Criteria for Cathodic Protection

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Appalachian Underground Corrosion Short Course

Overview

- Introduction
- Common Criteria for Steel and Cast Iron Piping
- Other Criteria for Steel and Cast Iron
- Criterion for Aluminum Piping
- Criterion for Copper Piping
- Criterion for Dissimilar Metal Piping

Documents

- 49 CFR 190 & 192 Appendix D - Liquid & Gas Pipelines
- NACE SP0169-2013 & 2007
- NACE TM0497 "Measurement Techniques Related to Criteria for Cathodic Protection on Underground or Submerged Metallic Piping Systems"
- "Cathodic protection criteria – A critical review of NACE Standard SP0169" by R. A. Gummow, published in MP September 1986

Grammar Lesson

- Grammar Basics
  - Criterion
    - Singular
    - "This is the criterion…"
  - Criteria
    - Plural
    - "These are the criteria…"

Criteria – NACE SP0169

- "Lists criteria and other considerations for cathodic protection that will indicate, when used either separately or in combination, whether adequate cathodic protection of a metallic piping system has been achieved."

Criteria for Steel and Cast Iron Piping

1. A Minimum of 100 mV of cathodic polarization. Either the formation or the decay of polarization can be measured to satisfy this criterion.

2. A structure-to-electrolyte potential of -850 mV or more negative as measured with respect to a saturated copper/copper sulfate (CSE) reference electrode. This potential may be a direct measurement of the polarized potential or a current applied potential. Interpretation of a current-applied measurement requires consideration of the significance of the voltage drops in the earth and metallic paths.

3. Criteria that have been documented through empirical evidence to indicate corrosion control effectiveness on specific pipeline systems may be used on those piping systems or others with the same characteristics

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Polarization

- The total potential shift from the native potential (excluding voltage drops in the soil), includes components due to environmental polarization and cathodic polarization.

Cathodic Polarization

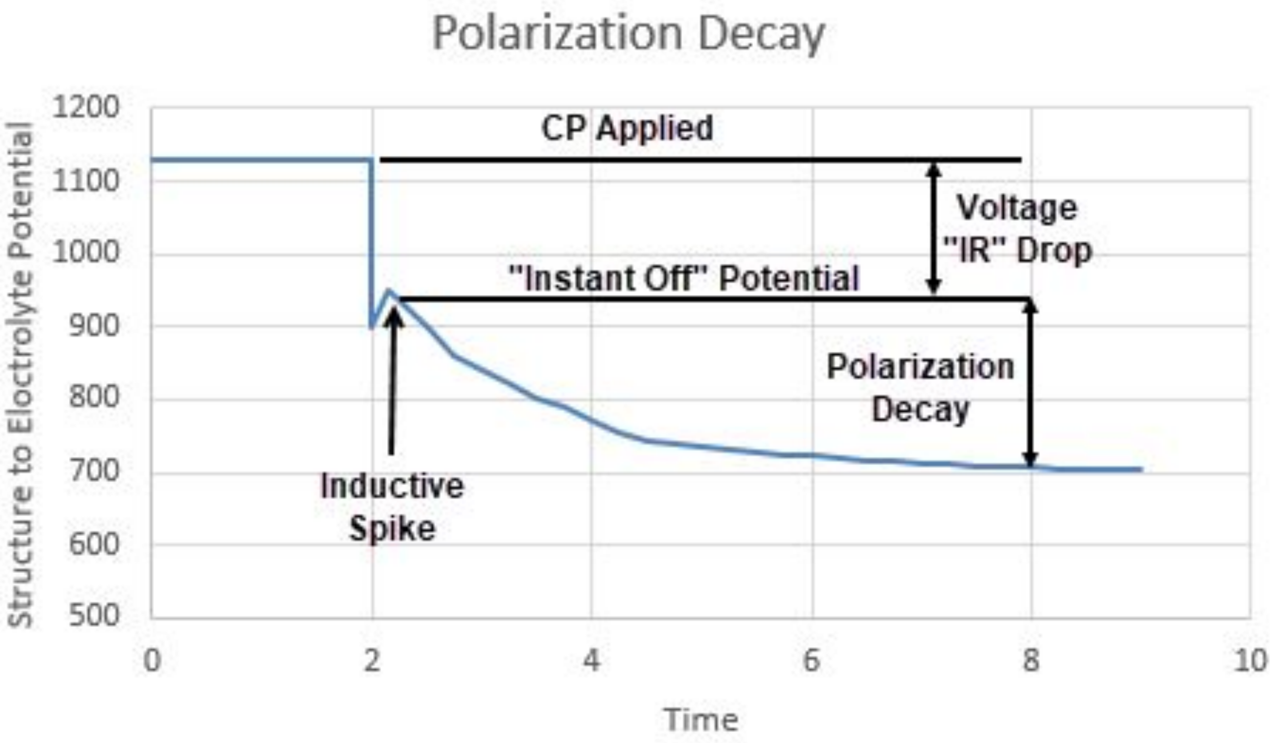
- The difference in potential between the native potential and the “Off” or polarized potential as a result of the application of the cathodic protection.

- The corrosion rate decreases and the rate of the reduction reaction on the metal surface increases as the underground structure is polarized in the negative direction from the native potential.

Environmental Polarization

- Beneficial changes in the environment at the metal surface including:
  - reducing oxygen
  - increasing the pH
  - and moving halides such as chlorides away from the metal surface
- These environmental changes decrease the corrosion rate

Polarization



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100 mV of Polarization

- "A minimum of 100 mV of cathodic polarization between the structure surface and a stable reference electrode contacting the electrolyte.
- The formation or decay of polarization can be measured to satisfy this criterion."

- Most fundamentally sound criterion

100 mV of Polarization

- Criterion Basis
  - The corrosion rate of a structure decreases by a factor of ten (order of magnitude) for every 100 mV cathodic shift in the polarized potential.
  - An order of magnitude decrease in the corrosion rate of an underground structure typically is more than adequate to effectively mitigate corrosion.

Measuring Polarization

- The magnitude of the polarization shift can be determined by measuring its formation or decay.

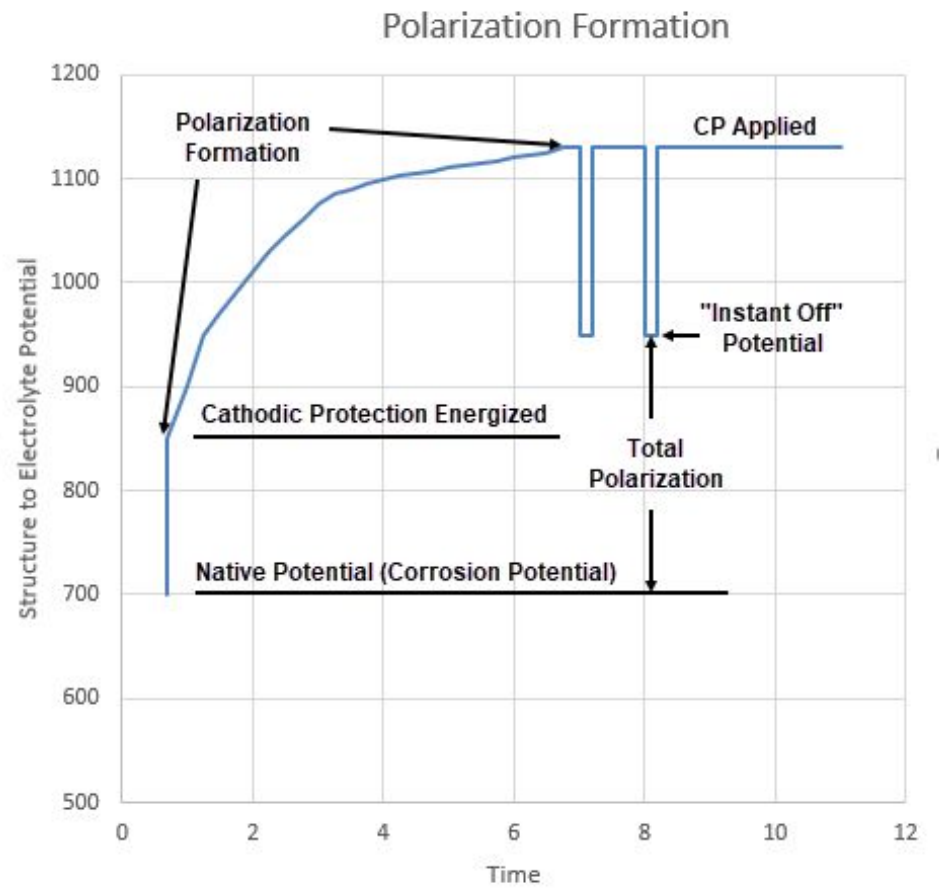
Polarization Formation

- Take a native potential reading
- Energize the cathodic protection system
- Allow time for system to polarize
- Monitor "On" readings at test point on structure
- When no measurable shift in "On" reading, take an "Off potential"
- Compare "Off" reading to Native reading
  - If Off – Native > 100 mV shift, criterion met at this location
- Repeat at all test points along structure

Polarization Formation - Alternative

- Take “On” reading immediately after energizing CP system
- Remeasure potential a few hours to days later
- Compare the two “On” readings
  - If difference is >100 mV in the negative direction, the criterion is met for this location.

Polarization Formation



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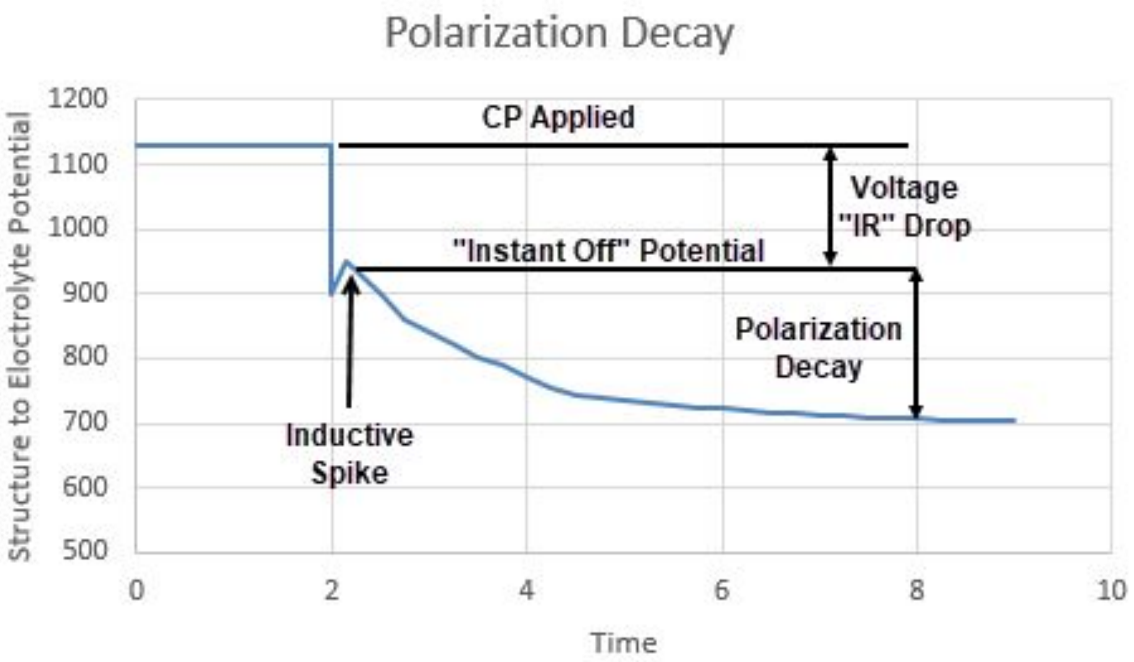
Polarization Decay

- Measuring polarization decay is the most common method of determining the amount of polarization
- When CP system turned off, will see instantaneous positive shift in the structure-to-soil potential
  - Eliminating IR drop in the soil
  - Allow spike to dissipate (200-500 milliseconds)
- After spike ends, take an "Off" reading
- Potential will decay exponentially from this point
- Wait a period of time and take another "Off" reading
  - Compare the readings; if difference is >100 mV negative, criterion is met

Polarization Decay



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Application

- Most commonly used on poorly-coated or bare structures where it is difficult or costly to achieve either of the -850 mV Criterion.
- Minimize CP disbondment of coatings or hydrogen embrittlement of steel
- Used in combination with other criteria
- Used for metals other than steel

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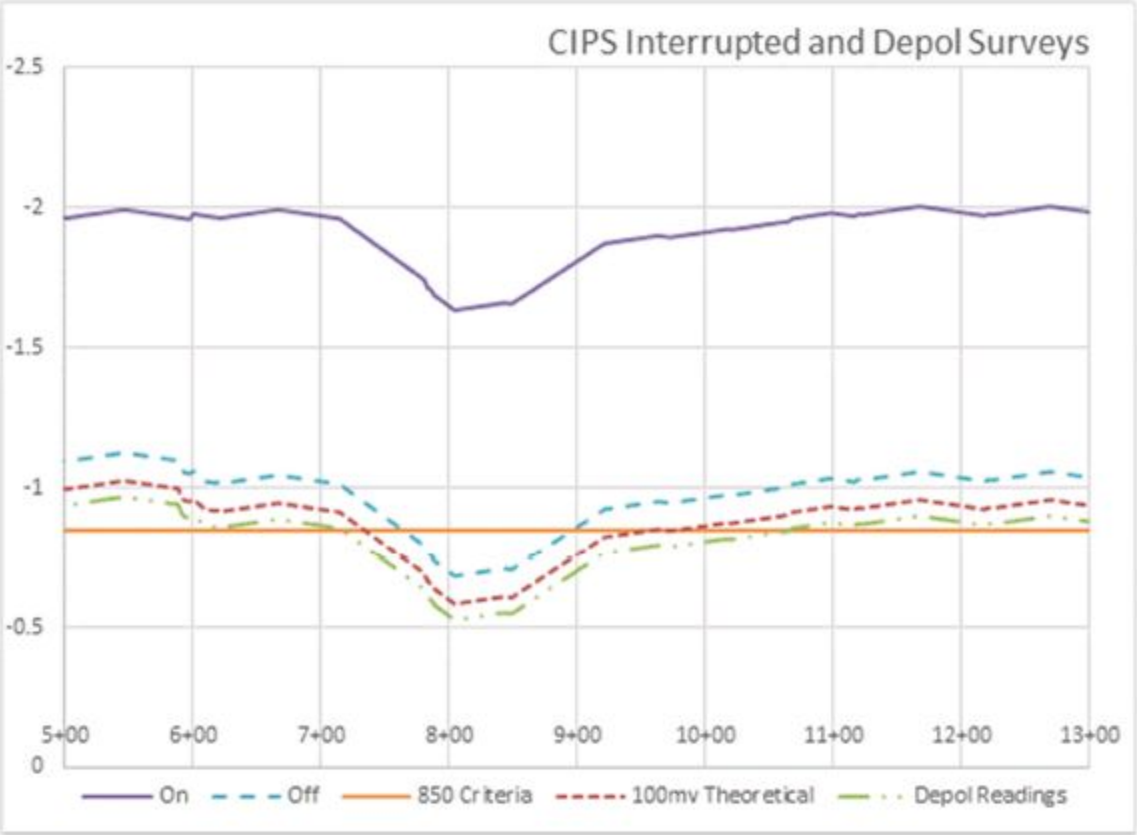
Limitations

- Time required for full depolarization (days to weeks)
  - Usually don't need to wait for full polarization
- Economics of initial measurements
- Should not be used in areas subject to stray currents
  - Generally not possible to interrupt the sources of stray current to accurately measure depolorization
- Should not be used on structures that contain dissimilar metals
  - 100 mV may not be enough to protect active metal
- Should not be used on structures where SCC is suspected
  - Application of 100 mV criterion may put structure in potential range for cracking

Illustration of 100mV Polarization Compliance



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Structure-to-Electrolyte Potential of -850 mV Criteria

- Direct Measurement of the Polarized Potential
- Current Applied Potential
  - Current-Applied Measurement Requires Consideration of the Significance of the Voltage Drops in the Earth and Metallic Paths

Polarized Potential of -850 mV Criterion

- A negative polarized potential of at least 850 mV relative to a saturated copper/copper sulfate reference electrode

- The polarized is the potential across the structure/electrolyte interface
  - Sum of the Corrosion Potential and the Cathodic Polarization

Polarized Potential

- Measured directly following interruption of ALL current sources and is often referred to as the "off" or "instant off" potential
- Minimizes or eliminates IR voltage drop errors

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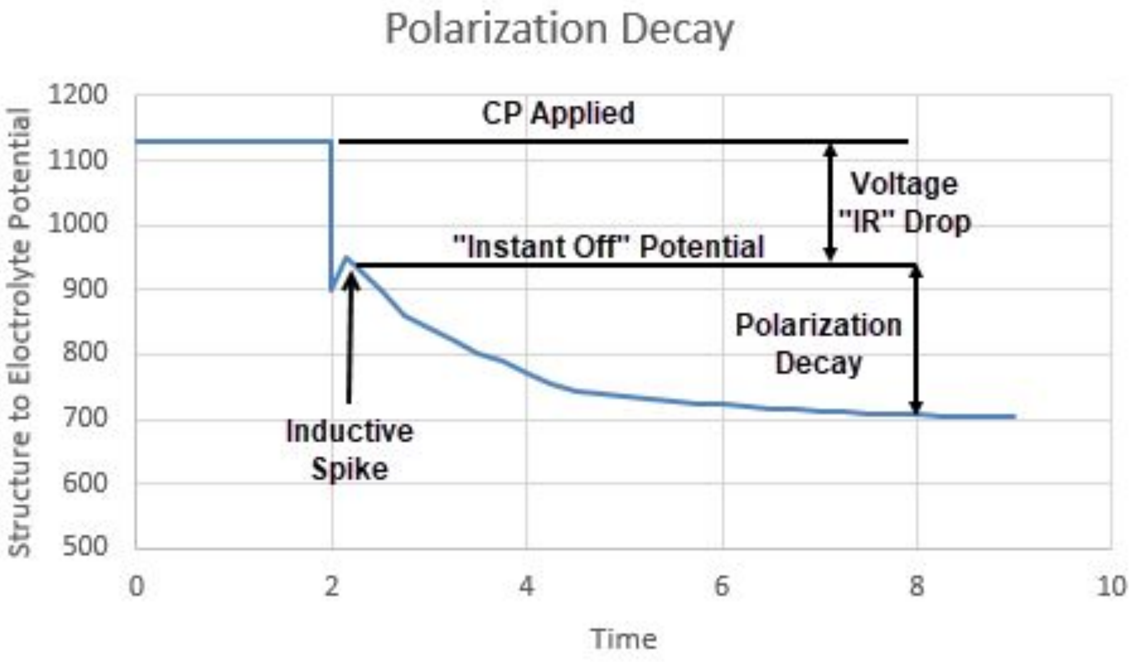
Polarized Potential



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Application

- Interrupting the DC current sources removes the IR drop errors in the measurement circuit
- The Cathodic Polarization at the structure -to-electrolyte interface is the only part of the “ON” reading that contributes to a reduction in the rate of corrosion of the structure
- Most commonly applied to coated structures where the sources of DC current can be readily interrupted

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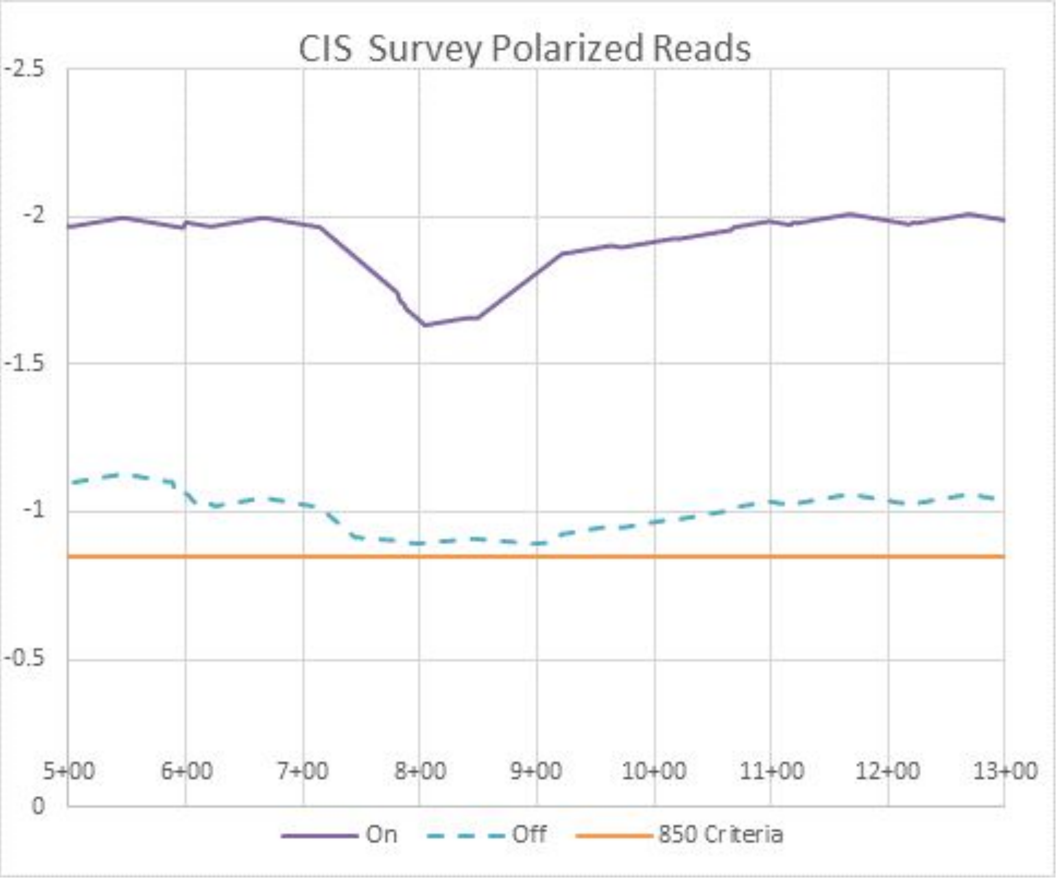
Limitations

- All sources of DC current must be interrupted
  - Interruption must be synchronized
  - No direct connect DC sources
- Reference electrode placement
- Costly to protect poorly coated or bare structures
- Potential variation from point to point
  - Potentials less negative than -850 mV CSE can exist between the measurement points
  - Close Interval Surveys can detect this issue

Limitations

- Bacteria or hot pipe.
  - Current Required can increase by a factor of two for every 10 degrees C increase in temperature.
  - A potential of -0.950 mV may be used.
- General consensus is to avoid polarized potentials more negative than -1.200 V CSE
  - Overprotection can result in coating damage and may promote hydrogen damage in susceptible steels
- Seasonal Variations
- Accurately Measuring Potentials
  - Tellurics, shielding, etc
- Dynamic Stray Current (DC Transit Systems, Mining Activity)

Illustration -850mV Criterion w/Polarized Potentials



- Figure 4-4

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-850 mV With CP Applied Criterion

- "A negative (cathodic) potential of at least 850 mV Cu-CuSO4 with the cathodic protection applied”
- Potential measured with respect to a saturated copper/copper sulfate reference electrode contacting the electrolyte

Voltage Drops

- Voltage drops other than those across the structure-to-electrolyte boundary must be <u>considered</u> for valid interpretation of this voltage measurement

- Normally due to current flow through the electrolyte and are called IR voltage drops

Voltage Drop in Measurement Circuit

- Resistances make up Voltage Drops
  - Negative Measuring Lead
  - Contact Negative Lead to Reference Cell
  - Reference Cell
  - Contact Reference
  - Electrolyte
  - Polarization Film
  - Structure
  - Structure Test Lead
  - Contact Structure Lead to Positive Measuring Lead
  - Positive Test Lead
  - Internal Meter Resistance

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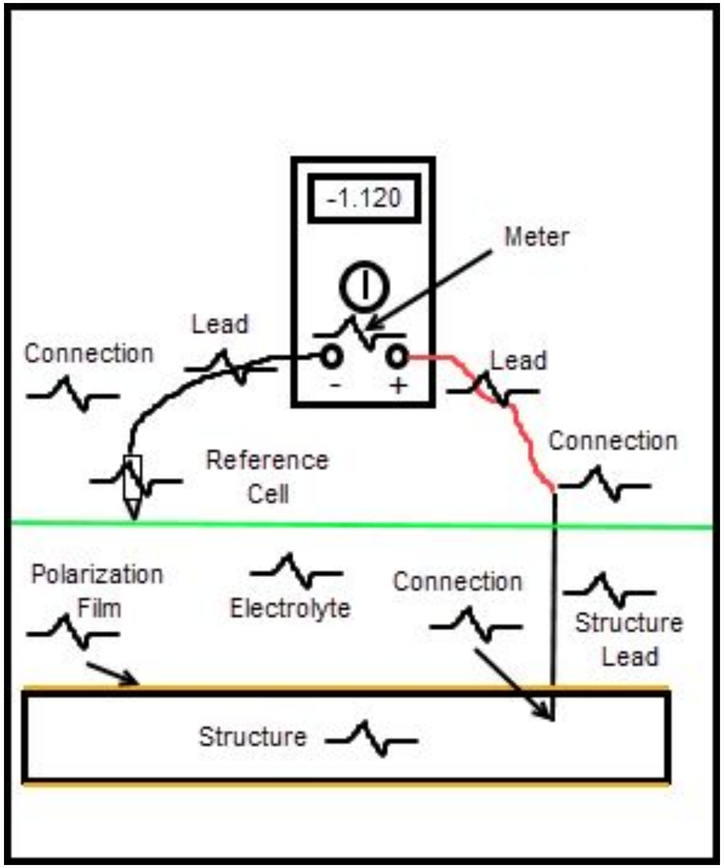
Illustration Voltage Drops



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Consideration

- “Consideration is understood to mean application of sound engineering practice in determining the significance of voltage drops by methods such as:
  - Measuring or calculating the voltage drop(s),
  - Reviewing the historical performance of the cathodic protection system
  - Evaluating the physical and electrical characteristics of the pipe and its environment; and
  - Determining whether or not there is physical evidence of corrosion."

IR Voltage Drops

- More prevalent in the vicinity of an anode bed or in areas where stray currents are present and generally increase with increasing soil resistivity
- Bare or very poorly-coated structures – placement of reference electrode
- Coated structures - interrupt ALL current

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Application

- Most widely used for buried or submerged steel or cast iron
- Voltage Drops are more prevalent in the vicinity of an anode bed or in areas of stray currents
- Voltage Drops generally increase with increasing soil resistivity
- Place reference electrode directly above and as close as possible to structure being tested
- For the Majority of coated structures, most of the voltage drop is across the coating

History

- Adopted based on the observation that the most negative native potential observed for coated underground steel structures was about -800 mV Cu-CuSO4. A potential of -850 mV was adopted to provide a 50 mV margin of protection.

- The effectiveness of the criterion has been demonstrated over many years of application.

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Limitations

- Reference electrode placement
- Costly to protect poorly coated or bare structures
- Potential variation from point to point
  - Potentials less negative than -850 mV CSE can exist between the measurement points
  - Close Interval Surveys can detect this issue
- Bacteria or hot pipe.
  - Current Required can increase by a factor of two for every 10 degrees C increase in temperature.
  - A potential of -0.950 mV may be used.

Limitations

- General consensus is to avoid polarized potentials more negative than -1.200 V CSE
  - Overprotection can result in coating damage and may promote hydrogen damage in susceptible steels
- Seasonal Variations
- Accurately Measuring Potentials
  - Tellurics, shielding, etc
- Dynamic Stray Current (DC Transit Systems, Mining Activity)

Break

Take a 10 Minute Break

Cathodic Protection (CP) Coupons

- CP coupon is intended to represent a structure at coating holiday
- Attached to structure through a test station so it can receive CP current
- Are used to help determine the level of CP on a buried structure

Cathodic Protection (CP) Coupons

- Test that can be made with CP coupons
  - Measure coupon to electrolyte with the coupon connected to structure
  - Measuring the coupon-to-electrolyte potential after disconnecting the coupon from the structure (coupon instant disconnect potential)
  - Measuring the current flow between the coupon and the structure

Cathodic Protection (CP) Coupons

- The coupon-to-electrolyte potential is typically measured with the reference electrode in close proximity to the coupon.
  - Permanently installed reference electrode near the coupon
  - Placing a portable reference electrode in a soil access tube

Cathodic Protection (CP) Coupons

- Measurements made with coupons can help determine if a criterion has been met:
  - Since the coupon to electrolyte potential is measured with the reference electrode in close proximity to the coupon, the voltage drop is minimized for a current applied potential.
  - Measuring the coupon to electrolyte potential after disconnecting the coupon from the structure is a way of interrupting all sources of cathodic protection current in order to obtain a direct measurement of the polarized potential.
  - Measuring the coupon to electrolyte potential after disconnecting the coupon from the structure is a way of interrupting all sources of cathodic protection current in order to obtain an "off" reading to be used in determining the level of polarization.

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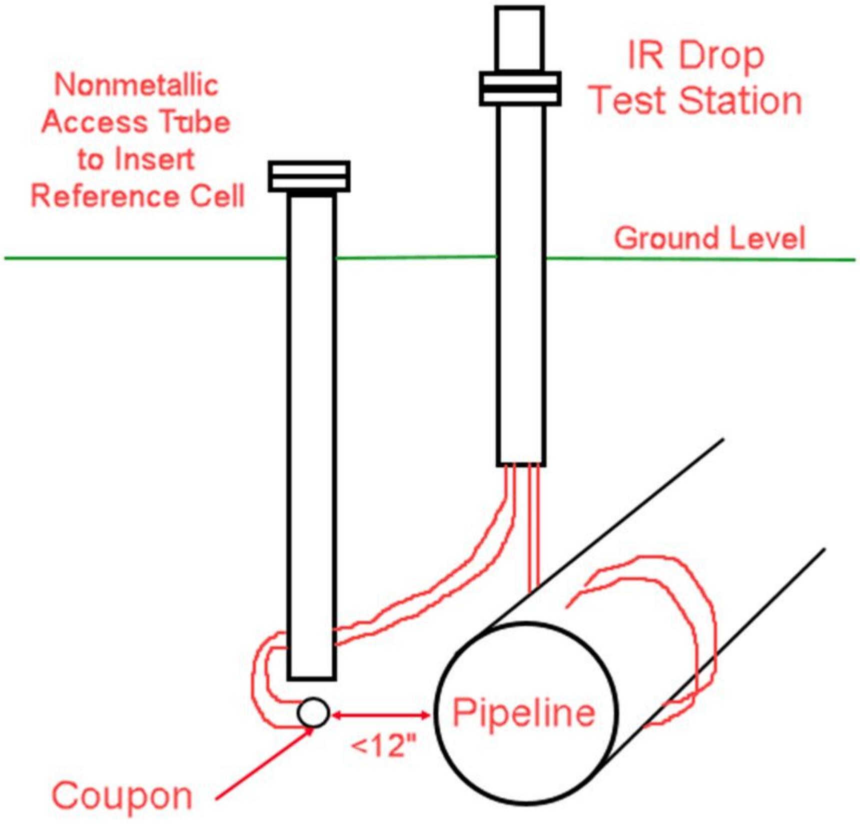
Cathodic Protection (CP) Coupons

- Situations where using a cathodic protection coupon could be used include:
  - Current interruption on multiple rectifiers affecting the structure that cannot be synchronized
  - Foreign CP systems that are affecting the structure being tested cannot be interrupted
  - The presence of directly connected sacrificial anodes

Example of IR Coupon Installation



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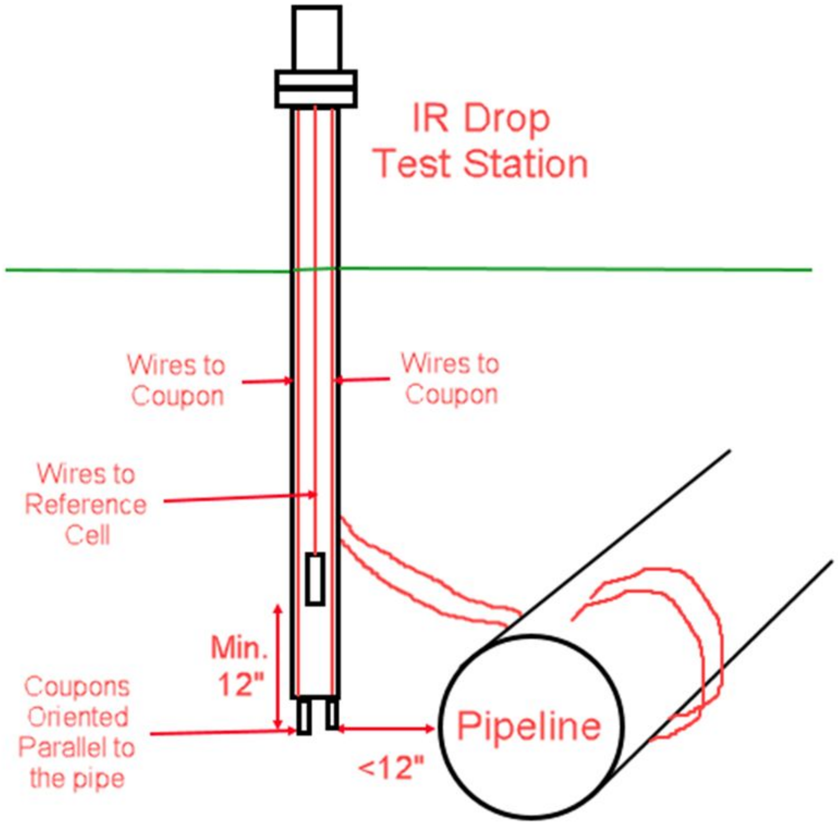
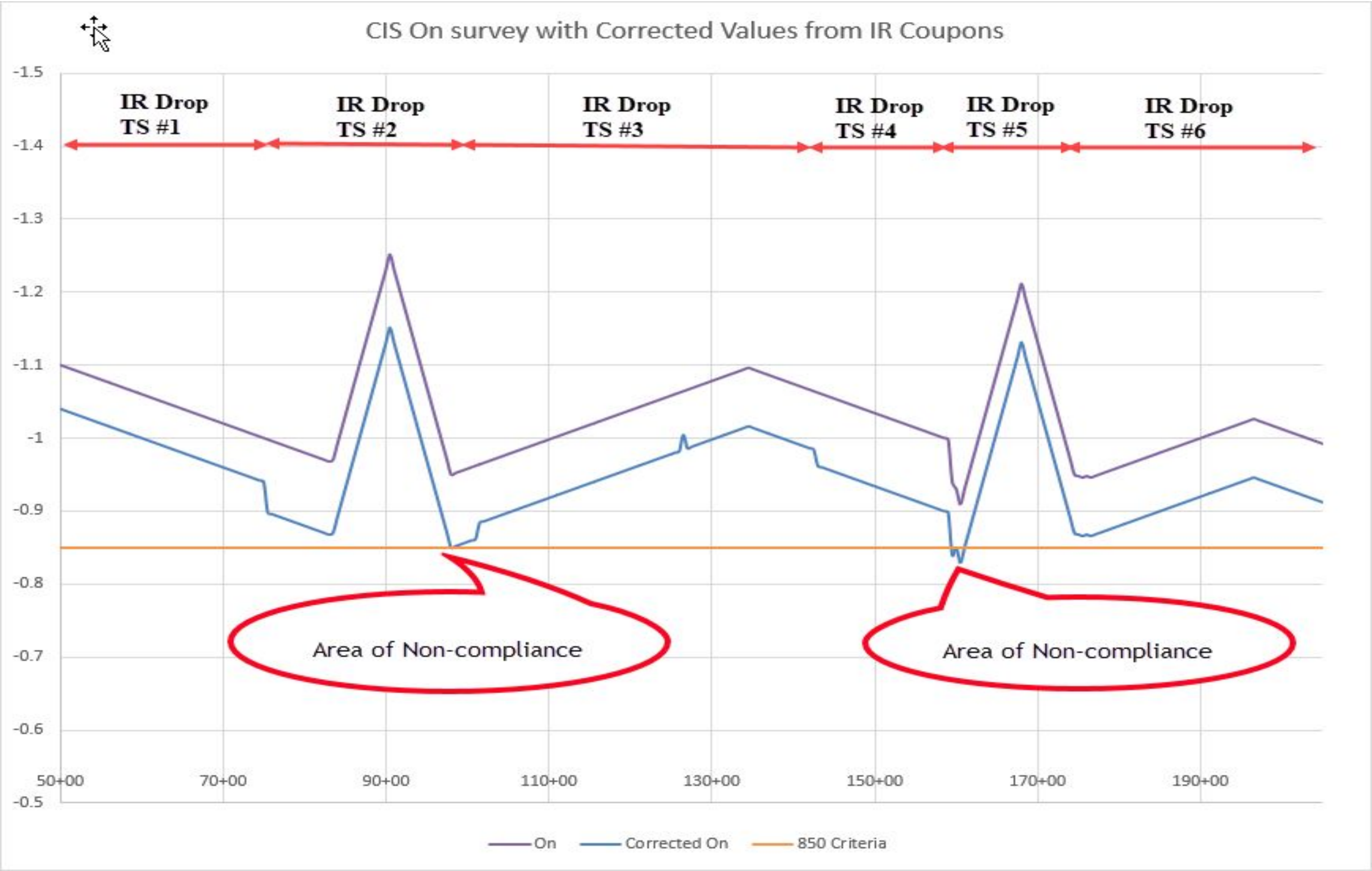
Example of IR Coupon Installation





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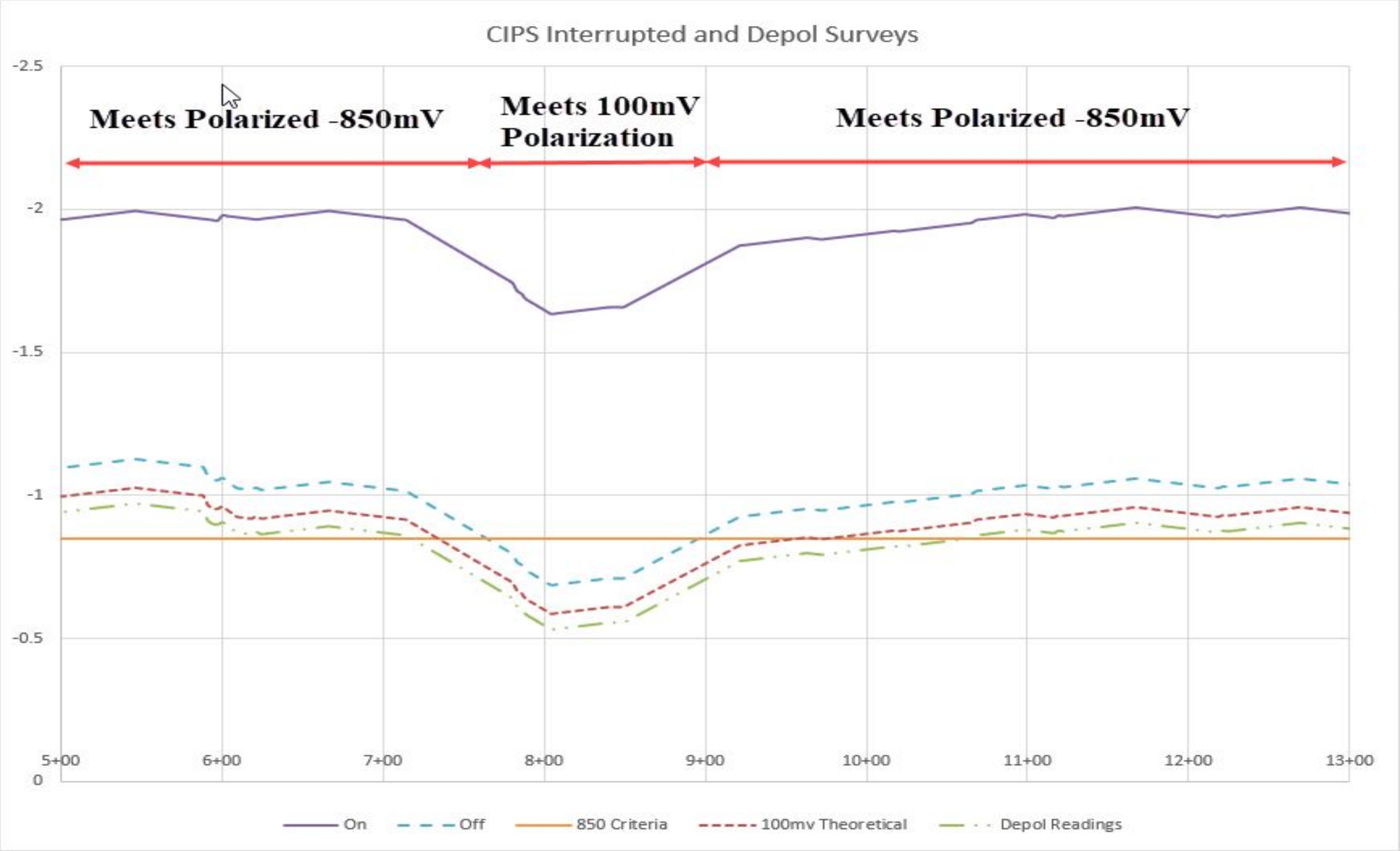
Using Multiple Criteria

- Multiple criteria to prove the compliance of a facility.
- Using the -850 mV criterion in conjunction with the 100 mV of Polarization Criterion
- With varying environmental or geological factors, meeting one criterion on complete structure may overdrive a certain section of the structure

Example Using Multiple Criteria



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Special Conditions for Steel or Cast Iron

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Other Criteria

- SP0169-2013 states in 6.2.1.1 that:
  - “Criteria that have been documented through empirical evidence to indicate corrosion control effectiveness on specific pipeline systems may be used on those piping systems or others with the same characteristics”.
- Examples include:
  - Net Protective Current
  - 300 mV Potential Shift
  - E-log-I Curve

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Net Protective Current Criterion

- "On bare or ineffectively coated pipelines where long-line corrosion activity is of primary concern, the measurement of a net protective current at predetermined current discharge points from the electrolyte to the pipe surface, as measured by an earth current technique, may be sufficient" for cathodic protection to be achieved.
  - SP0169-2007 – 6.2.2.2.1

Net Protective Current Criterion

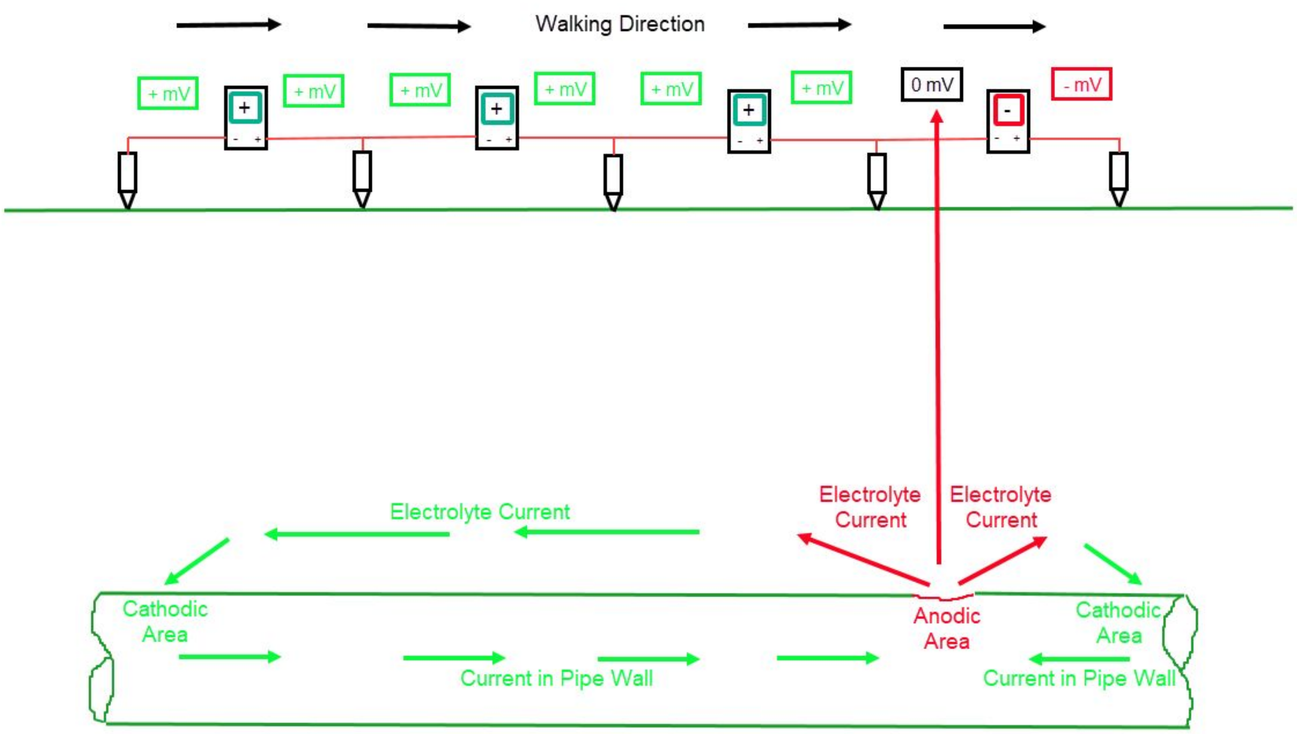
- Based upon the concept that, if the net current at any point on a structure is flowing from the electrolyte to the structure, there cannot be any corrosion current discharging from that point on the structure.

- However, if the polarized potential is more positive than the equilibrium potential, corrosion can occur.

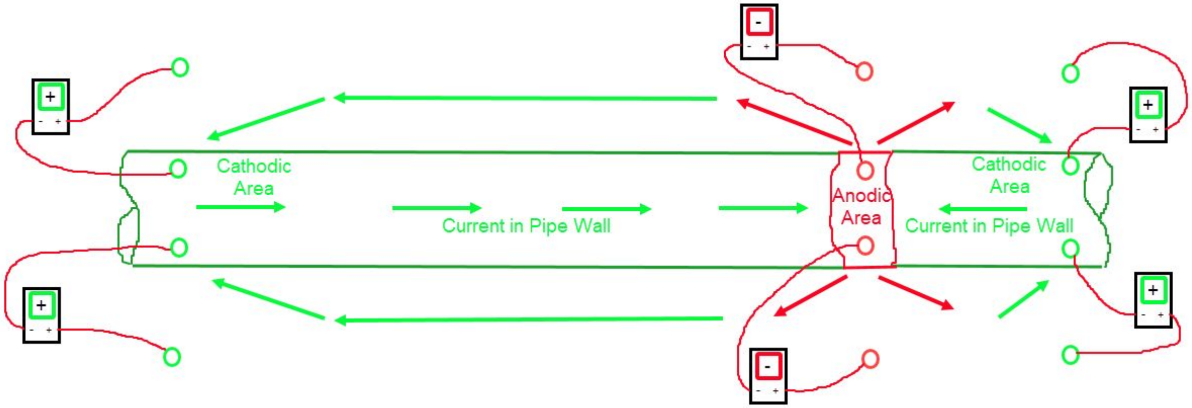
Field Application

- Depolarize structure
- Perform CIPS or cell to cell survey to locate anodic discharge points
- Energize CP system
- Use side drain method at anodic locations

Net Protective Current



Side Drain



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Application

- Normally used on poorly-coated or uncoated structures where the primary concern is long-line corrosion activity
- Only used in situations where other criterion cannot be easily or economically met

Limitations

- Used as a last resort criterion
- Stray current areas or common pipeline corridors
- High resistivity soils
- Deeply buried pipe
- Separation distance between cells is small
- Requires close measurements in anodic location typically every 2 to 20 feet

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300 mV Potential Shift Criterion

- "A negative (cathodic) voltage shift of at least 300 mV as measured between the structure surface and a saturated copper-copper sulfate half cell contacting the electrolyte. Determination of this voltage shift is to be made with the protective current applied."
- "This criterion of voltage shifts applies to structures not in contact with dissimilar metals."

300 mV Potential Shift Criterion

- Similar to the 100 mV Potential Shift Criterion
  - Native Potential
  - Energize CP system and monitor “On” potential
  - Measure “On” Potential
  - "The Corrosion Engineer shall consider voltage (IR) drops other than those across the structure electrolyte boundary for valid interpretation of the voltage measurements.“
- Cannot use Polarization Decay to satisfy this criterion

Application

- Mainly been used for mitigation of moderate rates of uniform corrosion of bare steel structures.
- Used for entire structure or hot spot protection.
- More applicable to impressed current CP systems.
- Most successful application of this criterion has been on steel reinforced concrete structures.

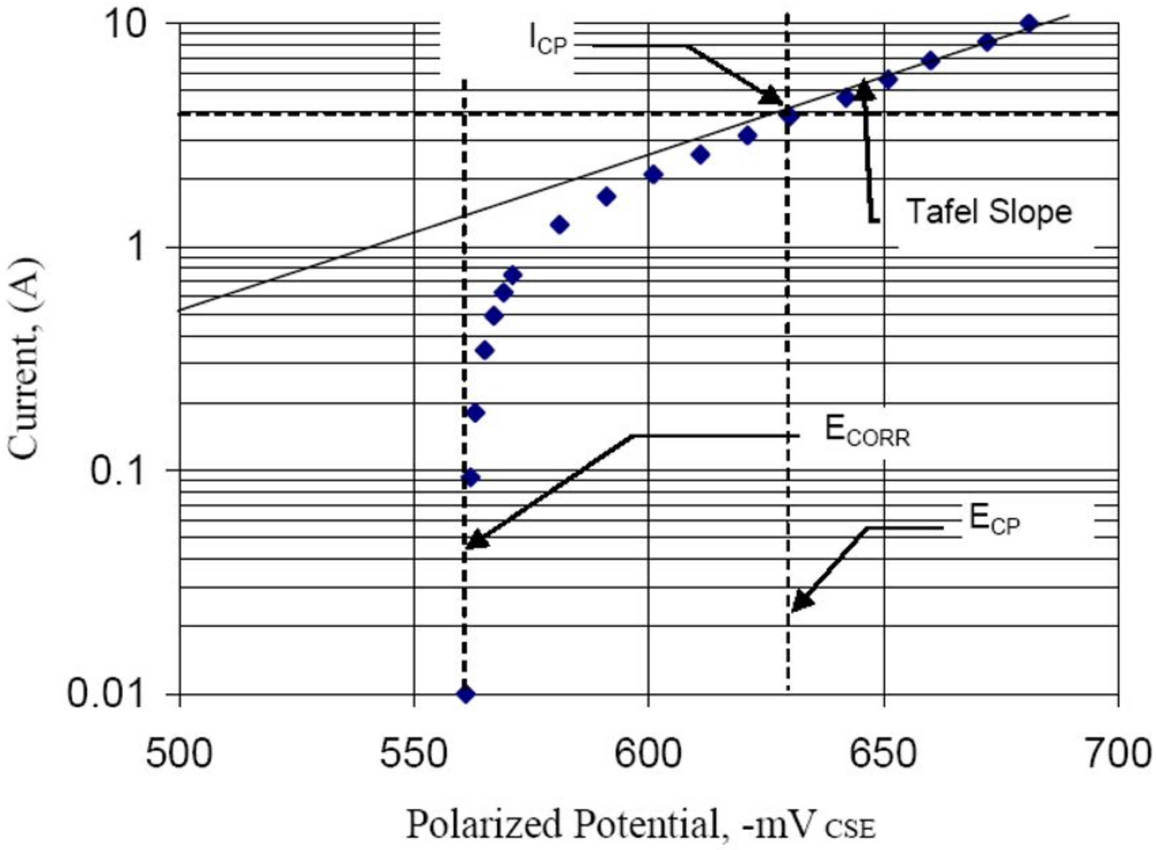
Limitations

- Time required for full depolarization
- Economics of initial measurements
- Should not be used in areas subject to stray currents
- Should not be used on structures that contain dissimilar metals
- Should not be used on structures were SCC is suspected
- Removed from primary list of criteria in SP0169-1992.

E-Log I Curve Criterion

- Adequate protection is achieved with
  - "A voltage at least as negative (cathodic) as that originally established at the beginning of the Tafel segment of the E-Log I curve. This voltage shall be measured between the structure surface and a saturated copper-copper sulfate half cell contacting the electrolyte."
- Based upon incorrect interpretation

E Log I Curve



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Applications

- Rarely used for evaluating existing cathodic protection systems.
- Most commonly used to determine the minimum current required for protection.
- Typically use “Off” potentials to establish E-Log I curve.
- Monitor by checking current output and potential with reference cell placed at same location as original test.
- Used on river crossings, well casings, piping networks in concentrated areas.

Limitations

- Generally limited to structures where conventional means of assessment are difficult
- Stray current areas
- Reference electrode must be placed in the same location when measuring potential.
- Repeat tests may not yield same results as original curve.

Criterion for Aluminum Piping

- "The following criterion shall apply; a minimum of 100 mV of cathodic polarization between the structure and a stable reference electrode contacting the electrolyte. The formation or decay of this polarization can be used in this criterion."

- Same wording as 100 mV Potential Shift, however there are two precautions
  - Avoid excessive voltage – -1,200 mV Cu-$CuSO_4$
  - Avoid high alkaline conditions

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Criterion for Aluminum Piping

- Amphoteric Metal - suffer corrosion in acidic or alkaline environments
  - The protective passive films on aluminum break down in high pH electrolytes, leading to significant increases in the corrosion rate, even at relatively negative potentials.

Limitations

- Time required for full depolarization
- Economics of initial measurements
- Should not be used in areas subject to stray currents
- Should not be used on structures that contain dissimilar metals

Criterion for Copper Piping

- A minimum of 100 mV of cathodic polarization
- The formation or decay of this polarization can be used in this criterion

Limitations

- Time required for full depolarization
- Economics of initial measurements
- Should not be used in areas subject to stray currents
- Should not be used on structures that contain dissimilar metals

Criterion for Dissimilar Metal Piping

- "A negative voltage between all pipe surfaces and a stable reference electrode contacting the electrolyte equal to that required for the protection of the most anodic metal should be maintained."

- "Amphoteric materials that could be damaged by high alkalinity created by cathodic protection should be electrically isolated and separately protected."
  - Amphoteric metals include aluminum, titanium and zirconium.

Limitations

- Criterion only applies where carbon steel or cast iron is coupled to a more noble metal such as copper.
- Isolation or cathodic protection can be expensive.

Questions?