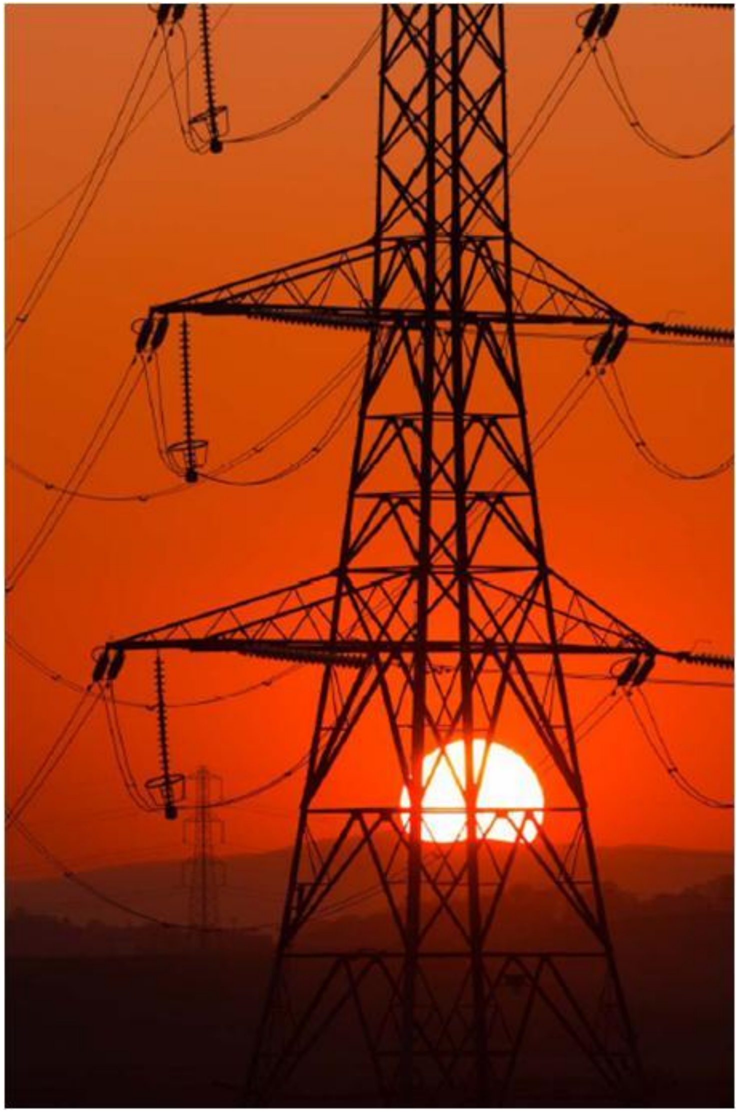
AUCSC Advanced Course

Period 3

AC Interference Mechanisms and Mitigation Strategies



Prepared for AUCSC by
Kurt Lawson
Mears Group, Inc.

Purpose

- To discuss electrical safety hazards on pipelines during construction and operation
- To illustrate how pipelines are electromagnetically coupled to HVAC transmission and distribution lines
- Provide methods for recognizing hazards and protection from hazards
- Impact on Corrosion
- Basic Mitigation Strategies

AC Interference Safety and Risk to Personnel

Lightning & Fault Safety

These procedures may not be sufficient to prevent personal injury resulting from lightning or a fault.

- Work should be suspended when there is the possibility of lightning
- Work should be suspended when there is the higher possibility of a line fault.

Human Resistance To Electrical Current

DRY SKIN	1,000,000 TO 5,000,000 OHMS
WET SKIN	1,000 OHMS
STANDING OR LYING IN WATER	150 OHMS
INTERNAL BODY-HAND TO FOOT	400 TO 500 OHMS
INTERNAL BODY-EAR TO EAR	(ABOUT) 100 OHMS

60 Hz ALTERNATING CURRENT VALUES AFFECTING HUMAN BEINGS

CURRENT	EFFECTS
1 mA OR LESS	NO SENSATION - NOT FELT
1 TO 8 mA	SENSATION OF SHOCK - NOT PAINFULL INDIVIDUAL CAN LET GO AT WILL MUSCULAR CONTROL NOT LOST.
8 TO 15 mA	PAINFUL SHOCK - INDIVIDUAL CAN LET GO AT WILL - MUSCULAR CONTROL NOT LOST.

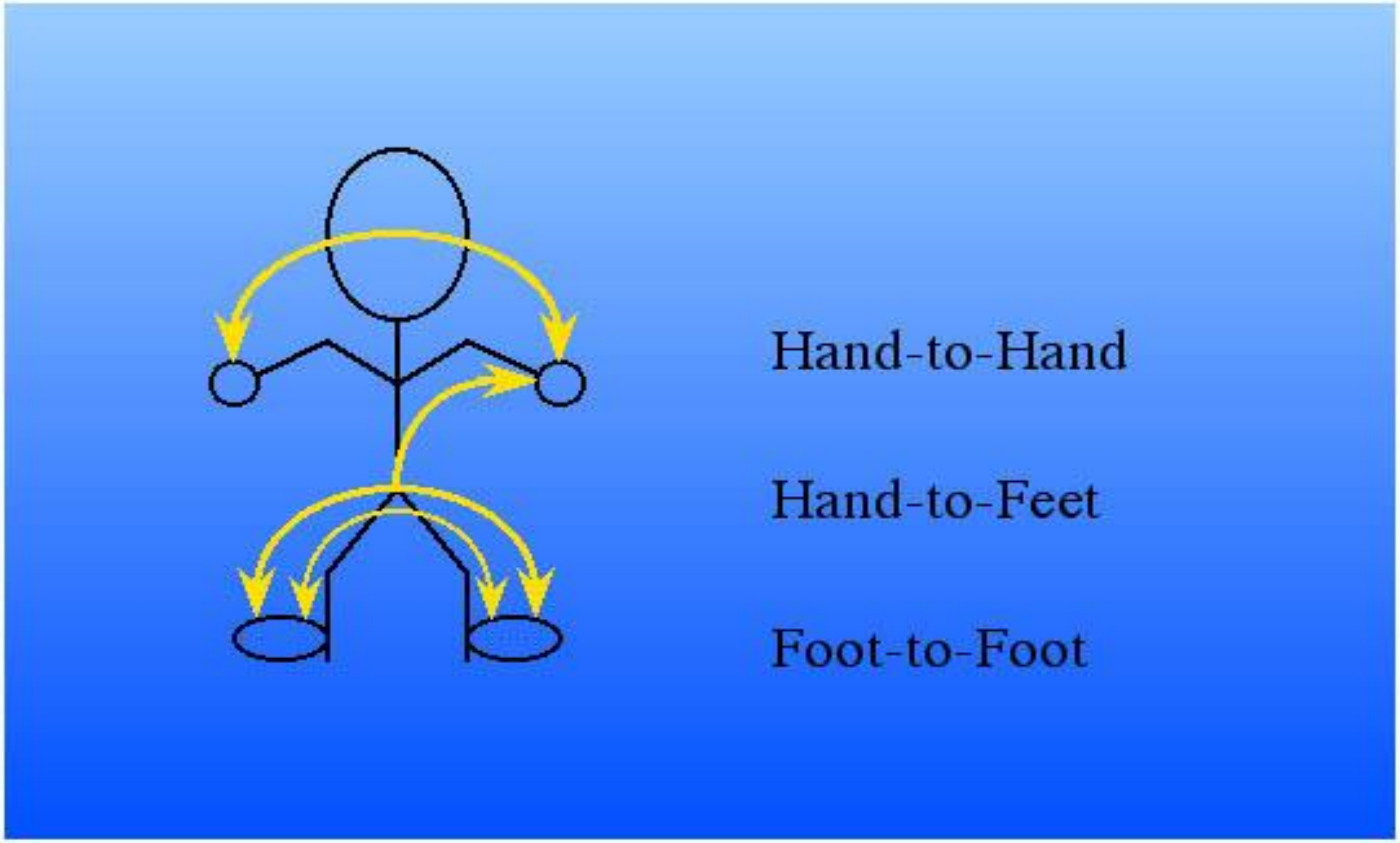
60 Hz ALTERNATING CURRENT VALUES AFFECTING HUMAN BEINGS

CURRENT	EFFECTS
l5 TO 20 mA	PAINFUL SHOCK -MUSCULAR CONTROL LOST, CANNOT LET GO.
20 TO 50 mA	PAINFUL SHOCK -SEVERE MUSCULAR CONTRACTIONS1 BREATHING DIFFICULT.
50 TO 100 mA (POSSIBLE)	VENTRICULAR FIBRILLATION -DEATH WILL RESULT IF PROMPT CARDIAC MASSAGE NOT ADMINISTERED.

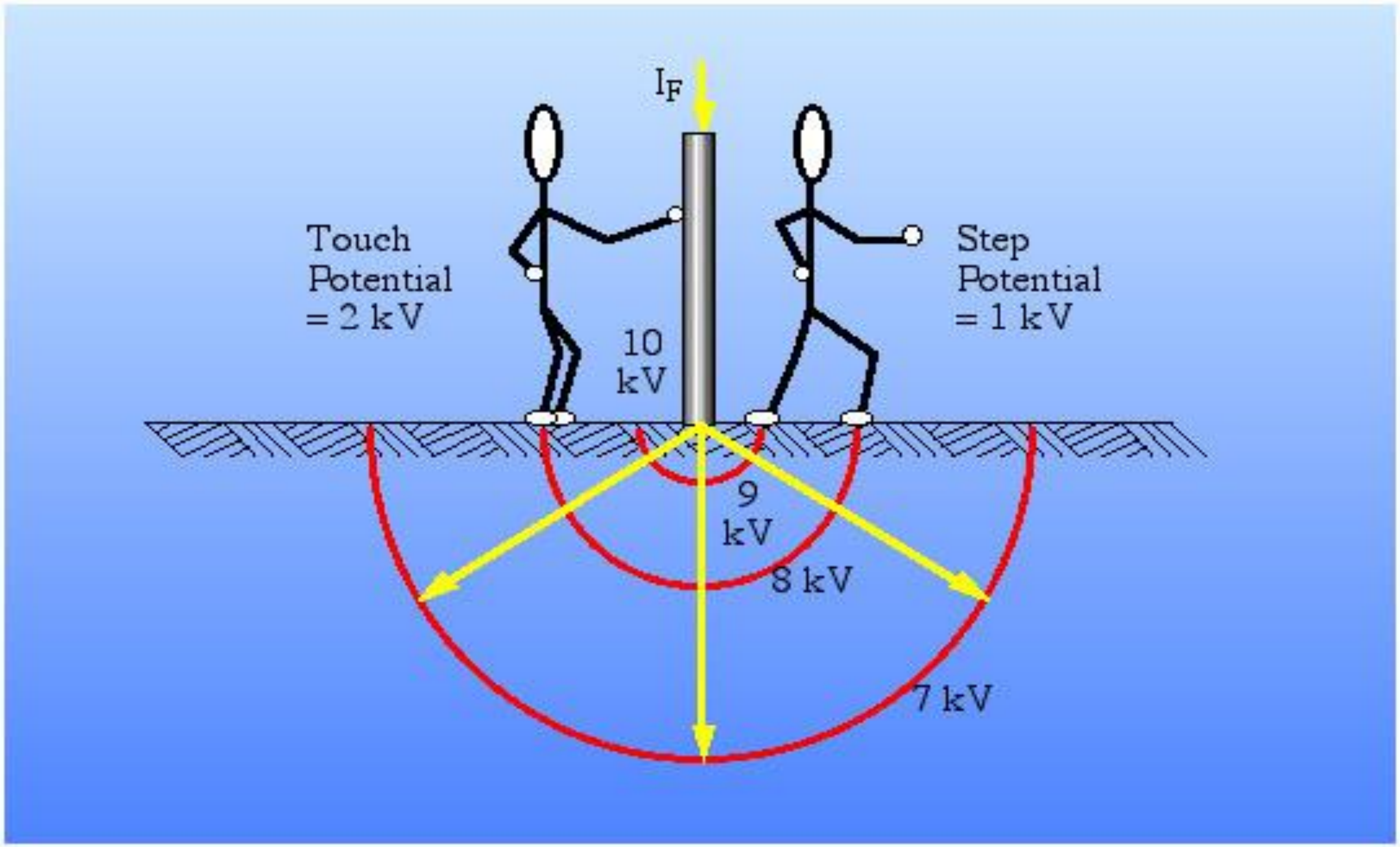
60 Hz ALTERNATING CURRENT VALUES AFFECTING HUMAN BEINGS

CURRENT	EFFECTS
100 TO 200 mA (CERTAIN)	DEFIBRILLATOR SHOCK MUST BE APPLIED TO RESTORE NORMAL HEARTBEAT. BREATHING PROBABLY STOPPED.
200 mA AND OVER	SEVERE BURNS - SEVERE MUSCULAR CONTRACTIONS CHEST MUSCLES CLAMP HEART AND STOP IT DURING SHOCK (VENTRICULAR FIBRILLATION IS PREVENTED), BREATHING STOPPED - HEART MAY START FOLLOWING SHOCK OR CARDIAC MASSAGE MAY BE REQUIRED.

Possible Body Current Paths



Possible Body Current Paths



Measurement and Safety Equipment

Equipment List:

- Two digital multimeters
- Two test leads at least 10 feet in length
- Clamp on AC ammeter
- Two earth contact probes preferably half cells

Measurement and Safety Equipment

- Rubber insulating gloves of at least 600V dielectric strength

Identifying Shock Hazards

Methodology

- The method employed is similar to how DC pipe-to-soil potentials are acquired
- Half cell needs to be placed in soil, and connected to the voltmeter before connection to the pipe.

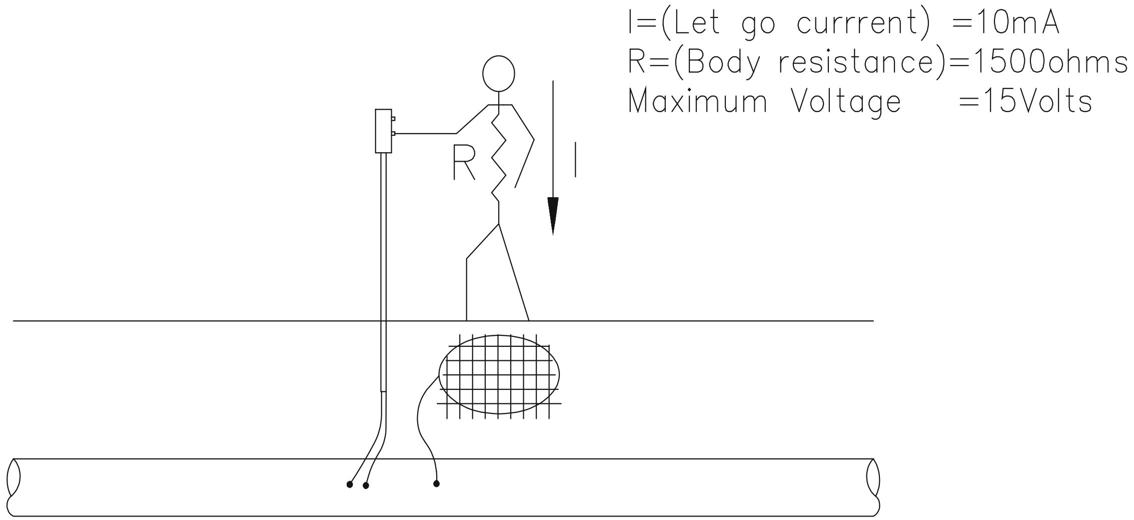
Identifying Shock Hazards

When to take AC voltage measurements

- Before work begins on a section of pipeline that parallels an HVAC transmission line
- Before working in close proximity to the parallel section of pipeline that is parallel to an HVAC transmission line

Hazardous AC Levels

Any AC measurement that exceeds 15 Volts AC across a span that is 10 ft. wide or less. Data is based on diagram shown below.

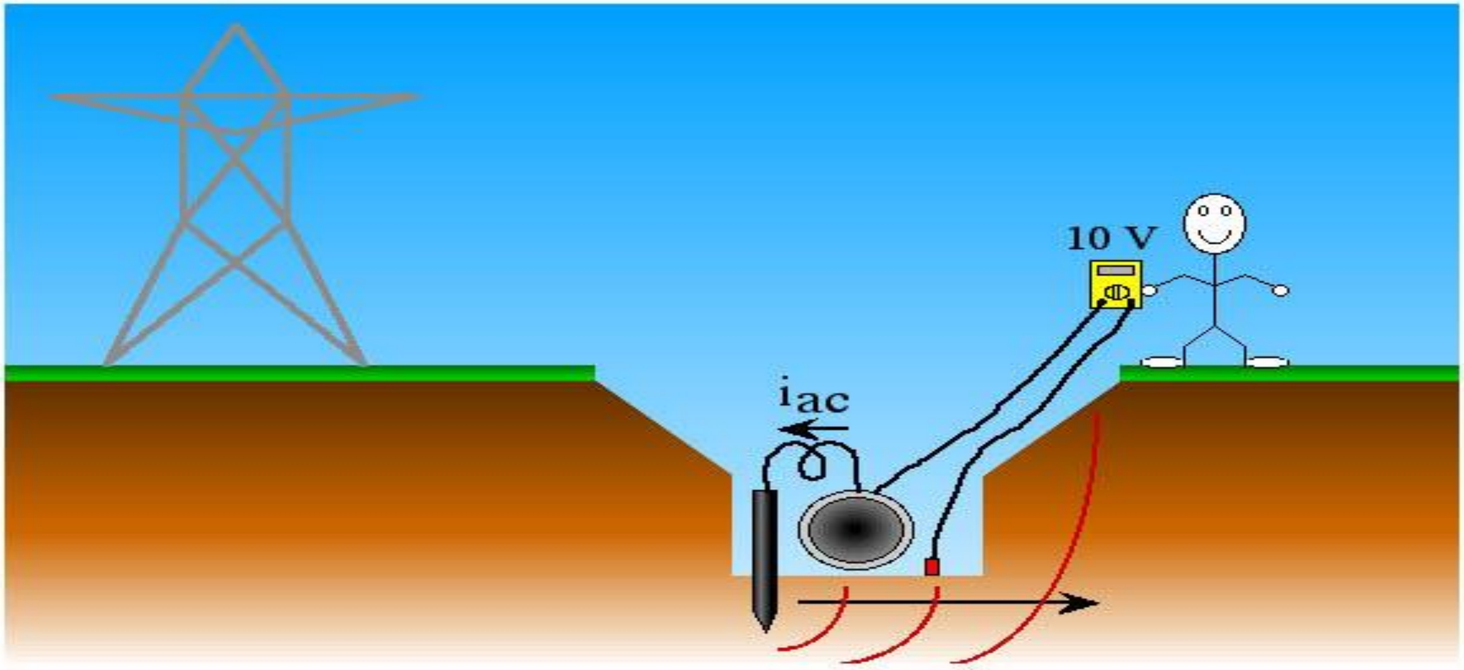


Hazardous AC Levels

Measured AC Voltage	Significance	Monitor	Mitigate
Less than 4V AC	Not Significant	N	N
Between 4V AC and 15V AC	Moderate	Y	N
At 15V AC or above	Significant	Y	Y

Hazardous AC Levels

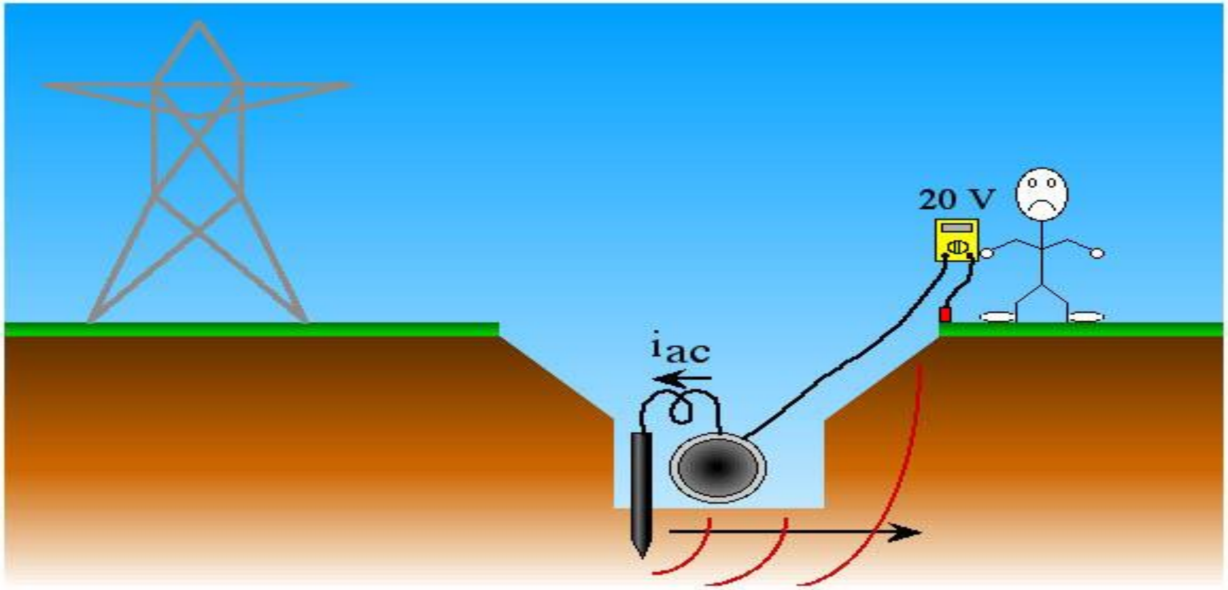
The importance of proper measurement distance



Distance is too short
(Image Courtesy of NACE International)

Hazardous AC Levels

The importance of proper measurement distance



Appropriate measurement span of 10 feet

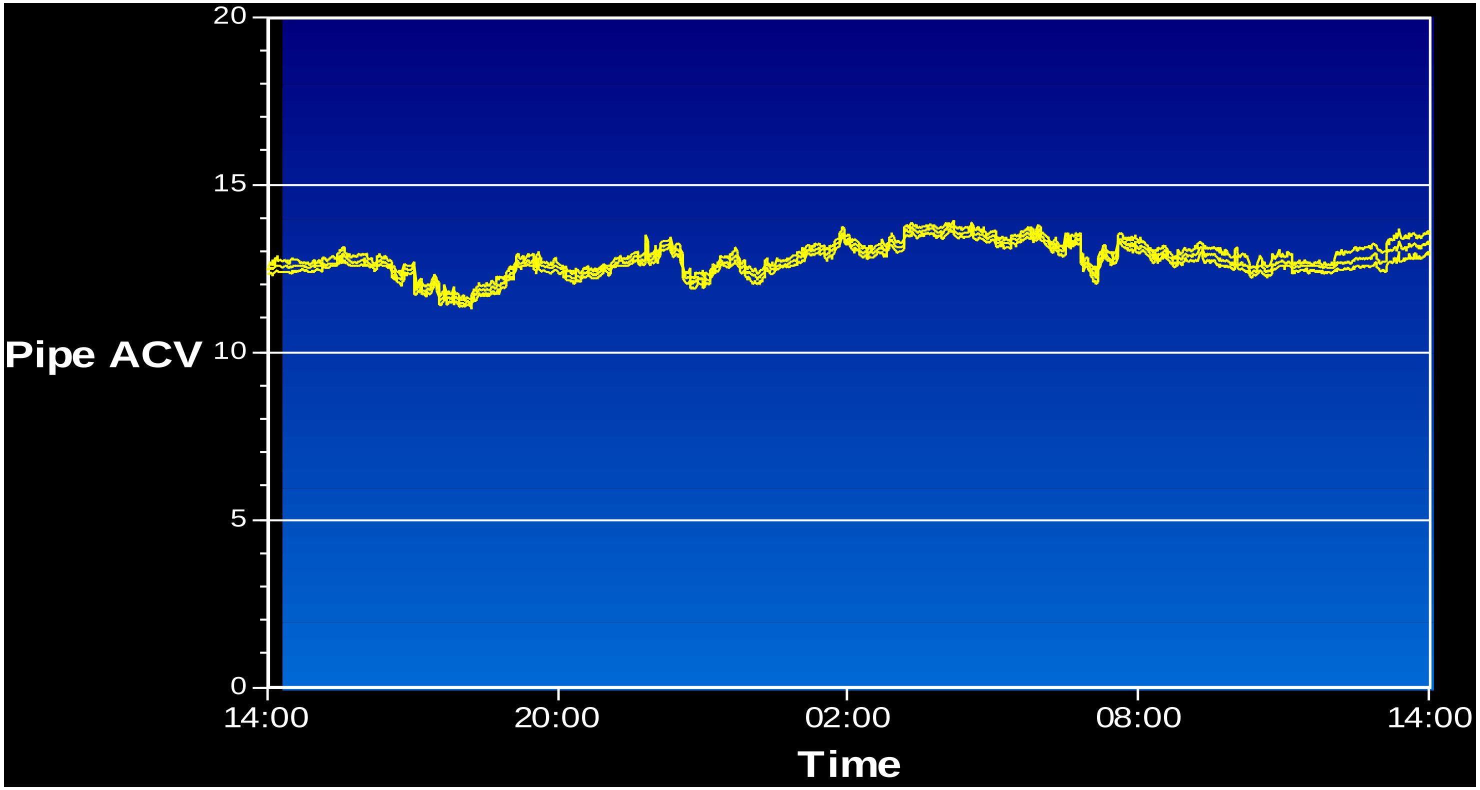
(Image Courtesy of NACE International)

Hazardous AC Levels

The importance of recorded measurement over time

- Induced AC voltages can change over time
- Initial measurements may indicate a non hazardous level.
- Environmental factors may affect AC voltages

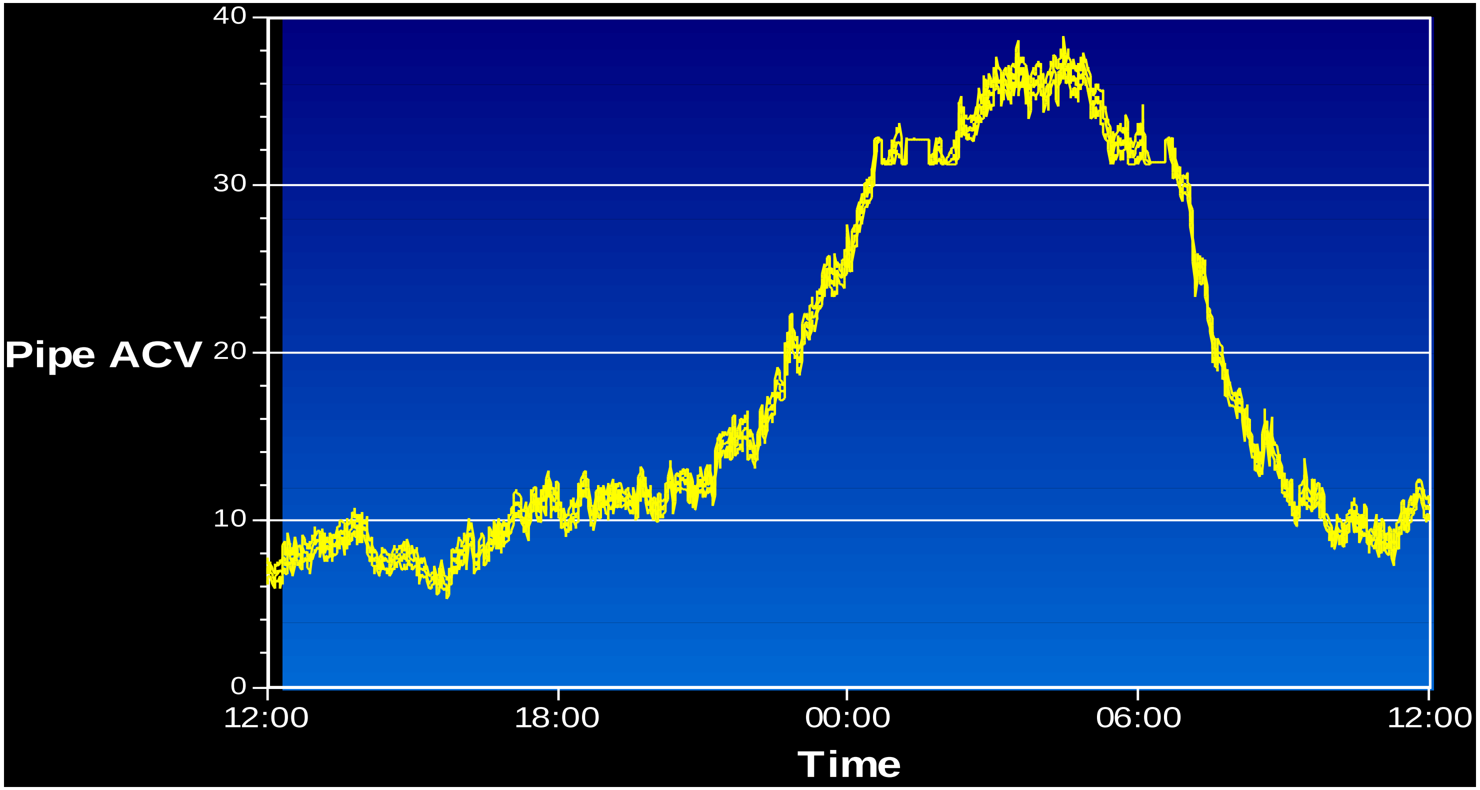
Hazardous AC Levels



Voltage vs. time with relatively constant load conditions

(Image Courtesy of NACE International)

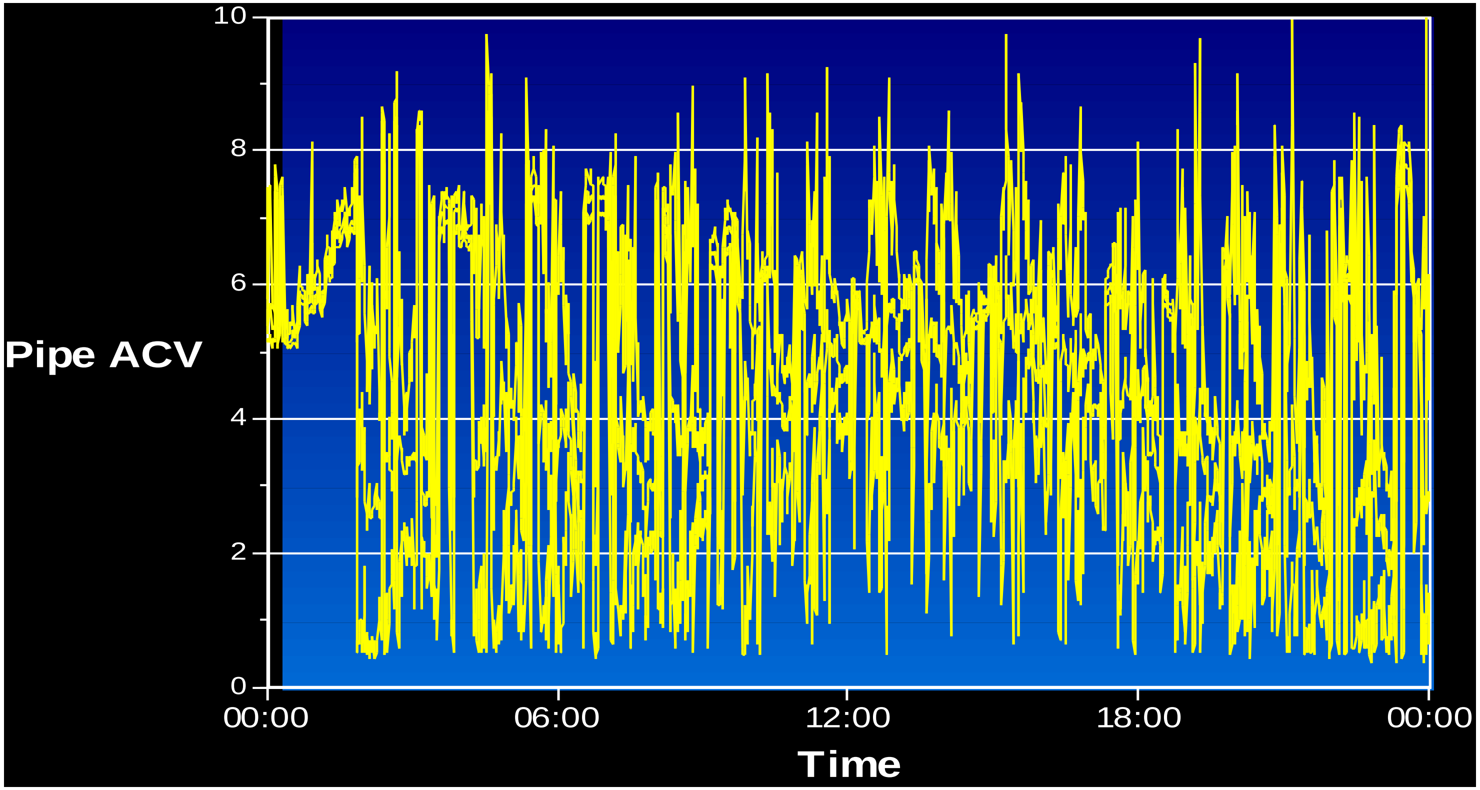
Hazardous AC Levels



Voltage vs. time showing a load change

(Image Courtesy of NACE International)

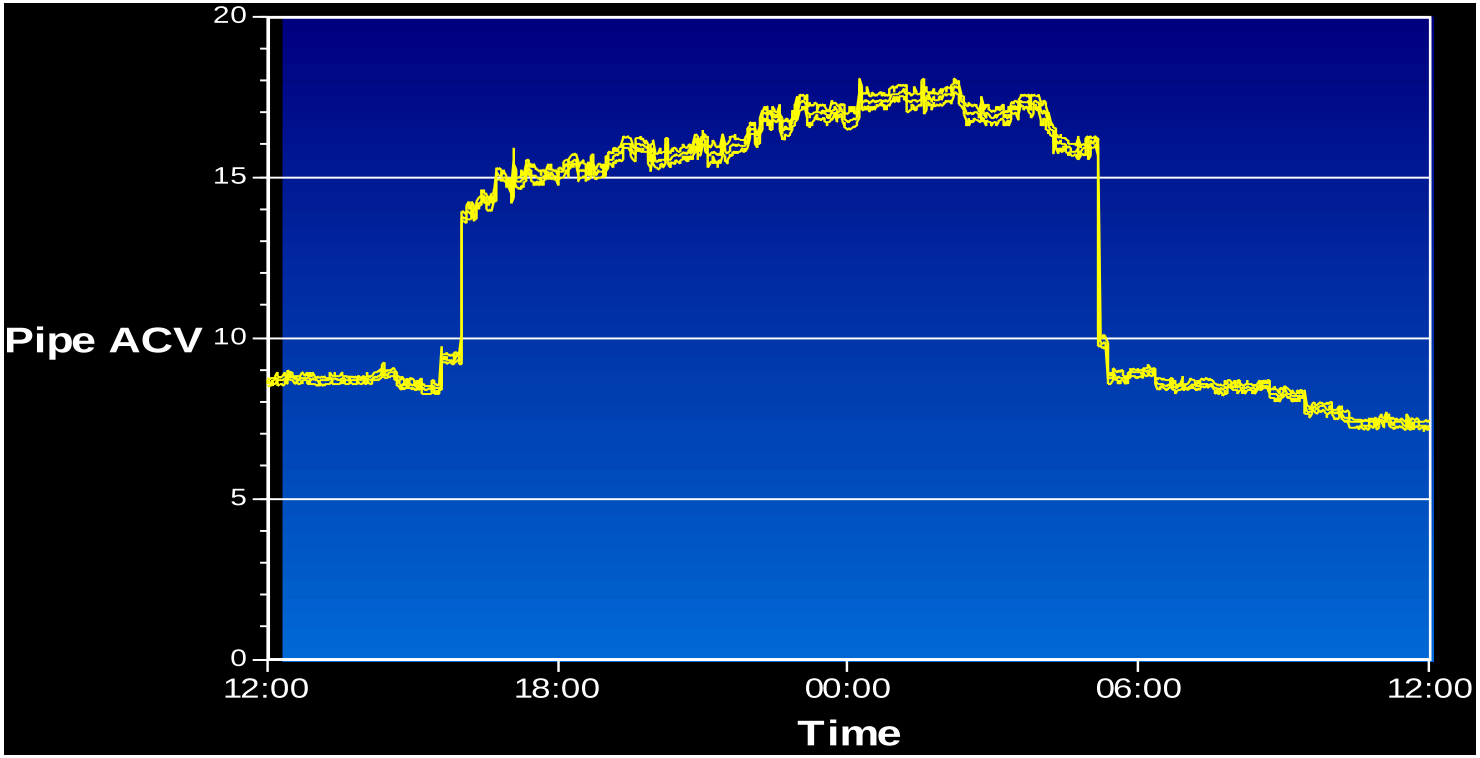
Hazardous AC Levels



Voltage vs. Time – Rapidly Changing Load

(Image Courtesy of NACE International)

Hazardous AC Levels



Voltage vs. Time -- Effects of Circuit Switching

(Image Courtesy of NACE International)

Discussion of AC Corrosion

- Reported since 19th Century
- Effects not well understood
- Studies in 1950's and 1960's concluded AC Corrosion effects were .1-1.0% of DC Effects
- Recent Studies have related metal removal power of AC
  - < 20A/m^2 – no corrosion
  - 20 – 100A/m^2 - corrosion is unpredictable
  - >100A/m^2 - corrosion is likely
- Electrochemical Model can be used to explain process

Cause of AC Corrosion on Pipelines

- Induced AC Leading to AC current discharge at Holidays.
- Contributing factors
  - Good coating quality leading to higher induced voltages and concentration effects.
  - Low soil resistivity leading to high discharge currents at Induced AC voltage.
- **AC Current Density**
  - $I_{Density} = 8*V_{AC} / d\rho\pi$

Required AC Voltage to Produce 100 A/m²

1 cm² Holiday in 10 ohm-m Soil

$$V_{ac} = \frac{i_{ac} \rho \pi d}{8}$$

$$V_{ac} = \frac{(100\ A/m^2)\ (10\ \Omega \cdot m)\ (3.14)\ (0.011 m)}{8}$$

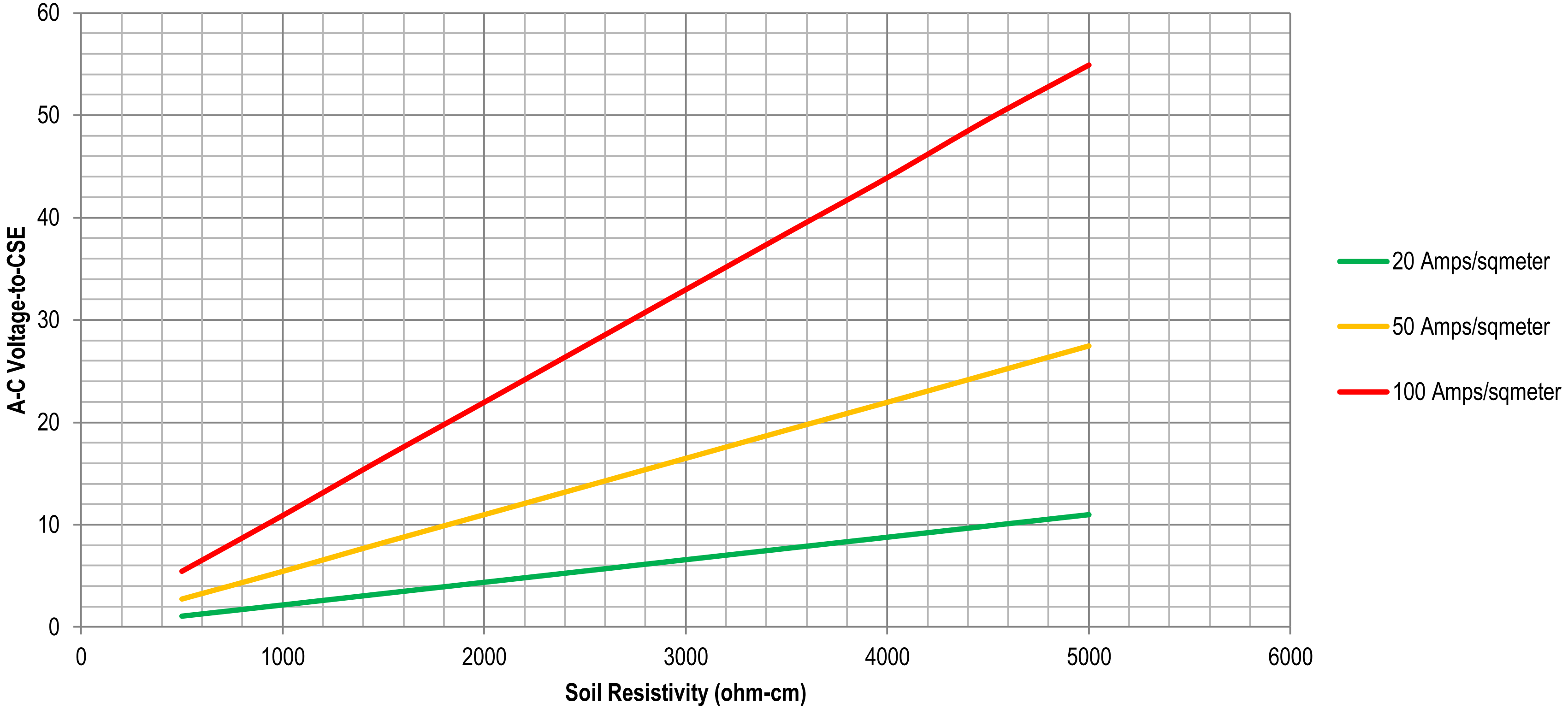
$$V_{ac} = 4.4\ V$$

A-C Corrosion as a Function of Holiday Current Density

No Corrosion Expected	$i_{ac} < 20\ A/m^2$
Corrosion Unpredictable	$20\ A/m^2 < i_{ac} < 100\ A/m^2$
Corrosion Expected	$i_{ac} > 100\ A/m^2$

Cathodic Protection is Not Effective in Controlling A-C Corrosion.

AC Voltage vs. Resistivity for Three Current Densities



Parameters Affecting Interference

- Geometry
- Soil and Coating Resistivity
- Transmission System Operating Characteristics

Geometry Factors

- Separation
- Depth Of Cover
- Pipe Diameter
- Angle of Collocation
- Tower Footing Design
- Phase Conductor Spacing and Average Distance Above Ground

Soil and Coating Resistance

- Coating Resistance
  - Affected by Type, Age and Moisture in Soil
    - Better equals Worse
- Power System Ground Resistance
  - Affected by Seasonal Variation
- Soil Resistivity
  - Affected by Seasonal Variation

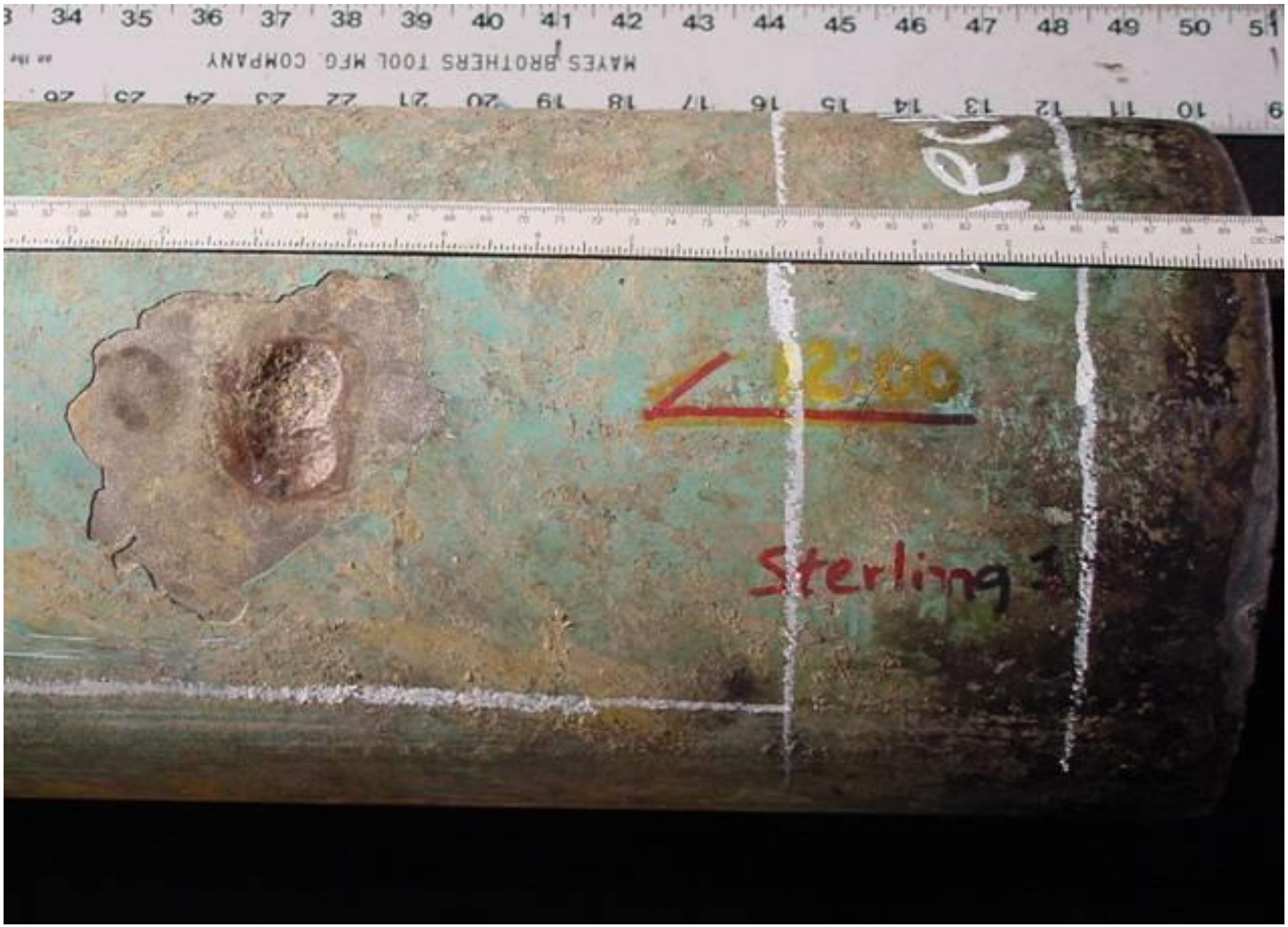
Transmission System Operating Parameters

- Phase Conductor Load
- Phase Balance
- Voltage and fault Current

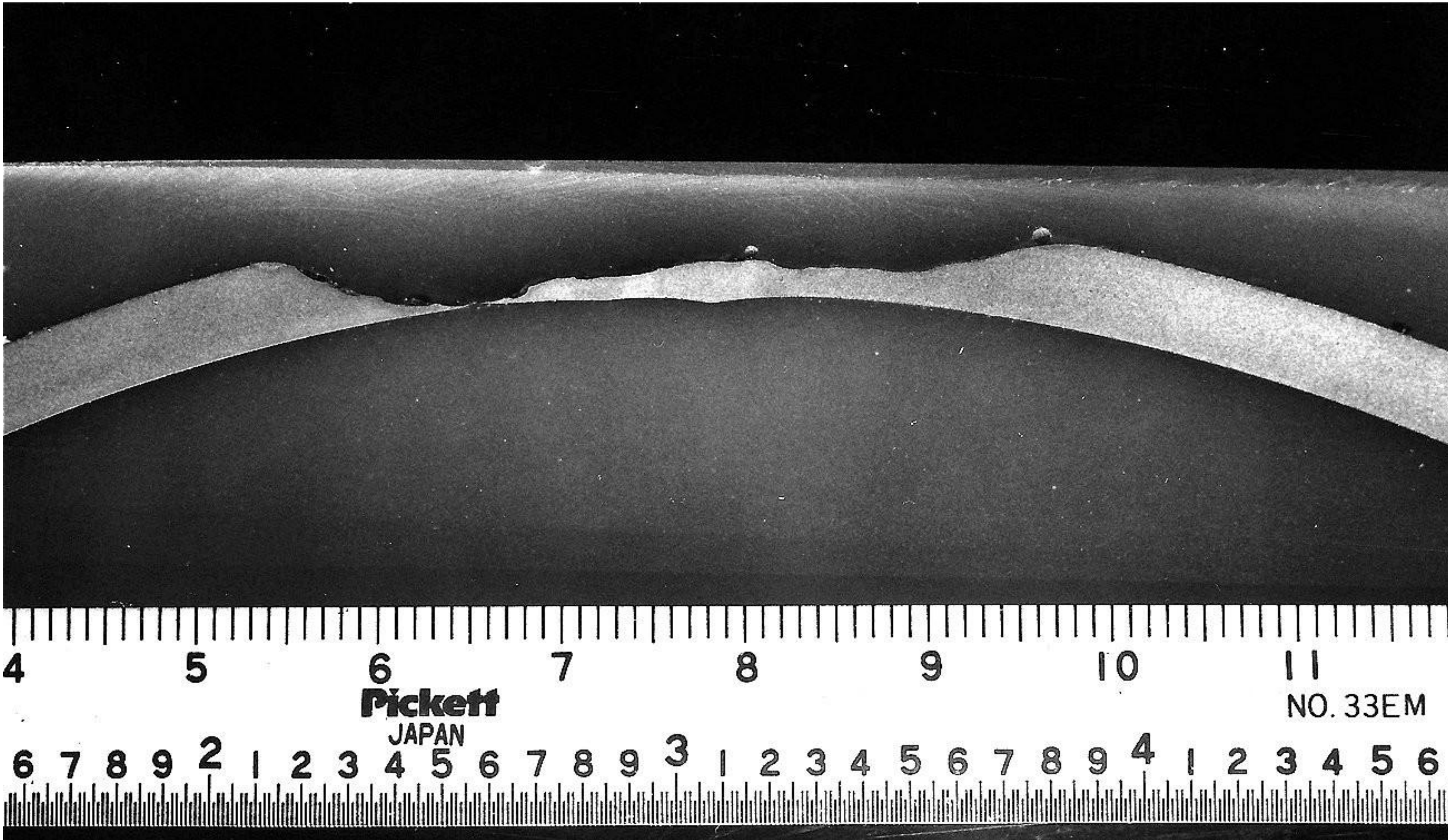
AC Stray Current Corrosion

- Characterized by round morphology
  - Unique shapes and colors
    - Almost perfectly round
    - Smooth edges
    - Pimpled Pattern
    - Brown discoloration
  - Corrosion product is not soluble
  - pH Neutral to Elevated
  - AC Current Densities > 100A/meter^2

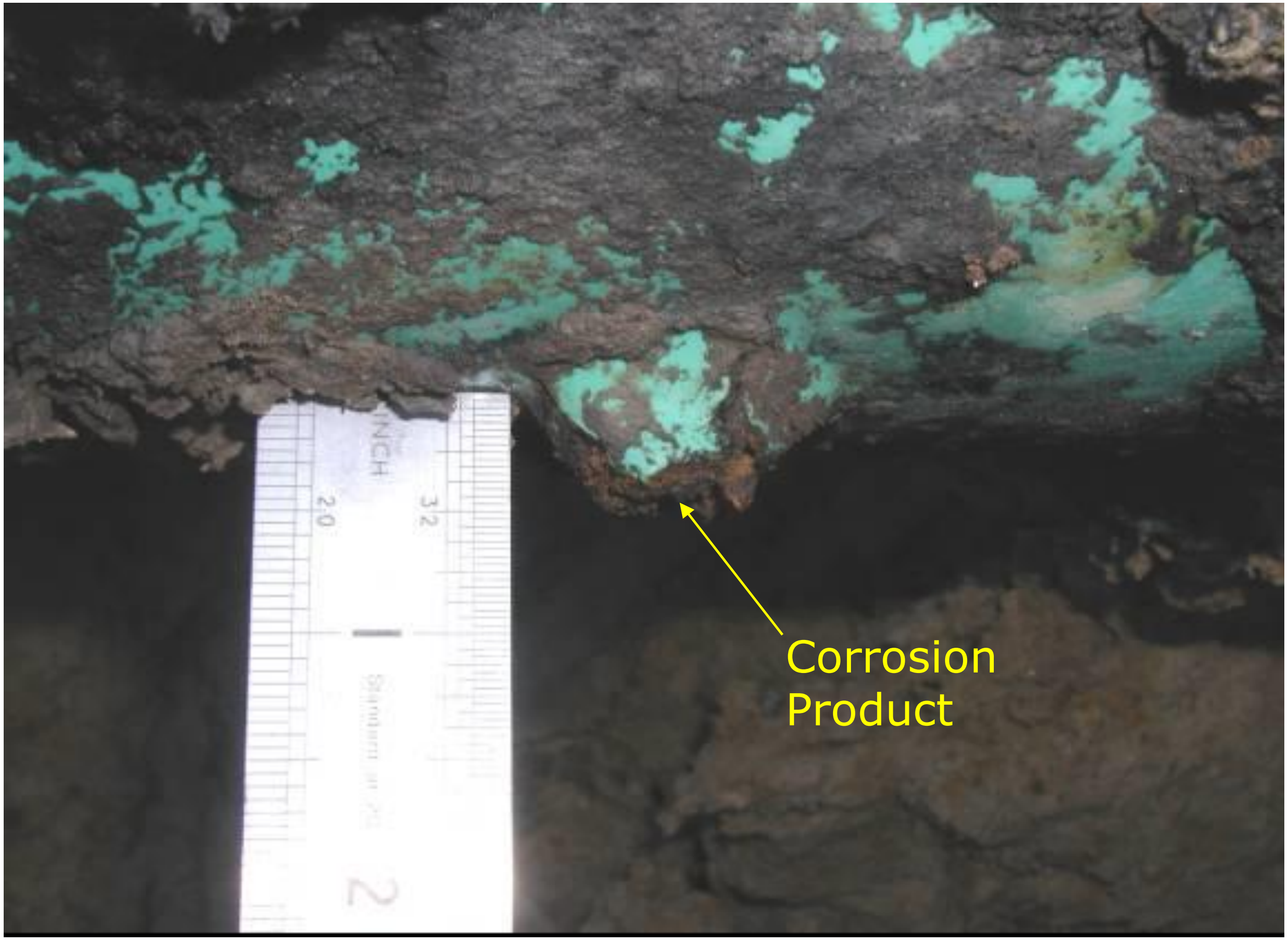
AC Corrosion on FBE Coated Pipeline Leaked 18 months After Installation



Metallographic Section

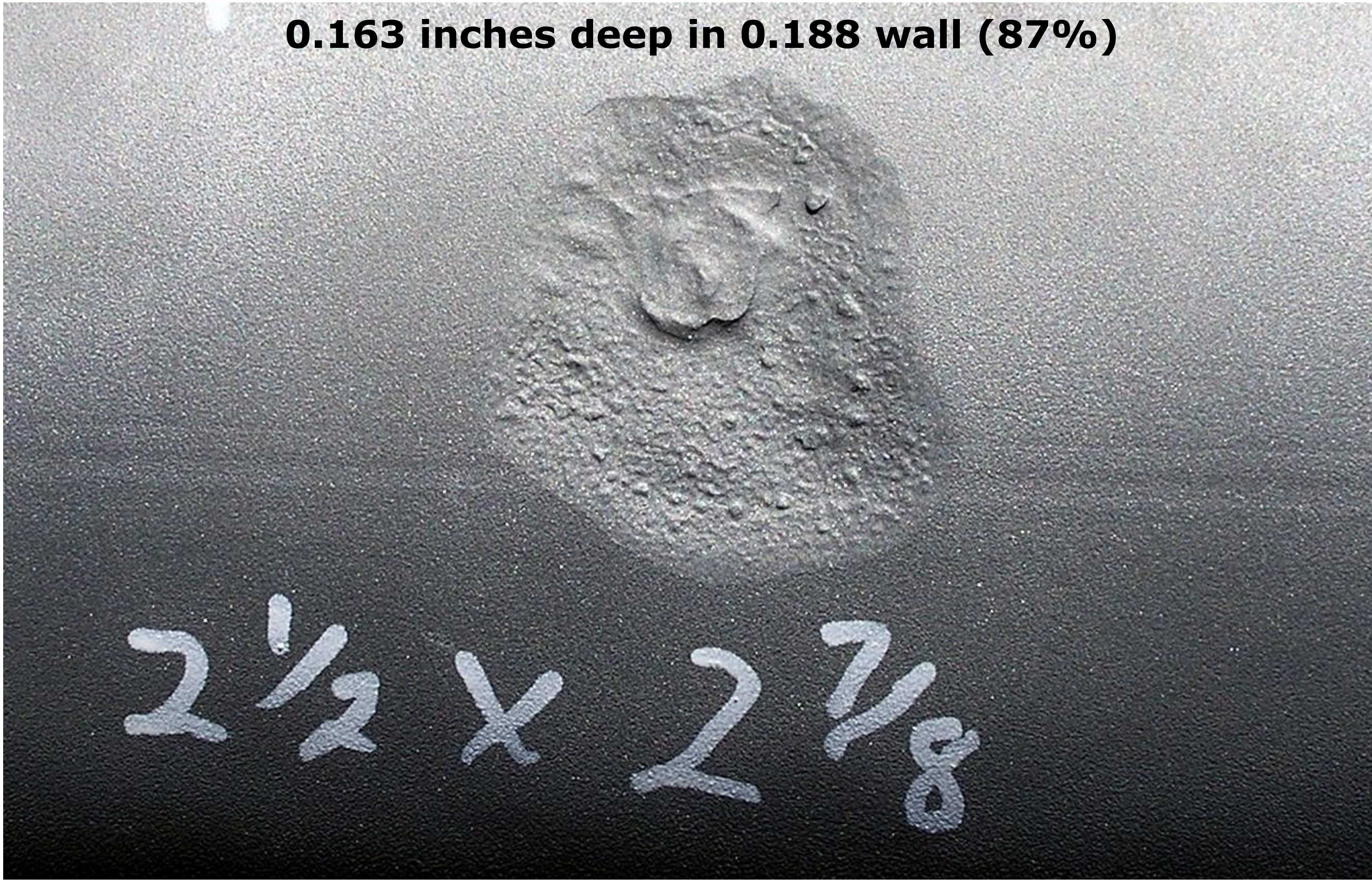


AC Corrosion on FBE Coated Pipeline




0.053 inches deep in 0.188 wall (28%)
1
2
3
4
5


08.08.2006 14:02


0.163 inches deep in 0.188 wall (87%)
2 1/2 x 2 7/8

Review/Conclusions

- AC corrosion exists
- Higher AC currents accelerate attack
- Possible at commercial frequencies
- Excessively High Corrosion rate
- No consensus on mechanism
- Scatter, testing conditions often not representative of real life

The electrical power grid in North America consists of three general circuit classifications

- Bulk or high voltage transmission lines from the generation source to primary substations typically run at 230 kV (kilovolts), 345 kV or 500 kV- and now 750 kV!
- Sub-transmission lines between major distribution centers operate at 69 kV, 115 kV, 138 kV or 161 kV.
- The distribution system at the customer level operates at 4.2 kV, 7.5 kV, 12.5 kV or 34.5 kV.
- From a practical standpoint HVAC lines 69 kV and under rarely have high enough phase load or available fault current to significantly affect the pipeline unless it is directly under the transmission line.

HVAC INTERFERENCE EFFECTS

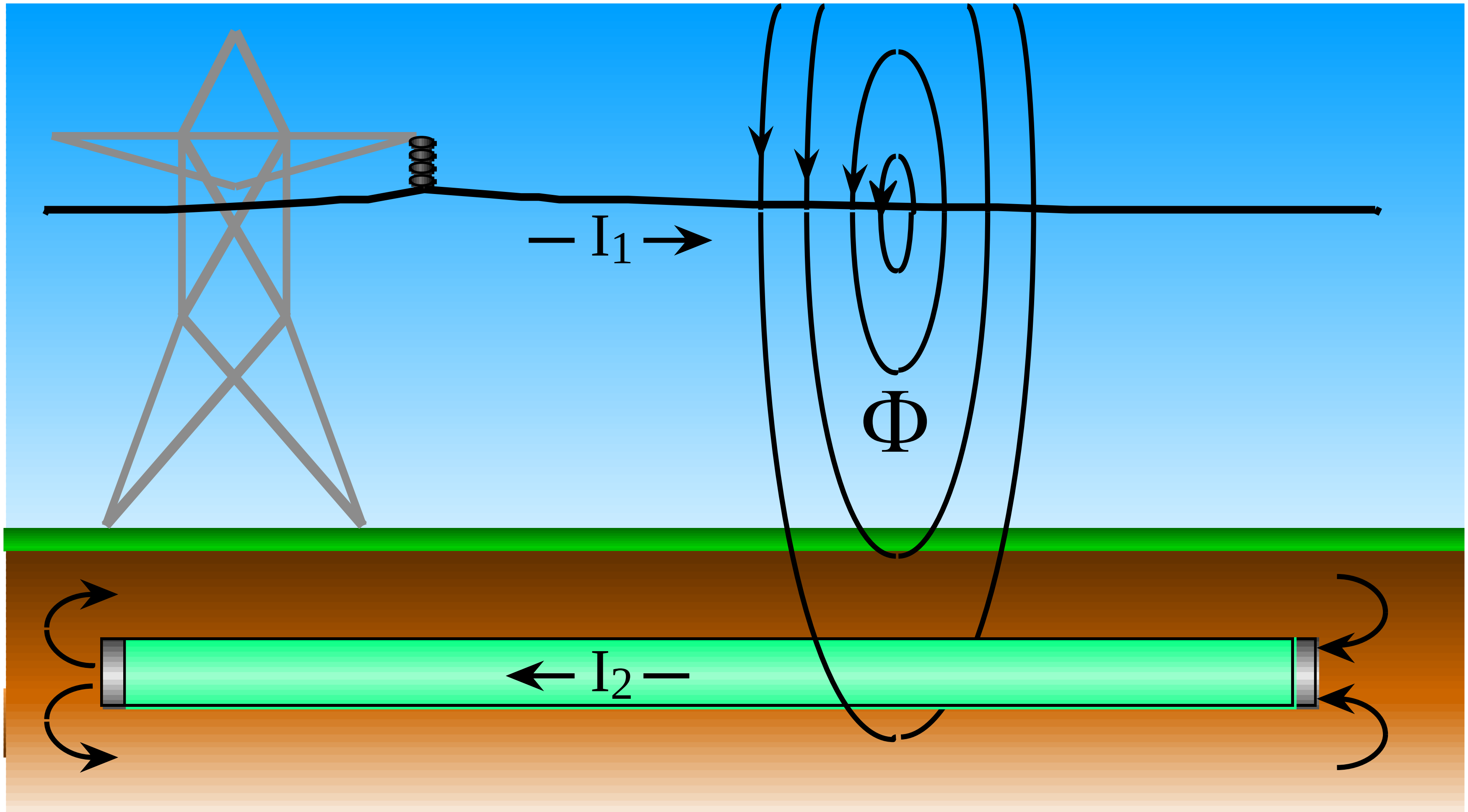
- Electromagnetic induction is the primary effect of the HVAC transmission line on the buried pipeline during normal (steady state) operation

- Conductive effects are primarily a concern when a fault occurs in an area where the pipeline is in close proximity to the transmission line and the fault currents in the soil are high

- Capacitive effects are primarily only a concern during construction when sections of the pipeline are above ground

- If these electrical effects are great enough during steady state normal operation or during a fault, a potential shock hazard exists for anyone that touches an exposed part of the pipeline, pipline damage can occur and AC corrosion mat occur.

Electromagnetic Coupling with Buried Pipeline



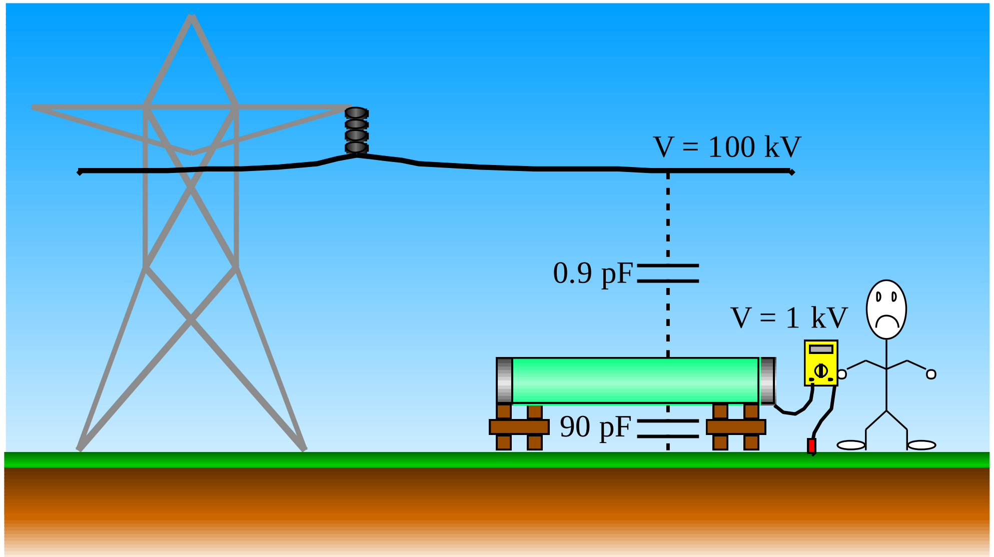
Electromagnetic (Inductive) Coupling

- Magnitude is a function of line current not voltage.
- Power transfer is
  - Proportional to line current
  - Proportional to length of parallelism
  - Inversely proportional to separation distance
- Can result in high voltages on long sections of pipeline.

Capacitive Coupling

RESULTS FROM ELECTROSTATIC CHARGES ON ABOVEGROUND METALLIC STRUCTURES.

EXTREMELY HAZARDOUS CONDITIONS MAY EXIST DURING PIPELINE CONSTRUCTION.

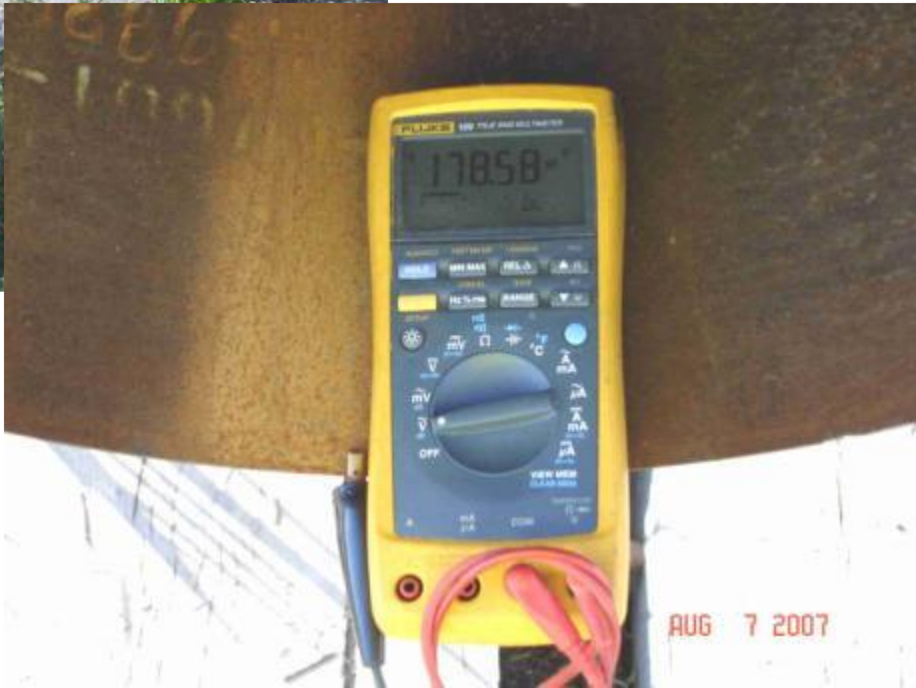


A function of line voltage, not current.
Can result in high voltages on short sections of pipeline, only if the pipeline is insulated from the earth.
Results in the transfer of very small amounts of electrical power to the pipeline, and so the current which can be transferred to a human body is relatively small.

Obvious Hazards During Construction

Not so Obvious Hazards During Construction

178 VAC!



242 VAC!!

65 VAC
Open

< 1 VAC
Grounded

Resistance Coupling

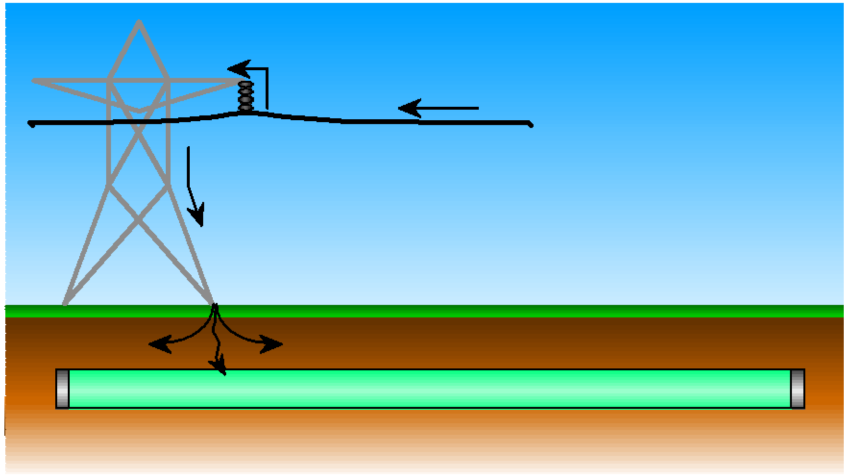
- Power Line Faults To Ground
- Very High Currents
- Infrequent
- Short Duration
- Cathodic Protection System Damage

Conductive or Resistive Coupling

- **OCCURS WHEN ENERGIZED CONDUCTORS OR SYSTEMS CONTACT METALLIC STRUCTURES OR WHEN GROUND FAULT CONDITIONS EXITS, CREATING POTENTIAL GRADIENTS IN SOIL.**

- **DIRECT CONTACT IS EXTREMELY DANGEROUS TO EQUIPMENT AND PERSONNEL.**

- **GROUND FAULT CONDITIONS CAN DAMAGE COATINGS AND PIPE WALLS.**



AC Fault Occurrences

- Relatively rare
- Short duration (e.g., 0.1 seconds)
- Generally due to adverse weather conditions
  - High winds
  - Lightning
- Sometimes due to structural failure, poor maintenance, or accidental damage to powerline structure.

Risk to Personnel

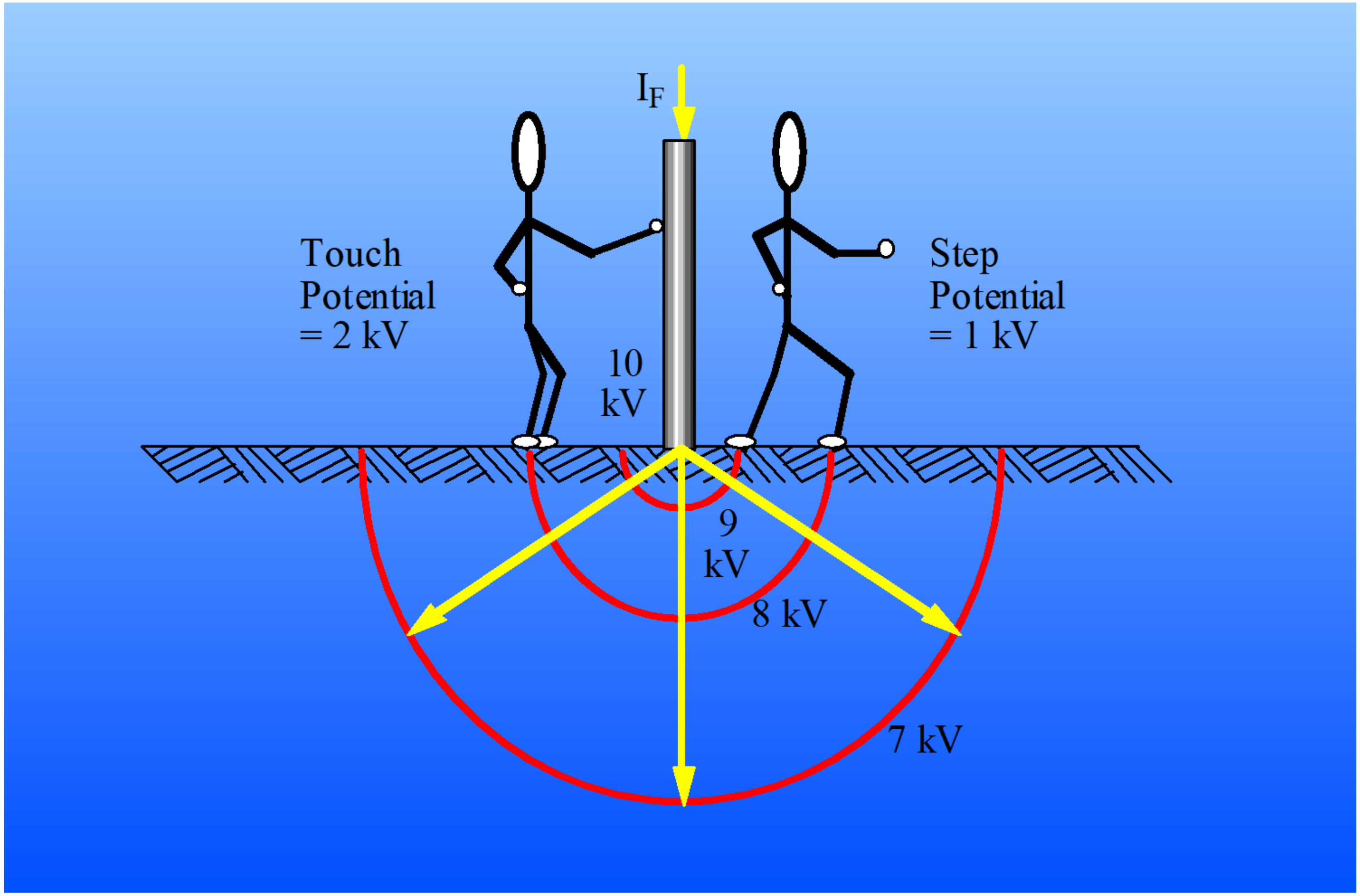
- Touch Potential (Normal Steady State and Fault Conditions)
  - Risk of Lethal Voltages And Current When Contacting A Structure
    - CP Test Stations
    - Valves
    - Aboveground Pipe Features
- Step Potential (Fault Conditions)
  - Risk of Lethal Voltages And Current When Standing with feet 1 meter apart

Nature of Power System Faults

- 70 % of AC Transmission Faults are Phase-to-Ground
  - Lightning
  - Insulator Failure
  - Mechanical Failure

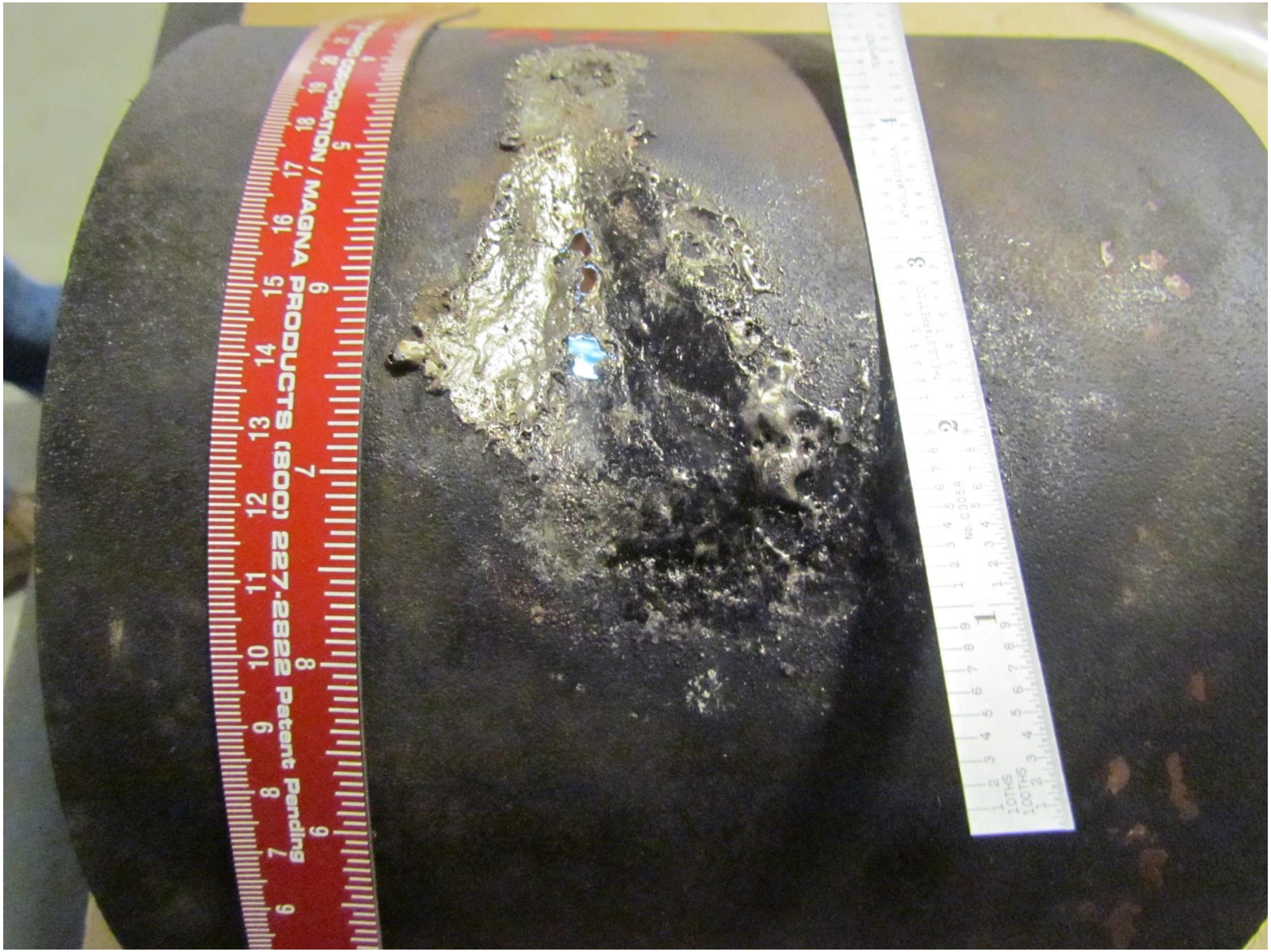
Touch & Step Potentials

at an Energized Grounded Structure



Pipeline Concerns

- Damage to coating and pipe wall due to intense heating effects at fault pick-up and discharge locations.
- Momentary voltage rise of pipe at appurtenances and test stations.
- Power-follow currents can damage bonds, flange insulation, dc decoupling devices, and rectifiers


CORPORATION / MAGNA PRODUCTS (800) 227-2822 Patent Pending

Parameters Affecting Interference

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- Transmission System Operating Characteristics

Geometry Factors

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- Depth Of Cover
- Pipe Diameter
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Soil and Coating Resistance

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- Power System Ground Resistance
  - Affected by Seasonal Variation
- Soil Resistivity
  - Affected by Seasonal Variation

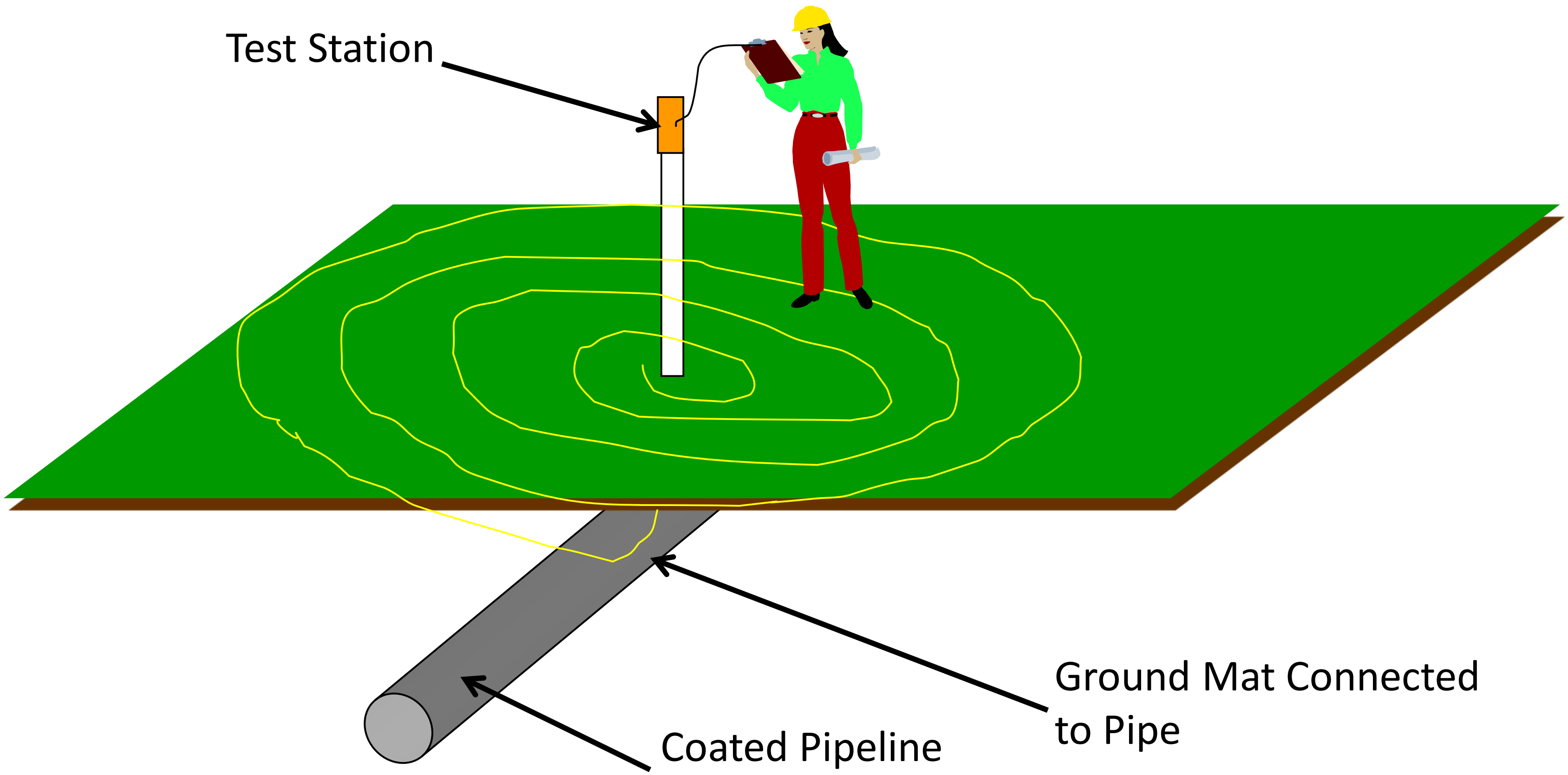
Transmission System Operating Parameters

- Phase Conductor Load
- Phase Balance
- Voltage and fault Current

Mitigation Strategy

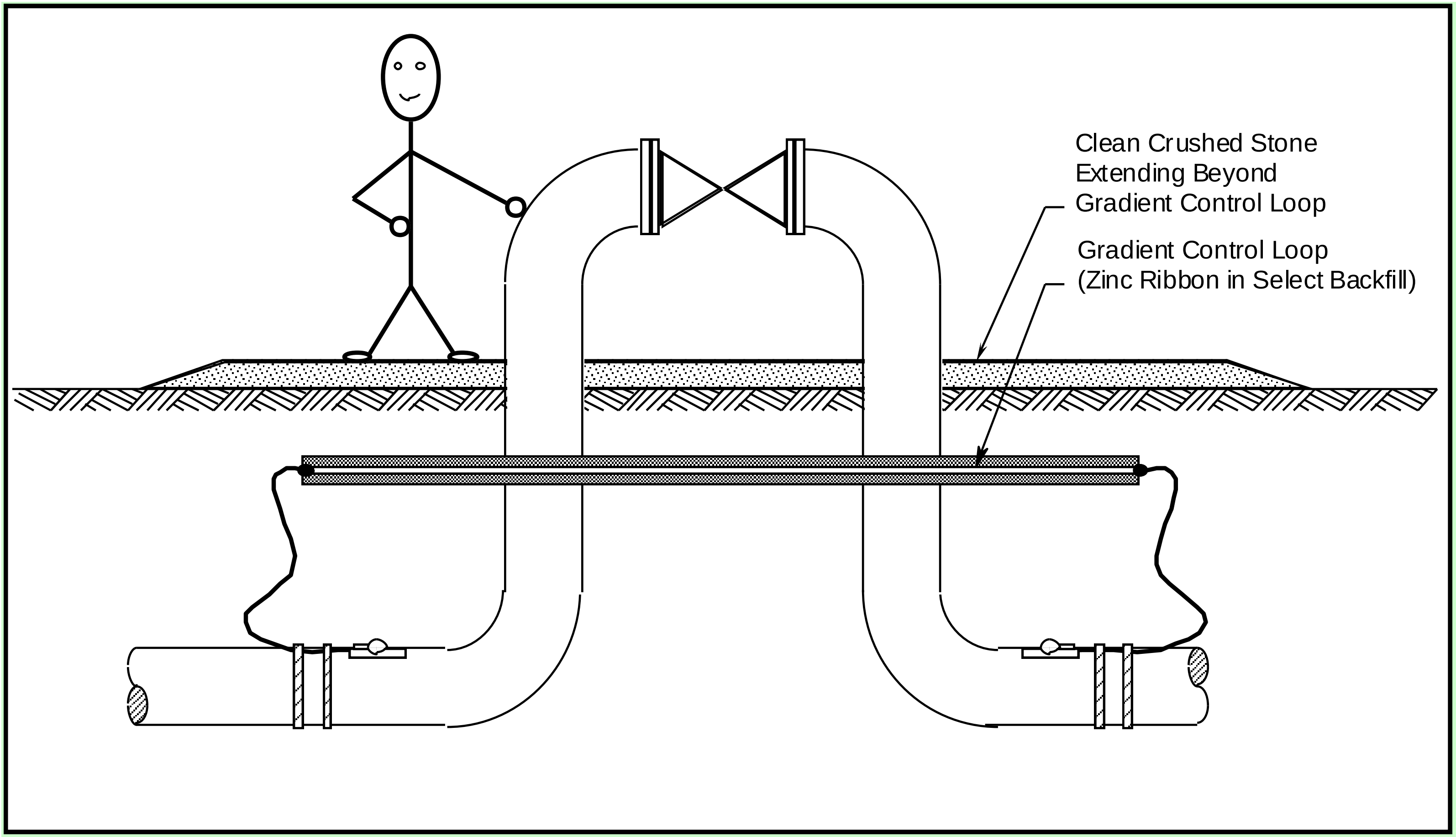
- Reduce AC Voltage along Pipeline to maintain Safe Step and Touch Potentials
  - NACE RP0177 - < 15 Volts A-C
- Mitigate AC Current densities to <20A/m2
- Provide for a Long Life for Grounding Material
  - Zinc
  - Magnesium
  - Copper
  - Proprietary materials
- Consider role of Soil Environment
  - High Resistivity Results in Higher Voltage Differences
  - Low Soil Resistivity Provides for Lower Voltage Differences
- Do Not Ground to Tower Facilities
  - Faults can be directly transferred
- Use Decouplers
- Consider Ground Mats and Crushed Rock to insulate from Ground at Appurtenances

Typical Gradient Control Ground Mat Used to Protect Personnel from Electric Shock



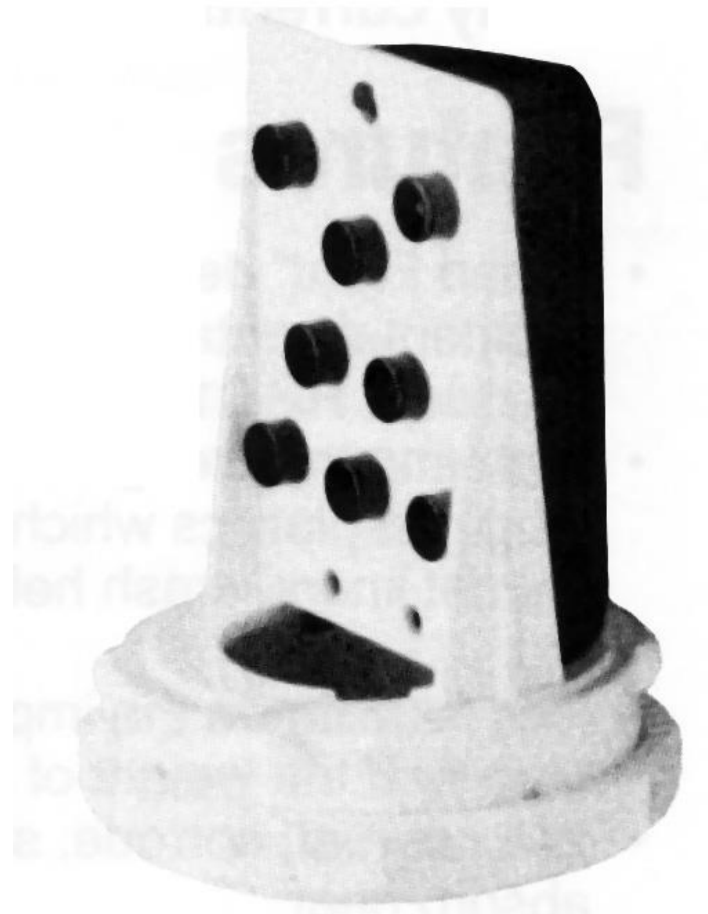
Mitigation of Touch Potentials

at Above-Ground Appurtenance



Power Corridor Test Stations
Dead–Front Test Station

- Best choice for personnel safety
  - Plastic construction
  - Prevents accidental contact with voltages on leads & terminals
- Good choice for public safety
  - Cover is lockable
  - Lock is plastic & cover can be broken open

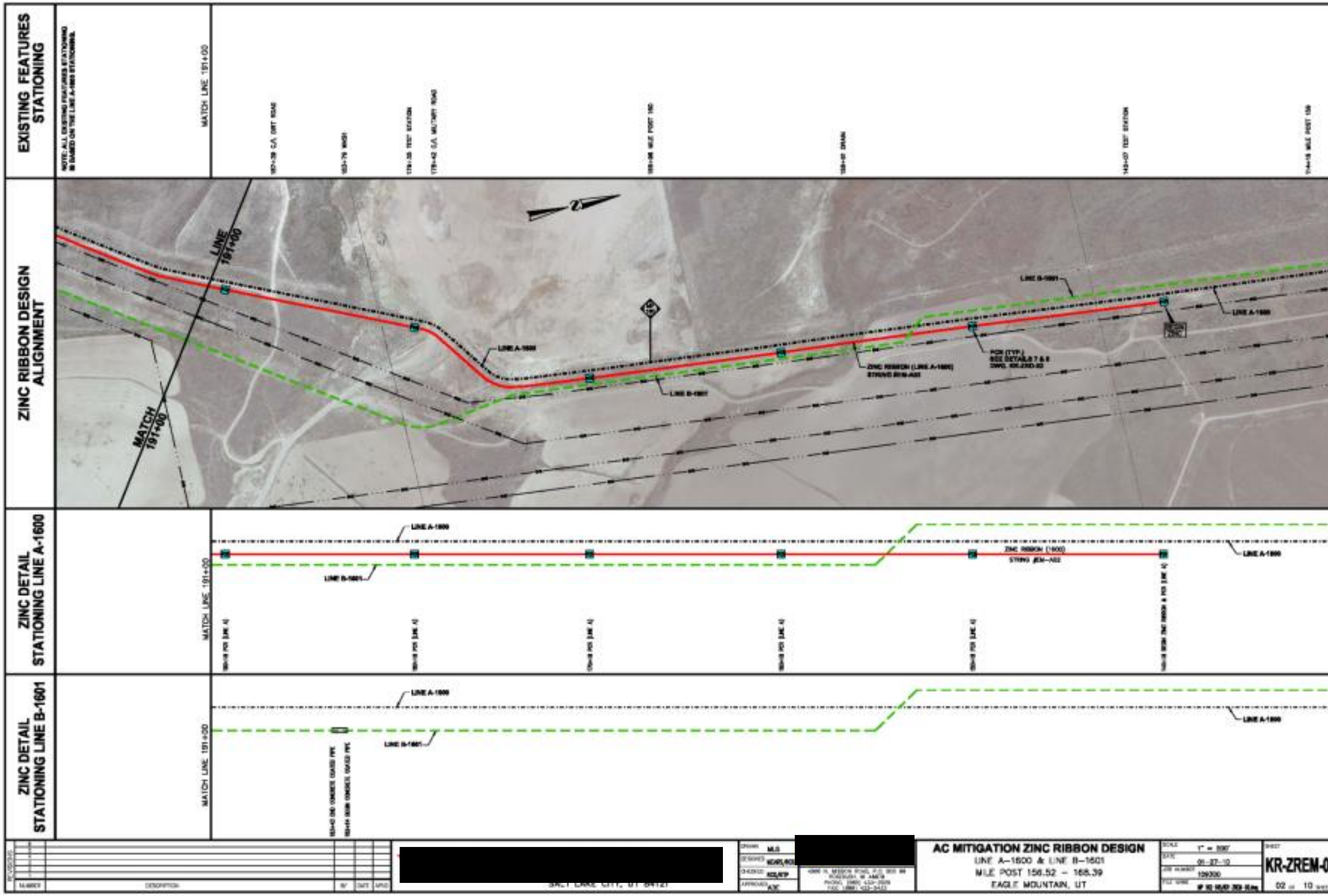


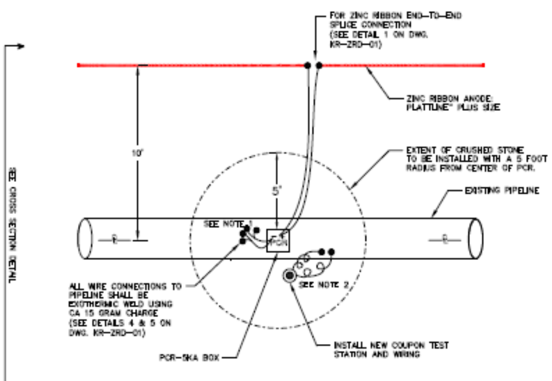
Solid-State DC Decoupler

- High DC impedance
- Low AC impedance
- Passes steady-state induced AC current
- Rated for lightning and AC fault current
- Fail-safe construction
- Third-party listed to meet electrical codes
- No power source req'd

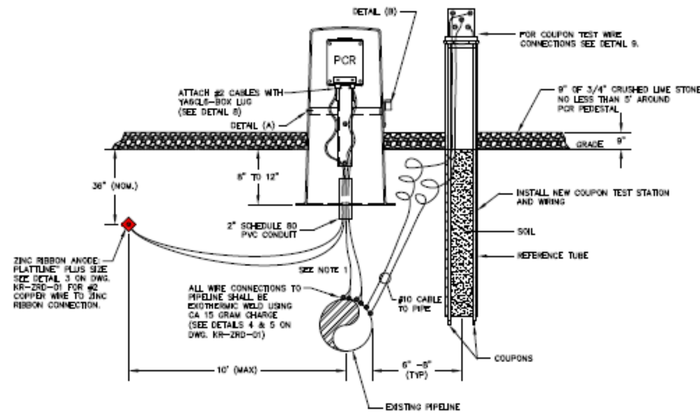
Solid State D-C Decoupler

- Limits D-C Conduction to less than 1 milliamp
- Low Impedance path for A-C <0.3 Ohms.
- Electrically Shorts for Large Voltage Potential Adross terminals and Clears when normal voltage is restores.
- Lead Lengths Must be Kept Short.


EXISTING FEATURES STATIONING
ZINC RIBBON DESIGN ALIGNMENT
ZINC DETAIL STATIONING LINE A-1600
ZINC DETAIL STATIONING LINE B-1601
MATCH LINE 191+00
LINE 191+00
MATCH 191+00
LINE A-1600
LINE B-1601
AC MITIGATION ZINC RIBBON DESIGN
LINE A-1600 & LINE B-1601
MILE POST 156.52 - 168.39
EAGLE MOUNTAIN, UT
KR-ZREM-02



PLAN VIEW



CROSS SECTION

DETAIL 7

TYPICAL – ZINC RIBBON CONNECTION TO PIPELINE PCR AT TEST STATION

NTS

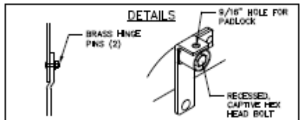
LEGEND

- ZINC RIBBON ANODE PLATTLINE™ PLUS SIZE
- NO. 2 AWG HMWPE STRANDED COPPER CABLE
- DC DECOUPLER (DAIRYLAND INDUSTRIES OR PCR-SKA)
- ANODE TO HEADER CABLE SPLICE
- EXOTHERMIC WELD TO PIPELINE
- COUPON TEST STATION

NOTES

1. NEGATIVE CABLES TO PIPE SHALL HAVE BLACK INSULATION; POSITIVE CABLES SHALL HAVE RED INSULATION.
2. COUPON TEST STATION SHALL BE INSTALLED ON POWERLINE SIDE OF PIPELINE.

DETAILS

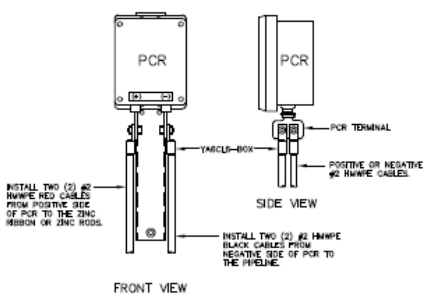


DETAIL A
NTS

DETAIL B
NTS

LINE A–1600 ZINC RIBBON LOCATIONS						
START STATION	END STATION	STRING NUMBER	DESCRIPTION	ZINC ROD TOTAL	ZINC RIBBON TOTAL	PCR TOTAL
395+12	44+35	EM–A01	ZINC RIBBON		6,310	
140+18	385+72	EM–A02	ZINC RIBBON		25,265	
464+90	612+50	EM–A03	ZINC RIBBON		14,760	
		EM–A01	PCR'S			7
		EM–A02	PCR'S			26
		EM–A03	PCR'S			16
TOTALS					46,335	49

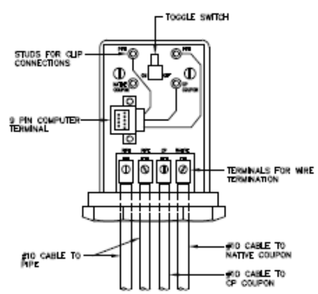
LINE B–1601 ZINC RIBBON LOCATIONS						
START STATION	END STATION	STRING NUMBER	DESCRIPTION	ZINC ROD TOTAL	ZINC RIBBON TOTAL	PCR TOTAL
391+45	27+29	EM–B01	ZINC RIBBON		4,620	
205+70	620+80	EM–B02	ZINC RIBBON		41,510	
		EM–B01	PCR'S			6
		EM–B02	PCR'S			43
TOTALS					46,335	49



DETAIL 8

PCR #2 CABLE CONNECTIONS

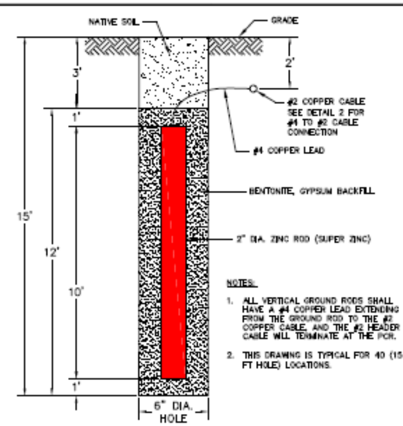
NTS



DETAIL 9

COUPON TEST STATION CONNECTIONS

NTS



NOTES:

1. ALL VERTICAL GROUND RODS SHALL HAVE A #4 COPPER LEAD EXTENDING FROM THE GROUND ROD TO THE #2 COPPER CABLE, AND THE #2 HEADER CABLE WILL TERMINATE AT THE PCR.
2. THIS DRAWING IS TYPICAL FOR 40 (15 FT HOLE) LOCATIONS.

DETAIL 10

VERTICAL ZINC GROUND ROD DETAIL

NTS

REVISIONS				
6				
5				
4				
3				
2				
1				
NUMBER	DESCRIPTION	BY	DATE	APVD

DRAWN	MLS
DESIGNED	MEARS/KCS
CHECKED	KCG/KTP
APPROVED	ADE

Mears Group, Inc.
4500 N. MISSION ROAD, P.O. BOX 66
ROSEBUSH, MI 48878
PHONE: (989) 433-2929
FAX: (989) 433-5433

AC MITIGATION ZINC RIBBON DESIGN

LINE A – 1600 & LINE B – 1601

CONSTRUCTION DETAILS

EAGLE MOUNTAIN, UT

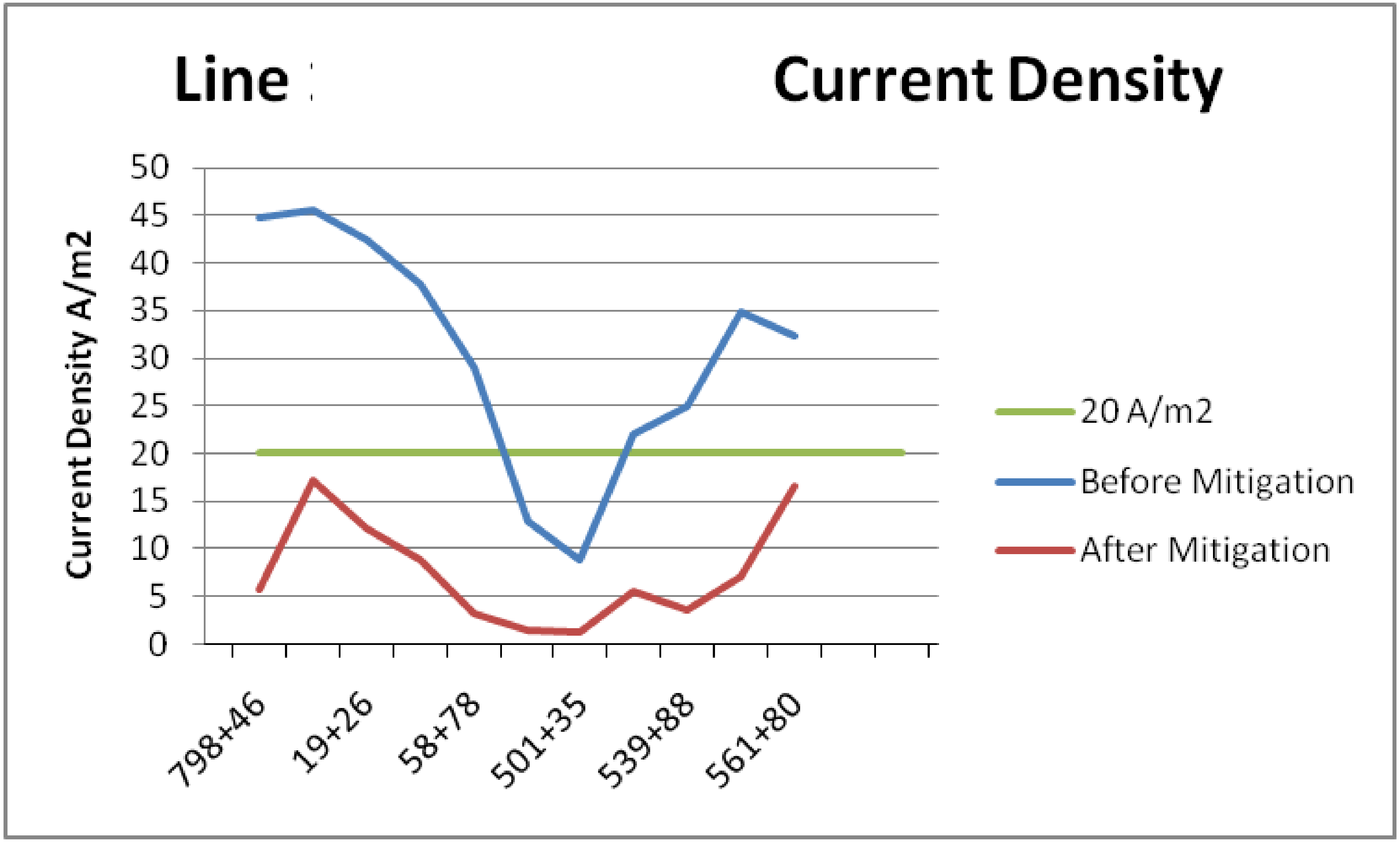
SCALE	NTS
DATE	1-27-10
JOB NUMBER	109300
FILE NAME	KR-ZRD-02.DWG

SHEET KR-ZRD-02

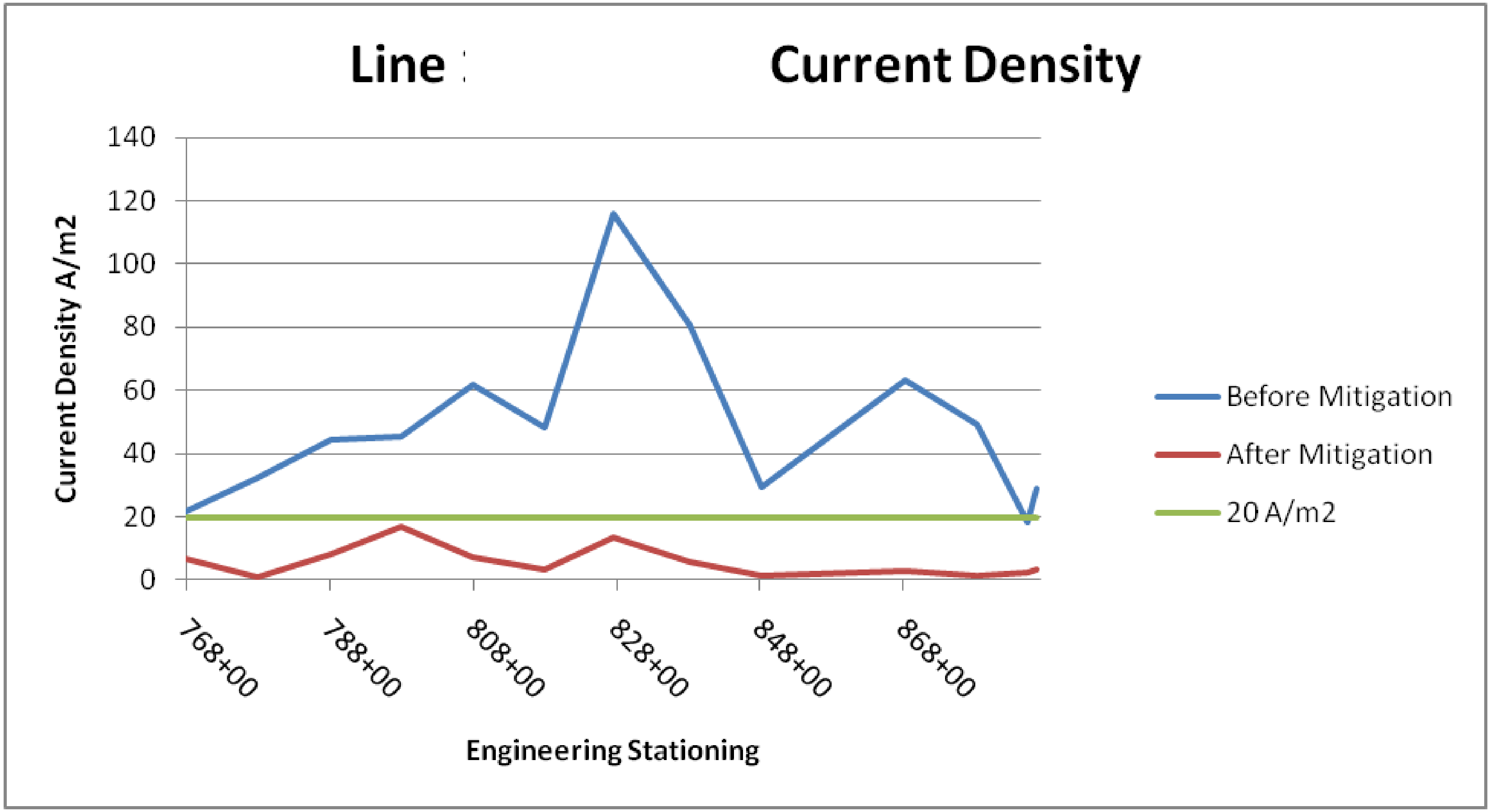
02 OF 02 SHEETS


CATERPILLAR
D7R
CATERPILLAR

Typical Results



Typical Results



YOU THINK YOU HAVE PROBLEMS?