart**

# Water Tank Internal Rehab



Cut out and replaced some floor metal, blasted all surfaces, then coated with new high-build material. Service life extended. **Investment.**

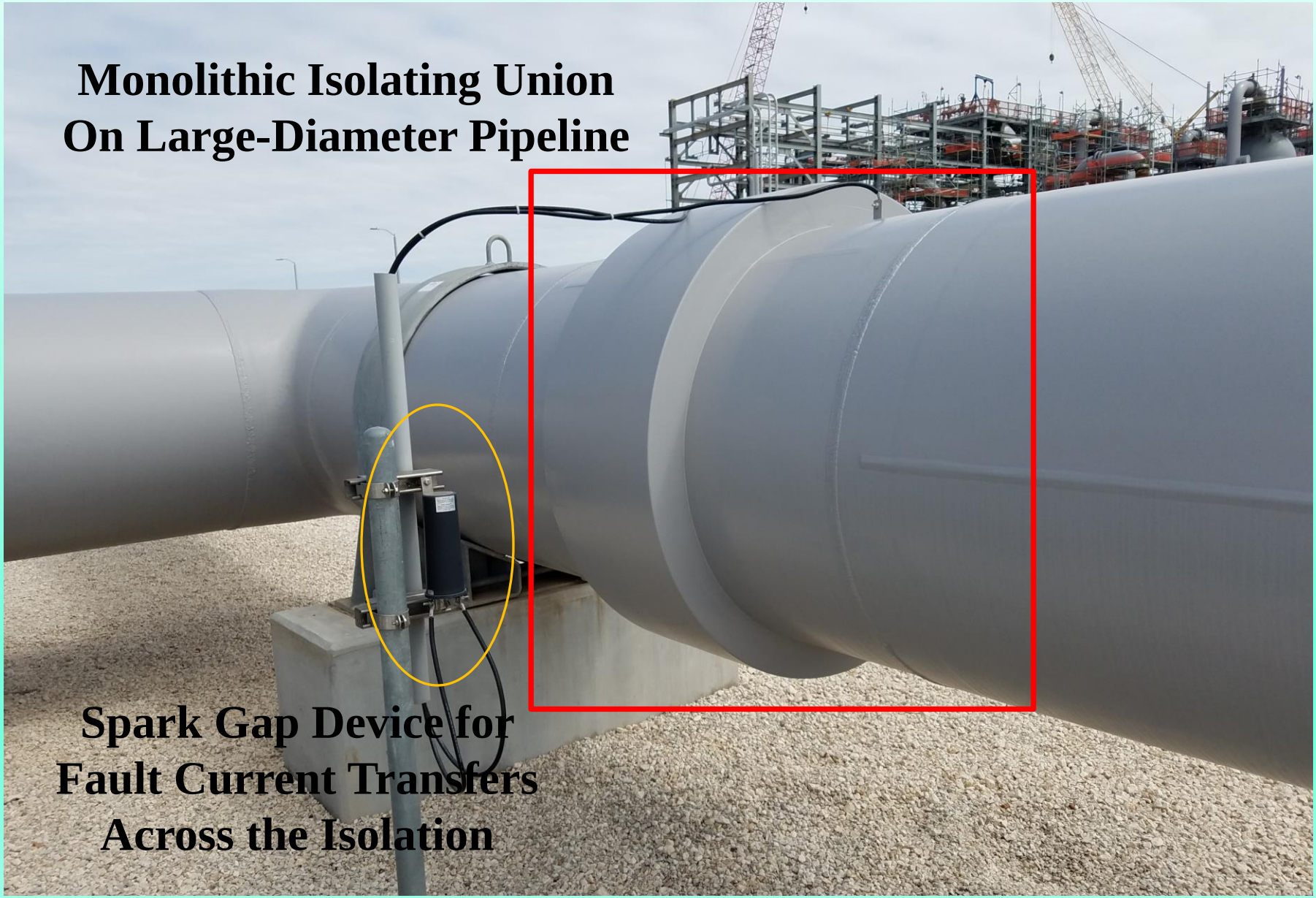
# Corrosion Protection Work Steps

**Use Coatings** – VITAL as the first "line of defense" against corrosion. Used to break the electrical connection between metal surface and the electrolyte, over as much surface area as PRACTICAL. AND THE ONLY PROTECTION ABOVE-GRADE.

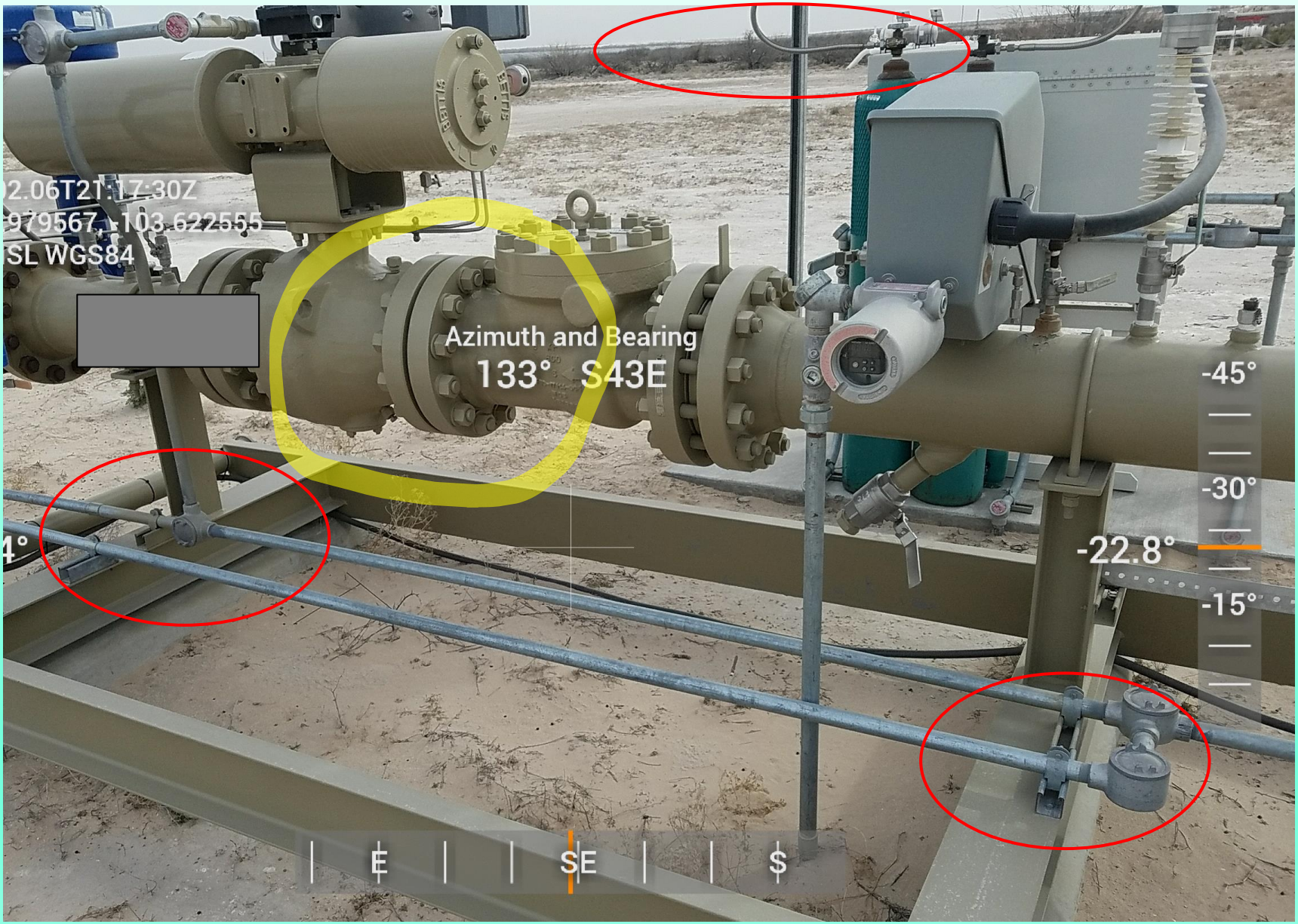
**Use Cathodic Protection (CP)** as complementary protection BELOW GRADE (IN THE ELECTROLYTE), with coatings.

**Isolation fittings** – used to break the electrical connection between different metallic structure sets. Cathodic protection is then applied to KNOWN amount of metal SURFACE AREA, in a "closed system" type of approach.

# Electrical Isolation Fittings



# Isolations? Yeah, we got ‘em!




But isolation flange set is shorted by other metal structures, highlighted.

# Keeping up with coatings . . .

San Francisco Bay/moist air, salt spray, with exposed metal.
Air to end-seal interface, for possibly aggressive corrosion.

# Cathodic Protection

**Do coatings deliver corrosion control for assets in underground service? Submerged service?**

**Not by themselves – they don't last forever. A coating is in best shape the first day on the job.**

- **Coatings age; they break down with moisture and temperature cycles, soil conditions, biological effects, etc.**
- **Coatings are never applied perfectly. They have defects, known as "holidays." These holes in the coating are present from beginning of job;**
- **Leading cause of coating issues is third-party damage, AFTER structure is installed. Who prevents this? How?**

**Cathodic protection is the backup plan for coatings.**

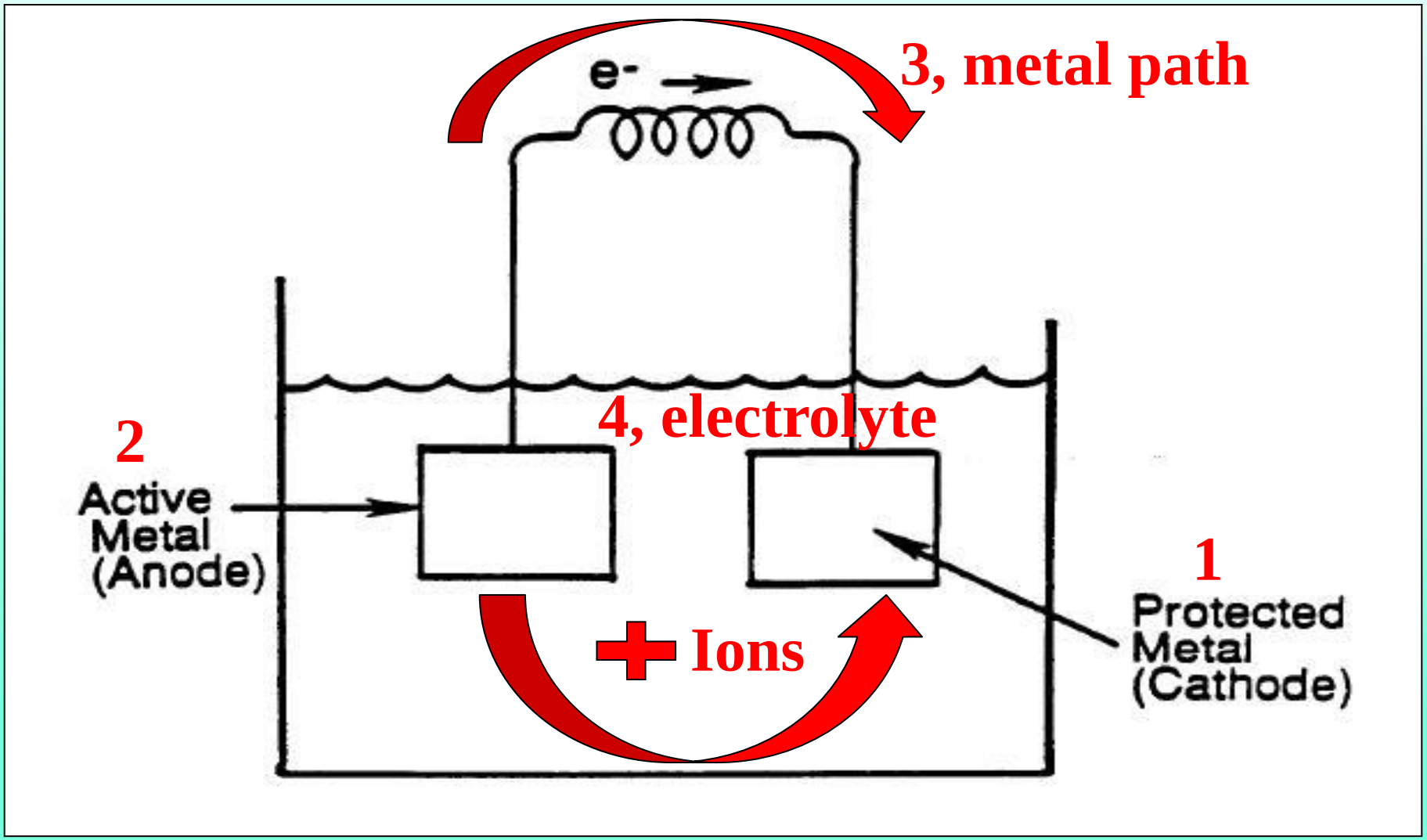
# Galvanic Anode CP Systems

Galvanic (or Sacrificial) Anodes – of Magnesium, Aluminum or Zinc (chosen by application)

Special Backfills A Must – the anode metal is placed within a bag containing special mix of sodium sulfate, bentonite, maybe other select powders; outside the bag, use native, non-rocky material of good electrical conductivity. **Water must be added to wet specialty backfill around each anode during install process.**

Galvanic (Sacrificial) Anode System – requires pre-packaged anodes that are connected, by cable through a dedicated test station, to the structure(s) needing protection.

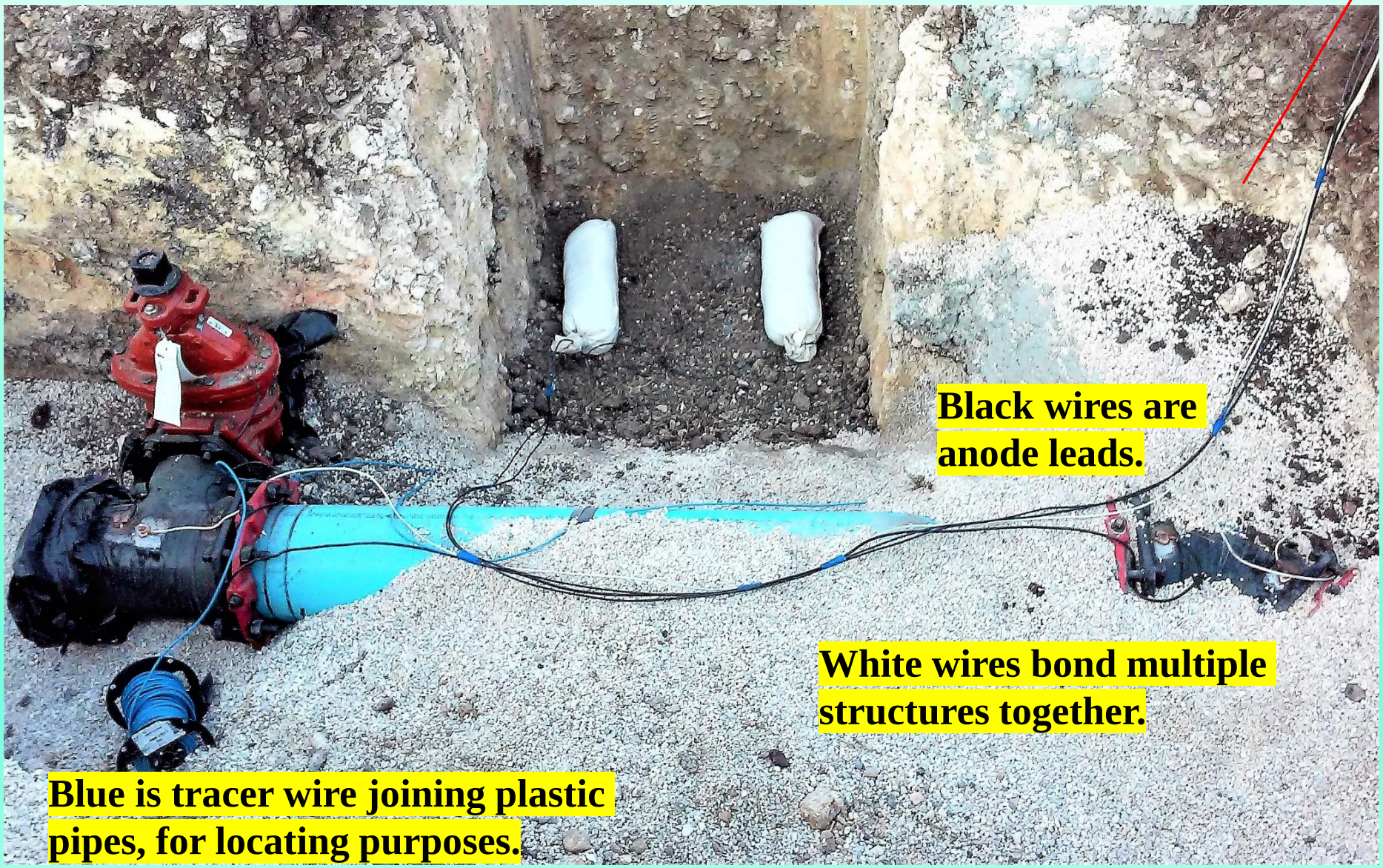
# Galvanic Anode CP System Sketch




**Remember, V = I * R. How much resistance can V overcome?**

**Which way does the current travel? (Trick question.)**

# Galvanic Anode CP System Example On Valves and Fittings Only (Plastic Water Line Pipe)



# Impressed-Current System for CP

Impressed-Current (IC) System, With "Anode Bed" – typically uses a rectifier with AC power, bonding cable run to structure(s), and a number of anodes installed in borings (for onshore work). **Anodes are not wired to structure directly. Soil or water is the "wire" (electrolyte) completing circuit.**

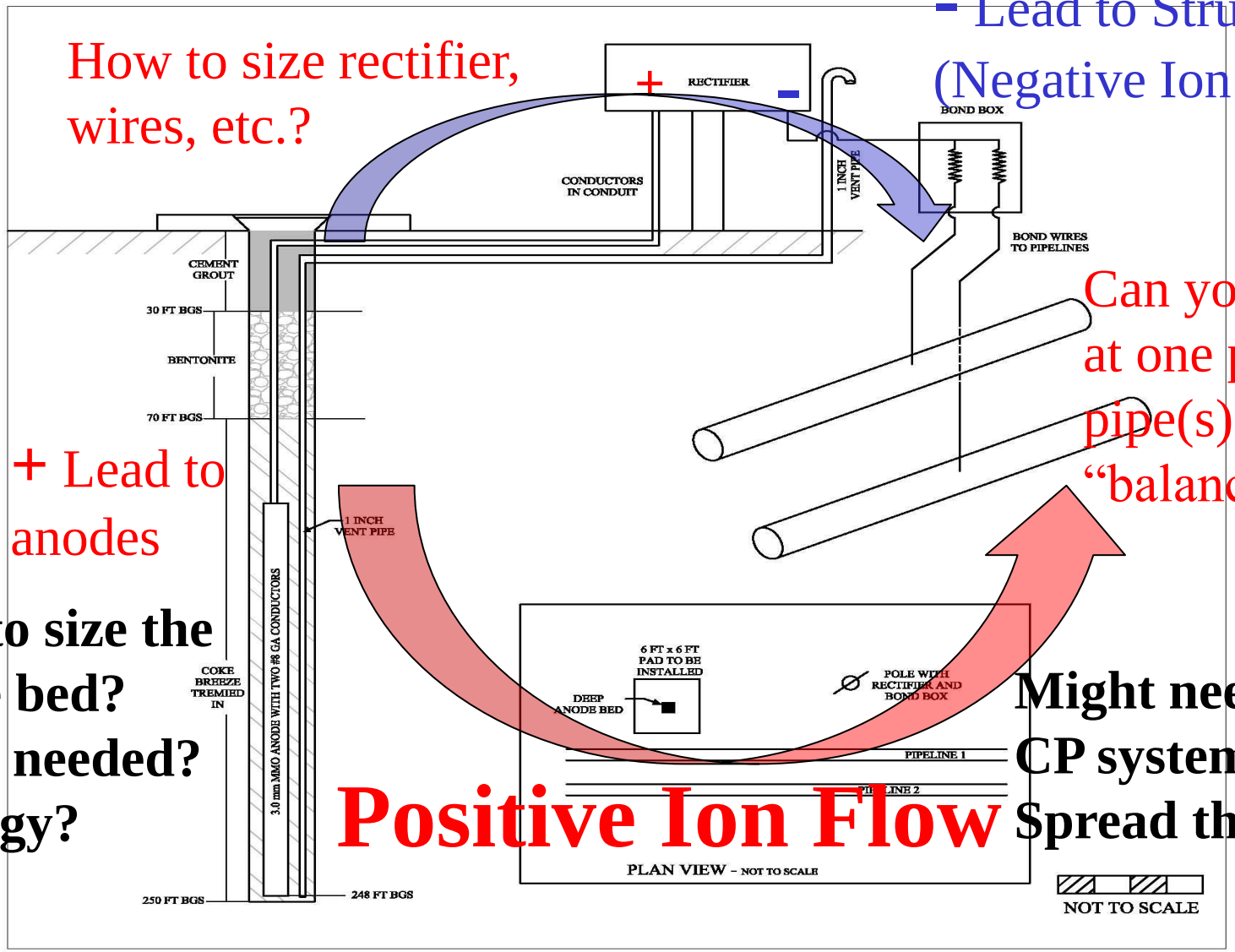
Impressed-Current Anodes chosen:

- Mixed-Metal Oxide –versatile and commonly used;
- High-Silicon Cast Iron – very heavy and brittle, but great performance when specified and installed right;
- Graphite – not usually suited for high-moisture-content conditions;
- Other specialty types. (Heard of anodic protection?)

# Impressed-Current CP System for Pipelines, Tank Bottoms, Other Structures

- Lead to Structures (Negative Ion Flow)

How to size rectifier, wires, etc.?




Can you bond at one point on pipe(s) and get "balanced" CP?

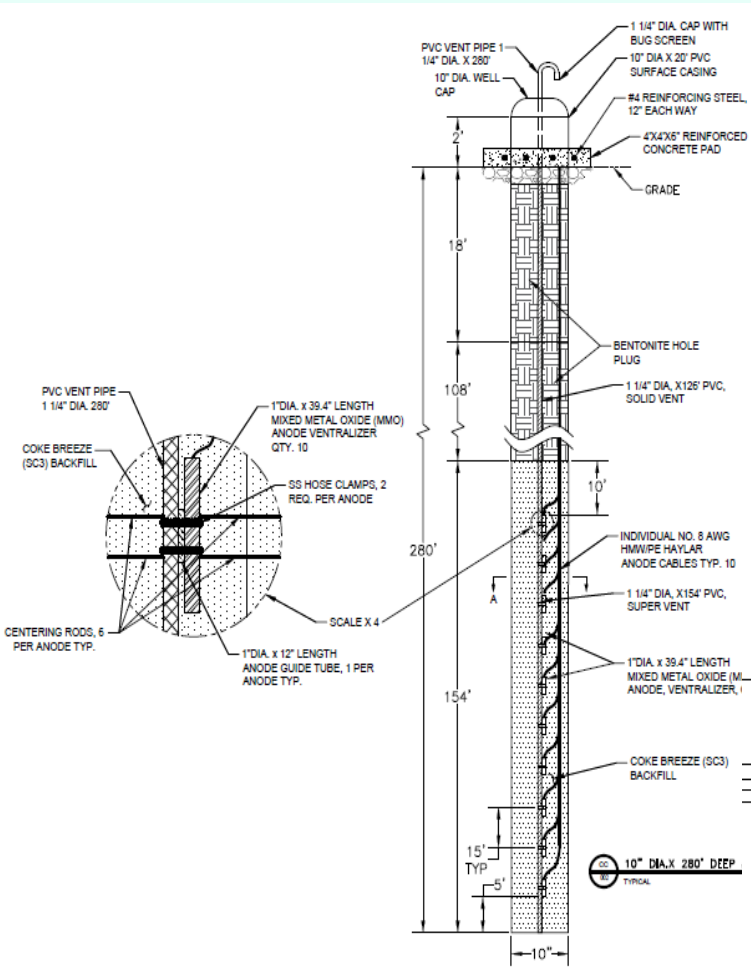
+ Lead to anodes

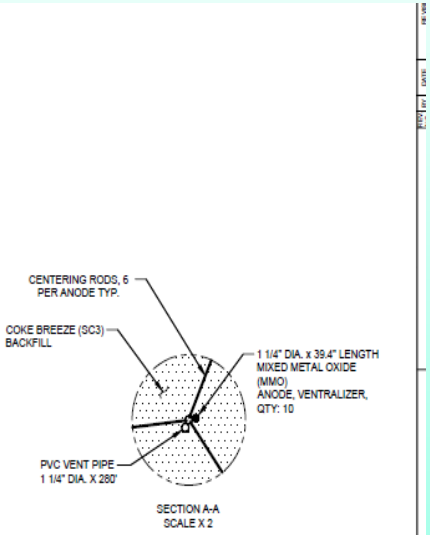
**How to size the anode bed?**
**Amps needed?**
**Geology?**

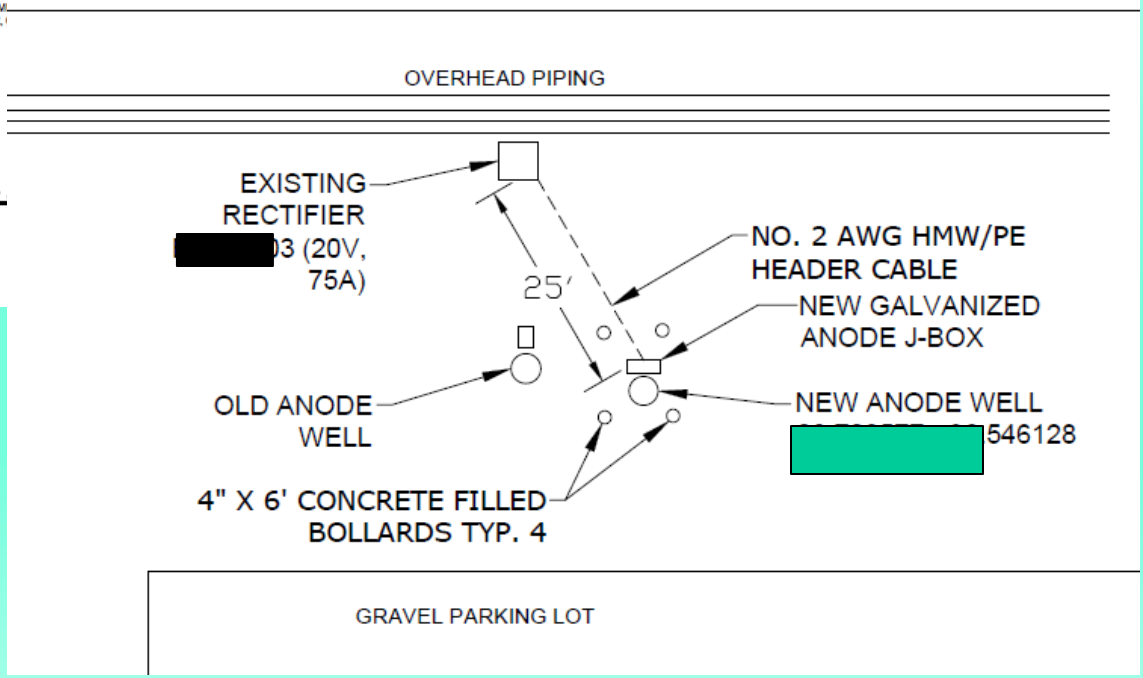
**Positive Ion Flow**

**Might need more CP systems.**
**Spread them out!**

# Impressed-Current CP System Layout, Typical Job



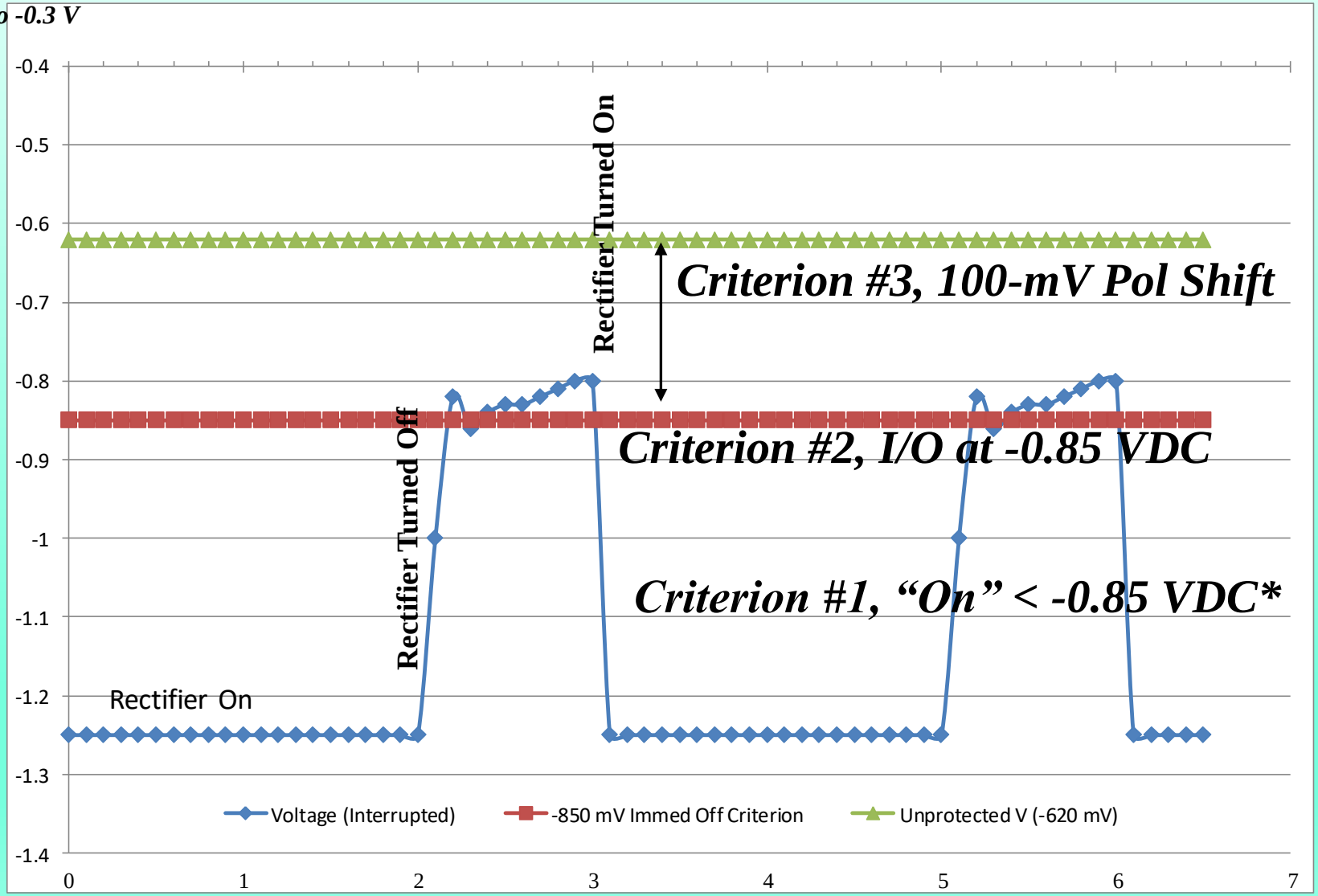
*Gold +0.1 to 0.2 V (to Cu-CuSO4)*

*Copper -0.1 to -0.2 V*

*Stainless steel 0 to -0.3 V*

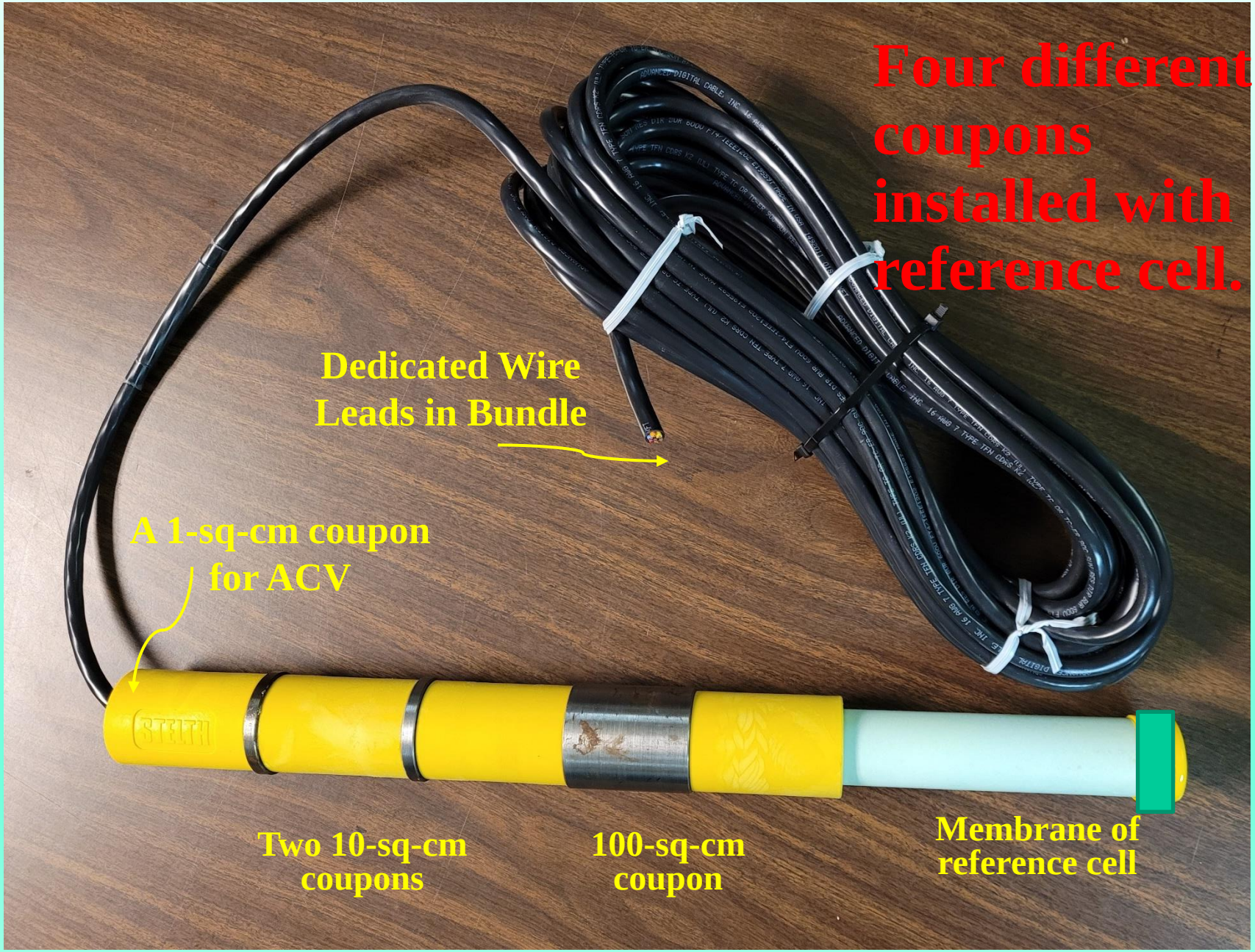
*Old Steel -0.4 V*

# Wanted: CP Polarization Shift, Pipe-to-Soil Voltages Vs. Time



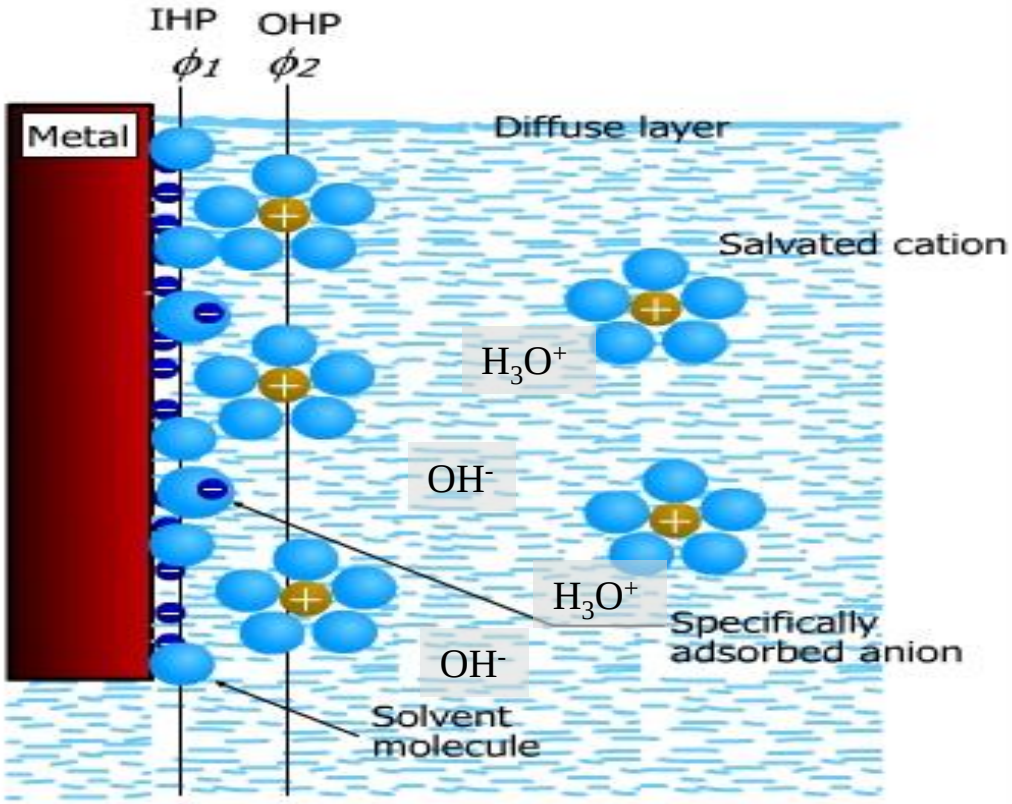
# Measuring DCV at Coupon Test Station

# Reference Cells and Coupons



# POLARIZATION SHIFT IS ELECTROCHEMICAL ACTIVITY.

## Helmholtz Capacitive Layers at steel surface – what we want.




Electric double layer showing inner and outer Helmholtz layer and diffuse layer.

http://faculty.kfupm.edu.sa/ME/hussaini/Corrosion%20Engineering/02.05.04.htm

**A CAPACITOR IS DEVICE WITH TWO OR MORE PLATES. EACH PLATE HAS A DIFFERENT CHARGE, POSITIVE OR NEGATIVE.**

**THIS ELECTROCHEMICAL SHIFT ARRANGES A SET OF "CHEMICAL CAPACITIVE" PLATES AT METAL SURFACE, BUT ONLY TEMPORARY. CURRENT MUST KEEP ARRIVING TO MAKE THE POLARIZATION STAY IN PLACE.**

# Costs of Corrosion Protection Are Really Investments

Adding good coatings and CP systems to capital projects is inexpensive compared to the costs of failures later.

Think of corrosion protection as "pay me a lot less now, or a lot more later" kind of approach.

Ever heard anyone say, "If this lasts five more years I'll be retired. Not my problem then!" Who pays the bill six years from now?

**How often do we design a structure for 20 years, then want it to last 50? Or 80? Or more?**

# Article in November 2023 ***World Pipeline*** Magazine Sustainability Issue

# Building it right the first time

**Cal Chapman, Chapman Engineering Inc., USA, argues that pipeline integrity management, and especially cathodic protection, is sustainability work.**

Underground carbon steel pipelines are, and will continue to be, the transportation mode of choice for many crude oil, natural gas, and other petroleum and petrochemical products. Similar underground or submerged metal pipelines are often used, too, for water, wastewater and other liquid or gaseous products. Taking one famous (indeed, iconic) pipeline as a discussion point, the 48 in. nominal diameter (122 cm) crude oil Trans-Alaska pipeline was put into service in August 1977, spanning a total length of 800 miles (1288 km). Now 46 plus years old in terms of active service, the original pipeline design was for 30 years of useful life. It has thus far performed for 50% more years than originally intended. Is this asset being sustained? Is it being operated in a sustainable fashion and, even now, for a long-term service outlook? This certainly seems to be the case.

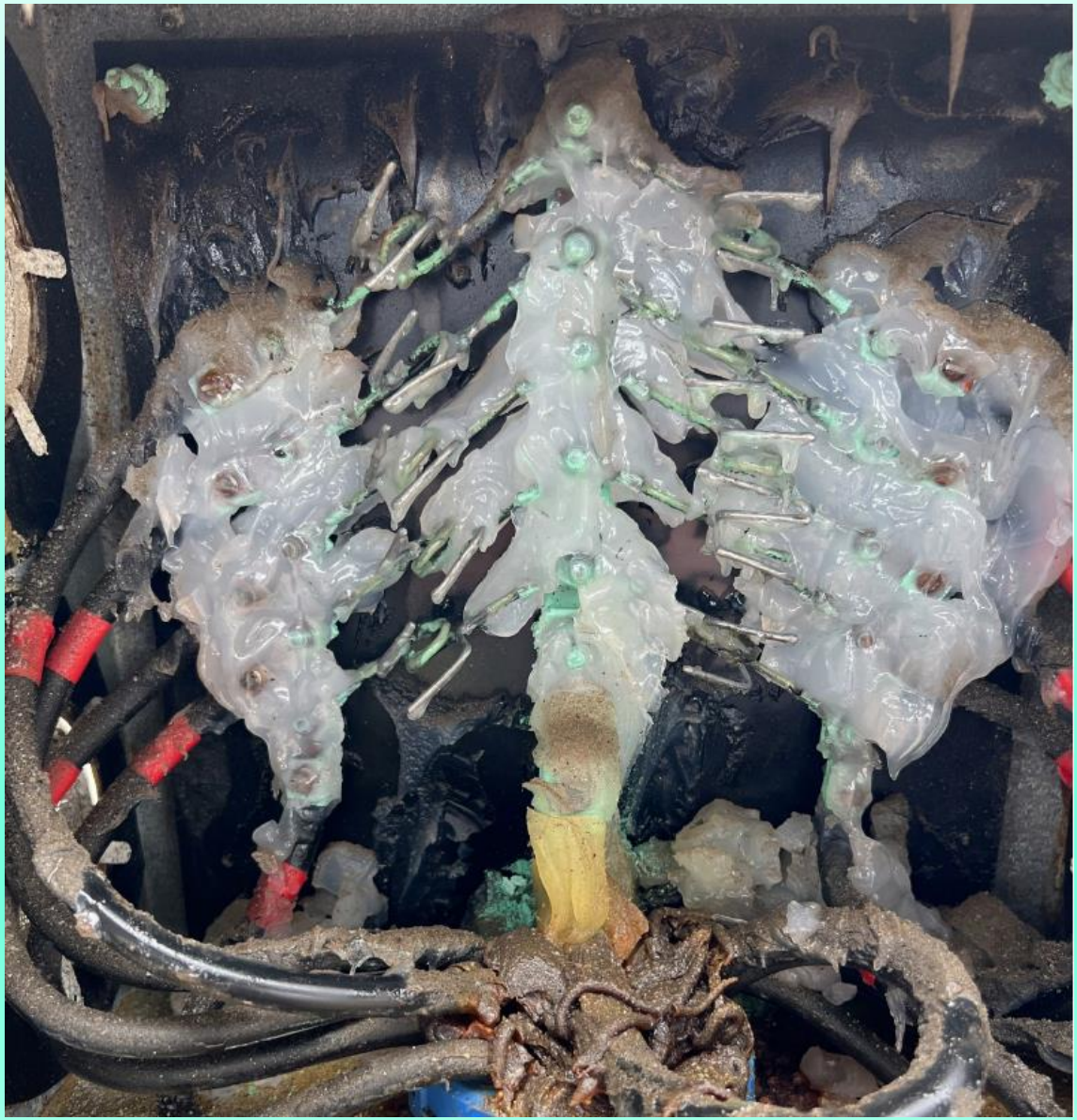
## The cost of corrosion

The pipeline industry over the last 30 years has greatly improved the general principles and practices that encompass asset integrity management. What is the motivation to do so? The first, and obvious motivation, is to avoid the need for complete asset removal and replacement. A study by NACE International (now called 'Association for Material Protection and Performance [AMPP]') released in 2016 described that the annual cost of corrosion damage across the globe was in the range of US$2.7 trillion.[1] This was true even though some industries were using corrosion control measures quite effectively. If, in 2016, the world's gross economic product produced was close to US$90 trillion, one could say that all metal infrastructure would need complete replacement every 30 years without significant asset integrity management practices in place. Proper coatings on

# Costs of NO Cathodic Protection (and lousy coating work at girth welds)

# Costs of NO Cathodic Protection (and lousy coating work, and dissimilar metals)

# How NOT TO DO Corrosion Protection



Chlorine Gas Intrusion from Impressed-Current Anode Bed, and Silicone Sealant Does Not Block It

# Improving Safety and Corrosion Protection – Any AC Power Involvements?

# Improving Corrosion Protection
# Major Port Facility

# Good Impressed-Current CP Work Looks Like –

# Why Are Casings/Cased Pipeline Crossings Used?


**To protect pipelines passing under railroad tracks**

# 2016 NACE IMPACT Study

**Return on Investment (ROI), for Corrosion Control Projects**

Most projects provided **ROI's of three to 20 (some up to 50 times)**:

- Spending $100,000 to battle corrosion often returned $500,000 or more. EXTEND ASSET SERVICE LIFE! SUSTAINING.

- Reduction of Failures, of Lost-time/Down-time, of Operating Costs, and Reduction of Risk!

**NACE Conclusions**

•Corrosion control should be part of business planning, ACROSS INDUSTRIES.

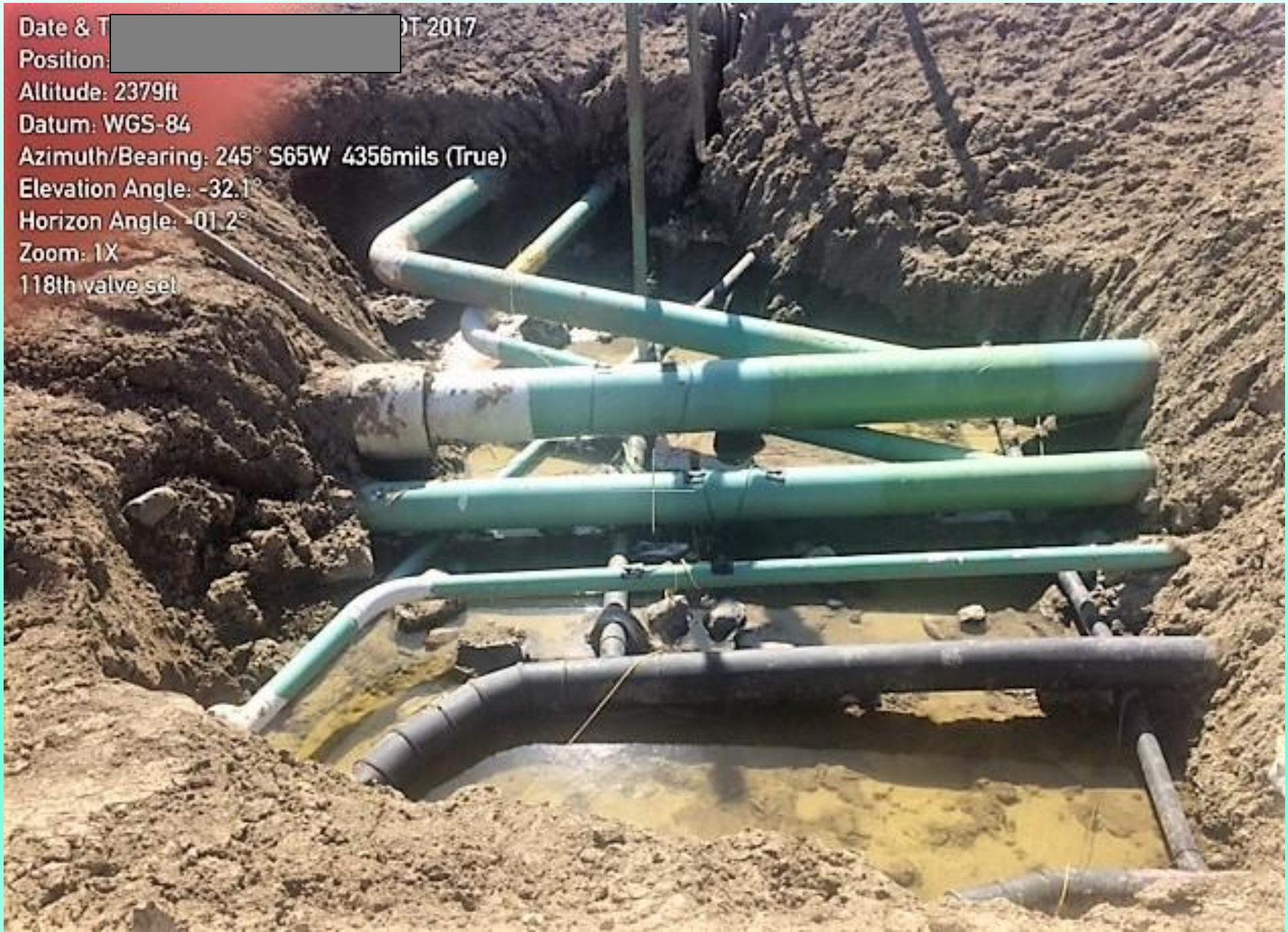
- Corrosion damage costs **$2.5 Trillion** per year worldwide
- Equal to 3.4 percent of the world's annual Gross Domestic Product, **so every 30 years, it's all useless –without corrosion control.**
- These costs DON'T include legal, environmental damage, and publicity issues.

**Who owns the problem? We all do!**

•Reference: NACE International "IMPACT" Study, page iii, United States Department of Defense

# Anybody know what's in that vault?

# What Is This? Integrity Concerns? Interference?




A water main break is pictured near the intersection of 22 Mile Road and Romeo Plank on Tuesday, Aug. 1, 2023. *Provided By Andrew Plunkett*

Do water leaks cause big issues?

Detroit, Michigan Area, 10-ft-diameter pipe failure.

**Boil water notices.**

# The Unveiling – Nobody's Data Described This And Your Company Owns It

**Casing upper left, no end seal, uncentered carrier pipe. Flanged fittings – all at road crossing, 1960 install? Crude oil line, poor coating, NOT PIGGABLE.**

Chapman Engineering

# Corrosion Protection or Corrosion Control – Pick at Least One!

***Proactive*** Corrosion Control & Management (Do it right the FIRST time!) is far more affordable than ***Reactive*** Management. or,

**HOW MUCH DOES IT COST TO DO IT RIGHT THE SECOND TIME?!**

P.O. Box 1305
Boerne, Texas 78006
1 - 800 - 375 - 7747
www.chapman.engineering
cchapman@chapman.engineering