Testing Cathodic Protection Systems

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Your Friendly TSC Corrosion Staff:

Jessica Torrey
Ph.D. Materials Science & Engineering
jtorrey@usbr.gov
303-445-2376

Daryl Little
Ph.D. Materials Science & Engineering
dlittle@usbr.gov
303-445-2384

Lee Sears
Ph.D. Materials Science & Engineering
lsears@usbr.gov
303-445-2392

Roger Turcotte, PE, CPS
Materials Engineer
rturcotte@usbr.gov
303-445-2383

Intern: Evan Sauls

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Today's Topics:

- Brief review of Corrosion and Cathodic Protection
- Safety in CP Testing
- CP System Components
- Testing Tools and Equipment
- Testing Guidelines
- GACP and ICCP Structure-to-Electrolyte Potentials
- Rectifier Inspection

Review of Corrosion and Cathodic Protection (CP)

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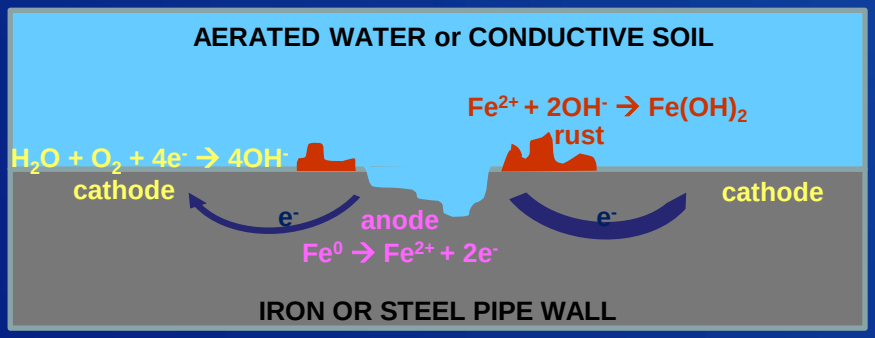
The Corrosion Reaction

ex. oxidation, “rusting,” electroplating, anodizing

Electrochemical Reaction Between a Metal and an Electrolyte

ex. steel, copper, aluminum

ex. soil, water



Four Required Components for Corrosion:

1. Anode (Corrodes)
2. Cathode (Protected)
3. Electrolyte (Usually Soil or Water)
4. Metallic Return Path (ex. Pipe)

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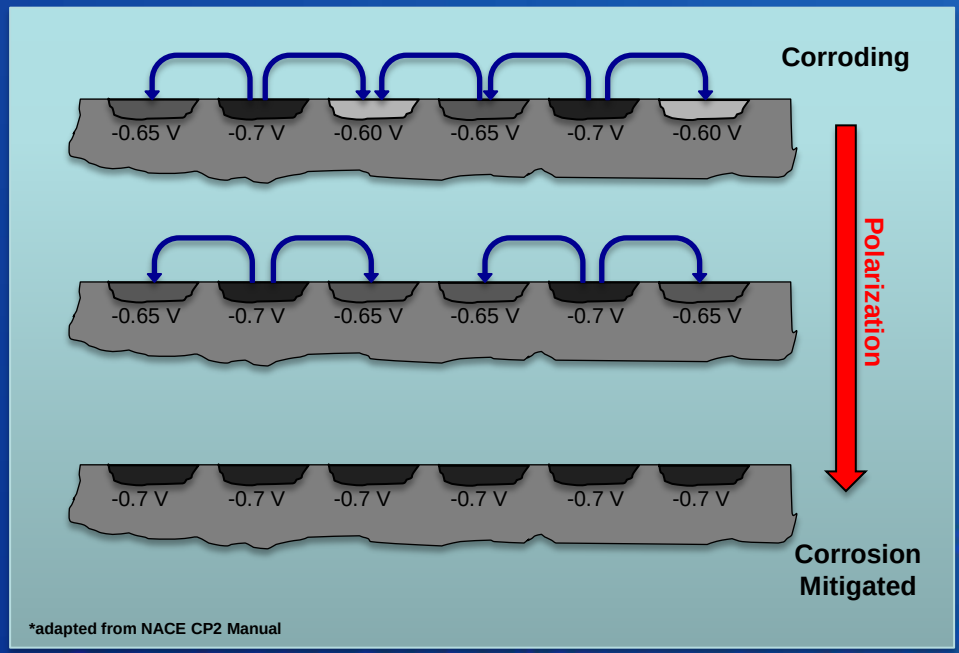
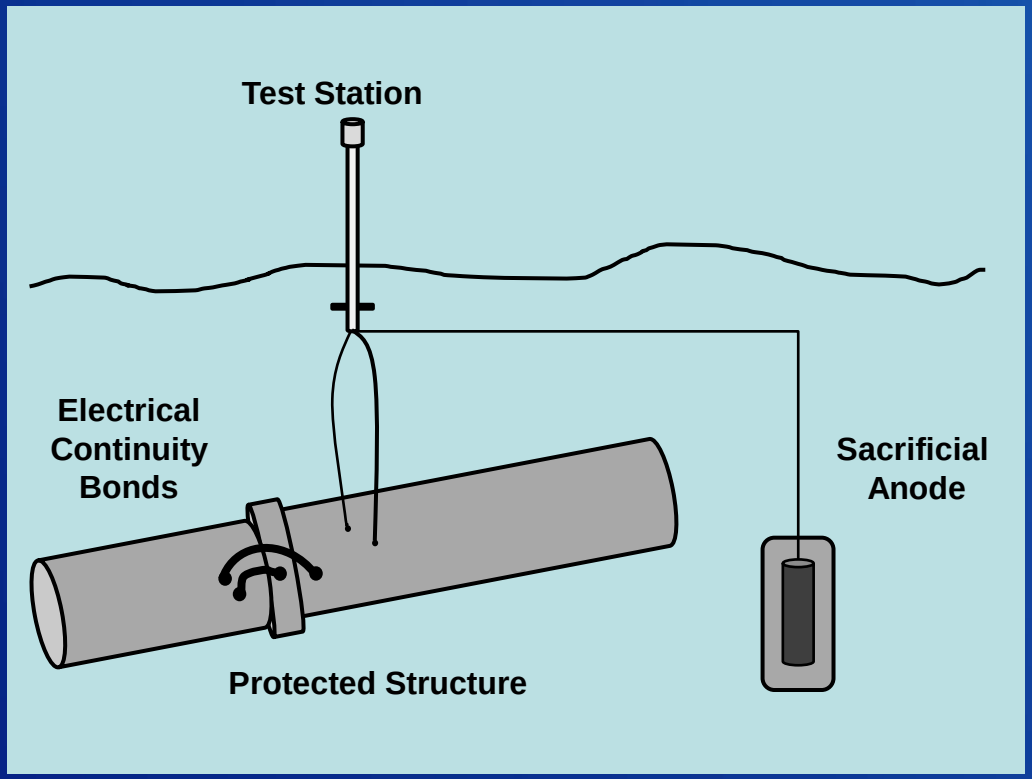
Cathodic Protection

- I_{DC} flows through Electrolyte from Anode to Structure
  - Polarizes structure to eliminate potential differences between anodic and cathodic areas on structure surface
  - Corrosion rate ceases or is greatly reduced
- Electrons are provided from source outside the structure
  - Via a more active metal to be sacrificed- galvanic anode CP
  - Via a rectifier- impressed current CP
- The most effective corrosion protection system for buried and submerged structures involves a good bonded coating and cathodic protection.

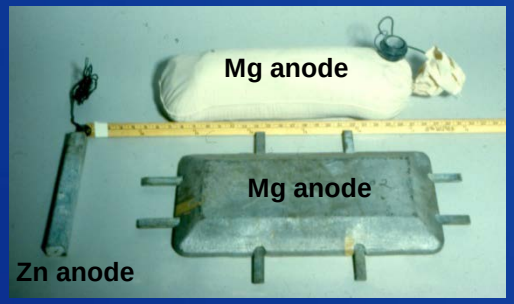


Galvanic Anode CP System



- Also known as **Sacrificial Anode Cathodic Protection**
- This system provides a cathodic current by **galvanic corrosion** or by sacrificing one material to prevent corrosion of the other material
- Both the structure and the anode must be in contact with the electrolyte

Galvanic Anode CP System



Anodes:

- Soil and Fresh Water- Magnesium and Zinc
- Brackish Water- Aluminum and Zinc

Applications:

- Pipelines, Fittings, and Valves
- Trashracks
- Hotspot Protection
- Gates
- Tanks
- Stray Current Interference Mitigation

New Mg Anode

Old Mg Anodes

Features:

- Low current requirements
- Typically protect smaller surface areas
- No external power needed
- Low maintenance

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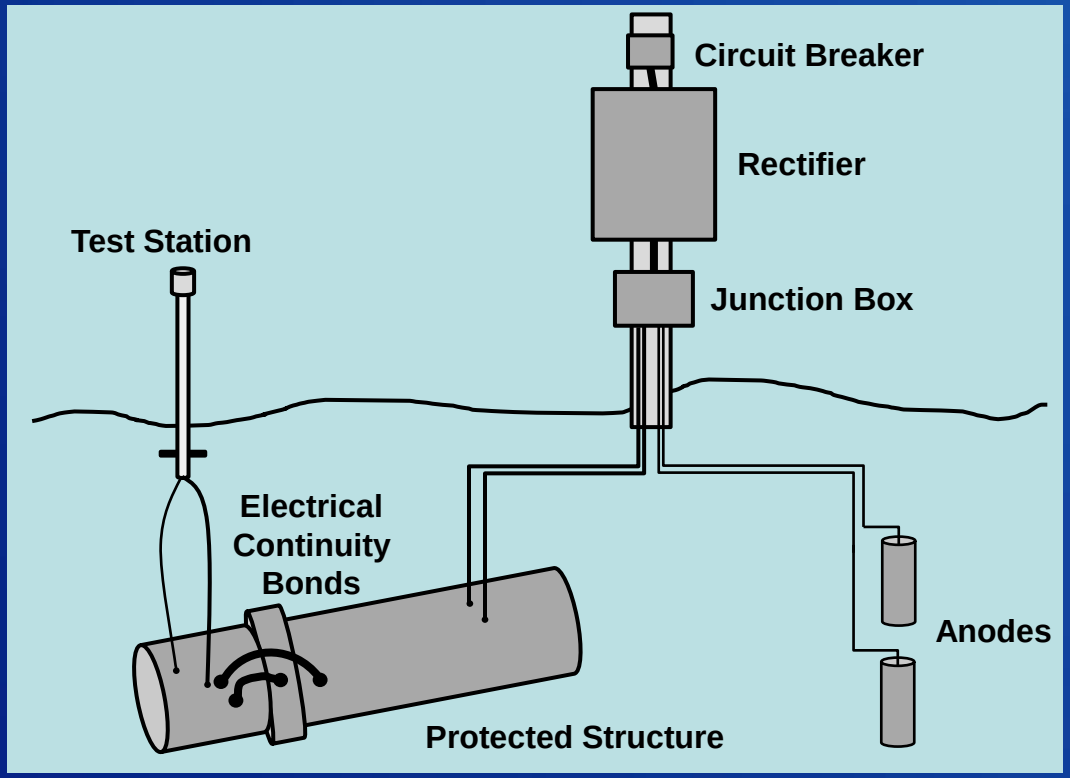
Impressed Current CP System



- This system provides a cathodic current from an external power source
- A direct current power source forces current to discharge from anodes, through the electrolyte, an onto the structure to be protected
- Both the structure and the anode must be in contact with the electrolyte

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Impressed Current CP System

Graphite Anodes

High-Si Cast Iron Anode

Anodes:

- Graphite, High-Si Cast Iron, Mixed Metal Oxide, Platinum, etc.
- Anodes Normally Connected Through Calibrated Shunts in Junction Box
- Installed via Linear or Deep Anode Ground Beds

Applications:

- Pipelines
- Reinforced Concrete
- Pumping Plant Pump Sumps
- Trashracks and Gates
- Tanks

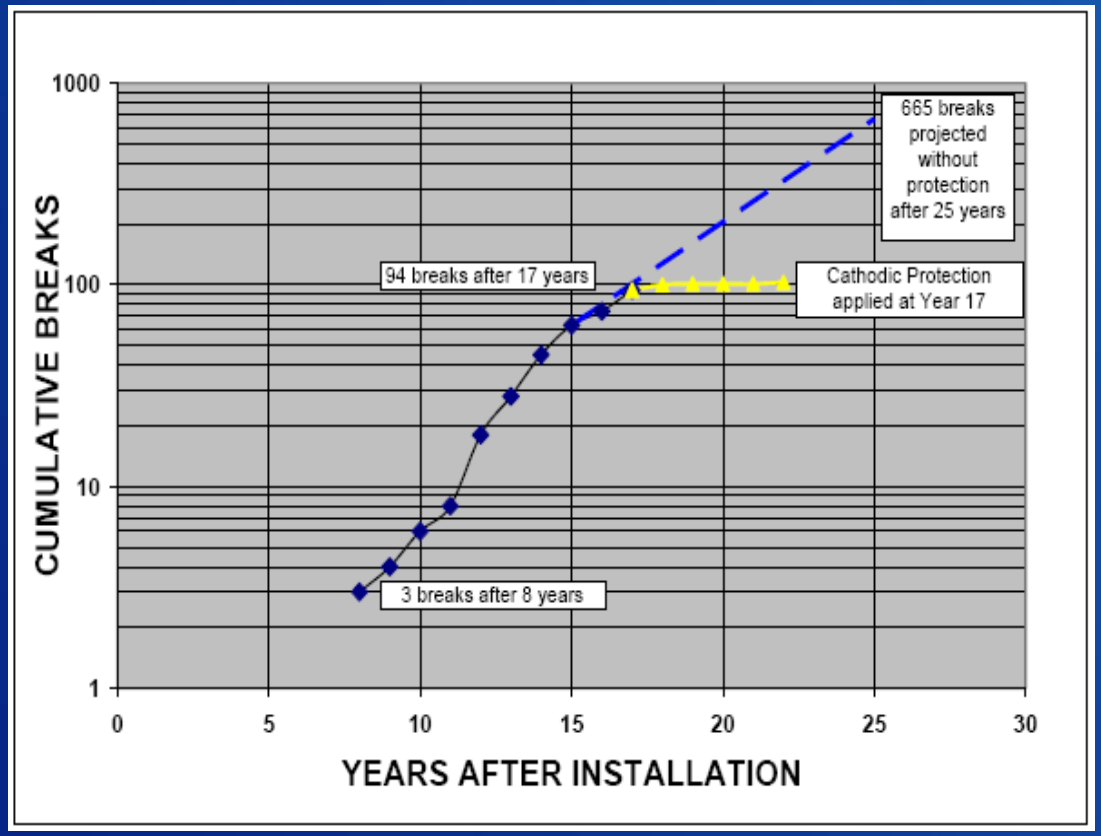
Requirements:

- High current requirements
- Can handle large or poorly coated structures
- More effective in high resistivity soils

Mixed Metal Oxide Disk Anode

Corrosion Management Programs

Effectiveness of Well Designed Program

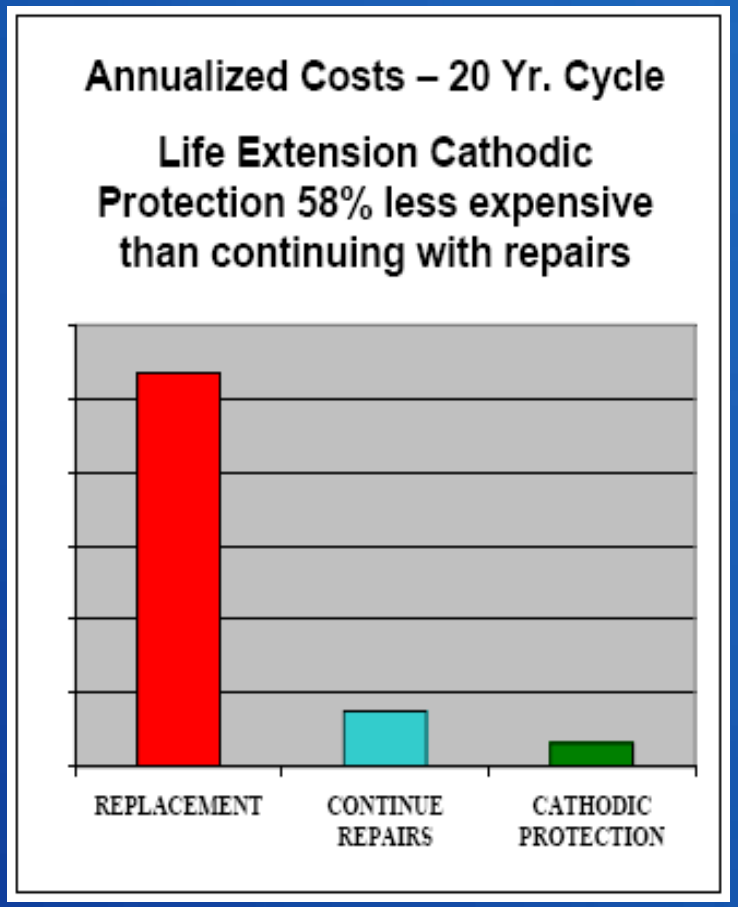


Durham Region, Ontario, Canada, Implemented in 1983

- 193 kilometers of ductile and cast iron water main cathodically protected,
- 17,032 anodes and 1,330 test stations
- ~100 know breaks/yr before CP down to 28 corrosive breaks in 2005
- $5m to install CP, less than 4% of estimated cost to replace of $135.4m

Ontario Centre for Municipal Best Practices, "*Best Practices Summary Report, Water Loss Management- Cathodic Protection*," February 2008.

Economic Benefits



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Safety in CP Testing

Remember: Safety First!!

- This module does not qualify you to test CP systems. It is intended only to familiarize you with system components, testing equipment, and techniques.
- Please follow all training requirements and safety guidelines from your office.
- TSC Corrosion staff is available for CP system testing, training, and diagnostics.

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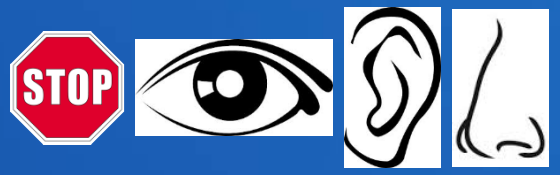
Effects of Electricity

Rectifier Input, typical: 115/230 V_{AC} @ 60 Hz, single phase
Rectifier Output, also at Junction Box, typical: $5V_{DC}$ up to $50V_{DC}$
At Test Station, typical: $<2V_{DC}$

AC Current (mA) @ 60 Hz	Physiological Effect	Voltage Required- Dry Skin (100,000 Ω)	Voltage Required- Wet Skin (1,000 Ω)
1	Threshold of perception	100	1
10-20	Let-Go Threshold, painful	1000	10
100	Fibrillation certain; max safe current between and arm and leg for 3 sec; death possible	10,000	100
DC Current (mA)			
5	Threshold of perception	500	5
50-75	Let-Go Threshold, painful	5000	50
300	Fibrillation certain; max safe current between and arm and leg for 1 sec; death possible	30,000	300

- **>15 V_{AC} on a pipeline is considered hazardous→ Take steps to reduce risk**
  - **This is mainly a risk if pipe runs along high voltage power lines**
  - **Can also install grounding mats and shock-resistant test stations**

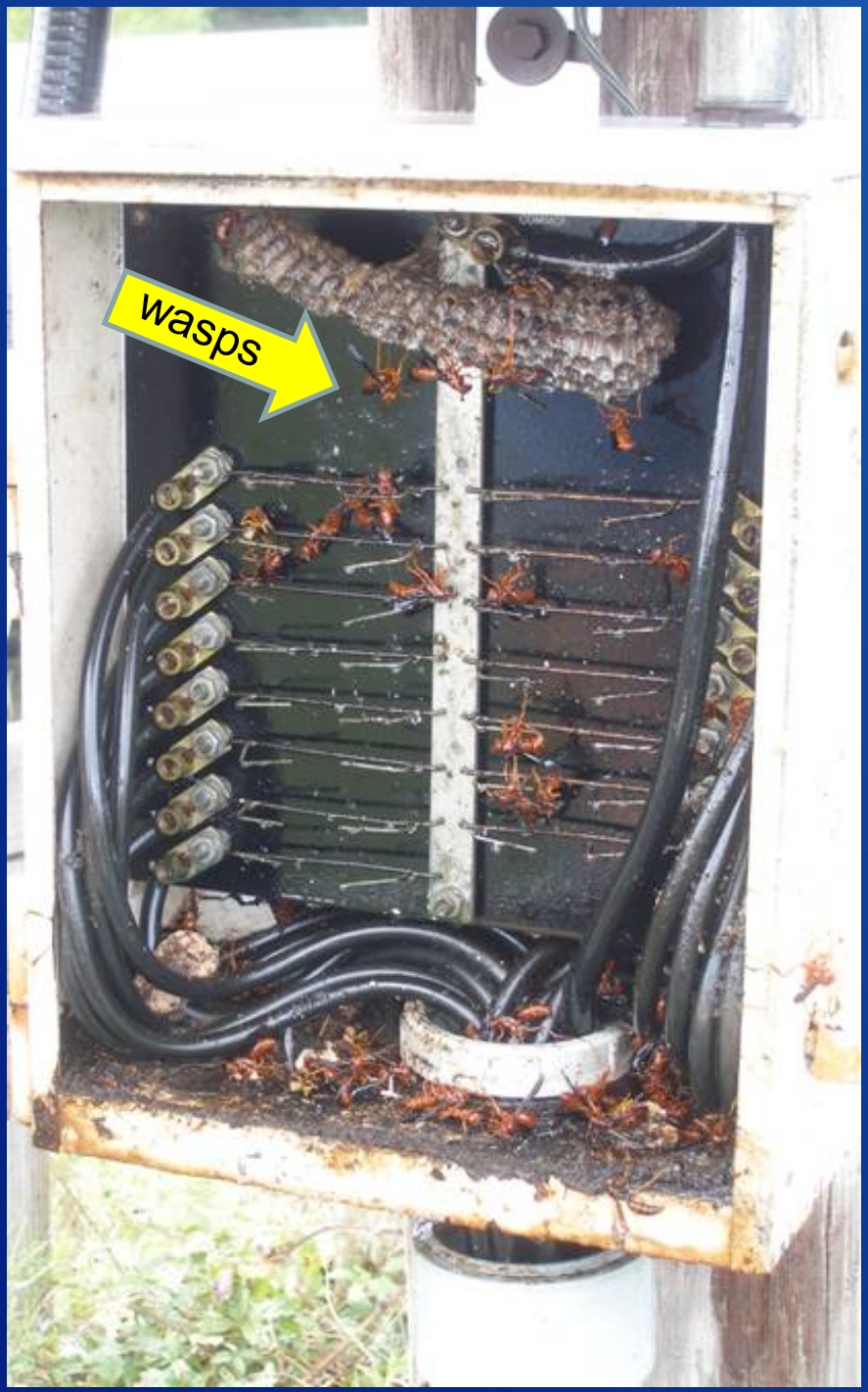
Inspecting Rectifiers

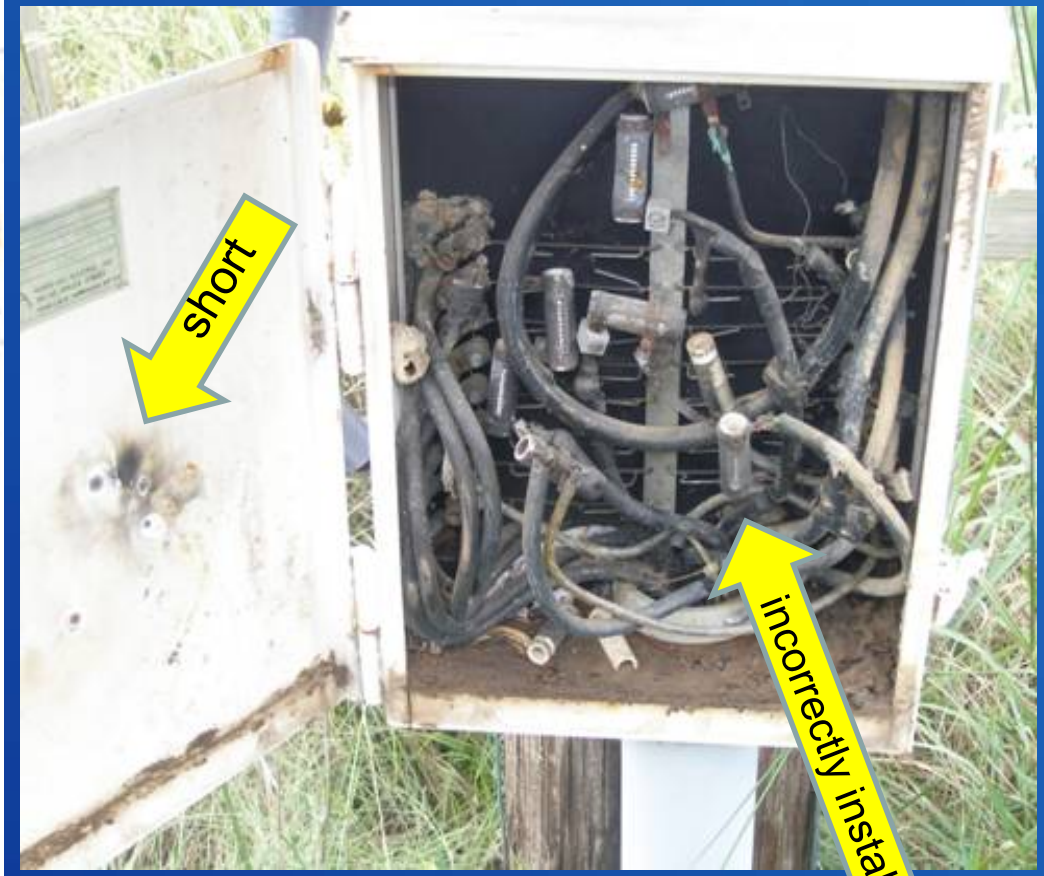


- **Survey area- look, listen, smell**
  - Be mindful of critters- wasps, snakes, rats?
  - Check for burn marks, crackling sound of sparking, signs of tampering
- **Check for Electrified Case**
  - Use a voltage indicator
  - If nothing else, touch the cabinet with the back of your hand
  - Do not grab!

- **Open Case, Check again**
  - Critters? Burn marks, loose wires?
- **Continue with Inspection**
- **Path of current is important.**
  - Across the heart is most hazardous
  - Work with only one hand in the rectifier cabinet at a time if possible
  - Use alligator clip leads

McGee Creek Aqueduct Cathodic Protection System - Atoka, OK - 2007





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PPE

PPE will be specific to your job site.

Standard Items Include:

- **Steel-toed boots with insulated soles**
- **Hardhat**
- **Work gloves**
- **Safety glasses**
- **Reflective vest**

CP System Components

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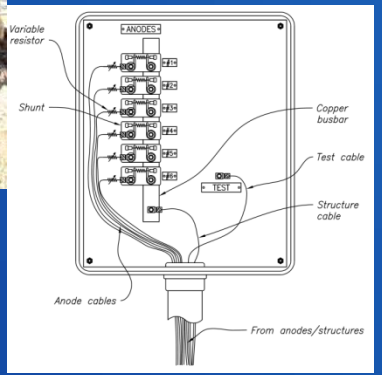
Above-Ground Components

Test Station

Rectifier



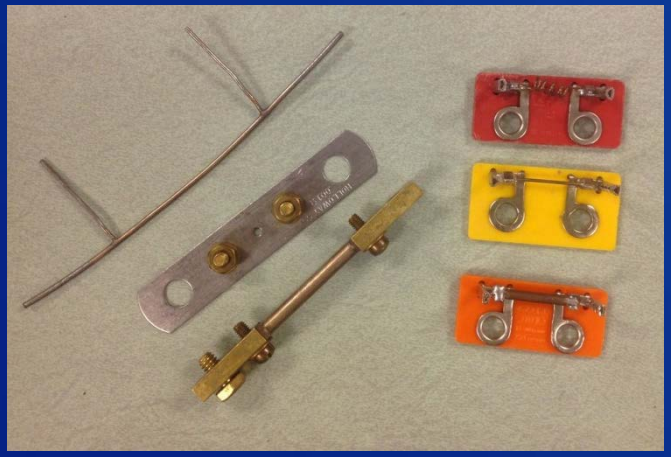
Junction Box

TS/JB Components

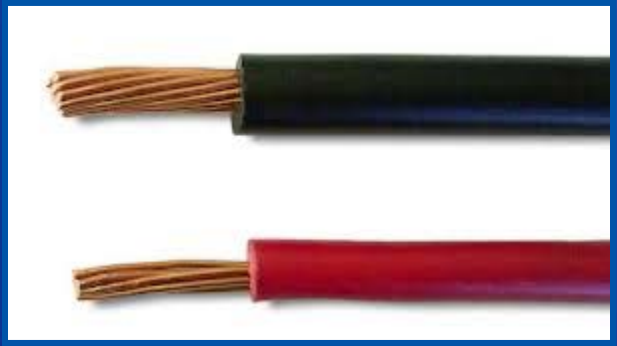
Hardware

Busbar

Bond Bar



Shunt



HMWPE Cu Cable

Variable Resistor

Rectifier Components

Coarse Tap

AC Primary Breaker

Shunt

Voltmeter

Positive DC Output - to anode

Fine Tap

AC Secondary Breaker

Ammeter

Negative DC Output - to structure

Lightning Arrestor

Buried/Submerged Components

Mg Anodes in GA horizontal bed

Graphite anodes in deep well IC system

Pt/Nb wire anode in slotted PVC tube for submersion

Metallurgical Bond

High-Silicon Cast Iron anodes

CP Testing Tools and Equipment

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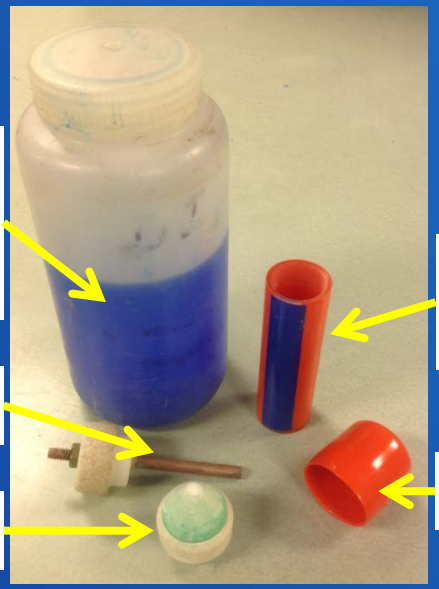
Portable Reference Electrode



<u>Reference electrode</u>: used to develop a baseline potential against which the potential of a structure in an electrolyte can be measured

Copper/Copper Sulfate ($Cu/CuSO_4$ or CSE) is standard for our work

- **Solution mixed with distilled water; should always be solid crystals in solution**
- **Periodically replace $CuSO_4$ solution and clean Cu rod and porous plug**
- **Keep electrical tape over window to prevent exposure to sunlight**
- **Calibrate field electrode to one kept in office/truck/lab. If more than +/- 5mV difference, you should clean and replace solution.**

Portable Multimeter

Portable Voltmeter:

- Minimum input impedance of 10 MΩ
- Capable of measuring DC voltages between +/- 0.1 millivolt to +/- 100 volts
- Two electrically insulated test leads- alligator clip leads are best for testing in rectifiers

Current Interrupters

<u>Current Interrupter:</u> used to automatically switch the current on and off at set intervals. Used to measure the polarized or "instant-off" potential.

- **Match Amp rating to rectifier output… $I_{rectifier} < I_{interrupter}$**
- **Options include GPS synchronization and programming**
- **Must interrupt all rectifiers on a pipeline to get a true V_{OFF}… this often means more than one interrupter is needed for testing**

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Close Interval Survey Equipment

Chainer: electronic distance counter using No. 32 AWG varnish-coated copper wire

Data Logger: data loggers or computerized DC voltmeters capable of recording all of the required data over duration of test; ruggedized for field use

Portable Reference Electrode: Cu/$CuSO_4$ attached to pole for ease of use and for triggering measurements.

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General Tools

Everything in My Tool Bag:

Linesman Pliers, 7/16” hex Nutdriver, Flat-head Screwdriver, CSE Reference Electrode, Misc Hardware, Multimeter, Bottle of Water, Large Jaw Pliers, Wire Crimpers- large and small, 5lb Hammer, PVC Saw, File, Non-metallic Sandpaper, Wire Brush, Cleaning Cloth, Electrical Tape, Corrosion Tape, Adjustable Wrenches, Various Pliers, Heavy-duty Wire Cutter, Utility Knife, Small Screwdriver Set, Permanent Marker, Pen, Camera, GPS

Essential Testing Tools:

- Linesman Pliers
- 7/16” hex Nutdriver
- Flat-head Screwdriver
- CSE Reference Electrode
- Misc Hardware
- Multimeter
- Bottle of Water
- Tool bag

Testing Guidelines

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Guidelines and Specifications

- **Water infrastructure is not required to have cathodic protection by law, as in the oil & gas industry**
- **Reclamation Corrosion staff follows the guidelines and criteria in NACE Standard SP0169 "Control of External Corrosion on Underground or Submerged Metallic Piping Systems"**
- **Other References:**
  - **Your USBR-TSC-MERL Corrosion Team**
  - **Cathodic Protection Survey Procedures, 2nd ed., NACE International, 2012**
  - **NACE RP0285 "Corrosion Control of Underground Storage Tank Systems by Cathodic Protection"**
  - **NACE SP0388 "Impressed Current Cathodic Protection of Internal Submerged Surfaces of Steel Water Storage Tanks"**
  - **NACE RP0196 "Galvanic Anode Cathodic Protection of Internal Submerged Surfaces of Steel Water Storage Tanks"**

When to Test

- **DO NOT test if the weather forecast is for thunder and lightning in area of structure**
  - **Lightning can travel miles down a pipeline**
- **Try to test at same time of year, e.g. every April**
  - **Don't test if ground is frozen**

Standard/ Guideline	Corrosion Inspection Frequency	Structure-to-Electrolyte Survey Frequency	Close-Interval Survey Frequency	Rectifier Inspection Frequency	CP System Data Analysis by TSC
NACE Standard SP0169		Annually		2-month intervals	
USBR Corrosion Staff	Annually. When structure is available due to dewatering, maintenance, etc.	Annually	Every 5 yrs; when leaks occur, survey adjacent line; if system has been off for an extended period of time	2-month intervals	Every 3-5 years

Record Keeping

- **Testing Records should include:**
  - **General:**
    - **Tester's Name**
    - **Date and Time of Test**
    - **Weather Conditions**
    - **Location of Test Site (GPS)**
  - **Measurement Data:**
    - **Type of Measurement (V_{ON}, V_{OFF})**
    - **Value**
    - **Polarity (+/-)**
    - **Units (V, mV, mA, etc)**
    - **Type of reference electrode (CSE)**
  - **Other Useful Information:**
    - **Drawings, photos, maps of site**
    - **Sketches or photos of rectifier/JB/TS**
    - **General inspection description**
    - **Description of problems or troubleshooting work**

*** Good historical record keeping is the best way to determine health of a CP system.**

Testing Submerged Systems

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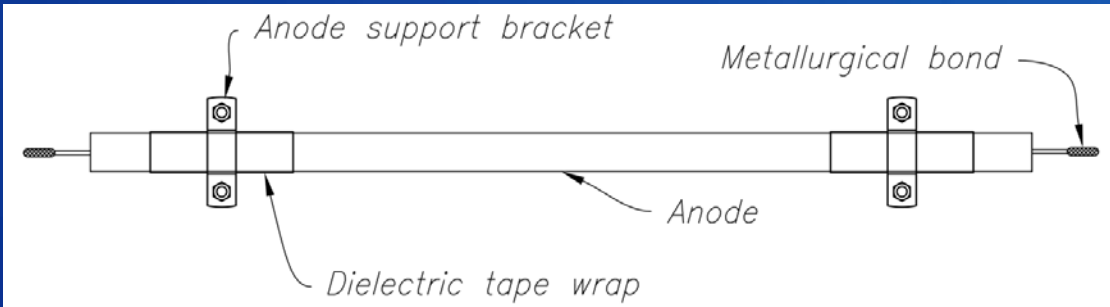
Testing Submerged CP Systems

- **Anodes on a submerged GACP system should be inspected whenever structure is removed for maintenance**
  - **What is condition of anode?**
  - **Are brackets still providing sufficient mechanical support?**
  - **Are metallurgical bonds still intact?**
  - **Is any cable between structure and anode still electrically connected?**

New Mg Anode

Old Mg Anodes



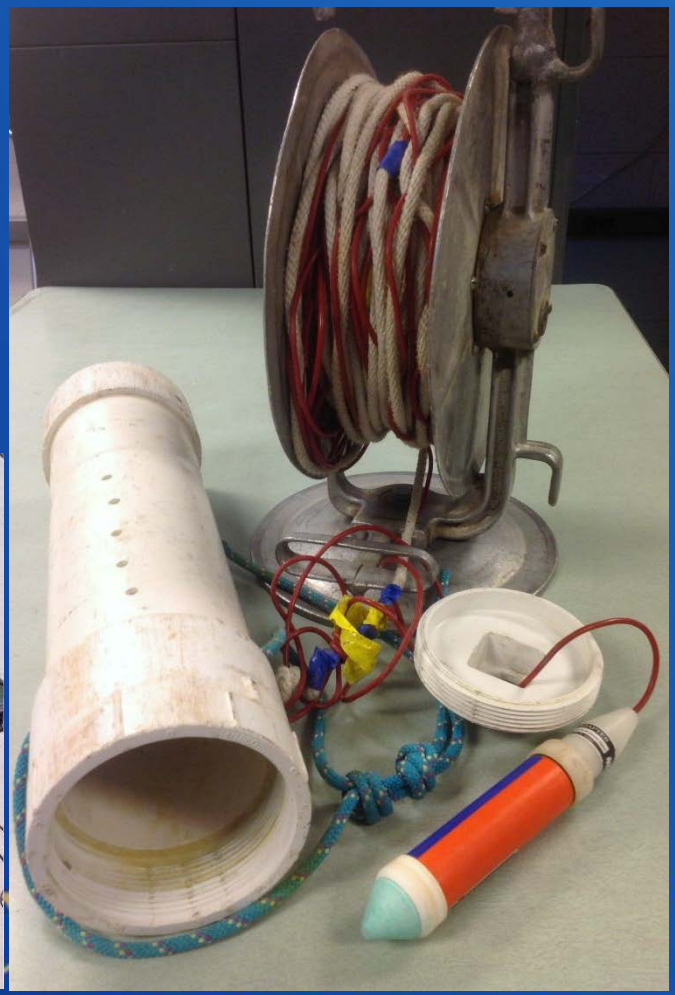
Testing Submerged CP Systems

On a submerged IC system

- Perform same inspections as for galvanic system

- Testing is very similar to that performed at a junction box on a pipeline
  - Difference: reference electrode goes in water
  - May use weighted submersible container to hold reference electrode securely, prevent loss of electrode, and position electrode at test depth


Gallegos Pumping Plant, NIIP, 2004



Testing Pipelines

Structure-to-Electrolyte Potential

Close Interval Survey

Inspection at Rectifier

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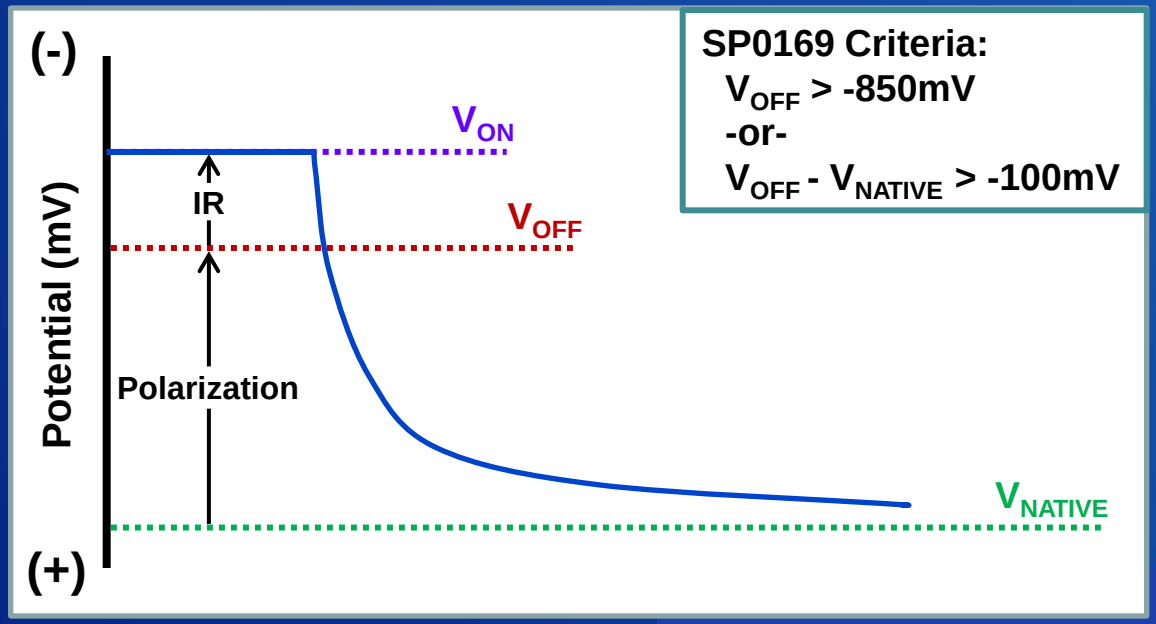
Structure-to-Electrolyte Testing

* aka Pipe-to-Soil Potential

- **Galvanic-**
  - Interruption is done manually

- **Impressed Current-**
  - Interrupter must be hooked up at rectifier
  - All rectifiers on a line must be hooked up to get a true V_{OFF}



Structure-to-Electrolyte Testing

- Bury cone end of $Cu/CuSO_4$ reference electrode in ground above pipe
- Make sure contact to soil it good- wet with water if necessary

ON Potential (V_{ON})

- Set multimeter to V_{DC}
- Connect positive lead to structure cable and negative lead to reference electrode
- Record value

Instant OFF Potential (V_{OFF})

- Set multimeter to V_{DC}
- Connect positive lead to structure cable and negative lead to reference electrode
- Detach structure cable
- Record 2nd value after disconnect
- NOTE- all structure cables must be detached from all anode cables in order to measure I/O

Anode Voltage (V_{anode})

- Set multimeter to V_{DC}
- Connect positive lead to anode cable and negative lead to reference electrode
- Detach anode cable
- Record value (close to -1.5 to -1.7 V)

Anode Current (I_{anode})

- Set multimeter to mV_{DC}
- Place leads on either side of shunt
- Record value, divide by shunt value to get mA
- ex. I_{anode} (mA) = V_{anode} (mV) ÷ 0.01 Ω

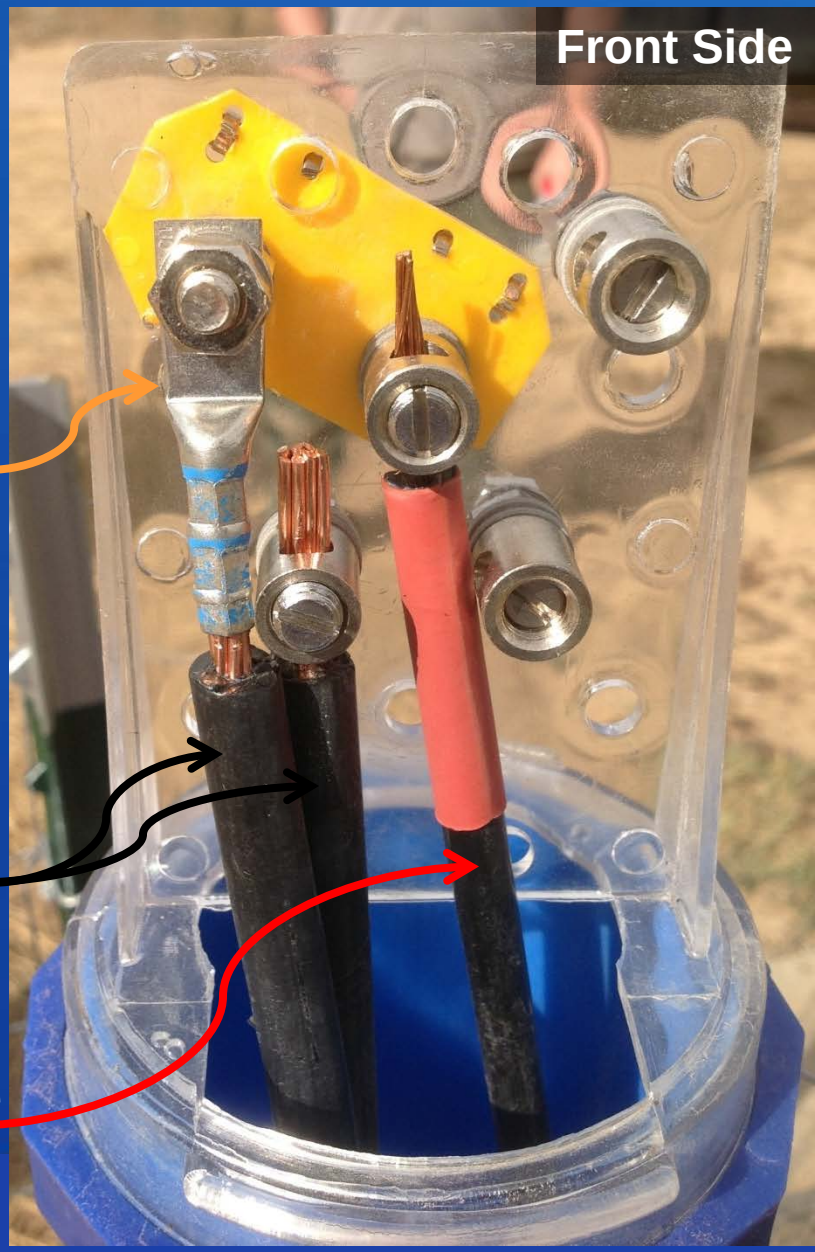
Testing Stations

Shunt

Remove for V_{OFF}

Structure Cables (black)

Anode Cable (red)



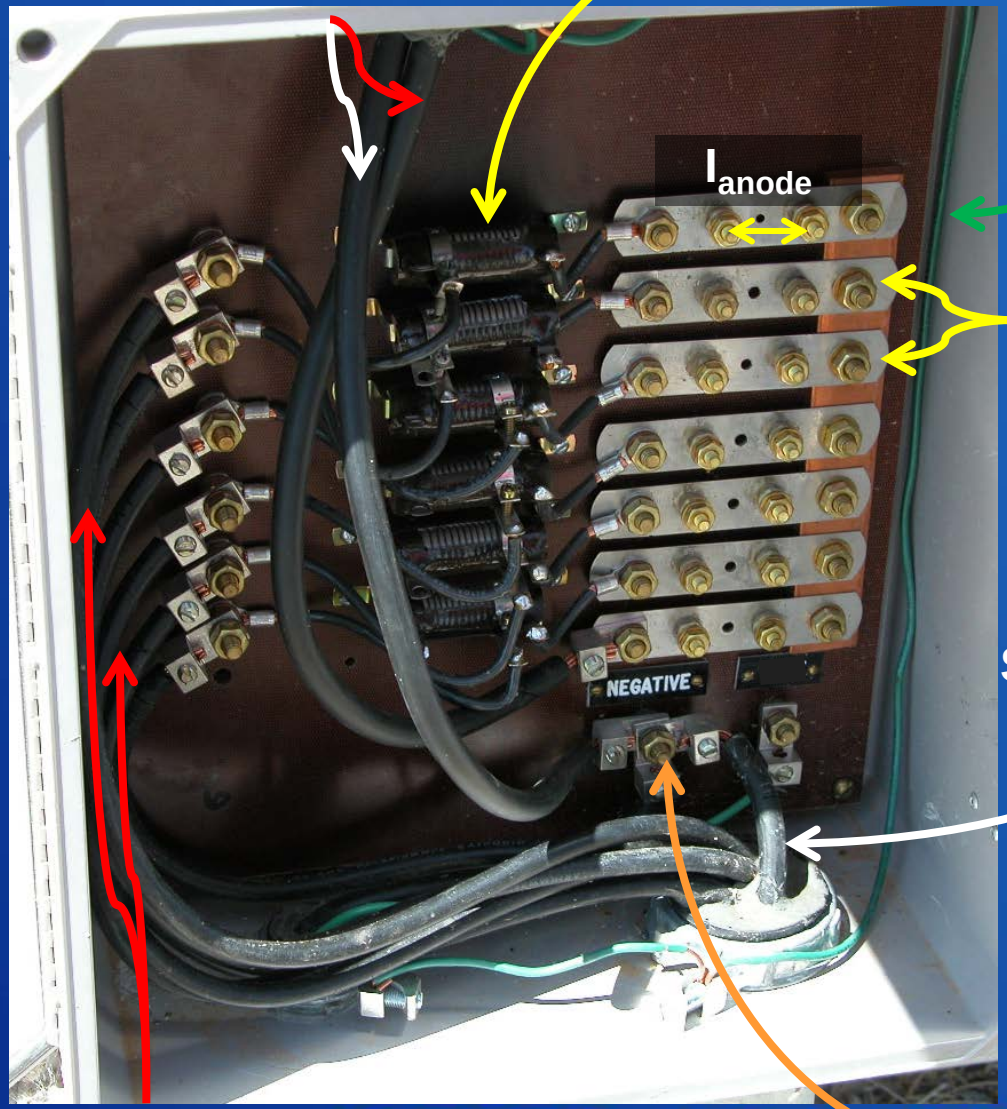
Junction Box

For GACP:

- Measure V_{ON} and V_{OFF} at structure cable, removing structure cable manually
- Measure I_{anode} for each anode across shunt
- Do not need to measure V_{anode} unless system is new or has been off for an extended period of time

For ICCP:

- Do not remove structure cable- attach interrupter to rectifier to measure V_{OFF}
- Measure I_{anode} across shunts
- Do not measure V_{anode}



Pipe-to-Soil Testing- GACP System

VIDEO

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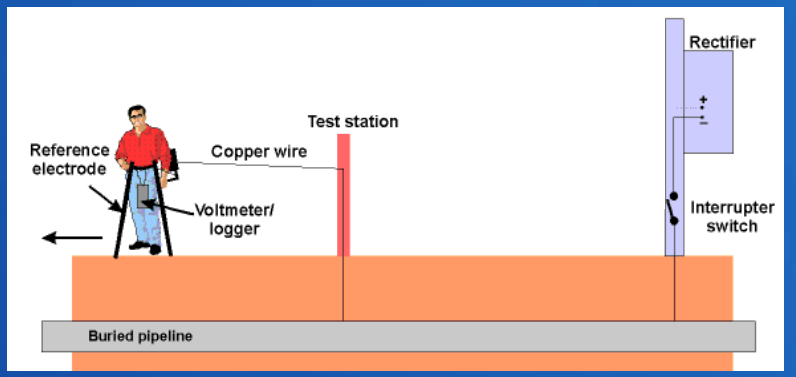
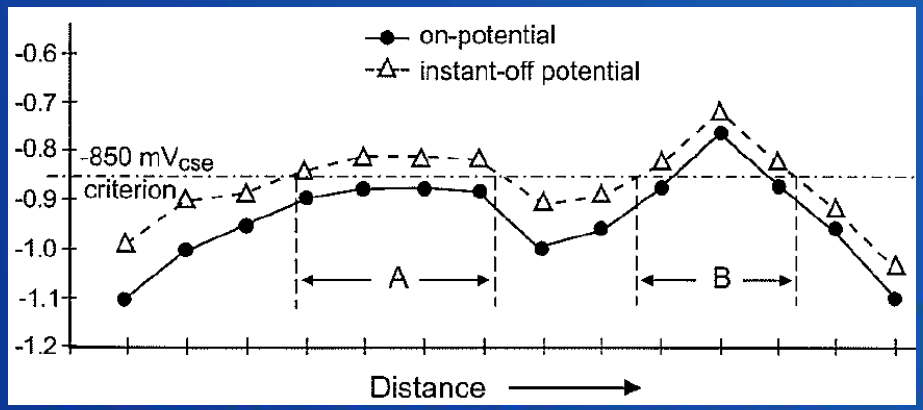
Close Interval Potential Surveys

- Conducted to assess effectiveness of CP and to identify possible corrosion problems over the entire length of the pipe.
- Secure Cu reel wire to positive terminal on voltmeter and to structure cable on first TS/JB; negative terminal goes to the reference electrode.
- Take structure-to-electrolyte potentials at ~3 foot intervals along pipe. Pipe locator is useful to follow line.
- Use current interrupters at rectifier to measure V_{ON}/V_{OFF} of ICCP systems. May also take V_{ON} only survey for GACP systems.





Rectifier Inspection

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One Last Note on Safety…

- **Rectifiers are electrical equipment**

TREAT ELECTRICAL EQUIPMENT WITH RESPECT

Even with the primary AC breaker off, there is still power coming in to the back of the rectifier.

"THINK SAFETY ----- WORK SAFELY!!!"

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Rectifier Inspection

- Perform critter and current check on rectifier before opening box
- Inspect rectifier for damaged wires, debris, etc.
- Is the rectifier on?
- If yes, proceed. If no, check breakers, check input V_{AC}. Call rectifier manufacturer or TSC Corrosion team for troubleshooting from rectifier site, or document problems with drawings or photos.
- Read and note V_{DC} and I_{DC}
- Don’t trust the gauges; use the portable voltmeter!
- Remove debris and clean, close and lock cabinet.

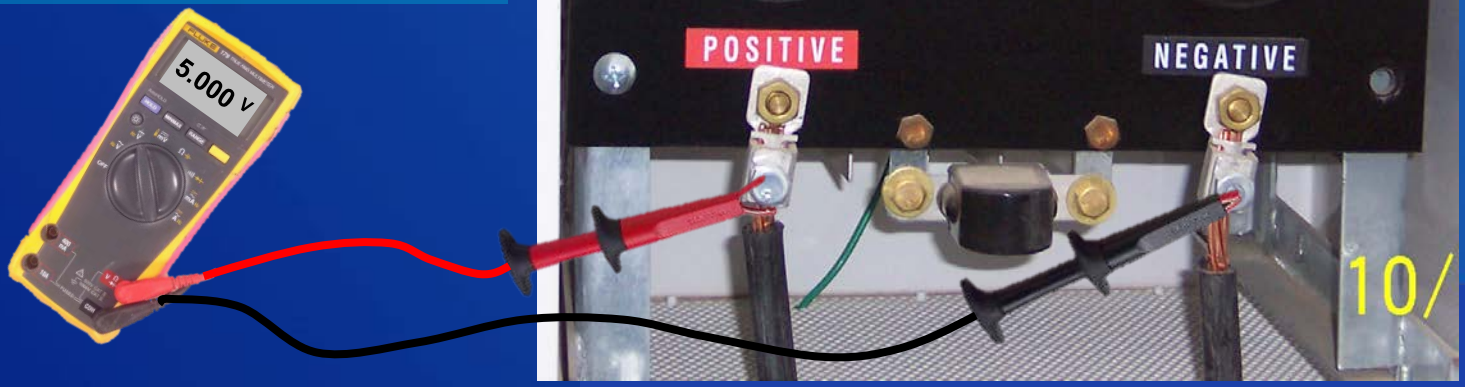
Rectifier Testing

DC Output Voltage (V_{DC})

- Set multimeter to V_{DC}
- Connect positive lead to positive terminal and negative lead to negative terminal
- Record value

DC Output Current (I_{DC})

- Set multimeter to mV_{DC}
- Place leads on either side of shunt
- Record value, divide by shunt value to get mA
- ex. I_{anode} (mA) = V_{anode} (mV) ÷ 0.01 Ω



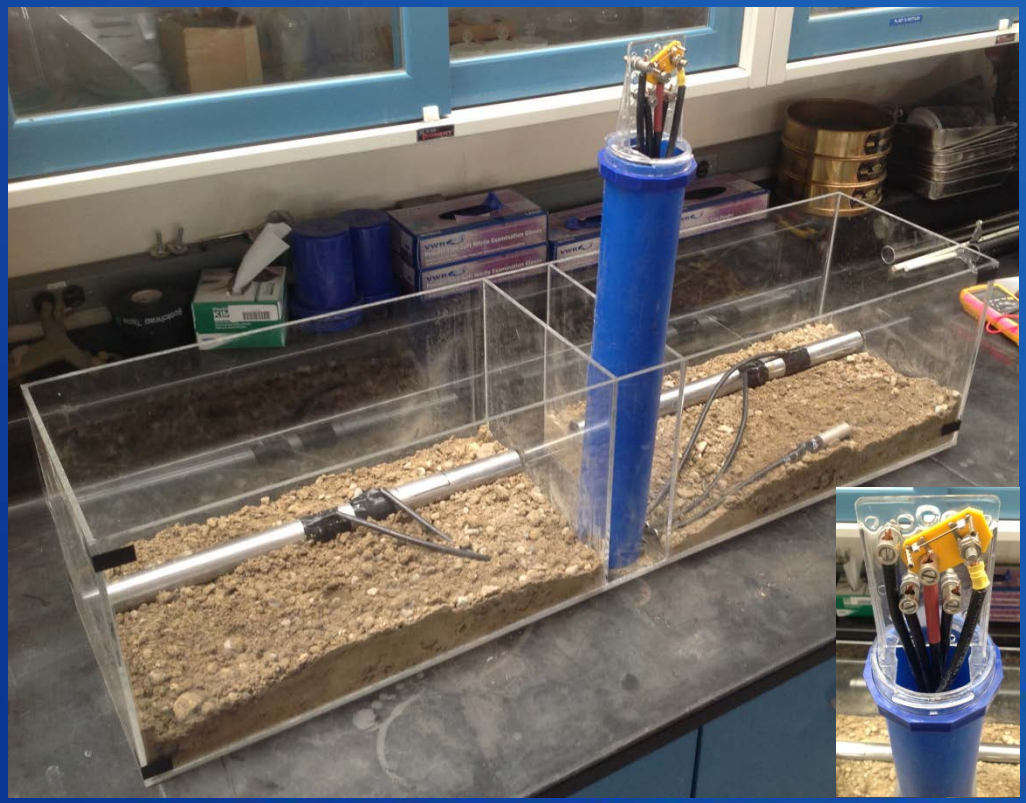
Resources

Call your TSC-MERL Corrosion Staff!! We can:

- Test your systems
- Write SOP and testing protocols specifically for your systems
- Provide training to local staff specific to your system
- Analyze CP system data and troubleshoot problems

Attend the Corrosion and Coatings School

- every October
- In-depth lectures and Hands-on training



Coatings and Corrosion Manuals

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Managing Water in the West

Technical Memorandum No. MERL-2012-40

Guidelines for Field Installation of Corrosion Monitoring and Cathodic Protection Systems

December 2012

U.S. Department of the Interior
Bureau of Reclamation

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Managing Water in the West

The 10% Soil Resistivity Method

December 2005

U.S. Department of the Interior
Bureau of Reclamation
Materials Engineering and Research Laboratory
Denver, Colorado

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Managing Water in the West

Technical Memorandum No. MERL-2011-36

Guidelines for Reporting Corroded Pipe

September 2011

U.S. Department of the Interior
Bureau of Reclamation
Technical Service Center, Denver, CO

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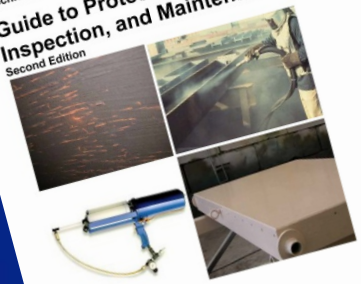
Technical Guide

Guide to Protective Coatings, Inspection, and Maintenance

Second Edition



April 2012

U.S. Department of the Interior
Bureau of Reclamation
Technical Service Center
Denver, Colorado

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FOR OFFICIAL USE ONLY

Technical Memorandum No. MERL-2013-39

Corrosivity Testing of Waters and Soils

FOR OFFICIAL USE ONLY

September 2013

U.S. Department of the Interior
Bureau of Reclamation
Technical Service Center
Denver, CO

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Technical Memorandum No. MERL-20xx-xx

Field Guide for Testing and Troubleshooting Cathodic Protection Systems

December 2012

U.S. Department of the Interior
Bureau of Reclamation

RECLAMATION

Upcoming Events

- **Next Corrosion Webinar:**
  - **Tentative: June 2014**
  - **“Cathodic Protection on Gates, Trashracks, and other Submerged Structures”**
  - **What do you want to hear about? Please suggest topics for future webinars!**

Questions? Comments?

De Sitter's "Law of Fives"

**$1 spent in getting the structure designed and built correctly
is as effective as spending
$5 when the structure has been constructed but corrosion has yet to start,
$25 when corrosion has started at some points, and
$125 when corrosion has become widespread.**