

Criteria for Cathodic Protection

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Appalachian Underground Corrosion Short Course

Overview

- Introduction
- Common Criteria for Steel and Cast Iron Piping
 - -850 mV with Cathodic Protection Applied
 - Polarized Potential of -850 mV Cu-CuSO₄
 - 100 mV Polarization
 - Net Protective Current Criterion
- Other Criteria for Steel and Cast Iron
 - 300 mV Potential Shift
 - E-Log-I Curve Criterion
- Criterion for Aluminum Piping
- Criterion for Copper Piping
- Criterion for Dissimilar Metal Piping

Introduction

- Grammar Basics
 - Criterion
 - Singular
 - “This is the criterion...”
 - Criteria
 - Plural
 - “These are the criteria...”

Introduction

- **Relevant Documentation**
 - 49 CFR 190 & 192 Appendix D - Liquid & Gas Pipelines
 - NACE SP0169-2015, “Control of External Corrosion of Underground or Submerged Metallic Piping Systems”
 - NACE TM0497 “Measurement Techniques Related to Criteria for Cathodic Protection on Underground or Submerged Metallic Piping Systems”

NACE SP0169

- “Lists the 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 that have been successfully applied on existing piping systems can continue to be used on those piping systems. Any other criteria used must achieve corrosion control comparable to that attained with the criteria herein”
 - We will discuss some of these “other” criteria later in this presentation.

Criteria for Steel and Cast Iron Piping

- There are three primary criteria
 - -850 mV (Cu-CuSO₄) with Cathodic Protection Applied
 - A Polarized Potential of -850 mV (Cu-CuSO₄)
 - 100 mV of Polarization
- Also discussed in SP0169
 - Net Protective Current Criterion



**Criterion 1:
-850 mV with Cathodic Protection Applied**

-850 mV with CP Applied

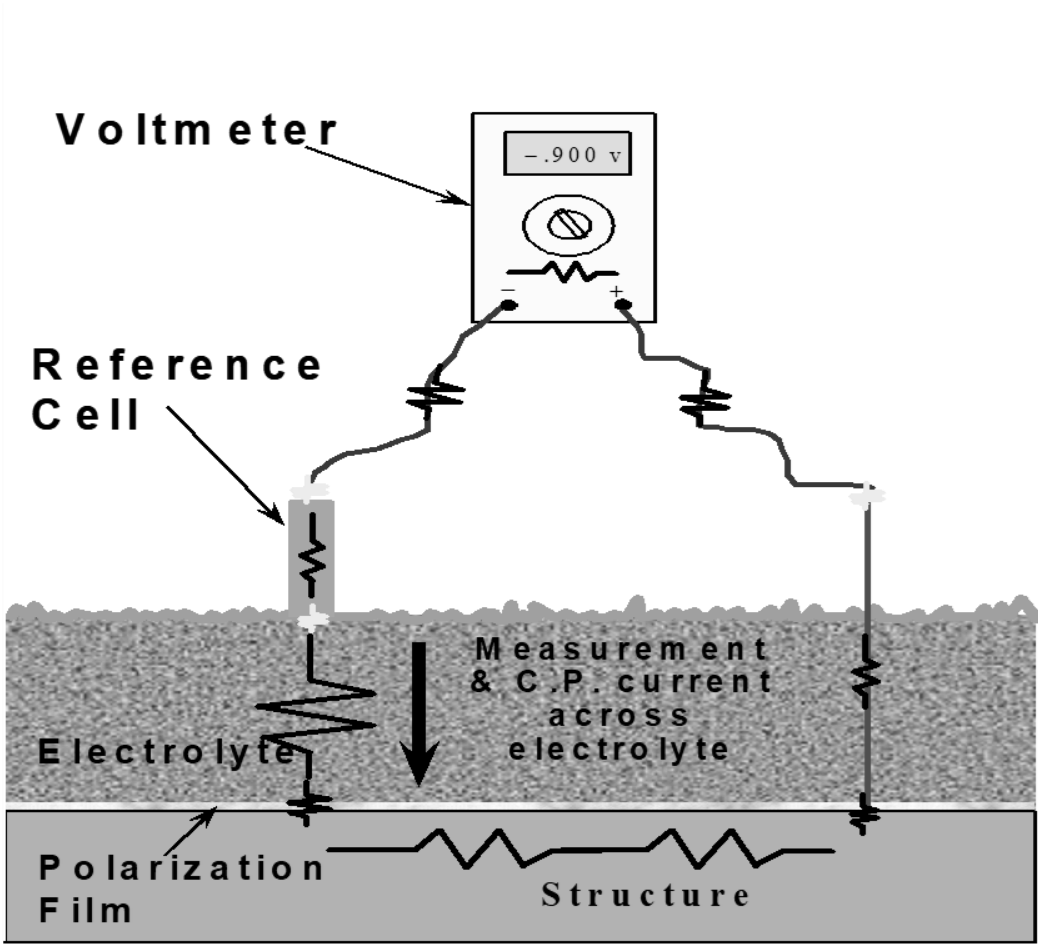
- Full Criterion states that adequate protection is achieved with
 - “A negative (cathodic) potential of at least 850 mV with CP applied.
 - This potential is measured with respect to a saturated copper/copper sulfate reference electrode contacting the electrolyte.
 - Voltage drops other than those across the structure-to-electrolyte boundary must be considered for valid interruption of this voltage measurement”
 - This is usually due to current flow through the electrolyte and is commonly referred to as “IR Drop”

-850 mV with CP Applied

- “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 or 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”

Resistances

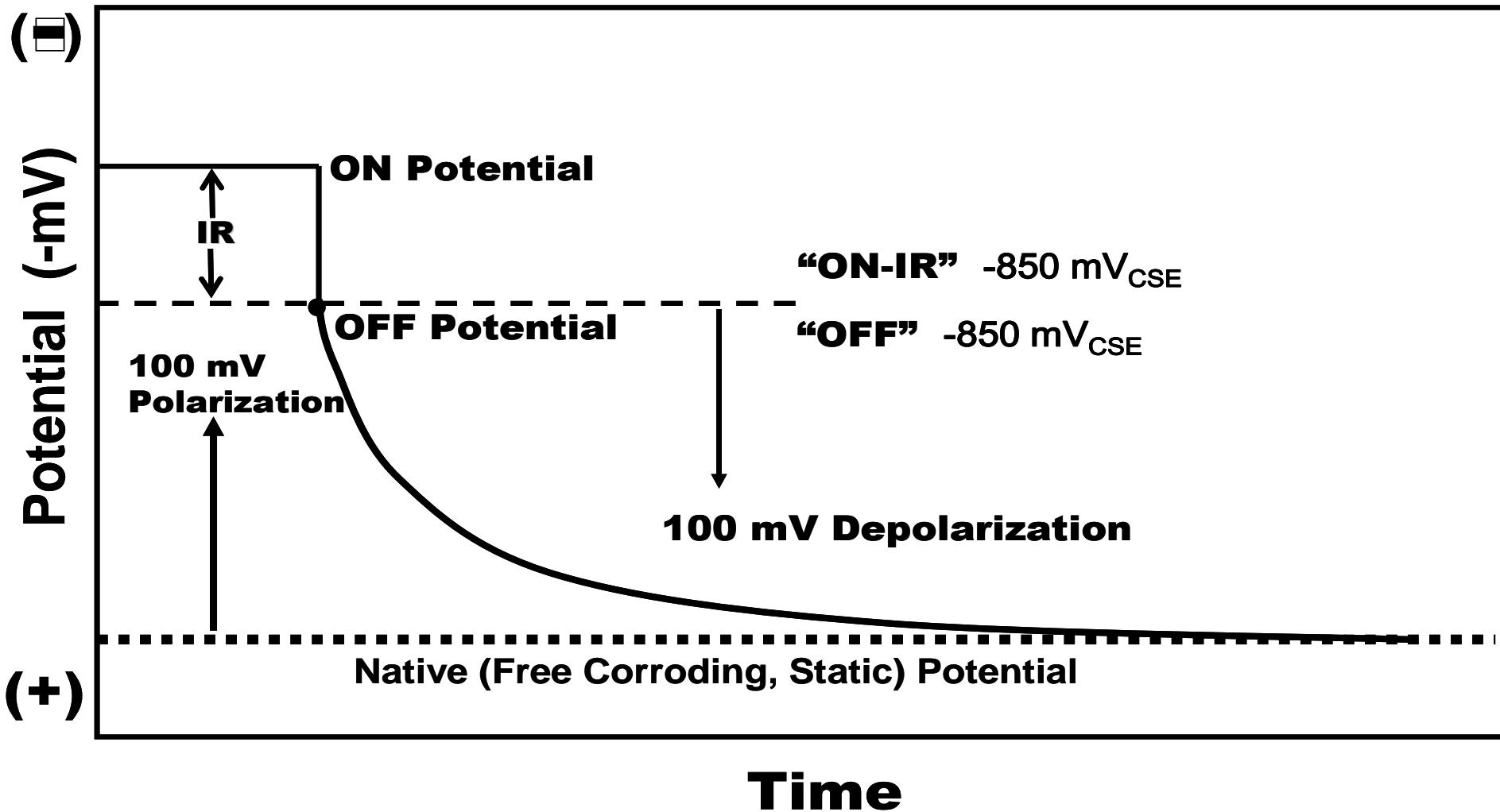
- Measuring Lead (+)
- Contact Lead (+)/Ref. Cell
- Reference Cell
- Contact Reference Cell to Electrolyte
- Electrolyte
- Polarization
- Structure
- Contact Test Lead/Structure
- Test Lead
- Contact Test/Measuring Lead
- Measuring Lead (-)
- Internal Meter



Voltage Drops in a Measuring Circuit

Coatings in Conjunction with CP

NACE International -04/2006



Structure-to-soil Potentials

Coatings in Conjunction with CP

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-850 mV with CP Applied

- Application

- Most widely used criterion for determining if buried or submerged piping is protected
 - If the potential difference between the structure and a saturated Cu-CuSO₄ reference cell contacting the soil directly above and as close to the structure as possible is equal to or more negative than -850 mV, the structure is protected

IR VOLTAGE DROPS MUST BE CONSIDERED!

IR Voltage Drops

- More prevalent in the vicinity of an anode bed or in areas where stray currents are present
- Generally increase with increasing soil resistivity

IR Voltage Drops

- To minimize IR Voltage Drops
 - For bare or very poorly coated structures
 - Place the reference electrode as close as possible to the structure for bare or very poorly coated structures
 - For coated structures
 - Interrupt all sources of DC current on the Cathodic Protection System
 - Including any sources of stray current!
 - Measure the instantaneous “Off Potential”
 - Need to verify long-line currents are negligible
- Difference between “On Potential” and “Off Potential” represents your voltage drop error in readings

History of -850 mV Criterion

- Adopted based on observation that the most negative native potential observed for coated underground steel structures was -800 mV Cu-CuSO₄
- Assumption made that macro-cell (long-line) corrosion would be mitigated if sufficient CP current was applied to make the potential more negative than the native potential
- -850 mV was adopted to provide a 50 mV margin of protection
- Effectiveness has been demonstrated over many years of application across the industry

Limitations of -850 mV On

- Requires potential readings to be taken with reference electrode contacting the soil directly above the structure
 - Some times the reference electrode cannot be placed on top of the structure
 - River crossings, road crossings, HDD's, etc.
- Not practical or economical for bare or very poorly coated structures
 - Requires large amount of CP current to meet the -850 mV criterion

Limitations of -850 mV On

- Potential variations can exist between locations where measurements are taken
 - Could have areas less negative than -850 mV between test points
 - Can be addressed through Close Interval Surveys
- In areas of bacteria or hotter pipe, may need to be more negative than -850 mV to be protected
 - For every 18°F of temperature increase, the CP current required doubles to meet the adjusted criteria of -950 mV

Limitations of -850 mV On

- Overprotection can occur, leading to hydrogen and coating damage
 - Need to keep polarized (instant off) potentials less negative than -1.05 to -1.1 V Cu-CuSO₄ to minimize damage.
- Seasonal Variations can influence potentials
 - Frozen ground has a higher resistivity than moist, warm ground
- Stray current that cannot be interrupted can impact the readings
 - Telluric currents, dynamic DC stray currents, etc.



Criterion 2:
Polarized Potential of -850 mV

Polarized Potential of -850 mV

- Adequate protection is achieved with
 - “A negative polarized potential of at least 850 mV relative to a saturated copper/copper sulfate reference electrode.”
- Polarized Potential
 - “The potential across the structure/electrolyte interface that is the sum of corrosion potential and the cathodic polarization”

Polarized Potential of -850 mV

- Polarized Potential
 - Measured directly following interruption of all current sources
 - “Instant Off Potential”

Instant Off Potential – Native Potential = Polarized Potential

- Polarized Potential is the amount of polarization that has occurred as a result of the cathodic protection

Polarized Potential of -850 mV

- Application

- Most commonly applied to coated structures where the sources of DC current can be readily interrupted
 - Example: FBE coated gas transmission pipeline in a rural area with an impressed current cathodic protection system applied

Polarized Potential of -850 mV

- Limitations

- Requires ALL sources of DC current to be interrupted
 - Must be performed simultaneously on all current sources
 - May require a large number of interrupters
 - Need to interrupt all rectifiers, sacrificial anodes and bonds
 - Can be an issue where direct connect anodes exist
- May require high levels of CP current
 - Can lead to overprotection



**Criterion 3:
100 mV Polarization**

100 mV Polarization

- Adequate protection is achieved with
 - “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”
- This criterion has the most sound fundamental basis

100 mV Polarization

- Criterion Basis

- 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.
- Corrosion rate decreases by a factor of 10 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.

Environmental vs. Cathodic Polarization

- **Environmental Polarization**

- Environmental changes that result in a shift in the free corrosion potential of the pipe in the negative direction

- Examples:

- Reduced O₂
- Increased pH

- **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.

Polarization

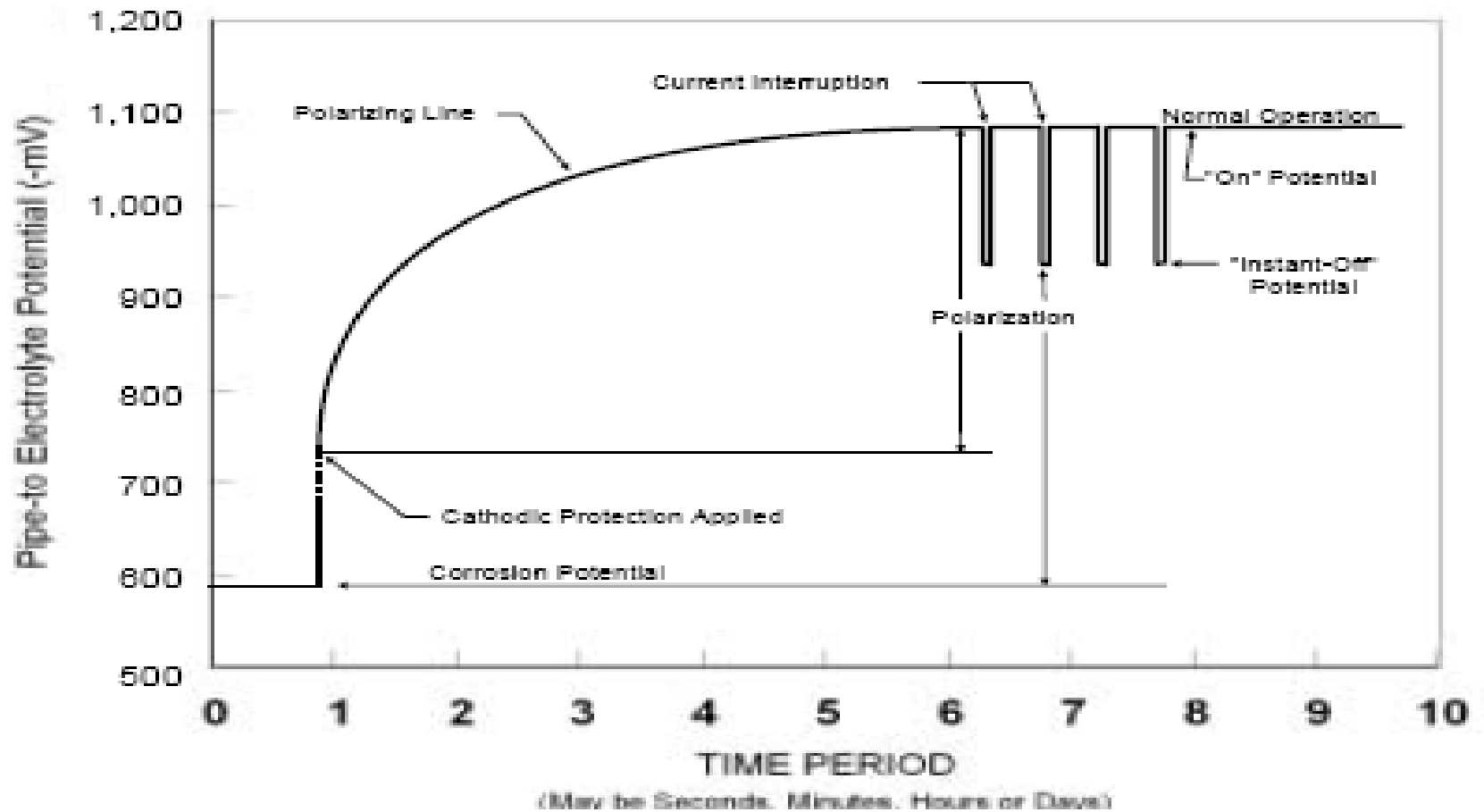
- The total potential shift from the native potential (excluding voltage drops in the soil) due to environmental polarization and cathodic polarization
- Can be measured using decay or formation of polarization

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 $\text{Off} - \text{Native} > 100 \text{ mV}$ 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.



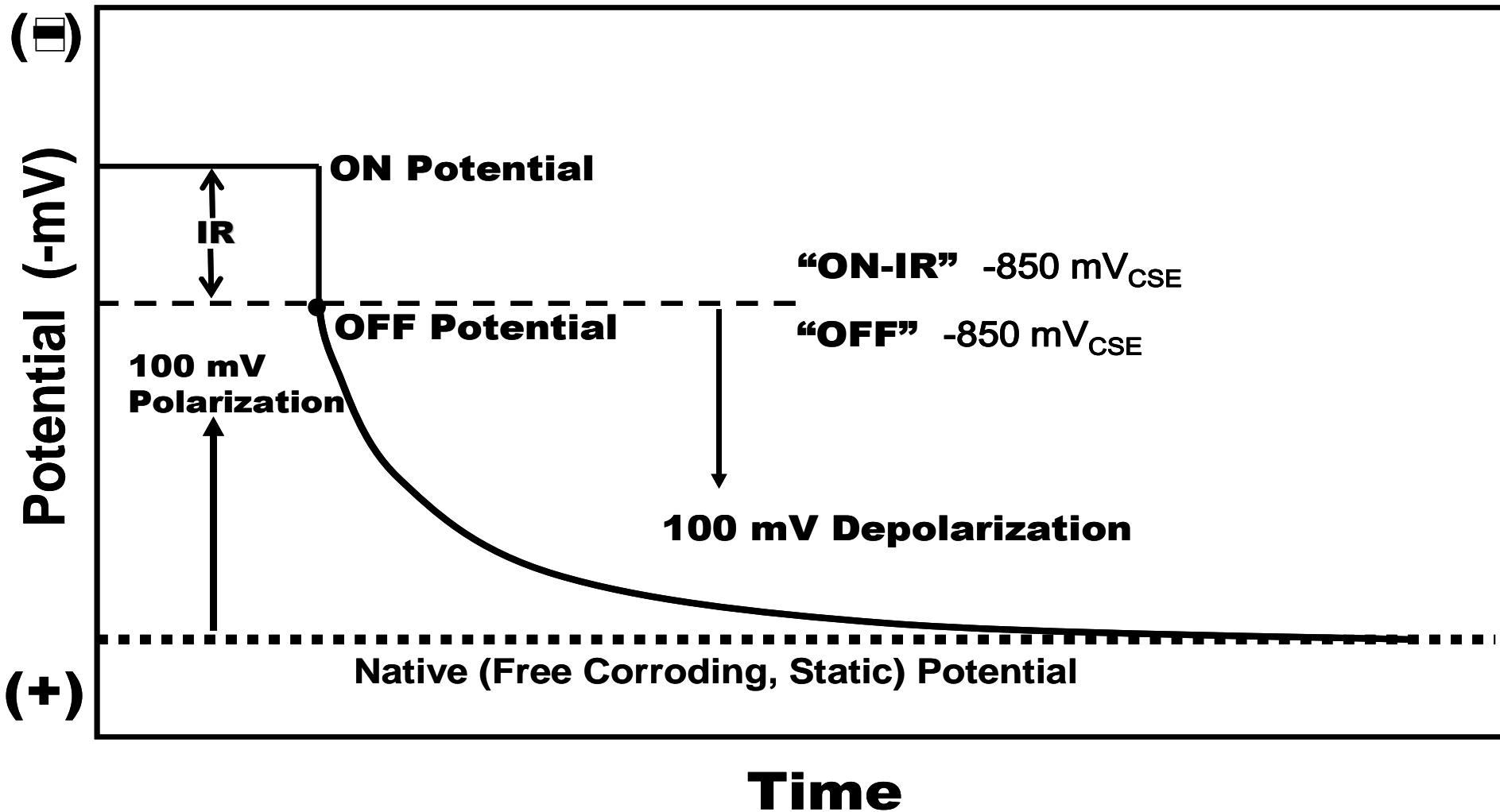
Polarization Formation

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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



Structure-to-soil Potentials

Coatings in Conjunction with CP

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100 mV Polarization

- Application

- Most commonly used on poorly coated or bare structures where it is difficult or costly to achieve either of the -850 mV criteria
- In many cases, this can be achieved when the off-potential is less negative than -850 mV Cu-CuSO₄
- Minimizes coating degradation and hydrogen embrittlement
- Can be used on metals other than steel where a specific potential requirement is not established

100 mV Polarization

- Limitations
 - Time required for full depolarization
 - Usually don't need to wait for full polarization
 - Economics of initial measurements and surveys
 - 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 where Stress Corrosion Cracking (SCC) is suspected



Break Time!!!



Cathodic Protection Coupons

Cathodic Protection Coupons

- Intended to represent a structure at coating holiday
- Attached to structure through a test station
 - Receives same CP current as the structure
- 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

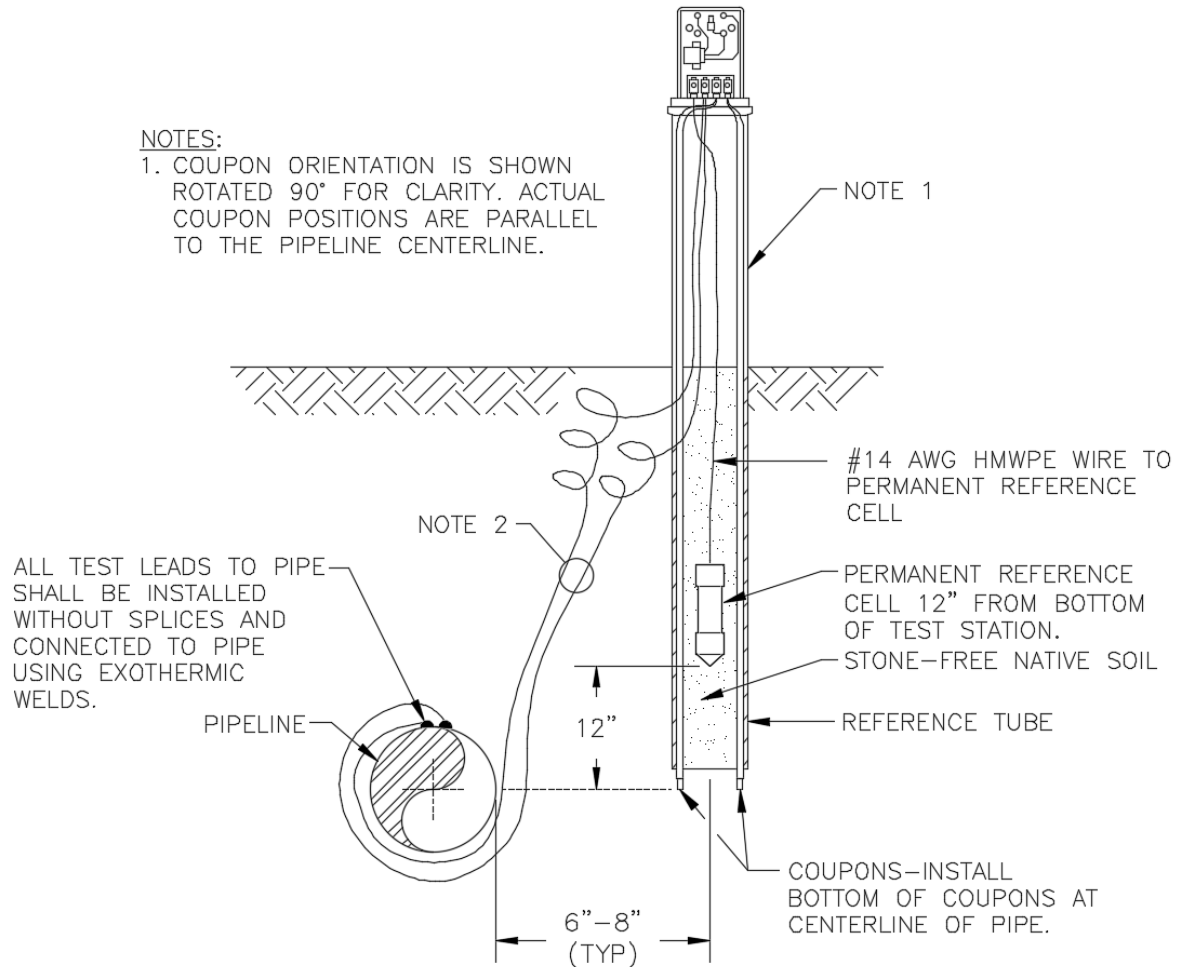
Cathodic Protection Coupons

- 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 Coupons

NOTES:

1. COUPON ORIENTATION IS SHOWN ROTATED 90° FOR CLARITY. ACTUAL COUPON POSITIONS ARE PARALLEL TO THE PIPELINE CENTERLINE.



Cathodic Protection 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 IR 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 maintain 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.

Cathodic Protection 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 cannot be interrupted
 - The presence of directly connected sacrificial anodes



Criterion “4”:
Net Protective Current

Net Protective Current Criterion

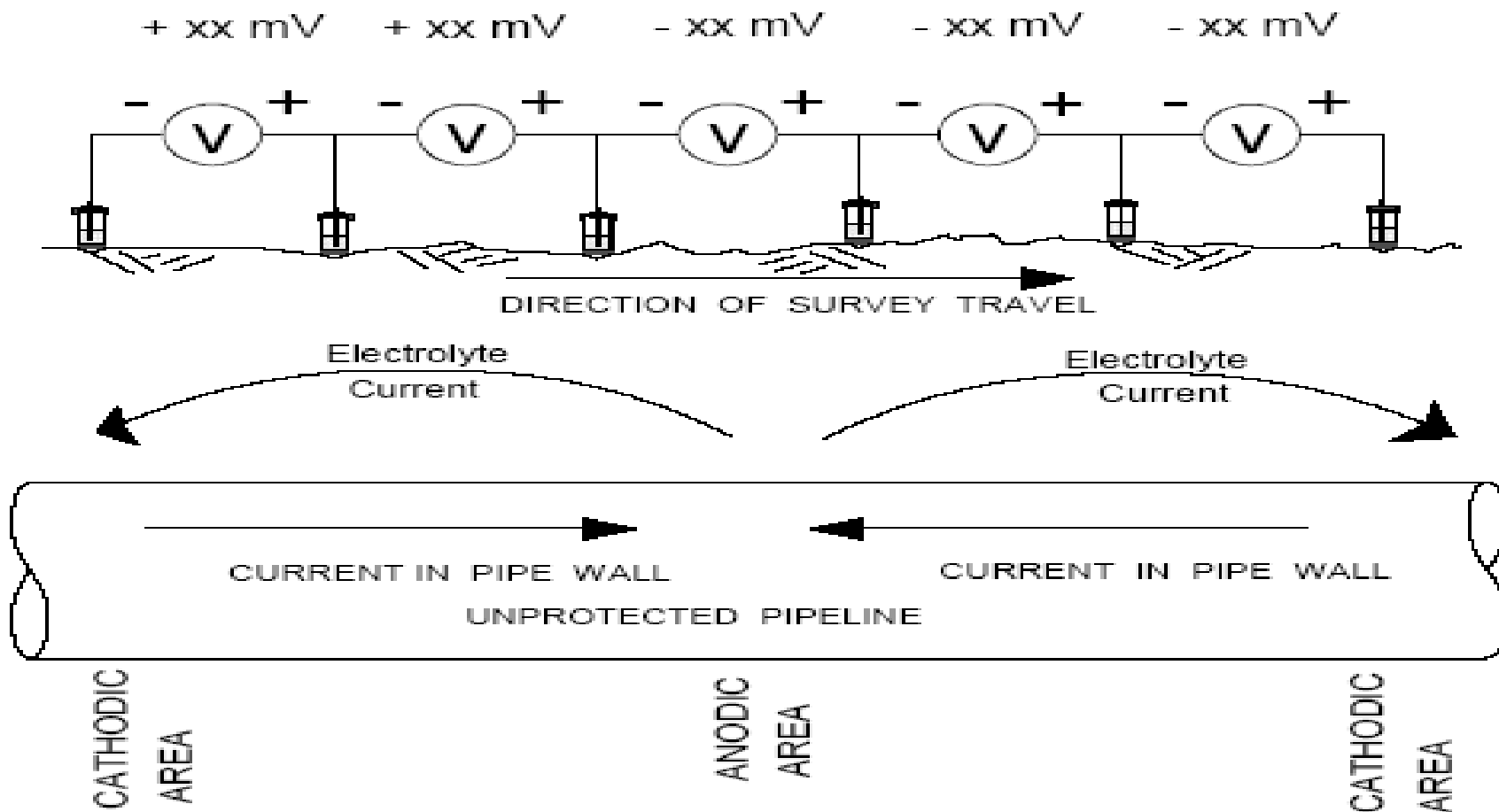
- “On bare or ineffectively coated pipelines where long-line corrosion activity is of primary concern, the measurement of a net protective current at predetermined current discharge points from the electrolyte to the pipe surface, as measured by an earth current technique, may be sufficient”

Net Protective Current Criterion

- Theory behind criterion
 - 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
- Electrochemical Kinetics Theory
 - Corrosion CAN occur at a point on a structure that is collecting net cathodic current from the electrolyte as long as the polarized potential is more positive than the equilibrium potential
- **HOWEVER**, the criterion can be effective since the collection of net cathodic current at any point on the structure produces beneficial cathodic and environmental polarization.

Net Protective Current Criterion

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



Bottle-to-Bottle Survey

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Net Positive Current Criterion

- 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



Other Criteria for Steel and Cast Iron

300 mV Potential Shift Criterion

- Adequate protection is achieved with
 - “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

300 mV Potential Shift

- Applications

- Mainly 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.

300 mV Potential Shift

- Limitations

- Time required for full polarization
- 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 where SCC is suspected

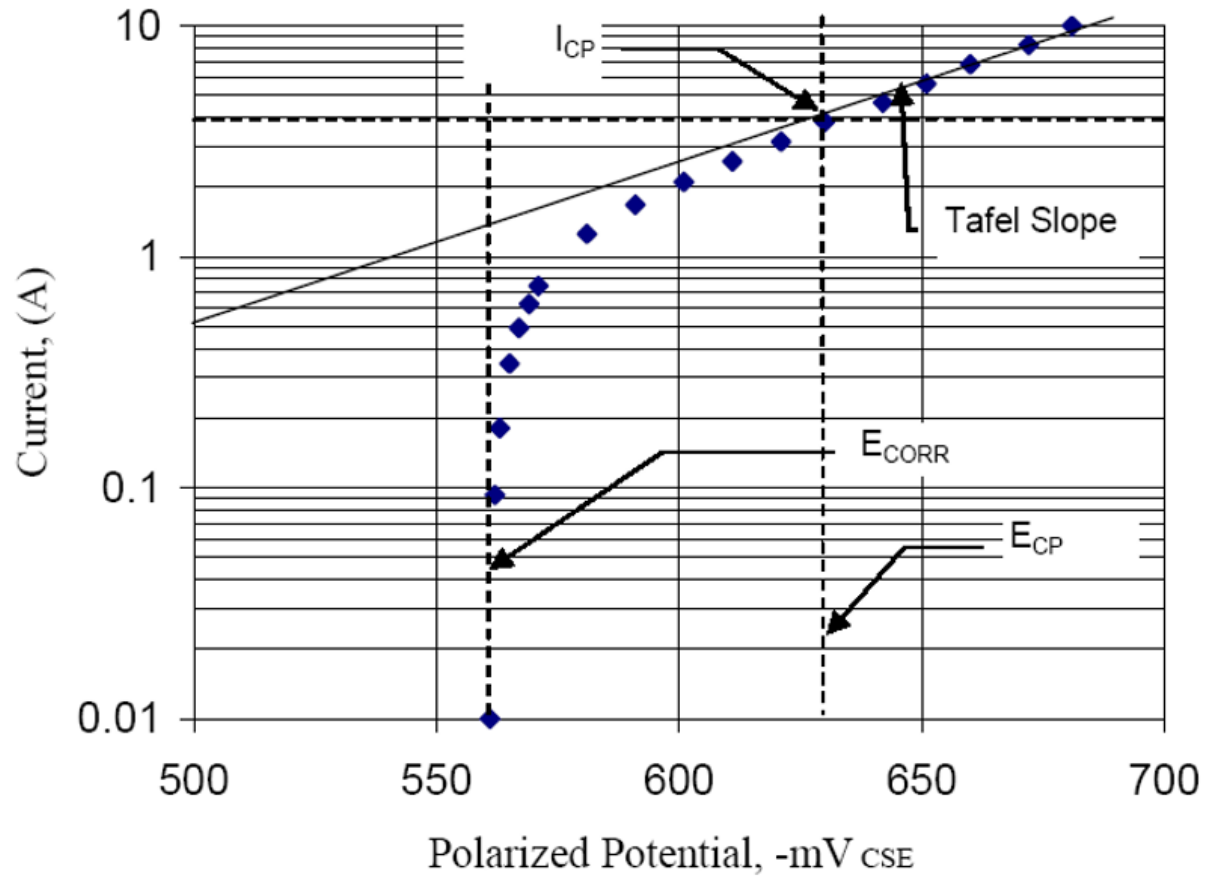


E-log-I Criterion

E-Log-I 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”

E-log-I Diagram



E-Log-I Criterion

- **Application**

- 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.

E-Log-I Criterion

- **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

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-CuSO₄
 - Avoid high alkaline conditions

Amphoteric Metal

- Suffer corrosion as a result of the buildup of alkali on the metal surface. 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

Criterion for Aluminum Piping

- **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
- Aluminum piping has to be isolated from other metals before CP is applied according to SP0169



Criterion for Copper Piping

Criterion for Copper 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."

Criterion for Copper Piping

- **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
- Desirable to eliminate such dissimilar metals couples before the application of cathodic protection



Criterion for Dissimilar Metal Piping

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.

Criterion for Dissimilar Metal Piping

- 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?