REX2024
PRCI Research Exchange

PRCI Project EC-08-11:
Pipeline Cathodic Protection Monitoring Using Real Time Current Measurement

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PRCI LEADING PIPELINE RESEARCH
Pipeline Research Council International

PRCI EC-08-11 Overview – Scope & Objectives

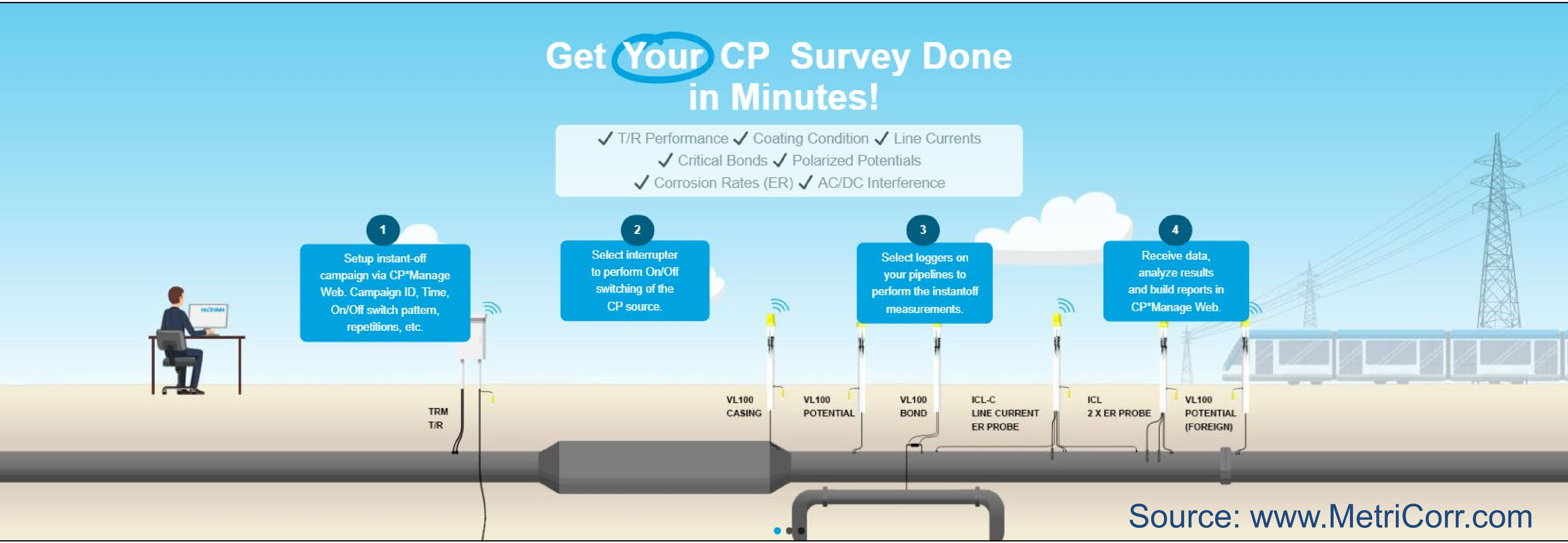
1) **Extensive field-based research to marry well-established manual pipe current measurements with high-resolution remote monitoring technology:**
   - What is the optimum (maximum) interval(s) for pipe current sensor remote monitoring units (RMUs)?
   - What are the pipe current monitoring requirements – Instrumentation? Data capture? Analytics?

2) **Ultimately:**
   - Practical guidance to industry on implementation of real-time pipe current monitoring
   - Improved pipeline corrosion protection surveillance and overall pipeline reliability/safety
   - Faster detection and resolution of corrosion control threats
   - Cost effective enhancement to overall *Integrated External Corrosion Management* (IECM) program
   - Reduction if not elimination of traditional periodic rectifier checks and annual test station surveys
   - Reduced O&M and regulatory compliance costs

3) **Deliverables:**
   - Research report
   - Guide manual
   - Excel-based life-cycle cost calculator and user's manual
   - Industry outreach to share research results

The "Pipeline of Things": 24/7/365 Real-Time Surveillance

- ✓ Can cost-effective remote monitoring reduce/replace periodic rectifier checks and annual CP test station surveys?
- ✓ Can it reduce or even replace close interval surveys?
- ✓ Will regulatory agencies such as PHMSA accept this alternative??



Source: www.MetriCorr.com

Research Report: Real-Time Pipe Current Monitoring

LEADING PIPELINE RESEARCH

Catalog No. R-229-203604-R01

Pipeline CP Monitoring Using Real Time Current Measurement

Project number EC-08-11

Contract PR229-203604

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Guide Manual for Real-Time Pipe Current Monitoring

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List of Figures and Tables

Life-Cycle Cost Calculator for Remote Monitoring Program

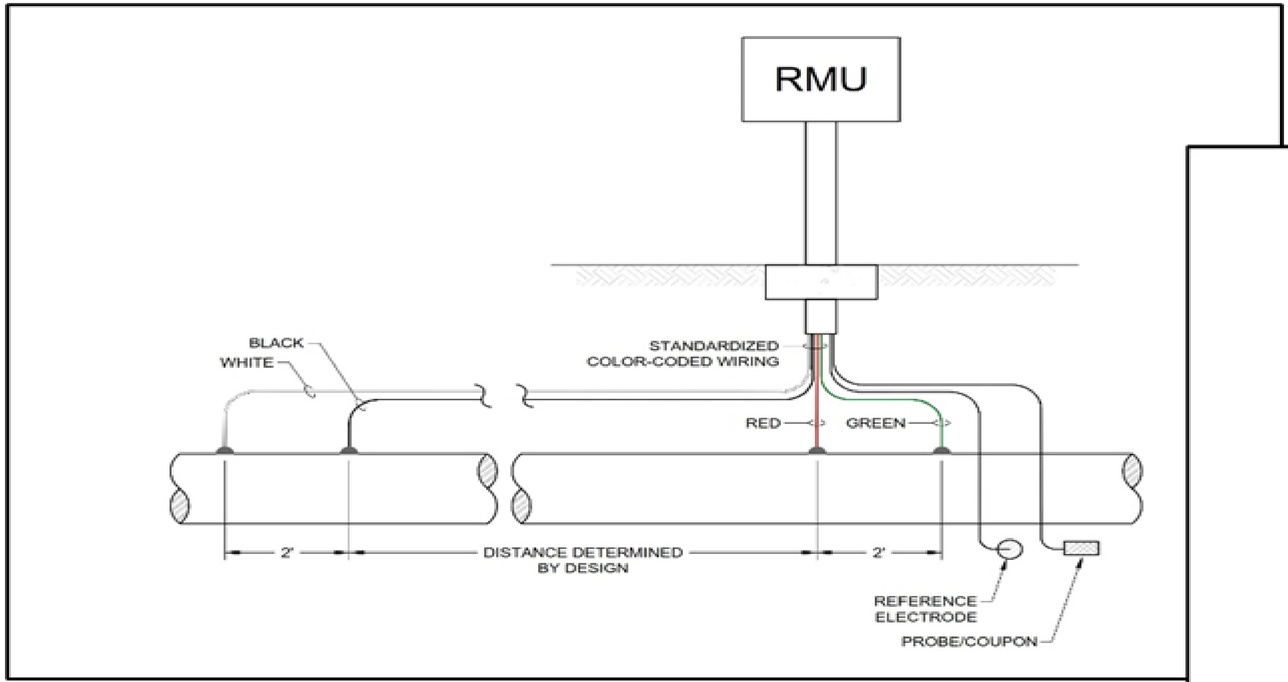
	PIPELINE/PROJECT NAME:						EXISTING OR PLANNED:	Planned	LENGTH (Miles):	100
	PREPARED BY:							DATE PREPARED:		
	TOTAL NO. OF PIPELINE RMUs:	12		NO. OF TEST STATIONS:		100		NO. OF CP CURRENT SOURCES:		4
			UNIT COSTS				EXTENDED COSTS			
REF. NO.	DESCRIPTION	QUANTITY	Material/ Equipment	Installation	Engineering /Start-Up/Other	Total Unit Cost	Material/Equipment	Installation	Engineering/Start-Up/Other	Total Extended Cost
	1) RMU INITIAL COSTS - Equipment & Installation									
1	RMU Type 1 - AC/DC Line Current/Potential/Corrosion Probe	12	$ 5,000	$ 2,000	$ 500	$ 7,500	$ 60,000	$ 24,000	$ 6,000	$ 90,000
2	RMU Type 2 - AC/DC Potential/Current Density/Corrosion Probe					$ -	$ -	$ -	$ -	$ -
3	RMU Type 3 - AC/DC Potential/Current Density					$ -	$ -	$ -	$ -	$ -
4	RMU Type 4 - AC/DC Potential					$ -	$ -	$ -	$ -	$ -
5						$ -	$ -	$ -	$ -	$ -
6						$ -	$ -	$ -	$ -	$ -
7						$ -	$ -	$ -	$ -	$ -
8						$ -	$ -	$ -	$ -	$ -
9						$ -	$ -	$ -	$ -	$ -
	1) SUBTOTAL - RMU INITIAL COSTS:	12	--	--	--	--	$ 60,000	$ 24,000	$ 6,000	$ 90,000
	2) OTHER INITIAL COSTS									
10	RMU Design	1	--	--	$ 8,000	$ 8,000	--	--	$ 8,000	$ 8,000
11	Prepaid Subscription/Connectivity Charge (1st year)	12	--	--	$ 120	$ 120	--	--	$ 1,440	$ 1,440
12			--	--		$ -	--	--		
13			--	--		$ -	--	--		
14			--	--		$ -	--	--		
15			--	--		$ -	--	--		
16			--	--		$ -	--	--	$ -	$ -
	2) SUBTOTAL - OTHER INITIAL COSTS:								$ 9,440	$ 9,440
	3) INITIAL COST SAVINGS (mainly applicable for new pipeline construction)									
17	Elimination of "standard" test stations	30	200	200	100	$ 500	$ (6,000)	$ (6,000)	$ (3,000)	$ (15,000)
18	Elimination of "typical" output voltage/current RMUs at CP current sources	4	2500	200	100	$ 2,800	$ (10,000)	$ (800)	$ (400)	$ (11,200)
19						$ -	$ -	$ -	$ -	$ -
20						$ -	$ -	$ -	$ -	$ -
21						$ -	$ -	$ -	$ -	$ -
22						$ -	$ -	$ -	$ -	$ -
23						$ -	$ -	$ -	$ -	$ -
	3) SUBTOTAL - INITIAL COST SAVINGS:									$ (26,200)
	4) TOTAL INITIAL COSTS - RMUs									$ 73,240
	Average Initial Cost Per RMU									$ 6,103
	Average Initial RMU Cost Per Pipeline Mile									$ 732

Pipeline/Project Name			
Prepared By			
Date Prepared	01/00/00	--	--
Existing or Planned Pipeline	Planned	--	--
Length (Miles)	100	--	--
Total No. of Pipeline RMUs	12	--	--
No. of Test Stations	100	--	--
No. of CP Current Sources	4	--	--
Annual Interest Rate (%)	3%	--	--
Economic Life (Years)	30	--	--
DESCRIPTION	TOTAL PRESENT VALUE	PRESENT VALUE PER RMU	PRESENT VALUE PER PIPELINE MILE
RMU Initial Cost	$ 73,240	$ 6,103	$ 732
RMU Total Life-Cycle Cost (Initial & O&M)	$ 187,460	$ 15,620	$ 1,875
Annualized RMU O&M Cost (per year)	$ 3,807	$ 317	$ 38
Traditional CP Monitoring Life-Cycle Cost	$ 418,774	--	$ 4,188
Annualized Traditional CP Monitoring Costs (per year)	$ 13,959	--	$ 140
Payback Period - RMUs vs. Traditional CP Monitoring	5.2 Years		
"Return on Investment" - RMUs vs. Traditional CP Monitoring	123%		
Cost Avoidance - Total Life-Cycle Cost	$ 756,897	--	$ 7,569
Annualized Cost Avoidance (per year)	$ 25,230	--	$ 252
Payback Period - RMUs vs. Avoidance Cost	2.9 Years		
"Return on Investment" - RMUs vs. Cost Avoidance	304%		

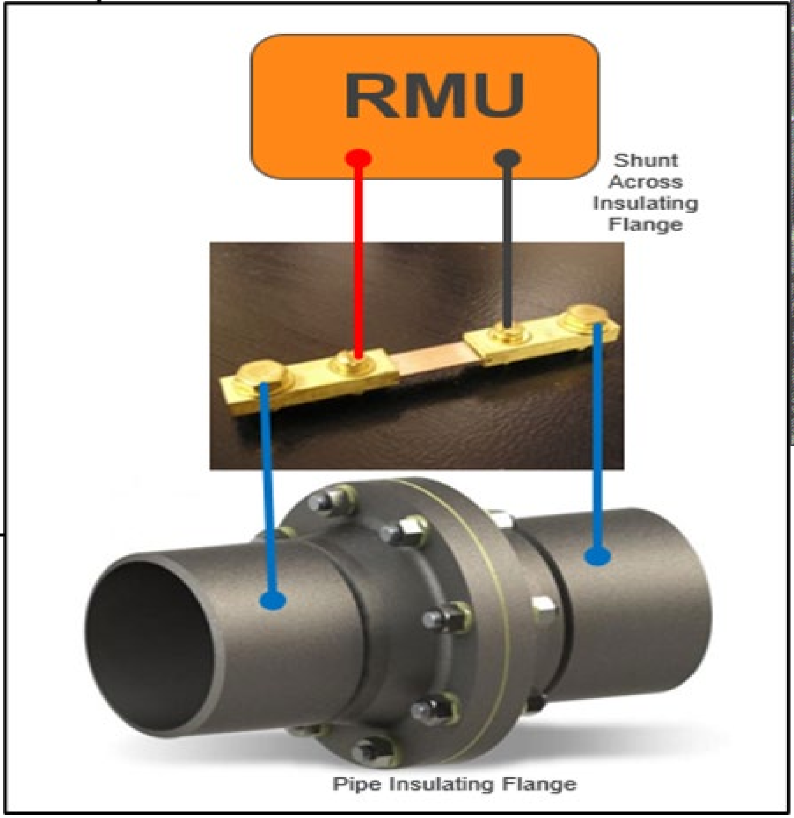
INPUT:
RMUs, CP monitoring, "avoidance costs"

OUTPUT: Present Value $, RMU payback period, RMU return on investment (ROI)

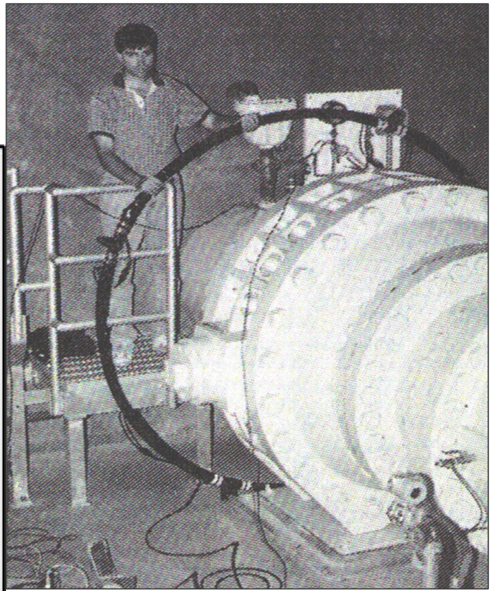
How does one measure/monitor pipe current?



Pipe Current Span
(typically 100+ feet)

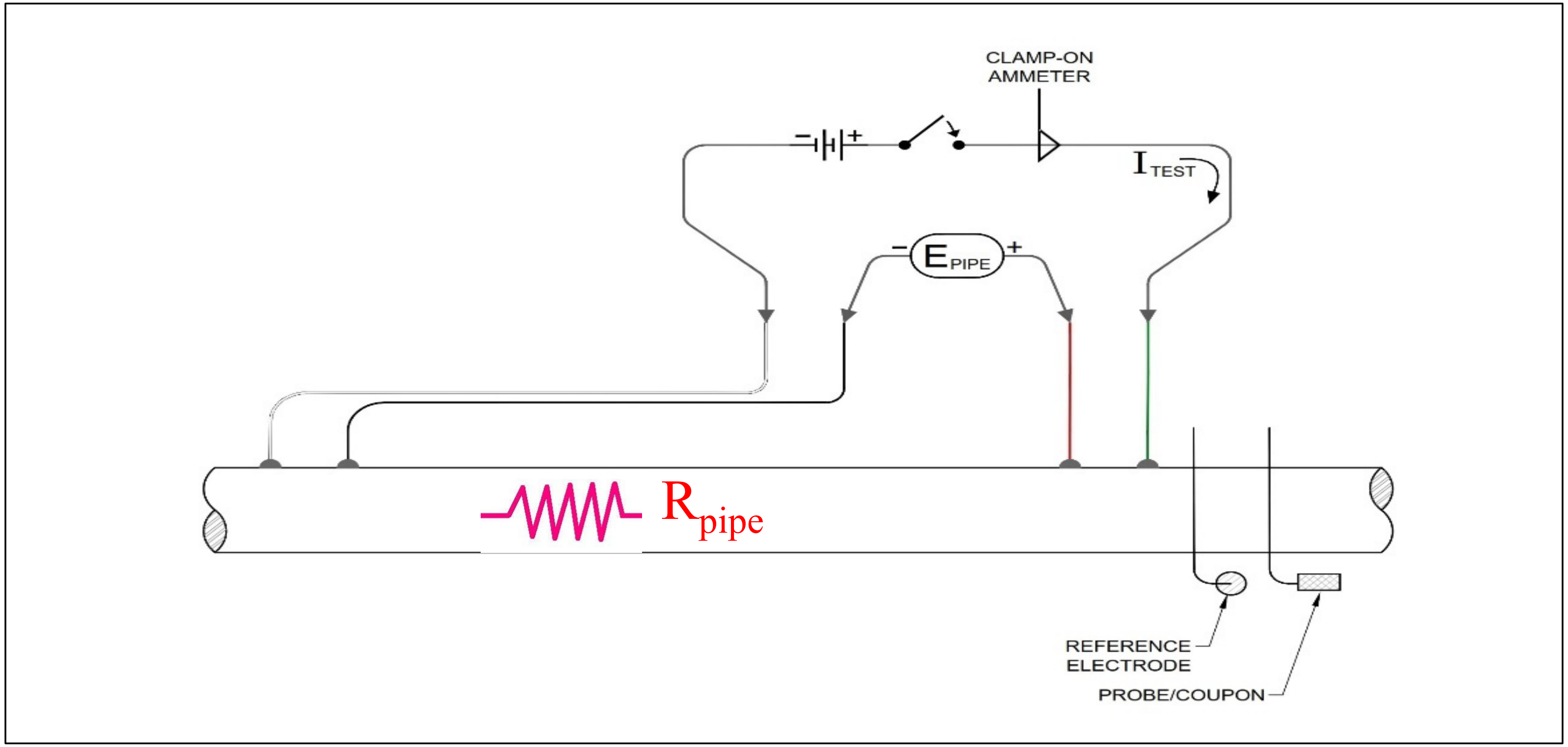


Calibrated Current
Shunt in Bond Cable



Clamp-On Ammeter
Around Pipe or
Bond Cable

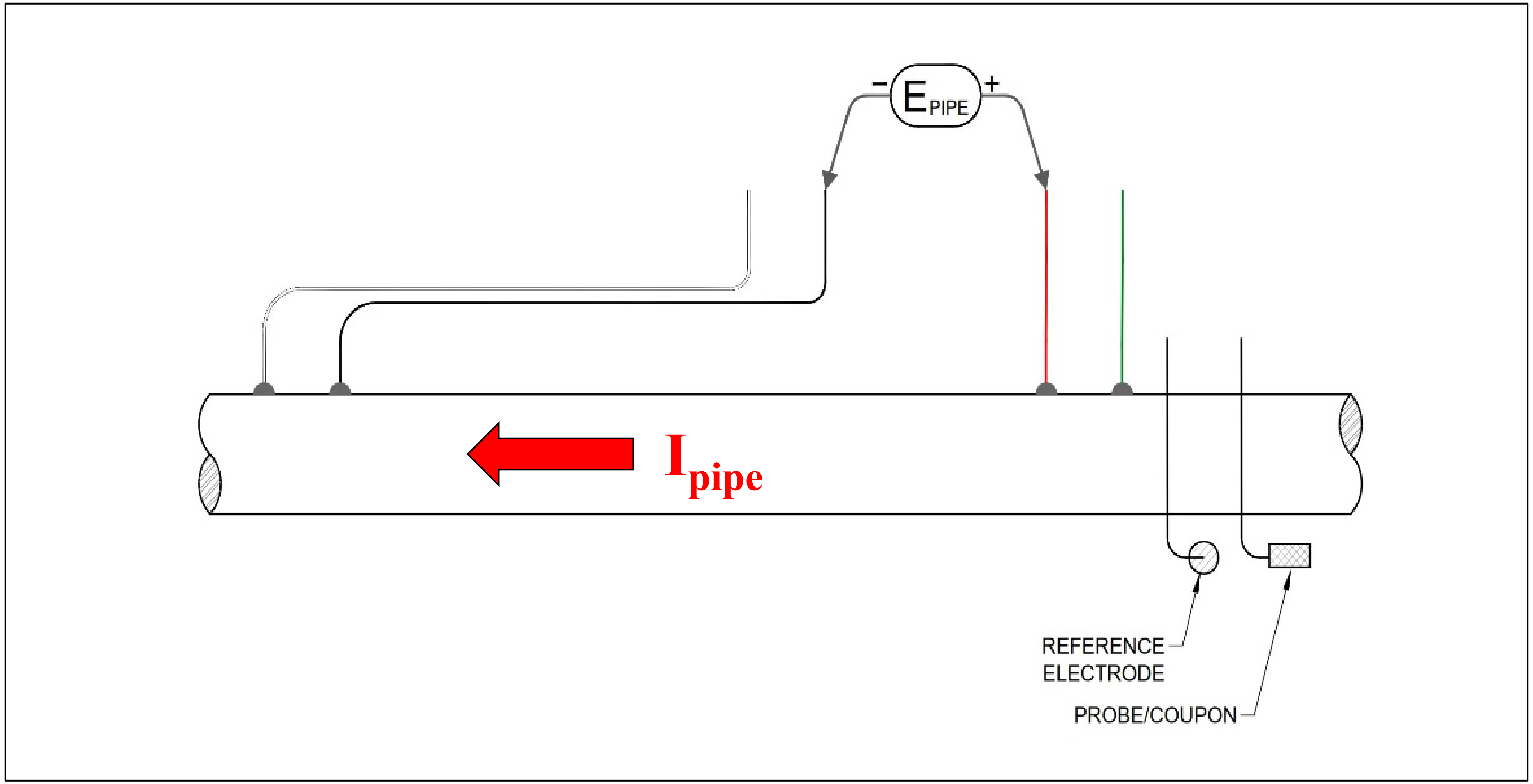
Pipe Current Span Resistance Measurements (Ohm's Law)



$$R_{pipe}\ (\text{milliohm}) = [E_{pipe\text{-}on}\ (\text{mV}) - E_{pipe\text{-}off}\ (\text{mV})] / I_{test}\ (\text{A})$$

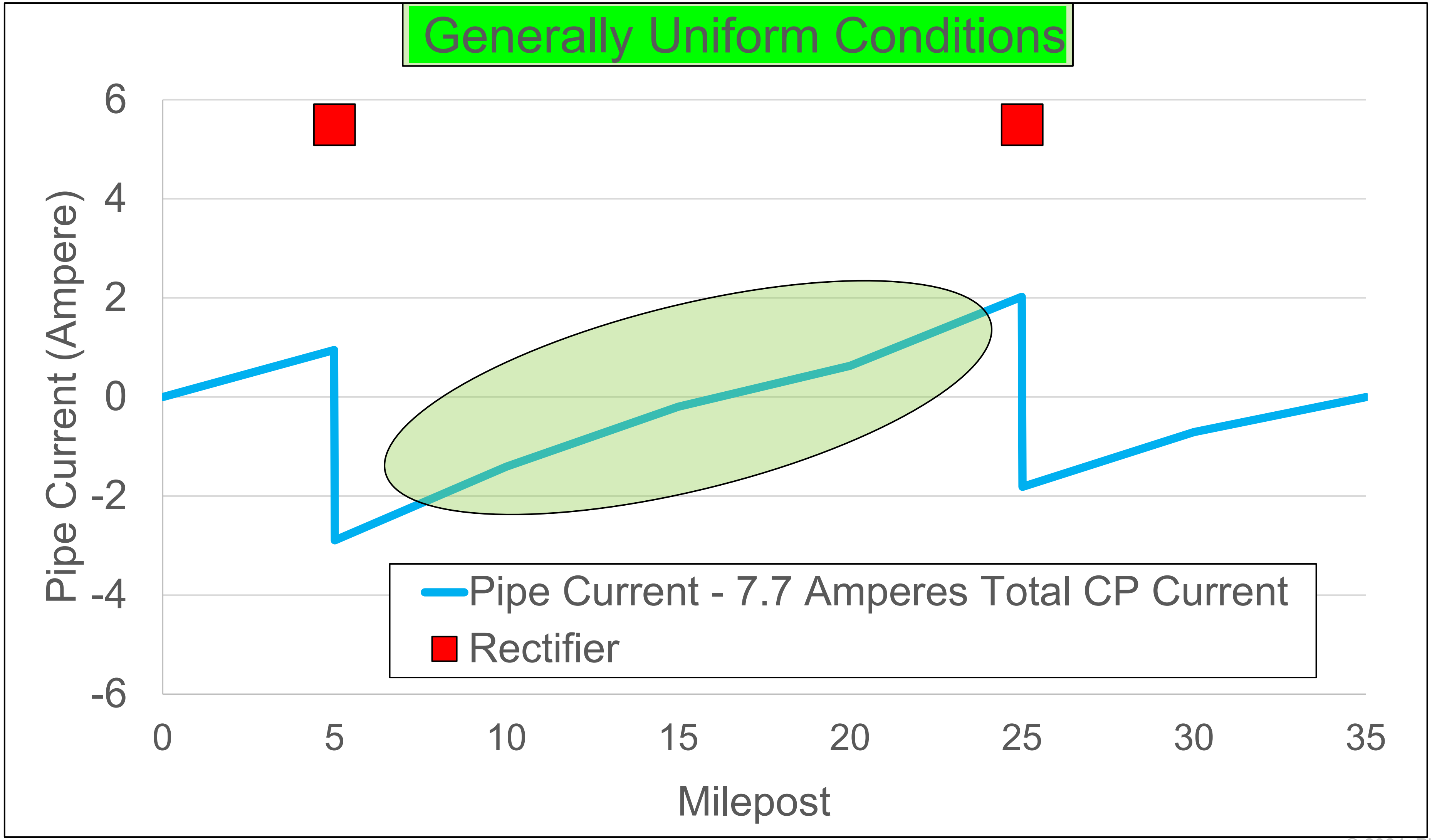
$$C_f\ (\text{A/mV}) = 1 / R_{pipe}$$

Pipe Span Voltage Converted to Line Current (Ohm's Law)

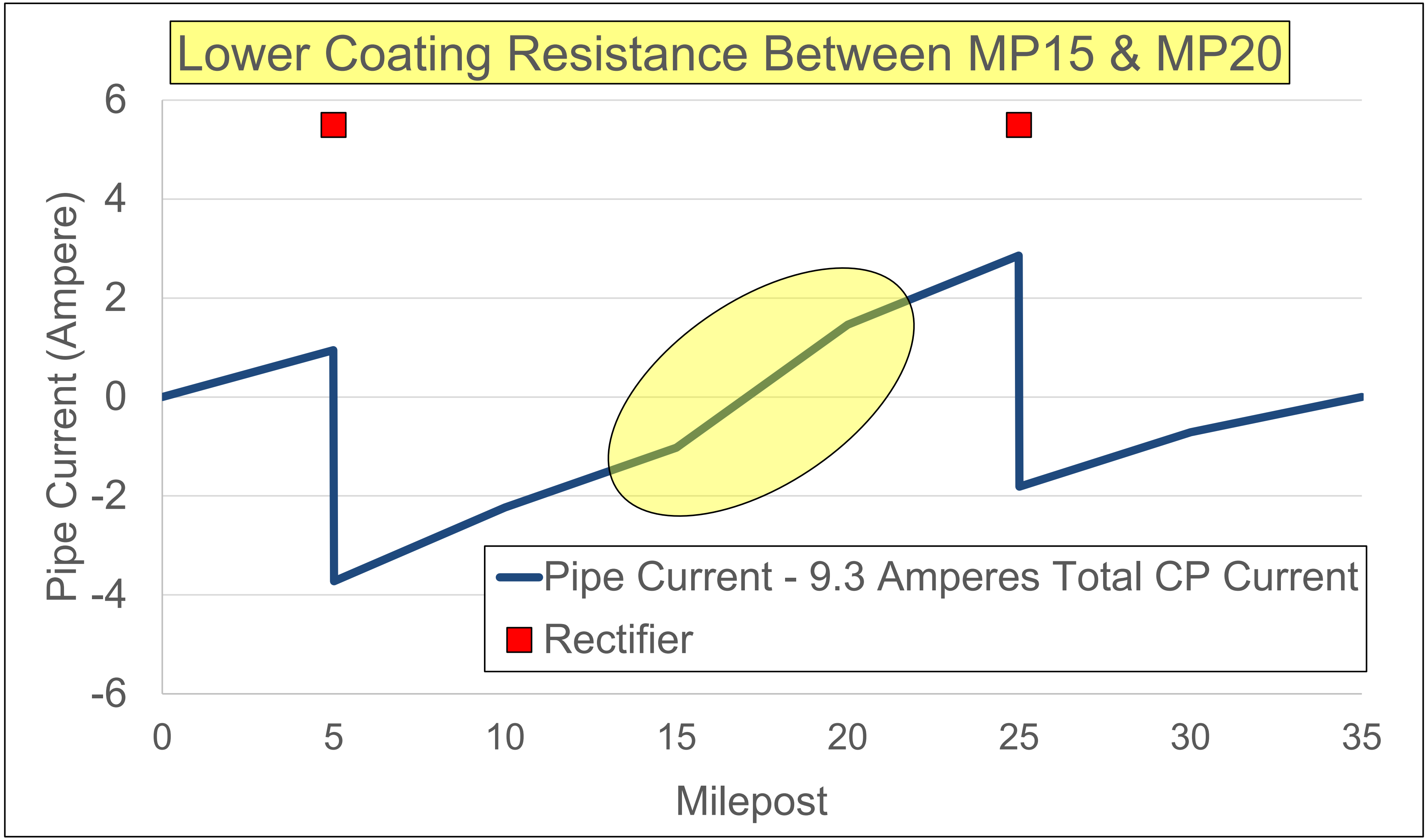


$$I_{pipe}\ (A) = E_{pipe}\ (mV) \times C_f\ (A/mV)$$

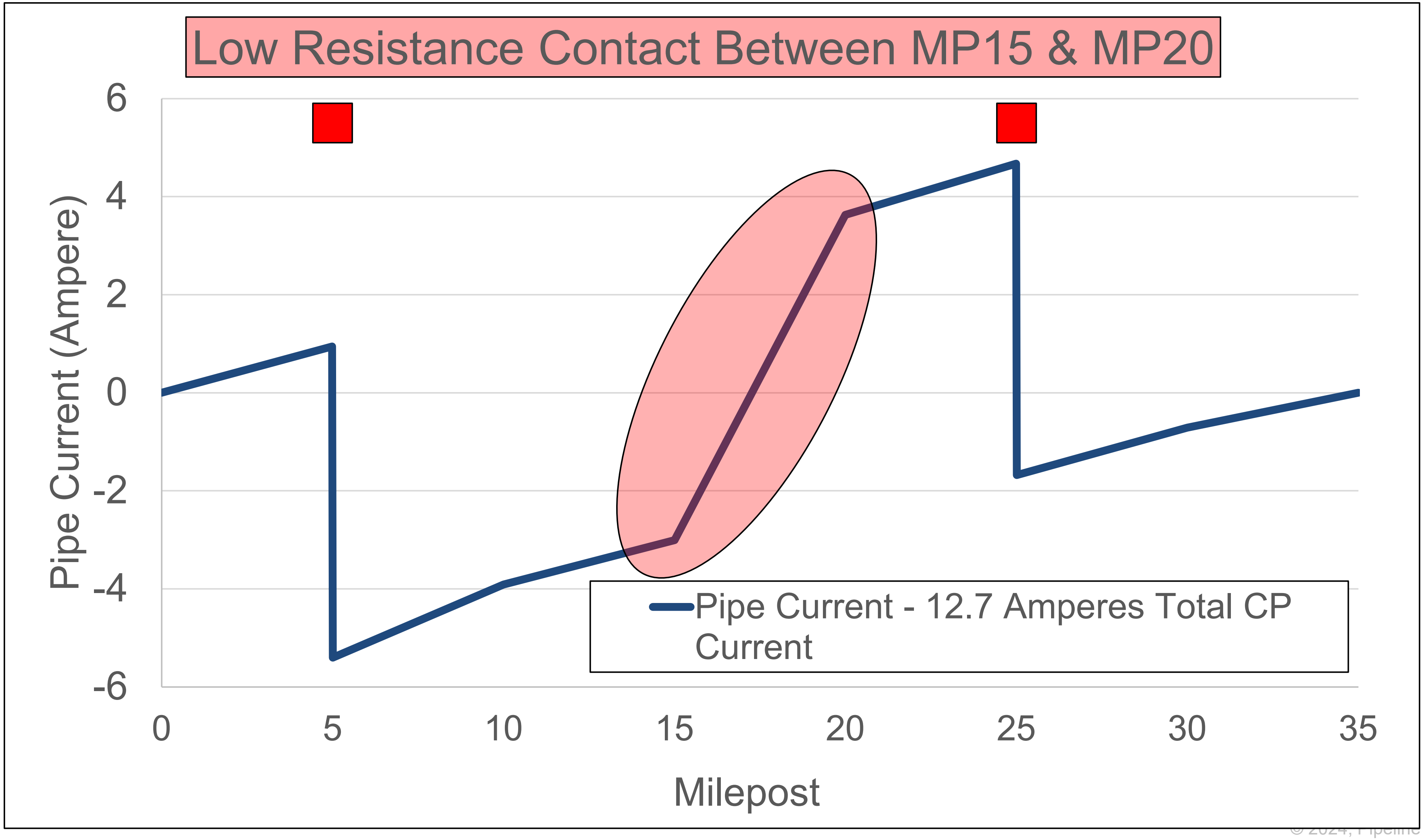
Cathodic Protection Current Distribution (1 of 3)



Cathodic Protection Current Distribution (2 of 3)

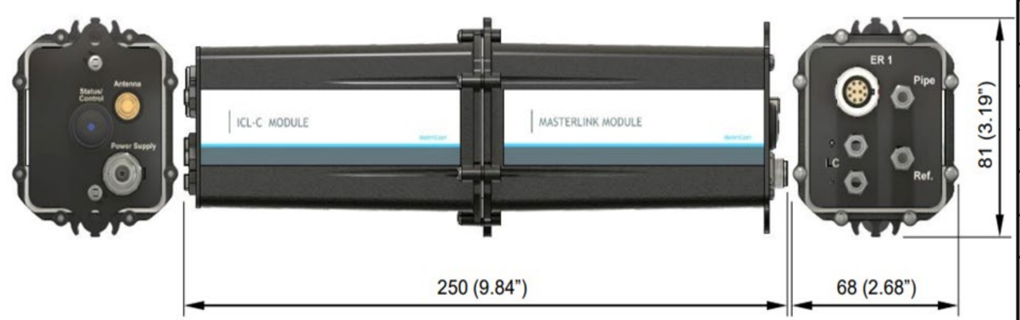


Cathodic Protection Current Distribution (3 of 3)



Extensive Field-Based Research – 6 pipelines, 253 miles

- 6 pipelines, 253 miles total, assorted coating quality and pipe-to-earth resistance
- 72 temporary pipe current/potential RMU locations across the 6 pipelines – average spacing = 3.3 miles, maximum = 13.5 miles
    - Precision RMU used with 0.1 microvolt resolution (1-3 mA pipe current resolution)
    - Data sampling rate = 1 measurement set (pipe potential & current) every 10 minutes
- 74 total simulated upset conditions



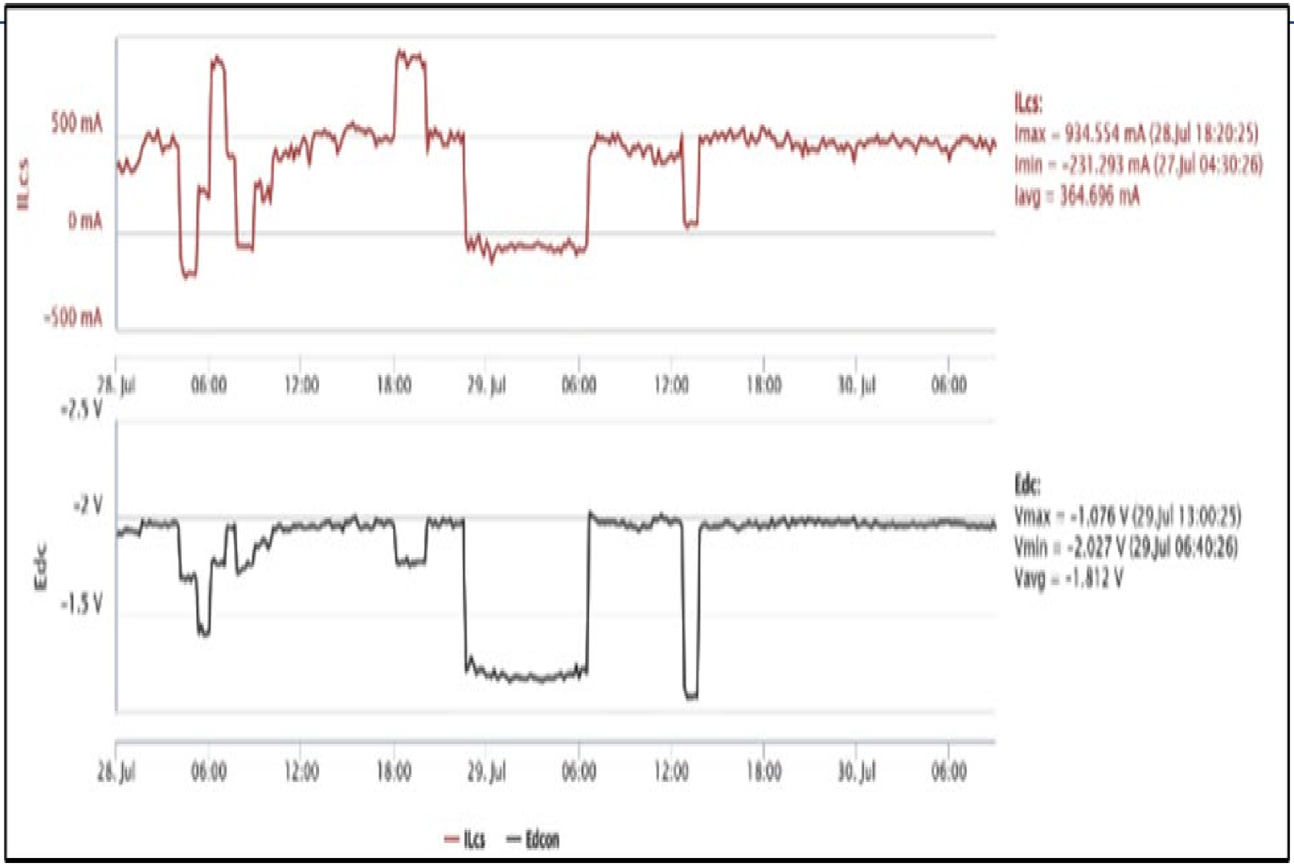
Pipeline No.	State	Coating	Diameter (Inch)	Evaluation Section - From Milepost	Evaluation Section - To Milepost	Evaluation Length (Miles)	Cathodic Protection Current Demand Per Mile (A/Mile)	Average CP Current Density (µA/Sq.Ft)
1	OK	FBE	16	29.8	72.4	42.6	0.12	6
2	PA	FBE	12	0.1	31.1	31.0	0.08	5
3	TX, LA	X-Tru-Coat	12	121.2	181.0	59.8	1.0	61
4	LA	Coal Tar	22	83.8	126.1	42.3	1.7	56
5	TX	FBE	8	0.0	8.2	8.2	2.3*	207*
6	IL	FBE / Coal Tar	36/22	15.9	50.3	68.9	0.10	1
TOTAL						252.8	--	--

* Pipeline 5 has multiple interconnects and bonds. CP current demand and current density values shown do not account for the interconnects & bonds, i.e. values for pipeline alone would be less than shown.

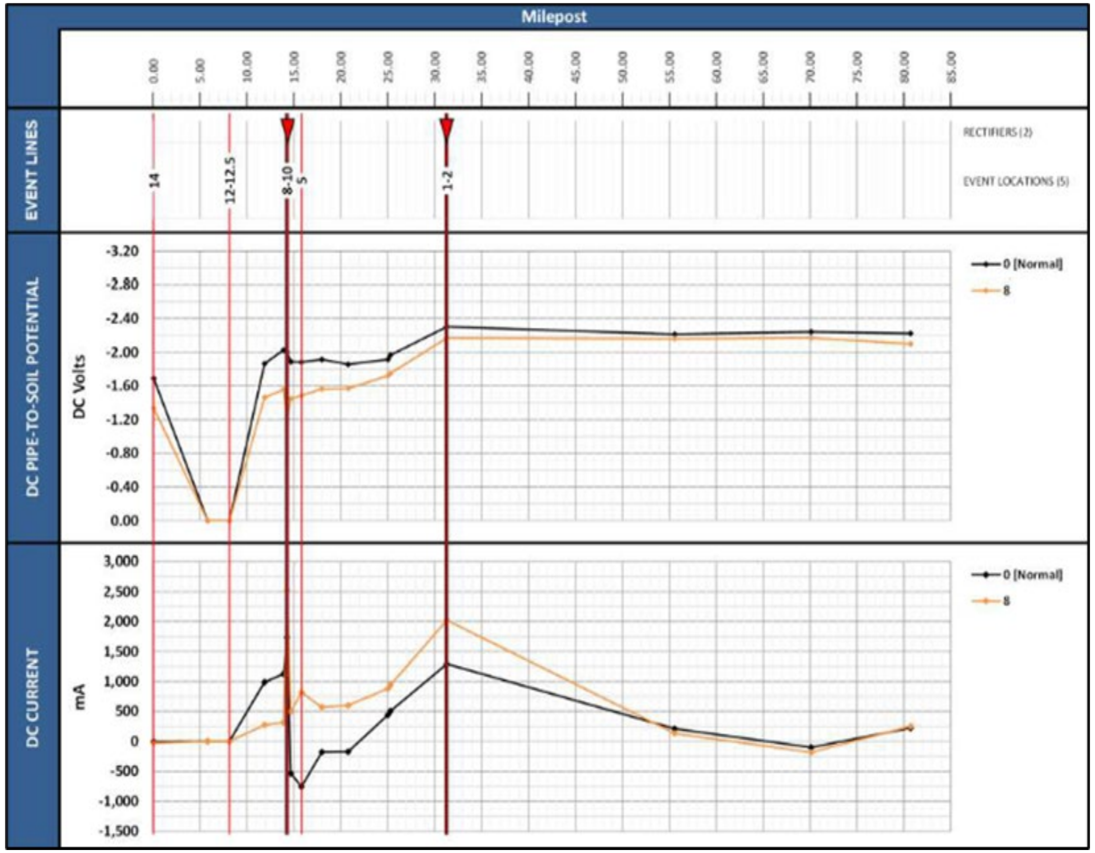
Simulated Upset Conditions – 74 total

1) Interference from a nearby cathodic protection system
2) Temporarily shorting the pipe to electrical ground
3) Temporarily shorting the pipe to a casing
4) Localized coating damage, simulated by temporarily connecting the pipe to a probe rod driven into the ground a few feet
5) Loss of cathodic protection for a portion of the pipeline system
6) Temporarily turning off one or more cathodic protection rectifiers associated with the pipeline being evaluated, individually and together

Representative Field Data and Results

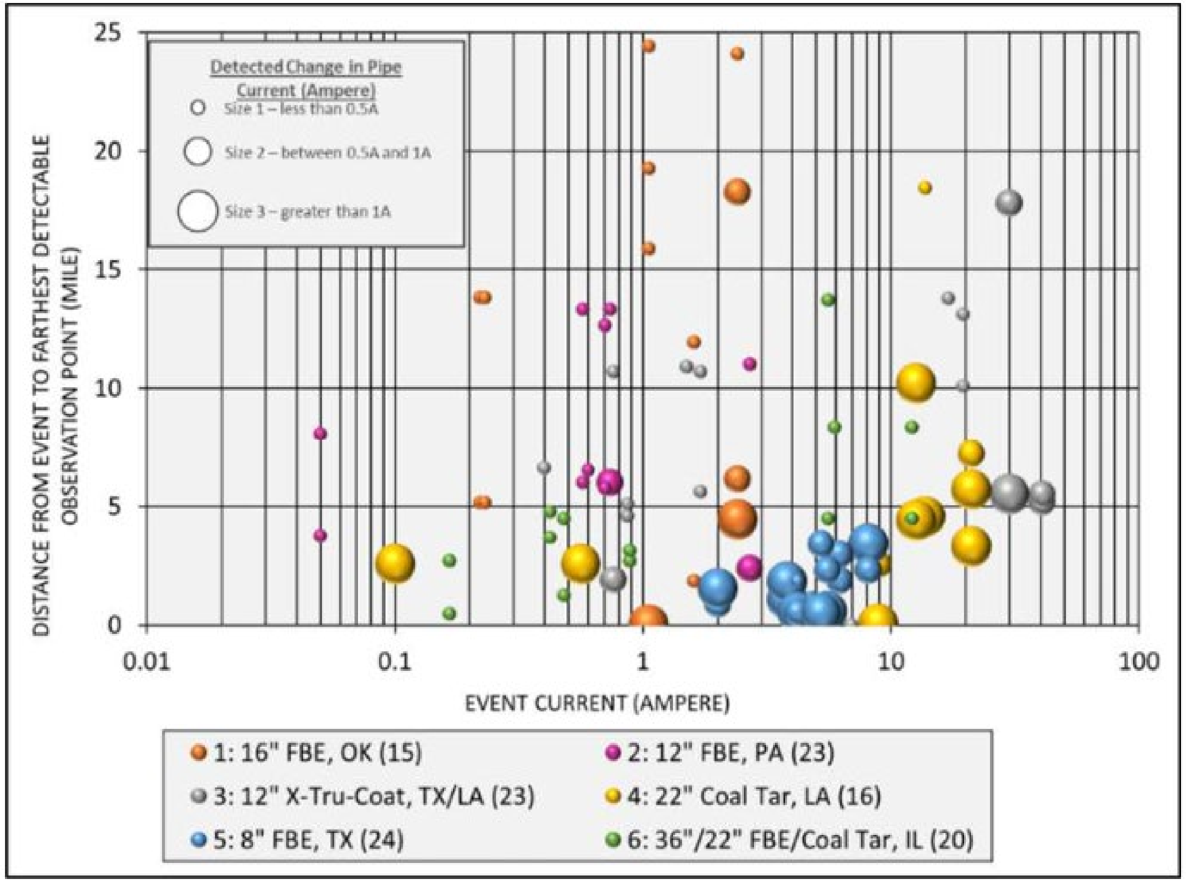


DC Pipe Current & Potential vs. Time – 3 days before, during, and after assorted simulations

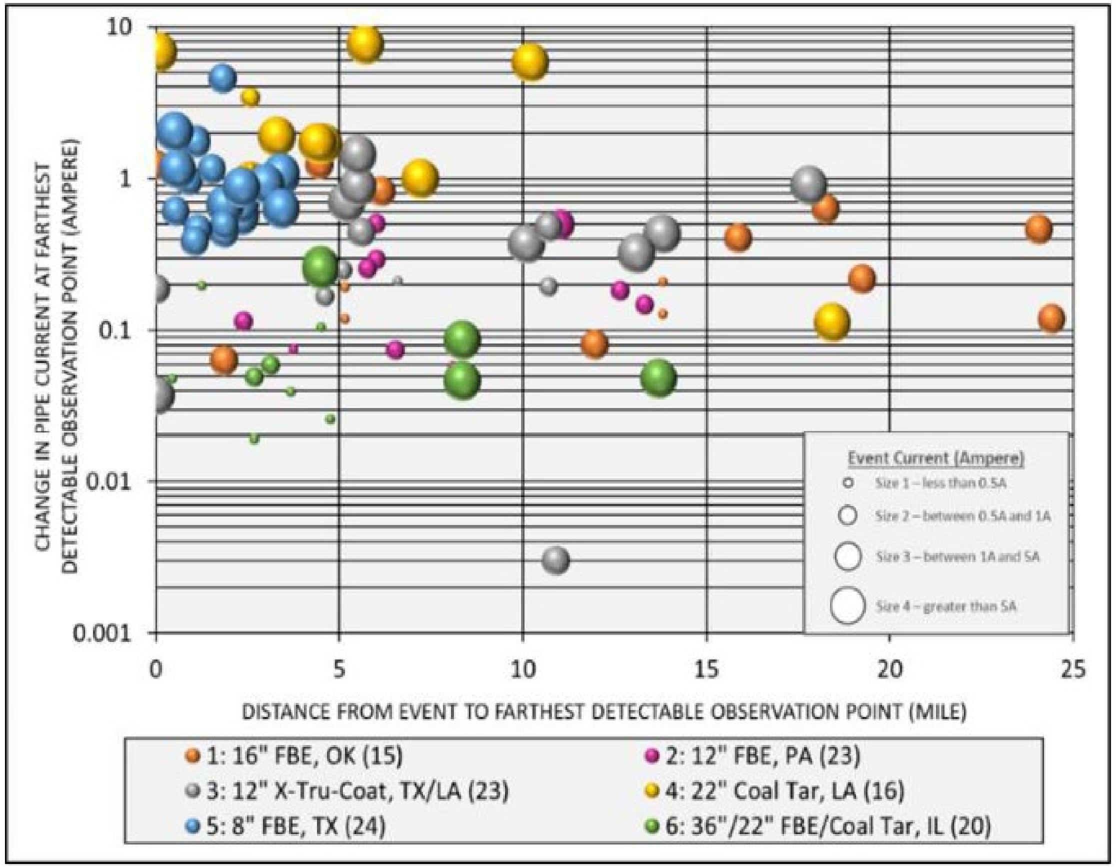


DC Pipe Current & Potential vs. Distance – 85 miles
“Normal” vs. simulated event
Simulated event readily observed 15+ miles away

Lots and lots of data to analyze!



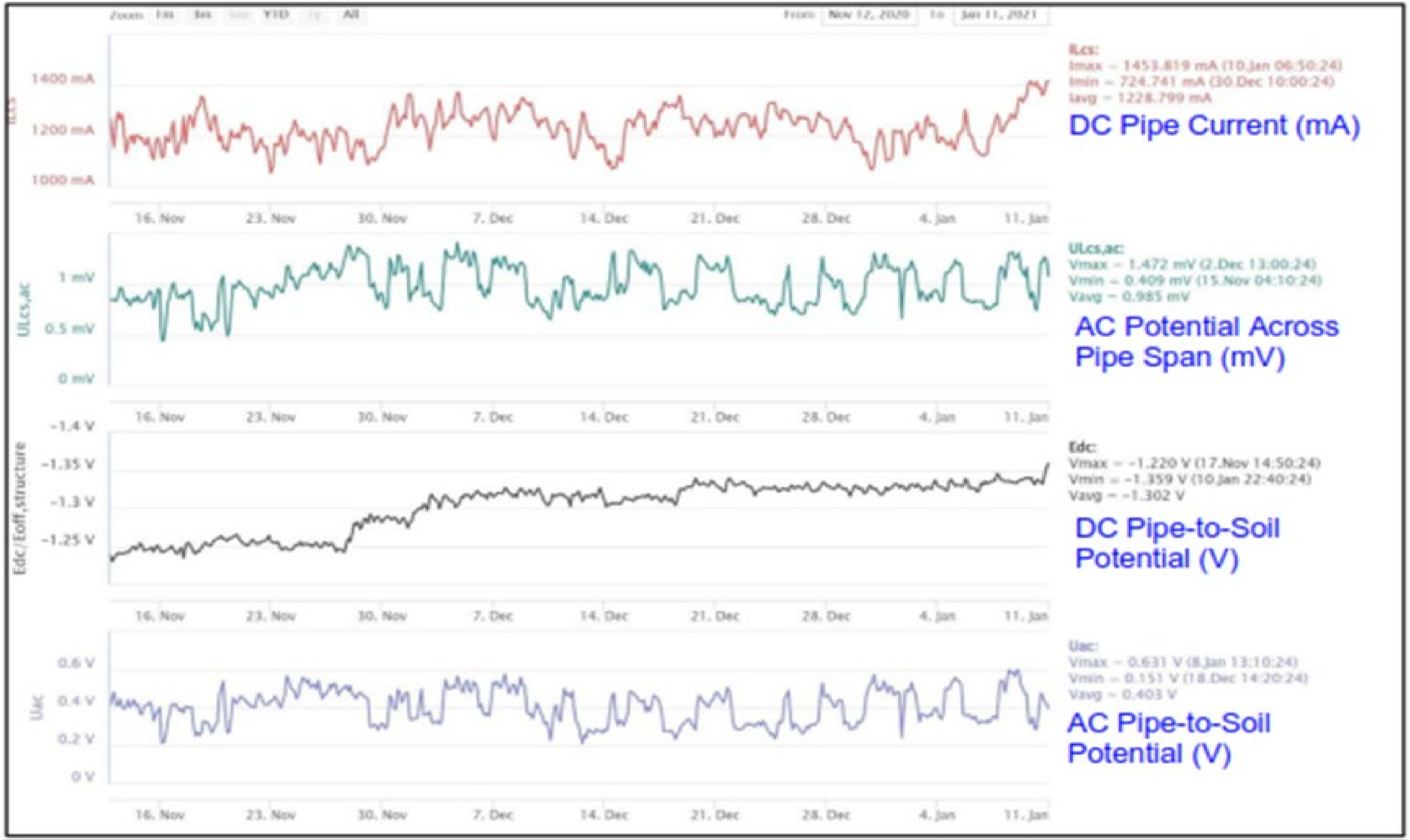
Observation distance (miles) vs. controlled event current (amperes)



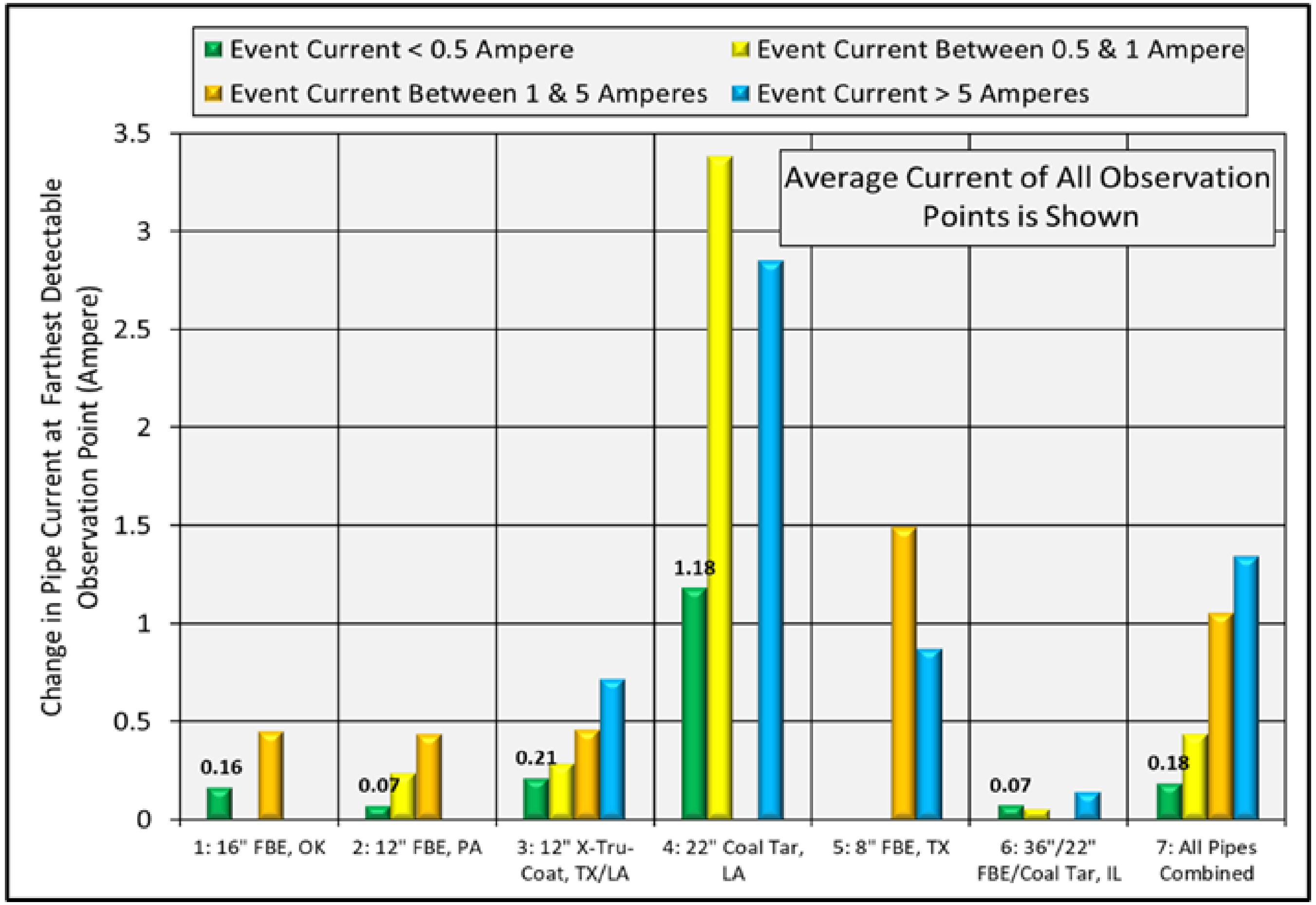
Pipe current change (amperes) vs. distance from controlled event (miles)

“Normal” doesn’t necessarily mean “constant”

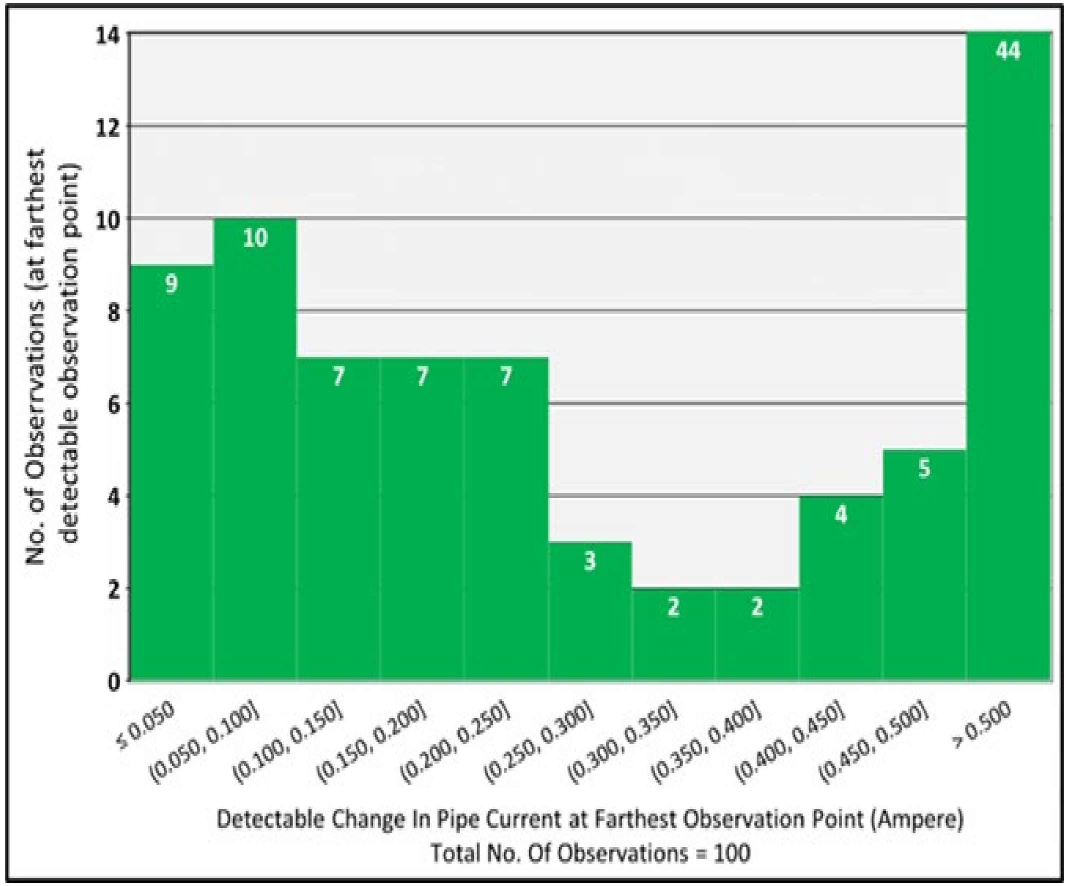
2-month monitoring period



Key Findings (1 of 2)

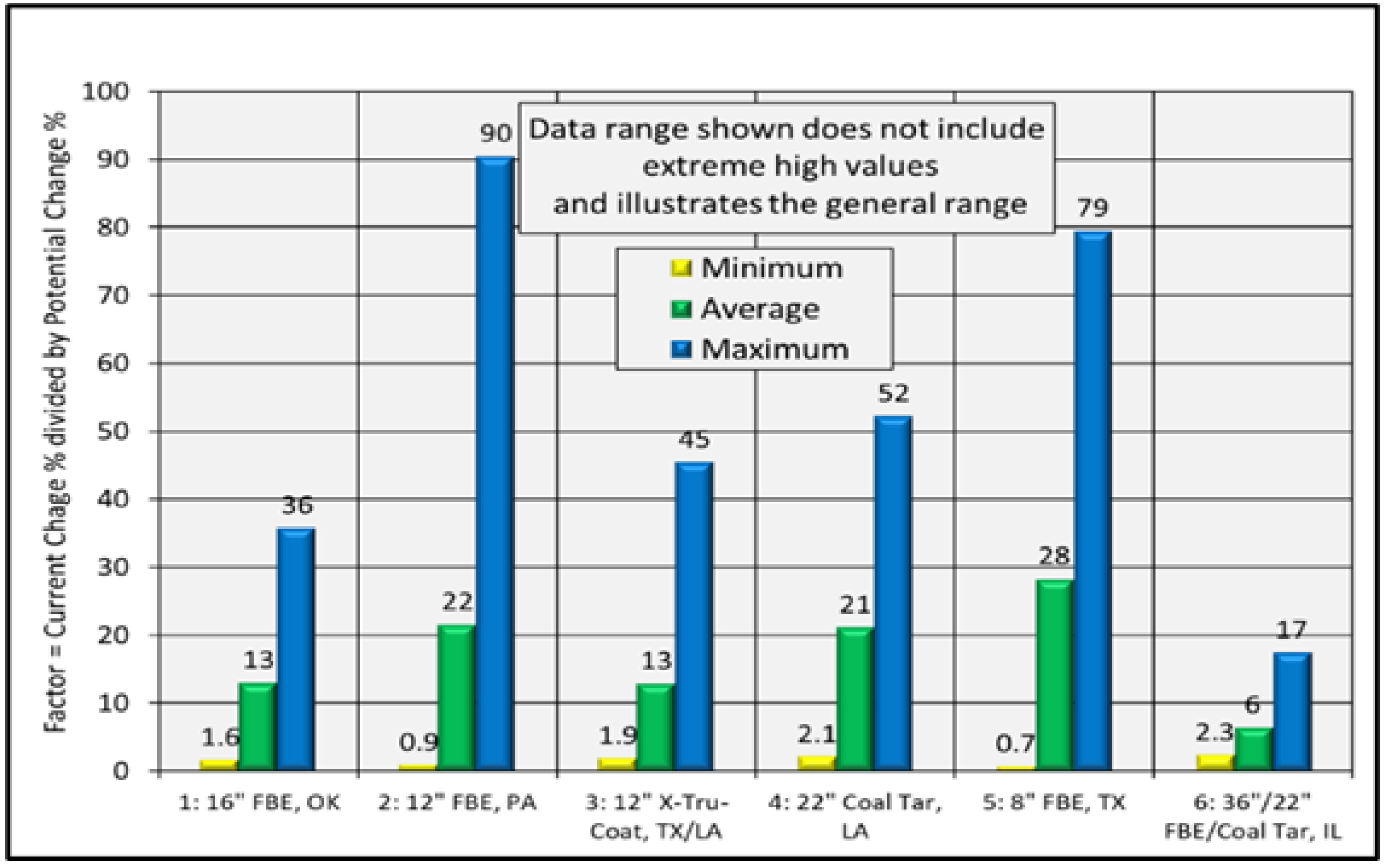


Detectable Change in Pipe Current miles away
(average values)



Histogram
Detectable Change in Pipe Current miles away
(all pipelines combined)

Key Findings (2 of 2)



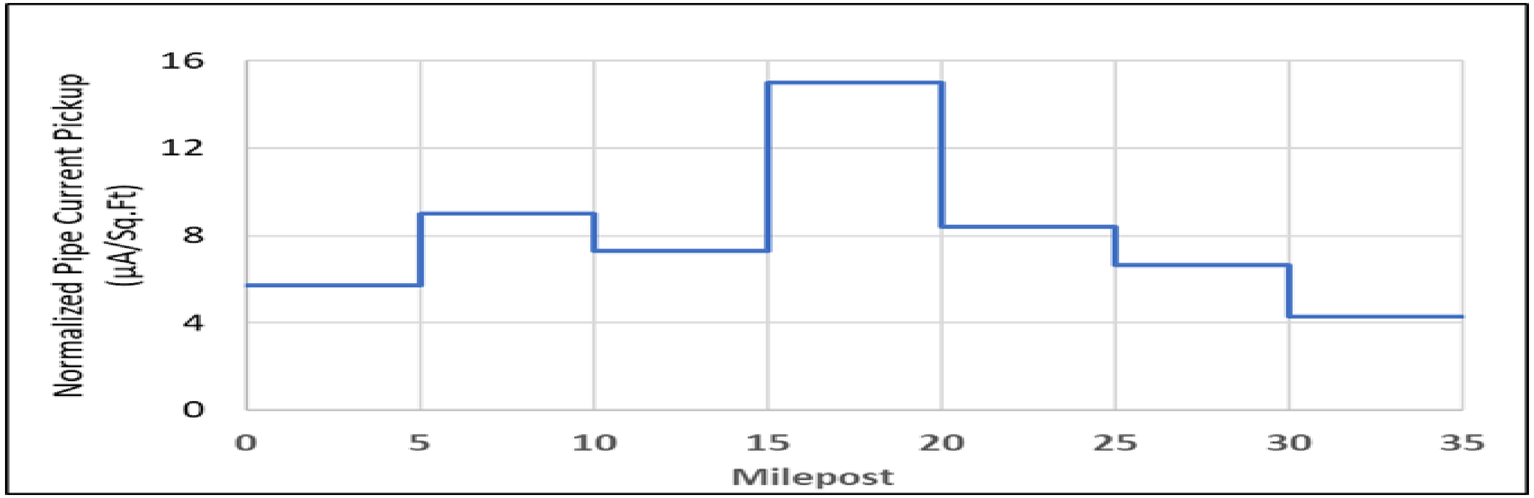
Pipe current monitoring is consistently more sensitive than pipe-to-soil potential at a given observation point

Nominal Interval Between Pipe Current Sensors to Detect < 0.5 Ampere Upset/Change	
High quality coating, electrically isolated	8-10 Miles, Possibly Further
Modest quality coating, electrically isolated	4-5 Miles
Poor quality coating, electrically grounded, and or multiple interconnects	2-3 Miles Maximum

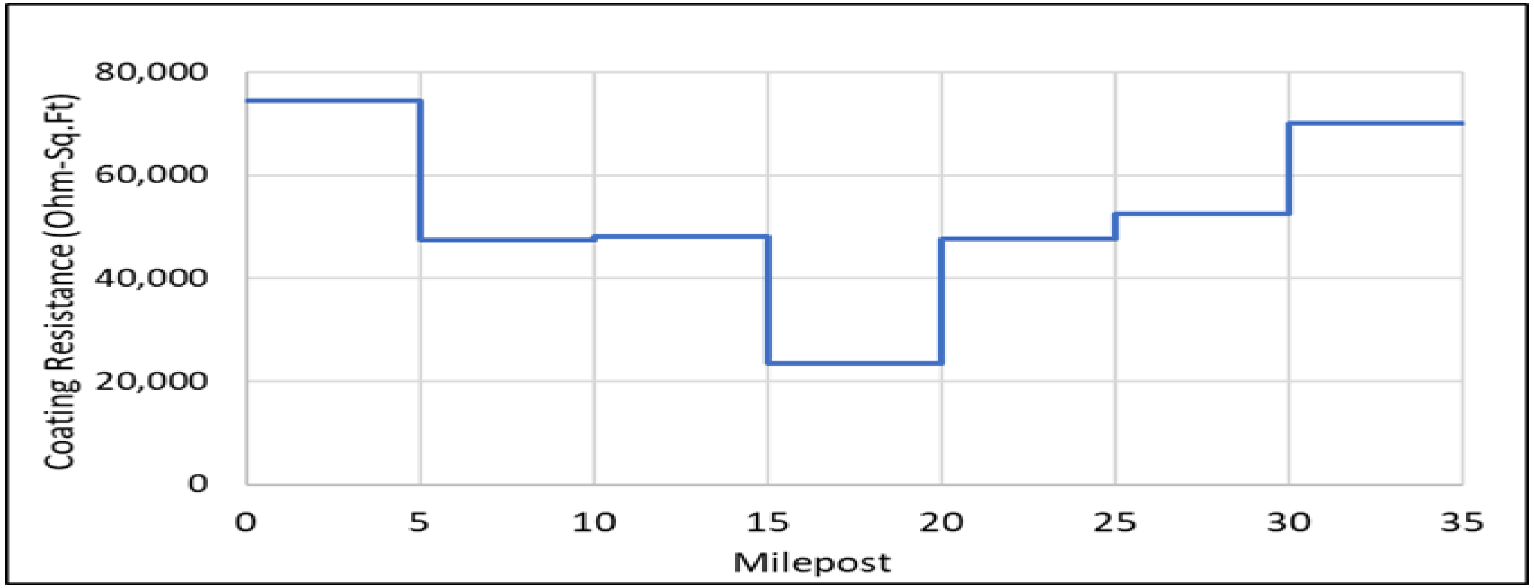
General guidance on pipe current RMU spacing (pipeline-specific RMU plan should be tailor-made based on known and potential future corrosion risks, acknowledging dynamic conditions & changes over time, following guidelines in manual)

Trending data over distance and time

Normalized
Pipe Current
Pickup
(µA/Sq.Ft.)



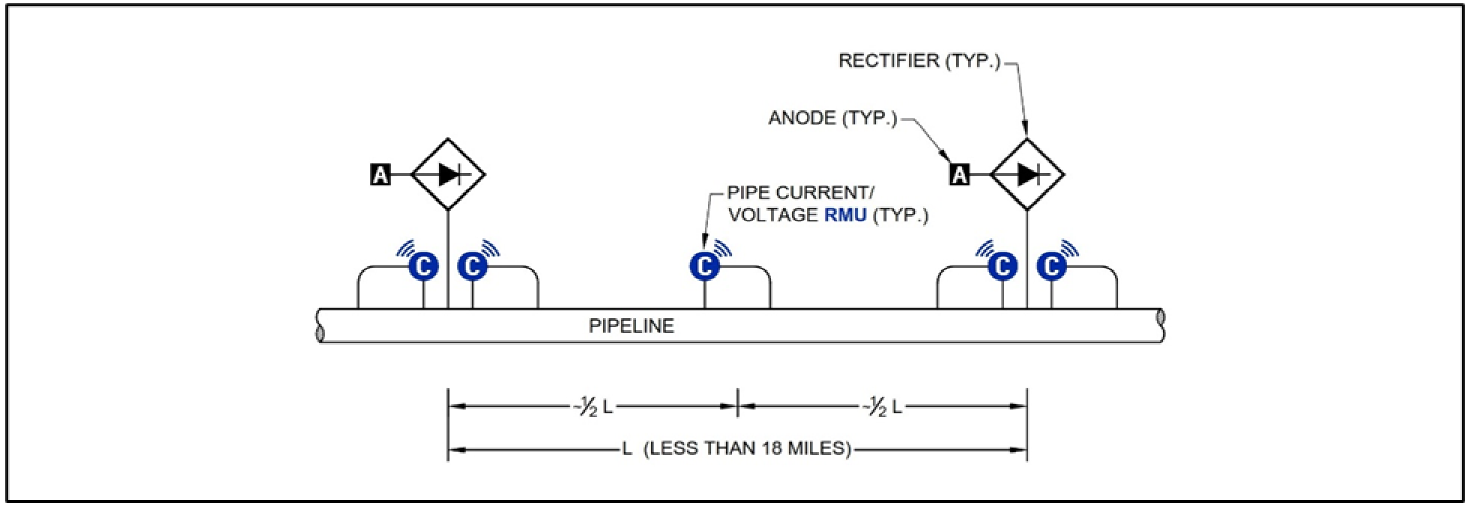
Normalized Pipe
Coating
Resistance
(Ohm/Sq.Ft.)



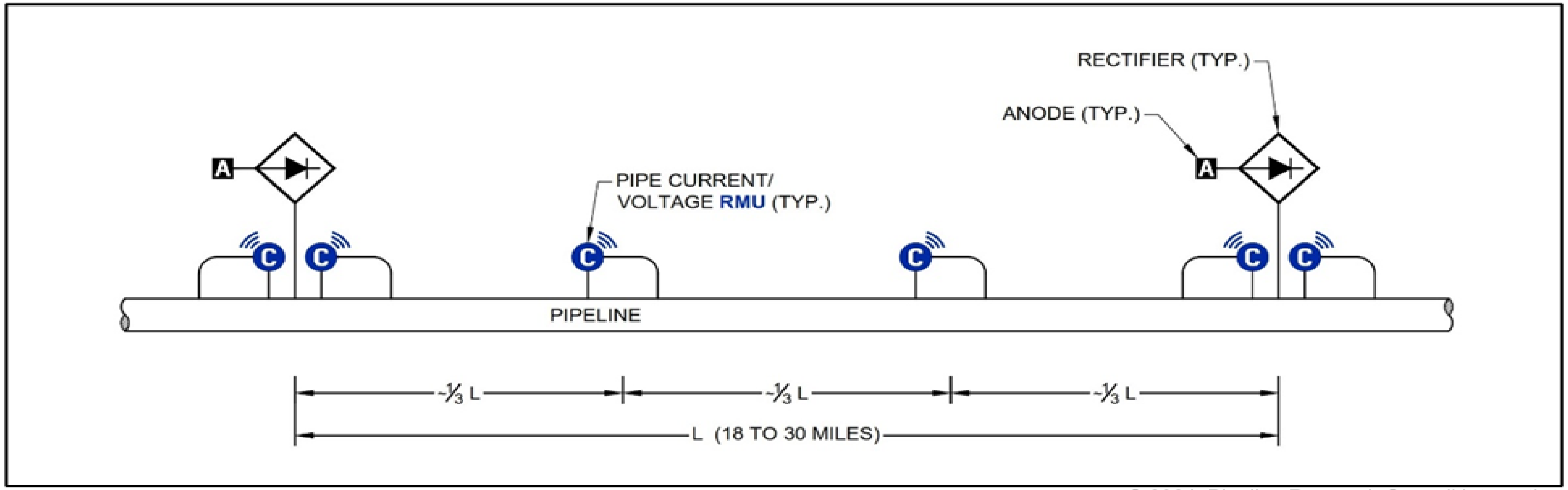
Selecting Pipe Current RMU Locations

(minimum locations determined by CP current source "zones")

Scenario #1: CP current sources <18 miles apart = **3** pipe current RMUs between sources

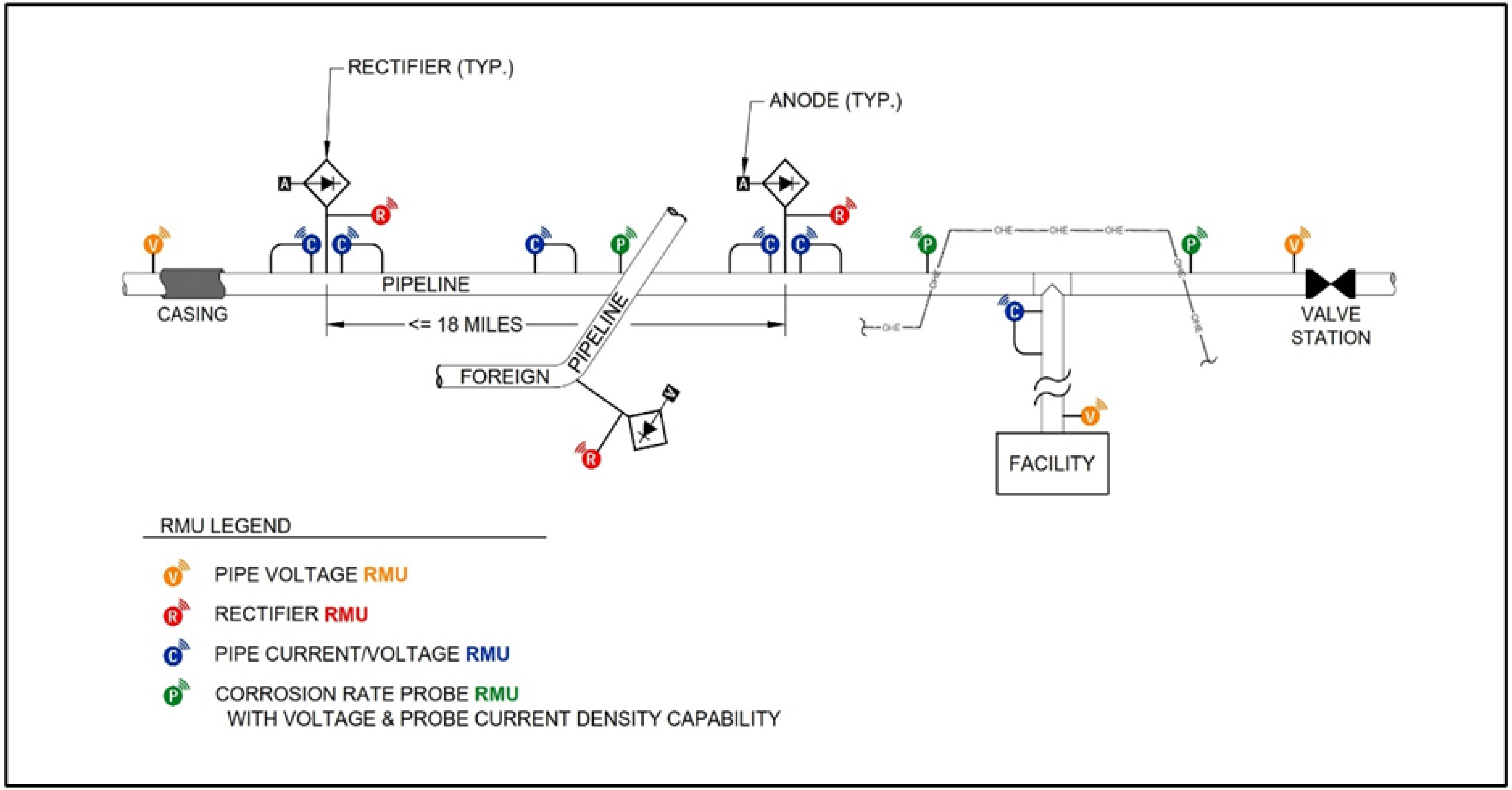


Scenario #2: CP current sources 18-30 miles apart = **4** pipe current RMUs between sources



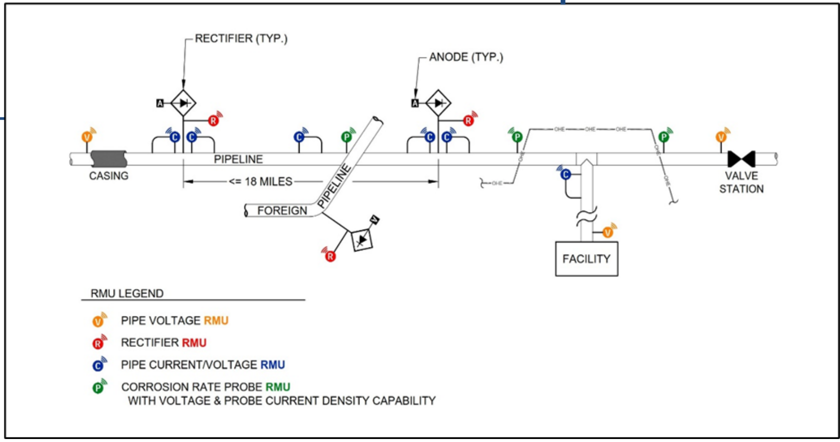
"The Smart Pipe"

RMU/sensor type(s) and locations should be tailor-made based on known and potential future corrosion risks, acknowledging dynamic conditions & changes over time



Summary

"The Smart Pipe"



1) Continuous real-time pipe current measurements should be an integral part of a CP remote monitoring program

2) Small pipe currents and small changes in pipe current are readily detected with commercially available high-resolution instrumentation

3) Pipe current monitoring is more sensitive to upsets when compared to pipe-to-soil potential monitoring alone

4) Remote monitoring is cost effective and applicable to existing and new pipelines

5) Machine learning and artificial intelligence can enhance the smart pipe monitoring process

thank you

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