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UNIFIED FACILITIES MANUAL (UFM)

OPERATION AND MAINTENANCE: CATHODIC PROTECTION SYSTEMS

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FOREWORD

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UNIFIED FACILITIES MANUAL (UFM)

OPERATION AND MAINTENANCE: CATHODIC PROTECTION SYSTEMS

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CHAPTER 1 INTRODUCTION

1-1 PURPOSE AND SCOPE.

This UFM provides guidance for operation and maintenance of CP systems. It should be used by field personnel to perform scheduled inspections and preventive maintenance and to troubleshoot and repair CP systems. Information on non-routine field measurements is also included to enable technical assistance personnel to troubleshoot problems beyond the normal capability of field personnel to isolate or correct.

1-2 APPLICABILITY.

CP is an electrochemical (half electrical and half chemical) method used to control corrosion of buried or submerged metallic structures. It prevents corrosion by making the protected structure a cathode by installing a more anodic metal (sacrificial or galvanic) anode or a metallic (impressed current) anode connected to a direct current (DC) power source. When the proper amount of current is applied, all of the anodic areas on the structure are changed to the same potential, thereby removing all of the anodic locations and allowing the entire structure to become a cathode. Since all corrosion occurs at the anode, the structure no longer corrodes. The electrons move in the metallic path, reduction (chemical) reactions occur at the surface of the cathode, and oxidation (chemical) reactions occur at the surface of the anode. Reduction reactions at the cathode result in a hydrogen coating and a more alkaline environment, and the oxidation reaction at the anode results in corrosion and a more acidic environment. After a CP system is installed and adjusted to provide adequate protection, currents and potentials should remain relatively stable; typically, a plus or minus ten percent change in currents or potentials indicates a problem.

Employ CP within the following equipment/systems:

- Underground fuel storage tanks and ground-level tank bottoms.
- Fuel distribution and storage systems.
- Elevated and ground-level water storage tank interiors and ground-level tank bottoms.
- Potable water distribution systems.
- Natural gas or propane distribution systems.
- Compressed gas distribution systems, such as air, oxygen, and nitrogen.
- Fire protection water storage tanks, piping, or water lines.
- Sewage tanks, lift stations, and effluent pipelines.
- Steel sheet pile seawalls, pier support/fender piles, and other submerged steel structures.
- Concrete reinforcing steel.

- Industrial waste pipelines.
- Dams and lock systems.
- Cooling towers.
- Recirculating water systems (hot or cold).

1-3 OCCUPATIONAL SAFETY AND HEALTH ADMINISTRATION (OSHA).

Comply with all OSHA requirements, as applicable.

1-4 REFERENCES.

Appendix A contains a list of references used in this document. The publication date of the code or standard is not included in this document. Unless otherwise specified, the most recent edition of the referenced publication applies. Comply with all applicable provisions of the current issues of these consensus standards as follows and as noted elsewhere in this document. Appendix G contains additional useful references.

1-5 GLOSSARY.

Appendix E contains acronyms, abbreviations, and terms.

1-6 BENEFITS.

For utilities, there are two choices: (1) install and maintain CP; or (2) periodically replace the utility when the leak failure rate becomes an operational (or financial) burden. Properly installed and maintained CP systems dramatically reduce life cycle costs by indefinitely extending a utility’s lifetime. CP systems also reduce the government’s potential liability from premature failure of utilities, such as gas line explosions and jet fuel leaks. Environmental cleanup, transportation, and disposing of contaminated soil, monitoring requirements, and other costs connected to a “reportable” leak can cost the government over $1 million. Notices of Violations (NOVs) can carry stiff fines and penalties. CP is essential to maintaining any metallic structure in a corrosive environment at the lowest life cycle cost.

1-7 CP SYSTEM MAINTENANCE.

System performance can be monitored by measuring the supplied current, by measuring the potential of the structure to the electrolyte with proper reference cell, or (preferably) by a combination of the two methods. Scheduled maintenance and preventive maintenance may include inspection and adjustment of equipment items, such as current rectifiers or anodes; unscheduled maintenance may include troubleshooting and repair of items identified as defective during scheduled inspections, such as anode beds or electrical conductors and connections.

1-8 CP PROGRAM ELEMENTS.

A CP program includes:

- Corrosion control by CP design.
- Corrosion control during in-house and contracted job orders, work orders, and projects.
- Use of CP to eliminate electrochemical reactions (corrosion).
- Use of protective coatings to reduce CP current requirements.
- Location of CP components for excavation permits.
- Scheduled inspections and preventive maintenance.
- Troubleshooting and repair.
- Failure analysis and initiation of corrective actions on corrosion failures caused by materials, design, construction, or the environment.
- Historical records and documentation required for demonstration of compliance and efficient operations and maintenance of CP systems.

Note: Guidance in this UFM applies to both galvanic anode cathodic protection (GACP) and impressed current cathodic protection (ICCP) systems.

CHAPTER 2 CRITERIA

2-1 POTENTIAL MEASUREMENT.

To comply with environmental regulations, public law, and industry standards, adequate CP is required to stop corrosion on all protected structures. Adequate CP is a level of CP that meets one, or all, of the criteria detailed in this chapter. This chapter includes criteria and inspection actions that, when used either separately or in combination, indicate whether adequate CP of protected structures (infrastructure) has been achieved. The effectiveness of CP or other corrosion control measures can be affirmed by visual observation, measurements of pipe wall thickness, or by use of internal inspection devices. Because such methods sometimes are not practical, meeting any criterion or combination of criteria in this chapter is evidence that adequate CP has been achieved. When access to or excavations of the structure are made for any purpose, the protected structure should be inspected for evidence of corrosion and/or coating condition. See Chapter 4, or apply sound engineering practices as defined in Appendix B, to determine the methods and frequency of testing required to satisfy these criteria.

Potential measurement, based on the theory of measuring an unknown potential by relating it to a known reference electrode, is the principal test procedure used to determine the efficiency and adequacy of CP systems. In evaluating the potential measurement results against existing criteria, sources of error and the limitations of criteria must be considered.

The most commonly protected structures are buried or submerged metallic pipeline systems. The criteria herein are taken from National Association of Corrosion Engineers (NACE®) International SP0169, with minor revisions. The current revision of this standard should be consulted. Other types of infrastructure may use other NACE International Standards. References to other standards are contained in Appendix G-2.1.

2-1.1 Sources of Potential Error.

Before taking a potential measurement of a structure to determine if adequate CP has been achieved, there are five sources of error that must be addressed to ensure accurate measurements.

2-1.1.1 Accuracy of Equipment.

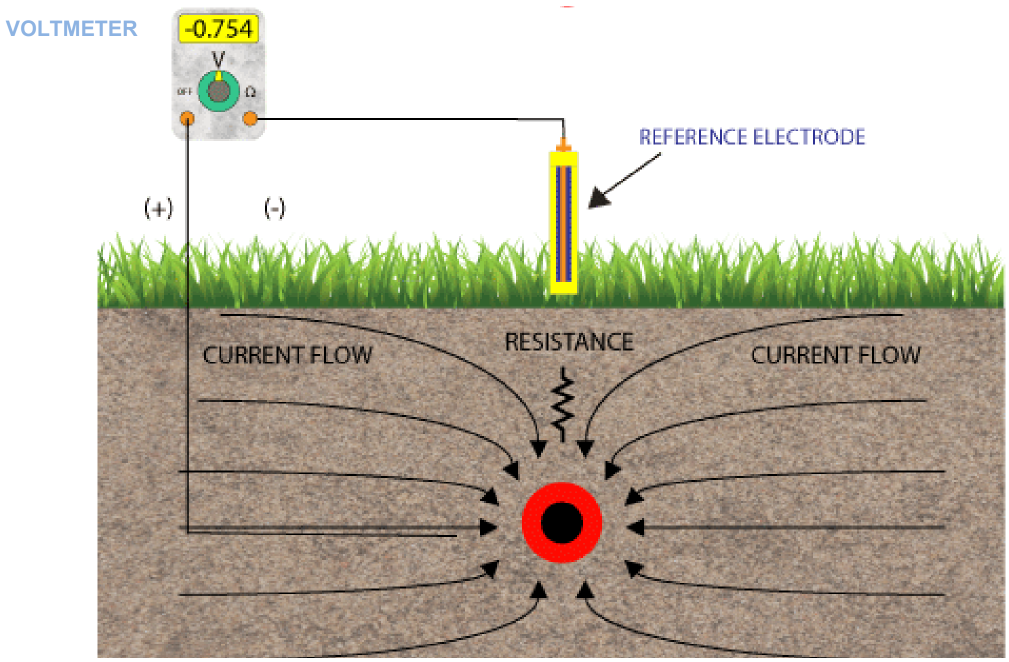
The accuracy of the reference electrode and meter being used must be verified or certified. Voltmeters must be calibrated annually. The reference electrode must be maintained according to manufacturer’s specifications annually and must be verified before use.

WARNING
Metered leads should be fully insulated and undamaged to ensure electrical safety and accuracy of measurement. Employ applicable electrical safety practices to avoid damage to equipment or electrical shock to personnel.

2-1.1.2 Voltage Drop.

A voltage drop is caused by current flowing through resistance. See Figure 2-1. When CP is enabled, the current flowing through the electrolyte causes a voltage drop between the reference electrode and the protected structure, adding a more negative component to the displayed voltage on the meter (i.e., −0.85 volts DC versus −0.75 volts DC). This error increases with higher currents or resistivities and with greater distances from the reference electrode to the structure or nearest holiday.

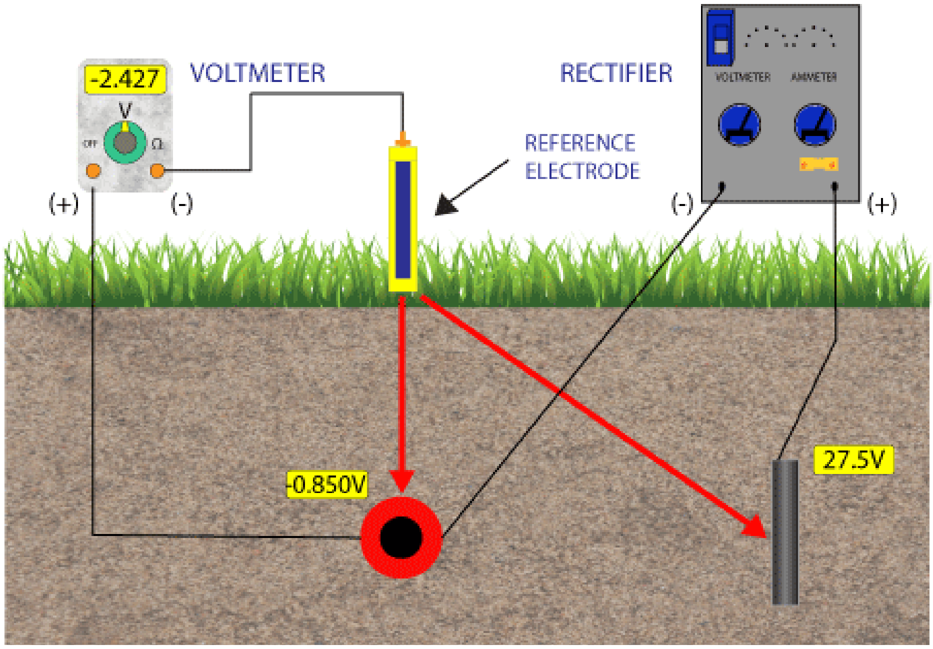
Figure 2-1 Voltage Drop



2-1.1.3 Anode Gradient Field.

The voltage gradient of the anode causes an error when the anode is connected in the circuit during testing (current is on). See Figure 2-2. For galvanic anodes, the potential must be taken as remote as possible from the anodes and as close as possible and directly over the structure being tested. For ICCP systems, when current is applied, the rectifier voltage at the anode is a component of the potential measurement throughout the system. All rectifiers must be synchronized and interrupted to remove this error. Well coated structures and CP systems with high rectifier voltages or distributed anode systems must be interrupted to provide accurate potential measurements.

Figure 2-2 Anode Gradient Field



2-1.1.4 Contact Resistance.

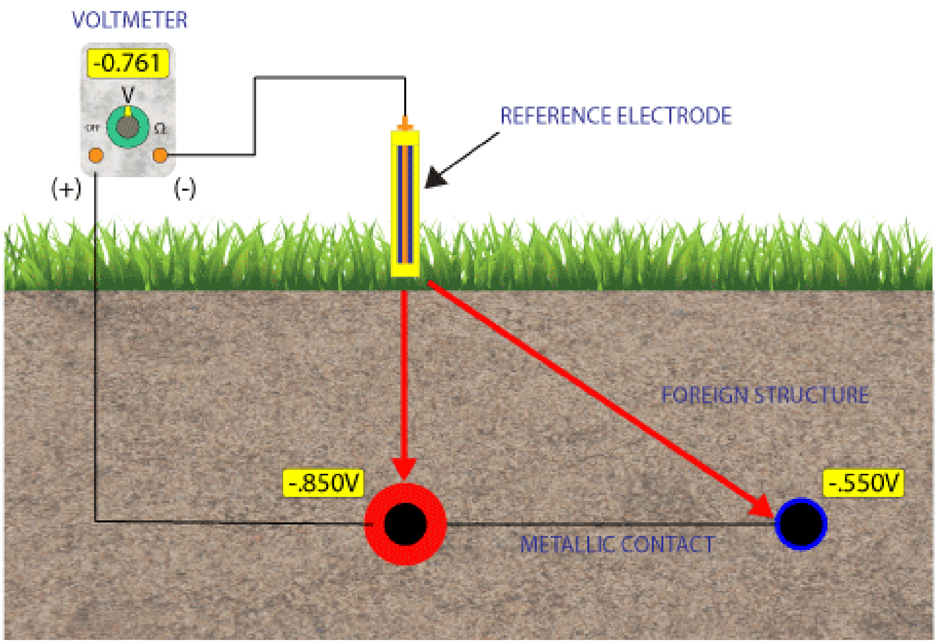
Contact resistance error is present when the reference electrode is not in good contact with the electrolyte. This resistance provides a positive error in the measurement. A high input impedance voltmeter also reduces this error. A selectable input resistance voltmeter can be used to determine if this error is present. By increasing the input resistance, the measurement becomes more negative when this error is present.

The application of water to the electrolyte at the reference electrode contact point reduces this error. In dry or high resistivity areas, water or an extremely high input impedance meter or both must be used to obtain accurate measurements.

2-1.1.5 Mixed Metal Potential.

This error results when a potential measurement being taken on the structure is mixed with the potential of other structures also connected to the circuit being tested. See Figure 2-3. If the structure being tested is not isolated from other structures or has bimetallic components (composed of different metals), the potential measurement is a weighted average of the different metals and must be considered to determine adequate protection. For all bimetallic or non-isolated structures, the 100 mV drop criteria must meet the criteria for the most negative metal and, in the case of steel, must meet the 850 instant off criteria as described in 2-1.2. In the case of connection to a more active metal, such as zinc ribbon or magnesium anodes in ICCP systems, there are negative errors that must be considered.

Figure 2-3 Mixed Metal Potential



2-1.2 Criteria for CP.

The criteria in this section have been developed through laboratory experiments and/or have been verified by evaluating data obtained from successfully operated CP systems. Situations may exist where a single criterion for evaluating the effectiveness of CP may not be satisfactory for all conditions. Often, a combination of criteria is needed for a single structure.

2-1.2.1 Corrosion Leak History.

Corrosion leak history is valuable in assessing the effectiveness of CP. However, corrosion leak history by itself must not be used to determine whether adequate levels of CP have been achieved unless it is impractical to make electrical surveys.

2-1.2.2 Applicability.

Special conditions in which CP is ineffective or only partially effective sometimes exist. Such conditions may include elevated temperatures, disbonded coatings, thermal insulating coatings, shielding, bacterial attack, and unusual contaminants in the electrolyte. Deviation from the recommended practice may be warranted in specific situations, provided corrosion control personnel in responsible charge are able to demonstrate that the objectives expressed in the recommended practice have been achieved.

Criteria are intended to serve as a guide for establishing minimum requirements for control of corrosion on the following systems.

2-1.2.2.1 New Piping Systems.

Corrosion control by coating supplemented with CP, or by some other proven method, should be provided in the initial design and maintained during the service life of the piping system, unless investigations indicate that corrosion control is not required. Consideration should be given to the construction of pipelines in a manner that facilitates the use of in-line inspection tools.

2-1.2.2.2 Existing Coated Piping Systems.

CP should be provided and maintained unless investigations indicate that CP is not required.

2-1.2.2.3 Existing Uncoated Piping Systems.

Studies should be conducted to determine the extent and rate of corrosion on existing uncoated piping systems. When these studies indicate that corrosion will affect the safe or economic operation of the system, adequate corrosion control measures should be taken.

2-1.2.3 References.

Personnel responsible for corrosion control are not limited to criteria in this chapter. 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 within this chapter.

All criteria described in this chapter are in accordance with NACE standards. See Appendix A.

2-1.2.4 Steel and Cast Iron Piping.

Corrosion control can be achieved at various levels of cathodic polarization depending on the environmental conditions. However, in the absence of specific data that demonstrate that adequate CP has been achieved, one or more of the following conditions shall apply:

2-1.2.4.1 Cathodic Potential of at Least −850 mV.

A cathodic potential of at least −850 mV with the CP applied must exist. 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 (S/E) boundary must be considered for valid interpretation of this voltage measurement.

Note: Consideration is understood to mean the application of sound engineering practices in determining the significance of voltage drops by methods such as:

- Measuring or calculating the voltage drop(s).
- Reviewing the historical performance of the CP system.
- Evaluating the physical and electrical characteristics of the pipe and its environment.
- Determining whether or not there is physical evidence of corrosion.

2-1.2.4.2 Polarized Potential of at Least −850 mV.

A polarized potential (the potential across the structure/electrolyte interface that is the sum of the corrosion potential and the cathodic polarization) of at least −850 mV relative to a saturated copper/copper sulfate reference electrode must exist.

2-1.2.4.3 Minimum of 100 mV of Cathodic Polarization.

A minimum of 100 mV of cathodic polarization must exist 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 may not be valid when bimetallic corrosion; such as when connected to copper grounding, is present.

2-1.2.4.4 Special Conditions.

- On bare or ineffectively coated pipelines where long line corrosion activity is a 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.
- In some situations, such as the presence of sulfides, bacteria, elevated temperatures, acid environments, and dissimilar metals, the criteria in paragraph 2-1.2.4 may not be sufficient.
- When a pipeline is encased in concrete or buried in dry or aerated high resistivity soil, values less negative than the criteria listed in paragraph 2-1.2.4 may be sufficient.

Note: Using polarized potentials less negative than −850 mV is not recommended for CP of pipelines when operating pressures and conditions are conducive to stress corrosion cracking.

Note: Use of excessive polarized potentials (greater than −1200 V) on coated pipelines should be avoided to minimize cathodic disbondment of the coating. Further investigation is required to determine if other current sources, such as interference pickup or previously installed galvanic anodes, are affecting the structure.

Note: Polarized potentials that result in excessive generation of hydrogen should be avoided on all metals, particularly higher strength steel, certain grades of stainless steel, titanium, aluminum alloys, and pre-stressed concrete pipe.

Note: The earth current technique is often meaningless in multiple pipe rights-of-way, in high resistivity surface soil, for deeply buried pipe, in stray current areas, or where local corrosion cell action predominates.

2-1.2.5 Aluminum Piping.

A minimum of 100 mV of cathodic polarization between the structure surface and a stable reference electrode contacting the electrolyte must exist. The formation or decay of this polarization can be used in this criterion.

2-1.2.5.1 Excessive Voltages

If aluminum is cathodically protected at voltages more negative than −1200 mV (measured between the pipe surface and a saturated copper/copper sulfate reference electrode contacting the electrolyte) and compensation is made for the voltage drops other than those across the pipe–electrolyte boundary, it may suffer corrosion as the result of the buildup of alkali on the metal surface. A polarized potential more negative than −1200 mV must not be used unless previous test results indicate that no appreciable corrosion will occur in the particular environment.

Note: Aluminum may suffer from corrosion under high pH conditions, and application of CP tends to increase the pH at the metal surface. Therefore, careful investigation or testing must be conducted before applying CP to stop pitting attack on aluminum in environments with a natural pH in excess of 8.0.

2-1.2.6 Copper Piping.

A minimum of 100 mV of cathodic polarization between the structure surface and a stable reference electrode contacting the electrolyte must exist. The formation or decay of this polarization can be used in this criterion.

2-1.2.7 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.

Note: Amphoteric materials that could be damaged by high alkalinity created by CP should be electrically isolated and separately protected.

2-1.2.8 Other Considerations.

2-1.2.8.1 Determining Voltage Drops.

Methods for determining voltage drop(s) must be selected and applied using sound engineering practices. Once determined, the voltage drop(s) may be used for correcting future measurements at the same location, provided that conditions (such as pipe and CP system operating conditions, soil characteristics, and coating quality) remain similar.

Note: Placing the reference electrode next to the pipe surface may not be at the pipe–electrolyte interface. A reference electrode placed at a coated pipe surface may not significantly reduce soil voltage drop in the measurement if the nearest coating holiday is remote from the reference electrode location.

2-1.2.8.2 Sound Engineering Practices.

When it is impractical or considered unnecessary to disconnect all current sources to correct for voltage drop(s) in the pipe–electrolyte potential measurements, sound engineering practices should be used to ensure that adequate CP has been achieved.

2-1.2.8.3 In-Line Inspection of Pipes.

In-line inspection of pipelines may be helpful to determine the presence or absence of pitting corrosion damage. Absence of corrosion damage or the halting of its growth may indicate adequate corrosion control. The in-line inspection technique, however, may not be capable of detecting all types of corrosion damage. The technique also has limitations in its accuracy and may report items that are not corrosion as anomalies. For example, longitudinal seam corrosion and general corrosion may not be readily detected by in-line inspection. Also, possible thickness variations, dents, gouges, and external ferrous objects may be detected as corrosion. The appropriate use of in-line inspection must be carefully considered.

2-1.2.8.4 Stray Currents and Stray Electrical Gradients.

Situations involving stray currents and stray electrical gradients that require special analysis may exist. If needed, interference testing may need to be performed (see Appendix B for more information).

2-1.2.9 Alternative Reference Electrodes.

2-1.2.9.1 Alternative to Saturated Copper/Copper Sulfate.

Other standard reference electrodes may be substituted for the saturated copper/copper sulfate reference electrode. Table 2-1 lists commonly used reference electrodes as listed in SP0169, *Control of External Corrosion on Underground or Submerged Metallic Piping Systems*.

Table 2-1 Common Reference Electrodes

Reference Electrodes	Electrolyte Solution	Potential at 25ºC (V/SHE)*	Potential at 25ºC (V/CSE)**	Temperature Coefficient (mV/ºC)	Typical Usage
$Cu/CuSO_4$	Sat. $Cu/CuSO_4$	+0.316	0	0.9 (0.5)	Soils, fresh water
Ag/AgCl	0.6 M NaCl (3.5%)	+0.256	−0.06	−0.33 (0.18)	Seawater, brackish
Ag/AgCl	Sat KCl	+0.222	−0.094	−0.70 (0.39)	
Ag/AgCl	0.1 N KCl	+0.288	−0.028	−0.43	
Zn	Saline solution	−0.79 ± 0.1	−1.1 ± 0.1		Seawater
Zn	Soil	−0.80 ± 0.1	−1.1 ± 0.1		Underground

**SHE – standard hydrogen electrode, **CSE – copper sulfate electrode*

2-1.2.9.2 Alternative Metallic Material or Structure.

An alternative metallic material or structure may be used in place of the saturated copper/copper sulfate reference electrode if the stability of its electrode potential is ensured and if its voltage equivalent referred to a saturated copper/copper sulfate reference electrode is established.

2-1.3 Criteria Limitations.

2-1.3.1 Mixed Metal Potentials.

The 100 mV criteria should not be used on bimetallic systems due to errors from mixed potentials. Adequate CP must be 100 mV from instant off to the most active potential of the most active metal. In the case of steel, instant off must be −850 mV.

2-1.3.2 Structure-to-Earth Resistance.

For small, well coated structures in high resistivity electrolytes and using galvanic anodes, it may be physically impossible to meet either −850 mV instant off or 100 mV shift. The structure may have a resistance to earth of over 200 ohms, and one galvanic anode may have a resistance to earth of over 50 ohms. After two anodes, additional anodes do not noticeably lower the resistance or provide additional current. It is generally accepted that if the on potential (mixed potential) is over 850 mV, what little corrosion exists is occurring at the anode. This is common in nonmetallic water systems with metallic elbows, tees, risers, or valves.

CHAPTER 3 SCHEDULED INSPECTIONS AND SURVEYS

3-1 GALVANIC.

To comply with environmental regulations, public law, and industry standards, preventive maintenance is required for all installed CP systems. Minimum maintenance actions for both GACP and ICCP systems are detailed in this chapter to ensure all protected structures comply with the criteria outlined in Chapter 2.

3-1.1 Galvanic Corrosion Survey.

The galvanic corrosion survey is conducted to determine if adequate CP exists on the protected structure. A close-interval potential survey (CIS) should be conducted after installation and polarization using the procedures in paragraph 3-2.5 for impressed current systems.

3-1.1.1 Survey Interval.

Conduct a galvanic corrosion survey at the following intervals:

- Within 30 days after major modification to the CP system or the protected structure.
- After any corrosion failure or leak of the protected structure.
- After any inspection or survey that indicates potential measurements are out of compliance.
- 1 year from last corrosion survey.

3-1.1.2 Minimum Requirements.

- Using data from the most recent CIS, or using sound engineering practices, choose a sufficient number of locations for potential testing to ensure the entire structure has adequate CP.
- Test CP system components in accordance with Table 3-1. Table 3-2 presents requirements for potential testing of the protected structure.

Table 3-1 Corrosion Survey Component Testing

CP System	Test Measurement(s)
GACP (at each test station)	• One S/E potential measurement with the reference electrode placed directly over/adjacent to the protected structure at the location(s) nearest the anode(s) • One S/E potential measurement with the reference electrode placed directly over/adjacent to the protected structure midway between anode(s) • One anode-to-electrolyte potential measurement with the reference electrode placed directly over/adjacent to the anode with the anode lead disconnected • Anode-to-structure current using (in order of preference): 1) a clamp-on milliammeter, 2) a multimeter measuring millivolts across a calibrated shunt, or 3) a multimeter connected in series measuring milliamperes
ICCP	Rectifier operational inspection (paragraph 3-2.1)

Table 3-2 Corrosion Survey Potential Measurements

Structure Type	Potential Measurement Locations
Pipelines	Locate the reference electrode: • Over the pipeline at all test stations and at all points where the structure can be contacted (where it enters/exits the ground, passes through a pit, or is exposed). • Over the pipeline at least every 1,000 feet (305 meters) for pipelines off the installation. • Over the pipeline at least every 500 feet (152 meters) for pipelines on the installation.
On grade storage tanks	Locate the reference electrode: • Next to the tank at four equally spaced locations around the tank circumference at compass points or as specified on a drawing. • At a distance one tank radius away from the tank at eight equally spaced locations around the tank circumference.
Underground storage tanks	Locate the reference electrode: • Over the center and over each end of the tank. • Over each end of the feed/return piping. • Over the manhole, fill pipe, and vent pipe. • Over all metallic structures in the area if readings indicate an isolated system is shorted to a foreign structure.

Structure Type	Potential Measurement Locations
Isolated structures	Take one S/E potential measurement on each side of all dielectric fittings/couplings without moving the reference electrode. **Note:** If the potential difference between measurements on each side of a dielectric coupling is less than 10 mV, verify its integrity using an isolation flange tester.
All structures with foreign line crossings	Locate the reference electrode: • Over the foreign line at all points where it crosses the protected structure. • Over the foreign line where it passes nearby the anode bed.
All structures with cased crossings	Locate the reference electrode: • Over the protected structure on each side of all casings. • Over each end of the casing on all casings. **Note:** If the casing is shorted or partially shorted to the pipeline and the potentials over the pipeline are depressed below the criteria described in Chapter 2, take immediate action to clear the short.
Waterfront structures	Take measurements at all permanent reference electrodes. Locate portable reference electrodes: • Adjacent to the structure at all test stations. • Every 150 feet (46 meters) along a continuous length of sheet pile wall at both the surface and at the bottom. • At other test points identified in maintenance manuals or past surveys.
Other structures	Locate the reference electrode at test points identified in the maintenance manual or other past surveys.
All structures	Annotate the soil condition (or tide level for waterfront structures) for comparison to past and future measurements.

3-1.2 Galvanic Anode System Check.

Conduct the galvanic anode system check to monitor the system between corrosion surveys.

3-1.2.1 Inspection Interval.

The check must include 10 percent of the test stations, including the three lowest and the three highest potential measurements from previous surveys. Conduct a galvanic corrosion survey as defined in the NACE standards and Department of Transportation (DOT) regulations.

3-1.2.2 Minimum Requirements.

a. Review all potential readings.

b. For all structures, compare the potential measurements to those previously taken at the same locations to identify changes. Low potentials can indicate a short or other problem. High potentials can indicate interference.

c. If the potential measurements reveal current output that does not satisfy criteria in Chapter 2, adjust or supplement the system as necessary. After 30 days, perform the survey again.

3-1.3 Galvanic Anode Check.

Conduct the galvanic anode system check to determine its operational condition.

3-1.3.1 Maintenance Interval.

Perform the galvanic anode system check as required to locate problems indicated by other surveys.

3-1.3.2 Minimum Requirements.

a. Measure the potential of the structure with the reference electrode located directly over the structure, adjacent to an anode (structure-to-earth, volts DC).

b. Measure the potential of the structure with the reference electrode located directly over the structure, midway between anodes (remote structure-to-earth, volts DC). In this case, remote is as far as possible from the anodes, directly over the protected structure.

c. Disconnect the anode lead from the structure and measure potential of the anode with the reference electrode located directly over the anode (anode-to-earth, volts DC).

d. Measure structure-to-anode current (anode output current, mA) using (in order of preference): 1) a clamp-on milliammeter, 2) a multimeter measuring millivolts across a calibrated shunt, or 3) a multimeter connected in series measuring milliamperes.

e. Compare measurements to those previously taken at the same location.

f. Inspect junction and test boxes, tighten any loose wire connections, and test insulating joints.

Note: Loss of anode-to-earth potential indicates a failed (consumed) anode or failed anode lead.

Note: Loss of anode output current with stable anode-to-earth potential indicates consumption of the anode and pending failure.

Note: Loss of structure-to-earth potential with stable anode-to-earth potential and anode output current indicates loss of isolation or other problems that require further troubleshooting.

3-2 IMPRESSED CURRENT.

3-2.1 Rectifier Operational Inspection.

The purpose of the rectifier operational inspection is to determine the serviceability of all components required to apply current to the anodes of the impressed current system. A thorough inspection ensures dependable current until the next inspection.

3-2.1.1 Inspection Interval.

Perform this inspection together with the CIS, the corrosion survey, and the water tank calibration, or when any inspection or survey indicates that problems with the rectifier may exist.

3-2.1.2 Minimum Requirements.

a. Visually check all rectifier components, shunt box components, safety switches, circuit breakers, and other system power components.

b. Tighten all accessible connections and check temperature of all components and connections.

c. Use vacuum or blower to clean inside of rectifier cabinet or more detailed cleaning as required.

d. Using a calibrated meter, measure the output voltage and current, and calibrate the rectifier meters, if present.

e. For rectifiers with more than one circuit, measure the output voltage and current for each circuit using a calibrated meter, and calibrate the rectifier meters, if present.

f. For rectifiers with potential voltmeters, using a calibrated meter, measure the potentials for each voltmeter, and calibrate that rectifier meter.

g. Using a maintained reference electrode, measure the potential difference to the installed permanent reference electrode by placing both electrodes together in the electrolyte with CP current off. If the difference is more than 10 mV, replace the permanent reference electrode.

h. Calculate the CP system circuit resistance of each circuit by dividing the rectifier DC voltage output of each circuit by the rectifier DC ampere output for that circuit.

i. Calculate the rectifier efficiency by dividing the calculated output DC power by the factored input alternating current (AC) power. (This also includes timing the revolutions of the kilowatt hours (kWh) meter and annotating the meter factor from the face of the kWh meter.)

3-2.2 ICCP System Check.

The ICCP system check ensures that the system is operating at the same level as the last CIS or corrosion survey. This is a non-interrupted check, and the potential measurements must be compared to previous ON cycle potential measurements.

The locations for the potential measurements must be taken from the last CIS or corrosion survey, whichever is most recent, to reasonably ensure that the current output of the system is still being applied and is still adequate.

3-2.2.1 Maintenance Interval.

Conduct the ICCP system check within 60 days of the last CIS, corrosion survey, or ICCP system check. More frequent checks may be required by public law or local regulations.

Note: Underground storage tank CP rectifiers must be inspected at a frequency not exceeding 60 days to ensure compliance with regulations. Check with state Environmental Protection Agency (EPA) authorities, as state regulations may be more stringent or may impose additional requirements.

3-2.2.2 Minimum Requirements.

a. Measure rectifier DC voltage and DC ampere outputs.

b. Verify the DC ampere output of the rectifier meets the current (ampere) requirement found on the last CIS or corrosion survey. If necessary, adjust the rectifier output, and measure outputs again. Repeat procedure as necessary.

c. Calculate the rectifier system circuit resistance by dividing the rectifier DC output voltage by the rectifier DC output current. If the rectifier has more than one circuit, calculate the resistance of each circuit.

d. Take S/E potential measurements at the locations of the three lowest and three highest potential measurements identified in the most recent CIS or corrosion survey.

e. Compare the potential measurements to previous measurements at the same locations and determine if changes have occurred. If potential measurements do not satisfy criteria in Chapter 2 and the rectifier current output meets the current requirement from the last survey, adjust or supplement the CP system as necessary. See Appendix B.

f. Conduct a corrosion survey 30 days after adjustment or modification to the CP system.

3-2.3 Corrosion Survey.

The corrosion survey is conducted to ensure adequate CP still exists as proven on the last CIS. The procedures are the same as the CIS, with different minimum requirements for the potential measurements. The CIS data should be used to determine where potential measurements must be taken to reasonably ensure that the criteria of CP are being met for the entire structure being protected and no interference problems exist on any foreign structures.

3-2.3.1 Survey Interval.

Conduct a corrosion survey at the following intervals:

- 30 days after major modification to the CP system or the protected structure.
- After any corrosion leak on the protected structure.
- After any inspection or survey that indicates that the current requirement of the last corrosion survey is not valid (low or high potential measurements at the proper current output level).
- 1 year from last CIS or corrosion survey.

3-2.3.2 Minimum Requirements.

a. Perform the rectifier operational inspection (paragraph 3-2.1).

b. Using data from the most recent CIS, or using sound engineering practices, choose a sufficient number of locations for potential testing to ensure the entire structure has adequate CP.

c. Test CP system components in accordance with Table 3-1. Table 3-2 presents requirements for potential testing of the protected structure.

3-2.4 Anode Bed Survey.

The impressed current anode bed survey is a non-interrupted survey of the anode bed to determine the condition of the anodes. It identifies any possible problem with the impressed current anodes. It may also be used to predict failure and to program replacement.

3-2.4.1 Survey Interval.

This survey would normally be done together with the CIS. It can also be done during troubleshooting.

3-2.4.2 Minimum Requirements.

At a minimum, an impressed current anode bed survey should include ON potential over the anodes at intervals described in Table 3-3, unless the system has incorporated other means for monitoring the anodes (e.g., individual anode leads in an anode junction box).

Table 3-3 Recommended Over-the-Anode Intervals for the Impressed Current Anode Bed Survey

CP System Type	Test Measurement
All ICCP	Perform rectifier operational inspection.
Remote shallow anode beds	• Measure anode-to-soil potentials at 2-foot (0.6-meter) intervals along the length of the anode bed, beginning 10 feet (3 meters) before the first anode and ending 10 feet (3 meters) past the last anode in the anode bed. • Plot test results on graph paper to give a visual indication of the anode bed condition.
Distributed shallow anode beds	Measure one anode-to-soil potential with the reference electrode located directly over each anode.
Deep anode beds	• In lieu of anode potential measurements, measure anode circuit current using (in order of preference): 1) a clamp-on milliammeter, 2) a multimeter measuring millivolts across a calibrated shunt, or 3) a multimeter connected in series measuring milliamperes. • Measure the anode current for each anode if separate leads are available.

3-2.5 Close-Interval Potential Survey.

The CIS is an interrupted potential survey on impressed current systems and a non-interrupted potential survey on GACP systems; it can be labor intensive. The purpose of this survey is to ensure that adequate CP is maintained over the entire protected structure. It identifies problems within the protected structure or any interference problem on all foreign structures.

The interruption cycle must have an ON cycle of minimum duration four times longer than the OFF cycle, and the OFF cycle should not exceed 1 second. For surveys on GACP systems, measurement errors must be considered, typically through application of sound engineering practices that address the location of the reference electrode, the protected structure, the anodes, the condition of the coating, the soil resistivity, and the depth of the protected structure (refer to Chapter 2). If test stations are installed at each anode, this also can be an interrupted potential survey.

3-2.5.1 Survey Interval.

Conduct CIS at the following intervals:

- 30 days after CP system is installed, energized, and properly adjusted.
- 5 years from the last CIS.

Note: Typically, DoD fuel pipelines are maintained by the Defense Logistics Agency (DLA)-Energy command via two Centrally Managed Programs (CMPs): Integrity Management Program (IMP) and CP. An IMP survey is typically executed every 5 years on a rotating schedule and is normally inclusive of a coating assessment, a CIS, a direct current voltage gradient (DCVG) or alternating current voltage gradient (ACVG) study, and an internal pipe/smart pig survey. Therefore, CP surveys typically do not include a CIS of fuel pipelines.

3-2.5.2 Minimum Requirements.

a. Test CP system components in accordance with Table 3-4 and perform potential measurements of the protected structure in accordance with Table 3-5.

b. Review all potential readings.

c. Annotate the low potential measurements, the high potential measurements, and other significant potential measurements to re-evaluate those locations when performing the corrosion survey.

d. If the data taken show that the current output is not sufficient to satisfy the criteria in Chapter 2, adjust or supplement the system as necessary. See Appendix B.

e. After 30 days, perform a corrosion survey for those locations identified in the paragraph above.

Table 3-4 Test Measurements for Close-Interval Potential Survey

CP System Type	Test Measurement
GACP (at each test station)	• One anode-to-soil potential measurement with the reference electrode placed over the anode and the anode lead disconnected. • Anode-to-structure current using (in order of preference): 1) a clamp-on milliammeter, 2) a multimeter measuring millivolts across a calibrated shunt, or 3) a multimeter connected in series measuring milliamperes. • S/E potential measurement with the reference electrode placed over the structure adjacent to the anode. • S/E potential measurement with the reference electrode placed over the structure remote from the anode.
ICCP	• Rectifier operational inspection (paragraph 3-2.1). • Impressed current anode bed survey (paragraph 3-2.4).

Table 3-5 Close-Interval Potential Survey Potential Measurement Locations

Structure Type	Potential Measurement Locations
Pipelines	Locate the reference electrode over the pipeline at intervals not to exceed the depth of the pipeline, normally every 3 to 5 feet (1 to 1.5 meters).
On grade storage tanks	Measure at permanent reference electrodes, if installed. Locate the reference electrode: • Next to the tank every 6 feet (1.8 meters) around the tank circumference. • At a distance one tank radius away from the tank at eight equally spaced locations around the tank circumference. • In pull tubes at intervals of 3 to 5 feet (1 to 1.5 meters), if installed.
Underground storage tanks	Locate the reference electrode: • Every 3 feet (1 meter) over the tank. • At least every 3 feet (1 meter) over feed and return piping. • Over the manhole, fill pipe, and vent pipe. • Over all metallic structures in the area if readings indicate that an isolated system is shorted to a foreign structure.

Structure Type	Potential Measurement Locations
Isolated structures	Take one S/E potential measurement on each side of all dielectric fittings/couplings without moving the reference electrode. **Note:** If the potential difference between measurements on each side of a dielectric fitting/coupling is <10 mV, verify its integrity using an isolation flange tester.
All structures with foreign line crossings	Locate the reference electrode: • Over the foreign line at all points where it crosses the protected structure. • Over the foreign line where it passes near the anode bed.
All structures with cased crossings	Locate the reference electrode: • Over each end of the casing on all casings. **Note:** If the casing is shorted or partially shorted to the pipeline and the potentials over the pipeline are depressed below criteria described in Chapter 2, high priority must be given to clear the short.
All structures in soil	Record the soil condition for comparison of past/future potential and current measurements.

3-2.6 Water Tank Calibration.

The water tank calibration is to ensure that CP is maintained over the entire surface of the tank interior, as well as to ensure there are no excessive voltages on any part of the tank interior that could damage the coating.

Water tank calibration comprises an interrupted potential survey on ICCP systems or a non-interrupted potential survey on GACP systems. The interruption cycle must have an ON cycle that is a minimum of four times longer than the OFF cycle where the OFF cycle is normally 1 second.

On a GACP system, measurement errors must be accounted for using sound engineering practices, including reference electrode placement, anode positions, and coating condition. If the system design permits, this may also include an interrupted potential survey.

3-2.6.1 Survey Interval.

Conduct water tank calibrations according to the following intervals:

- 30 days after the CP system is installed, modified, or adjusted.
- 1 year from the last water tank calibration.

3-2.6.2 Minimum Requirements.

Inspect water tanks in accordance with Tables 3-6 and 3-7. For all tanks, compare potential measurements to measurements previously taken at the same locations to determine if changes have occurred.

If potential measurements do not satisfy Chapter 2 criteria and the current output meets the current requirement from the last survey, adjust or supplement the system as necessary. See Appendix B. After 30 days, perform a water tank calibration.

WARNING
AC voltage (over 100 V) is still present inside the rectifier with the rectifier panel circuit breaker or power switch OFF. Employ applicable electrical safety practices to avoid damage to equipment or electrical shock to personnel.

Table 3-6 Water Tank Calibration CP System Component Test

CP System Type	Test Measurement
GACP	Measure anode-to-structure current using (in order of preference): 1) a clamp-on milliammeter, 2) a multimeter measuring millivolts across a calibrated shunt, or 3) a multimeter connected in series measuring milliamperes.
ICCP	• Perform the rectifier operational inspection (paragraph 3-2.5). • Calculate the rectifier efficiency by dividing the calculated output DC power by the factored input AC power.

Table 3-7 Water Tank Calibration Potential Measurements

Structure Type	Potential Measurement Locations
Tank walls	Position the reference electrode near the water surface, at mid-depth, and at the bottom in the following locations: • Next to the tank wall directly adjacent to each anode string. • Next to the tank wall midway between two adjacent anode strings.
Tank bottom	Locate the reference electrode: • 2 inches (5 centimeters) above the tank bottom directly beneath each anode string. • 2 inches (5 centimeters) above the tank bottom and as far away from the anode strings as possible.
Metallic riser (elevated water tanks)	Locate the reference electrode adjacent to the riser wall at intervals of 5 feet (1.5 meters) from the top to the bottom of the riser.
Permanent reference electrodes	Measure and compare the potential of each permanent reference electrode to a portable reference electrode to determine its accuracy.
All tanks	Annotate the water level for comparison to past and future measurements.

3-2.7 Leak Survey.

The leak survey identifies the cause of all leaks and the action required to prevent future leaks from occurring or to reduce the leak rate.

3-2.7.1 Survey Interval.

Conduct leak surveys after excavation and before backfilling of any leak on any pipeline or tank.

3-2.7.2 Minimum Requirements.

a. Measure the pH of the soil where it contacts the pipeline or tank.

b. Measure the “as found” S/E potential of the pipe or tank where it contacts the soil. “As found” means before any adjustments of existing CP systems, addition of any form of CP, or installation of isolation or bonding components.

c. Determine the cause of the leak.

d. Evaluate the condition and determine appropriate repairs to the pipe or tank coating system.

e. Measure the “as left” S/E potential of the pipe or tank where it contacts the soil. “As left” means after all actions are taken to prevent future leaks.

Note: If these actions are taken after backfill operations, surface potentials are acceptable as described in Chapter 2.

Note: If the leak survey determines the cause to be corrosion, determine the type of corrosion. Table 3-8 lists recommended corrective actions to prevent future leaks.

Table 3-8 Recommended Corrective Actions for Preventing Leaks

CP System Type	Recommended Action
Structure not cathodically protected	Take appropriate action to reduce the possibility of future leaks according to the type of corrosion found.
Structure cathodically protected	• Determine the presence of interference, and, if found, take action to mitigate interference corrosion. • Install isolation couplings, electrical continuity bonds, or CP as appropriate.

3-2.8 Resistance Bond Check.

The resistance bond check is an operational inspection of two metallic structures connected with some type of semiconductor or resistor. This survey ensures that the structures affected by the bond are maintained at adequate levels and interference is mitigated. The bond may include reverse current switches, diodes, resistors, or other protective devices whose failures would jeopardize structure protection. These bonds may be between different sections of a protected structure or may be between a protected structure and any other metallic structure (unprotected or protected with a different CP system).

This is a non-interrupted check and the potential measurements must be compared to previous ON cycle potential measurements taken at the same locations. The locations for the potential measurements and meter connections must be the same and the operational status of any CP systems must be known.

3-2.8.1 Survey Intervals.

- Every 60 days for critical bonds. (Critical bonds are bonds that, when failed, result in loss of adequate protection to the facility.)
- After each corrosion survey and CIS for non-critical bonds.
- Immediately after CP system failure on either or both sides of the bond (unless immediate repair is possible).

More frequent checks may be required by public law or local regulations.

3-2.8.2 Minimum Requirements.

- Potential measurement of protected structure at bond location.
- Potential measurement of structure bonded to protected structure.
- Measurement of structure-to-structure current direction and current magnitude (amps or milliamps, depending on current magnitude), using (in order of preference) 1) a clamp-on milliammeter, 2) a multimeter measuring millivolts across a calibrated shunt, or 3) a multimeter connected in series measuring milliamperes.
- Measurement of rectifier DC voltage and ampere output of the CP system on either (or both) side(s) of the resistance bond. For troubleshooting bonds with rectifiers on either (or both) structure(s), interrupting rectifier(s) may be required to troubleshoot or adjust bond.
- Evidence of proper functioning, which may include current output, normal power consumption, a signal indicating normal operation, or satisfactory CP levels on the structures, according to the function or design of the bond.
- Comparison of all measurements to previous surveys.
- If the potential measurements, current flow, current direction, or other measurement has changed from the last check, investigation to determine if bond is operating as intended or if troubleshooting or adjustments are required.
- Adjustment or repair of the component as necessary, and repeat of bond test.

3-2.9 Direct Current Voltage Gradient (DCVG) Survey.

A DCVG survey is an accurate method used to size and locate pipe coating defects (holidays). The technique is based on measuring the voltage gradients in the soil above a cathodically protected pipeline. In a DCVG, a DC signal is applied to the pipeline and the voltage (potential) gradient in the soil above the pipeline is measured. Voltage gradients, as measured between two calibrated reference electrodes spaced apart, arise as a result of the current pickup or discharge at pipeline coating holiday locations. This potential gradient can be detected between two electrodes placed on the soil surface with a sensitive analog mV meter; therefore, the location of the coating defect can be determined with precision of 4 to 8 inches (10 to 20 centimeters).

The size or severity of the coating defect is characterized by a relative number, the Indication Severity %IR calculation.

Once the survey technician has recorded the DCVG measurements and GPS locations, the %IR values are calculated. The calculations involve using the signal magnitude at a contact point and remote earth, creating a pipe-to-remote earth voltage gradient value. Over-the-line-remote earth value is then measured and the %IR value is calculated. See Equation 3-1.

Equation 3-1. %IR Calculation

$$\%IR = \frac{Over-\ the-\ Line-Remote-Earth-\ Value}{Calculated\ Pipe-to-Remote\ Earth\ Value} X100$$

Depending on the magnitude of the %IR, a determination can be made where physical examination of the pipe and coating repair are necessary. The DCVG survey uses the pipeline's ICCP system. If no ICCP system is installed, a temporary ICCP system can be used.

3-2.9.1 Survey Intervals.

Conduct a DCVG survey at the following intervals:

- 30 days after new pipeline installation.
- After a CIS has been performed.
- On demand when a coating evaluation is needed, such as when a pipeline excavation and recoat has been performed, when a third-party excavation has been performed and coating damage is suspected, when a new pipeline segment has been installed, when determined due to coating age and condition that a DCVG survey is required, and at the discretion of operations.
- Every 7 years when evaluating high consequence area (HCA).

3-2.9.2 Minimum Requirements.

- Perform DCVG survey at locations where potentials do not achieve criteria of CIS.
- Review all survey data.
- Annotate the locations indicating coating holidays and prioritize using the %IR.

CHAPTER 4 PRIORITIES FOR TESTING, TROUBLESHOOTING, AND REPAIR

4-1 INTRODUCTION.

To properly operate and maintain a CP system, it is essential to apply continuous protection to the protected structure. Interruptions in protection result in irreversible corrosion damage to the structure. Along with the importance or cost of the structure, the factors that affect the rate of corrosion also relate directly to priority considerations. The long-term strategy to prevent corrosion of infrastructure is outlined in USC Title 10-2228*, Office of Corrosion Policy and Oversight* and in DoD Instruction 5000.36, *Prevention and Mitigation of Corrosion on DoD Military Equipment and Infrastructure*.

While scheduled inspections and surveys are performed to ensure continued satisfactory performance of CP systems, problems that require troubleshooting and maintenance outside scheduled times can occur. These problems may require unscheduled maintenance actions. For instance, if potentials that do not meet the criteria for CP are found (see Chapter 2), troubleshooting and repair must be performed (see Appendix B). Addressing these issues ensures the consistent operation of the system and greatly reduces the life cycle cost of the infrastructure being protected. In addressing unscheduled maintenance issues, the priority of restoration of the system affected, as well as the budget and equipment available to correct the problem, must also be considered. A priority, either emergency or routine, must be assigned to restore adequate CP to affected structures. The following priority considerations are detailed to allow a knowledge-based priority determination.

4-2 EMERGENCY PRIORITY CONSIDERATIONS.

GACP systems are inherently maintenance-free. ICCP systems require a higher level of maintenance. Maintaining adequate CP on all protected, buried, or submerged metallic structures is critical to prevent or mitigate corrosion. An assignment of emergency priority means an issue needs to be addressed immediately.

Failure of CP systems that affect public safety and/or those that are federally regulated must be given emergency priority to repair or replace. This would include pipelines, underground storage tanks, aboveground storage tanks, and other structures with CP that contain hazardous chemicals, fuels, or natural gas. High-pressure transmission lines in HCAs should be given emergency priority.

Any metallic structure or utility that would adversely affect the mission capability if a failure occurs must be given high priority. This includes fire protection pipelines, sea walls, locks, flood gates, and other critical metallic structures or utilities required for mission accomplishment. Other examples include underground oxygen pipelines to hospitals and underground air, steam, or other pipelines whose failure would compromise mission requirements.

4-3 ROUTINE PRIORITY CONSIDERATIONS.

The factors affecting the scheduling of routine priority work orders for restoration of adequate CP depend on the type of utility, mission impact of failure, and seriousness of the corrosion probability. All inadequate levels of CP adversely affect the life cycle cost of the infrastructure. Corrosion problems listed below affect the rate of corrosion and should be considered for scheduling purposes to troubleshoot, repair, and restore adequate CP.

4-3.1 Interference.

The presence of interference can be extremely corrosive to structures where current picked up from a foreign source is discharging from a metallic structure or utility, especially if that utility is coated. Corrosion failures can occur in an extremely short amount of time, possibly in days if the interference is extremely serious. This usually occurs where underground pipelines cross other pipelines or electrical grounds where the interference is being applied by another CP system that is not isolated. The seriousness is determined by the potential measured and can easily be a positive potential to a saturated copper/copper sulfate reference electrode.

For every amp-year of current (1 amp for 1 year), 20.7 pounds of steel are lost. When this metal loss is discharging from coating defects, extremely short time to failure occurs. This mode of failure is usually only discovered after failure has occurred, and the highest possible priority must be given to mitigate further failures. If it is found before failure, the same applies—corrosion failure is imminent.

4-3.2 Corrosiveness of the Soil.

For underground or submerged metallic structures, the electrolyte resistivity is the basic measurement for the corrosiveness of the electrolyte—the lower the resistivity, the higher the corrosion rate. See Table 4-1.

Table 4-1 Soil Corrosiveness

Soil Corrosiveness	Soil Resistivity (Ω-cm)
Severely corrosive	0 to 500
Very corrosive	500 to 999
Corrosive	1,000 to 2,999
Moderately corrosive	3,000 to 9999
Slightly corrosive	10,000 to 25,000
Relatively less corrosive	>25,000

4-3.3 Determining Scheduling Priority.

The potential difference between the measured potential and the potential required for adequate protection should be considered and compared with the corrosiveness to determine priority. Other corrosiveness factors, such as high temperature and acidic electrolytes, increase the corrosion rate and elevate the priority.

Table 4-2 can be used as a tool to determine scheduling priority. For each factor, the appropriate measurement is taken. Based on the measurement, a factor value is assigned and a sum is then calculated.

- If sum is over 5, assign emergency priority.
- If sum is 5, schedule before any other action; expedite parts.
- If sum is 4, schedule immediately if possible; rush parts, maximum of 30 days.
- If sum is 3, schedule maximum of 60 days.
- If sum is 2 or below, schedule before next inspection cycle.

Table 4-2 Scheduling Considerations Based on Factor Value Sum

Factor	Factor Value								
	5	4	3	2	1	0	-1	-2	-3
Electrolyte resistivity (ohm-cm)	<1000	1001 to 2000	2001 to 4000	4001 to 8000	8001 to 16000	16001 to 100000	100001 to 200000	200001 to 400000	>400000
Temperature (ºF)	>210	201 to 210	191 to 200	181 to 190	170 to 180	33 to 169	0 to 32	<0	—
pH	<3.5	3.5 to 4	4.1 to 5	—	—	—	9 to 10	10.1 to 11	>11
Potential (mV)	>+200	0 to +200	0 to −200	−201 to −300	−301 to −400	−401 to −600	−601 to −700	−701 to −800	−801 to −850
Hazardous storage (Yes/No)	—	Yes	—	—	—	—	No	—	—
Mission essential (Yes/No)	—	—	Yes	—	—	—	No	—	—
HCA* (Yes/No)	—	—	—	—	Yes	—	No	—	—
High value or leak repair cost (Yes/No)	—	—	—	Yes	—	—	No	—	—
*For hazardous storage tanks and pipelines only.									

4-3.3.1 Scheduling Examples.

4-3.3.1.1 Example 1.

Example 1 concerns an underground water distribution pipeline in 2,500 ohm-cm soil at ambient temperature with pH 9.5. Instant off potential is –710 mV. It is not hazardous, mission essential, or of high value. See Table 4-3.

Table 4-3 Example 1 Values

Factor	Measurement	Factor Value Based on Table 4-2
Electrolyte resistivity (ohm-cm)	2,500	3
Temperature (ºF)	60	0
pH	9.5	–1
Potential (mV)	−710	–2
Hazardous storage (Yes/No)	No	–1
Mission essential (Yes/No)	No	–1
HCA* (Yes/No)	N/A	0
High value or leak repair cost (Yes/No)	No	–1
Sum	—	–3

The factor value sum is −3, so work should be scheduled before the next inspection cycle.

4-3.3.1.2 Example 2.

Example 2 concerns an underground fuel pipeline in 15,000 ohm/cm soil at ambient temperature with pH 7.5. Instant off potential is −612 mV. It is hazardous, not in an HCA, and not mission essential, and it is a high value for leak repair cost. See Table 4-4.

Table 4-4 Example 2 Values

Factor	Measurement	Factor Value Based on Table 4-2
Electrolyte resistivity (ohm-cm)	15,000	1
Temperature (ºF)	60	0
pH	7.5	0
Potential (mV)	–612	–1
Hazardous storage (Yes/No)	Yes	4
Mission essential (Yes/No)	No	–1
HCA* (Yes/No)	No	–1
High value or leak repair cost (Yes/No)	Yes	2
Sum	—	4

The sum of all factor values is 4, so work should be scheduled immediately if possible; rush parts, maximum of 30 days.

4-3.3.1.3 Example 3.

Example 3 concerns an underground fuel pipeline in 1500 ohm-cm soil at ambient temperature with pH 4.5 and instant off potential of –615 mV. It is hazardous, is not in an HCA and is not mission essential, and it is a high value for a leak repair cost. See Table 4-5.

Table 4-5 Example 3 Values

Factor	Measurement	Factor Value Based on Table 4-2
Electrolyte resistivity (ohm-cm)	1500	4
Temperature (ºF)	60	0
pH	4.5	3
Potential (mV)	–615	–1
Hazardous storage (Yes/No)	Yes	4
Mission essential (Yes/No)	No	–1
HCA* (Yes/No)	No	–1
High value or leak repair cost (Yes/No)	Yes	2
Sum		10

The factor value sum is 10, so work should be assigned emergency priority.

4-3.4 Estimated Time to Failure.

For any infrastructure not categorized above, the priority is dependent on the estimated time to failure compared to the resulting loss in life cycle costs or costs of the release, cleanup, and repair of the failure.

4-3.5 Past Leak History.

Past leak history can show a trend and should also elevate the priority to troubleshoot the cause of the previous leaks and apply a mitigation plan to prevent further failures. The leaks may not be caused by corrosion, and other steps may be necessary. If the leaks are caused by corrosion and have had adequate CP, additional actions may still be required. Increasing current density or additional actions, such as locating and repairing damaged or unbonded coatings, may be required.

4-4 INFRASTRUCTURE WITHOUT CATHODIC PROTECTION.

There may be metallic infrastructure without CP. A plan to evaluate all other metallic infrastructure should be in place. Periodic review of buried metallic or submerged metallic structures should be conducted to determine if CP would be economically feasible to lower the life cycle cost of these infrastructure investments.

4-5 CORROSION ISSUES BEYOND CAPABILITY OF EXISTING RESOURCES.

If problems cannot be completed due to economic, personnel, or other limitations, identify the requirement and submit a budgetary plan for required upgrades. Identify additional requirements that add reliability to existing systems. Identify and submit cost-effective initiatives to increase the CP to protected or unprotected structures. If the capability to maintain, troubleshoot, or repair CP systems is not available by government employees, submit requirements for contracted assistance to accomplish all of the goals of the Corrosion Control Program to mitigate corrosion and lower the life cycle cost of the infrastructure.

4-6 UPGRADE EQUIPMENT.

Consider cost-effective measures to make data collection more timely or effective or to make recordkeeping easier or more complete, or consider upgrading equipment to minimize time required for surveys, troubleshooting, or data collection.

4-6.1 Remote Monitoring.

Remote monitoring can be installed to instantly identify readings that are below or above set points. These remote monitoring systems can monitor rectifier AC input voltage, DC output voltage and current, structure potentials, and many other things such as structure bonds, resistance bonds, test station potentials, and galvanic anode currents. Immediate notification of these problems can greatly accelerate the time required to repair the cause of the alarm. These systems can accelerate the data collection and recordkeeping functions, as well as provide much needed data for effective troubleshooting.

4-6.2 Equipment.

New and upgraded equipment that greatly reduces survey time, troubleshooting time, and personnel is available. See TSEWG TP-24, *Cathodic Protection Test Procedures* for available equipment and capabilities.

4-7 COMMON PROBLEMS.

Common problems that can occur in GACP or ICCP systems outside of scheduled maintenance times can be found in Appendix B-1.1 and B-2.1, respectively. Specific references for Army, Air Force, and Navy can be found in Appendix G-3.

APPENDIX A REFERENCES

FEDERAL GOVERNMENT

10 USC Title 2228, Office of Corrosion Policy and Oversight
https://www.govinfo.gov/app/details/USCODE-2024-title10/USCODE-2024-title10-subtitleA-partIV-chap131-sec2228

DEPARTMENT OF DEFENSE

DoD Instruction 5000.67, *Prevention and Mitigation of Corrosion on DoD Military Equipment and Infrastructure*
https://www.esd.whs.mil/Portals/54/Documents/DD/issuances/dodi/500067p.pdf

Public Works Bulletin 420-49-29, *Operation and Maintenance of Cathodic Protection Systems*
https://www.wbdg.org/FFC/ARMYCOE/PWTB/pwtb_420_49_29.pdf

TSEWG TP-24, Cathodic Protection Test Procedures - (AFCEC/COSC, under development)

UFC 1-200-01, *DoD Building Code*
https://www.wbdg.org/dod/ufc/ufc-1-200-01

AIR FORCE

https://www.e-publishing.af.mil/

AF Form 1457, Water Treatment Operating Log for Cooling Tower Systems

AF 1459, Water Treatment Operating Log for Steam and Hot Water Boilers

AF 1686, Cathodic Protection Operating Log for Sacrificial Anode System (Not Local Reproduction Authorized [LRA])

AF 1687, Leak/Failure Data Record Resource Advocacy/Corrosion Control Metric

AF 1688, Annual Cathodic Protection Performance Survey (Not LRA)

AF 1689, Water Tank Calibration

ARMY

Army Regulations (AR) 200-1, Environmental Protection and Enhancement
https://armypubs.army.mil/epubs/DR_pubs/DR_a/ARN45467-AR_200-1-001-WEB-2.pdf

ASSOCIATION FOR MATERIALS PROTECTION AND PERFORMANCE (AAMP) / NACE INTERNATIONAL

SP0169, *Control of External Corrosion on Underground or Submerged Metallic Piping Systems*
https://content.ampp.org/standards/book/1073/Control-of-External-Corrosion-on-Underground-or

APPENDIX B BEST PRACTICES

B-1 TROUBLESHOOTING GALVANIC SYSTEMS.

Galvanic CP is inherently maintenance free. The current is a result of the potential difference of the two metals. Recurring maintenance checks are performed to ensure continued satisfactory performance. Galvanic anodes sacrifice themselves to protect the structure. They normally consume themselves at a constant rate, and failure can be predicted by current measurement versus time. The starting point for all troubleshooting for galvanic systems is at the anode (or anode connection). For galvanic systems, there must be an anode test lead for conclusive testing of the anodes.

B-1.1 Common Problems.

The most common problems in sacrificial anode systems are shorts or failure of dielectrics on isolated protected structures. Due to the very limited voltage, sacrificial anodes usually cannot supply sufficient current to protect the structures if isolation is lost. On well-coated structures, the contact resistance to earth is high. Other metals in the earth that are not coated have a very low contact resistance, providing a low-resistance path for anode current. Maintaining the dielectrics in an isolated system is essential to continued satisfactory performance of sacrificial anode systems. One failed dielectric can result in loss of protection for the entire system. See paragraph B-1.5 for detailed procedures to locate failed dielectrics.

B-1.2 Lead Wires.

Failure of the anode lead wires is uncommon, since copper exposed by nicks or insulation defects are cathodically protected by the anodes. However, these wires can be cut by extraneous excavations. Exercising control over digging permits in the areas of the anode ground beds may ensure that if the wires are cut, they can be repaired on site, before backfilling occurs. Troubleshooting to locate the break at a later date is usually not successful, and replacement of a prematurely failed anode is more economical in almost all cases. A sudden zero anode current output reading may indicate failed lead wires.

B-1.3 Anode Consumption.

When sacrificial anode systems reach the end of their useful life, potential, current, and voltage measurements begin to change. When performing recurring maintenance, a significant drop in anode current indicates imminent failure of the anode. Potential measurements over the protected structure begin to show dips or drops in the areas of failed anodes. A significant drop in anode potential indicates a failed anode. Anode current may actually reverse after failure, due to the copper center tap of the anode being cathodic to the protected structure. When drops in the potential of the protected structure begin to occur, a closer inspection should be made to determine the extent of the damage to the anodes.

B-1.4 Improper Use.

Except on small or extremely well coated structures, such as underground storage tanks or short pipelines with butyl rubber/extruded polyethylene coatings, it is normally not economical to replace a distributed galvanic anode system. When galvanic anodes begin to fail on a distributed system, ICCP should be considered.

B-1.5 Dielectric Testing Procedures.

B-1.5.1 Background.

If a CP system is designed to protect an isolated structure, shorted dielectrics normally result in loss of adequate protection to that structure. Shorts may also result in poor current distribution or shielding, resulting in the loss of adequate protection to areas of the structure. Testing an installed dielectric presents several problems. Since typical installations normally include many dielectrics, all of which are in a parallel circuit, failure of one dielectric can effectively short the entire system. There are indications of the shorted condition of one dielectric at many, or all, other dielectrics installed. Usually, the farther the distance between the dielectric being tested and the dielectric that is shorted, the easier it is to test that dielectric.

Most methods of testing a dielectric give a reliable indication of only one condition of the dielectric (either shorted or not shorted condition) and further testing may be required for the other condition. The radio frequency tester (insulated flange tester), because of its wavelength and the strength of the signal, is the only method that gives a totally reliable indication of the condition of that specific dielectric. This method does not read through other parallel paths, even when these paths are in the immediate vicinity. In fact, this method can pinpoint the fault to a particular flange bolt or the flange gasket. Therefore, this method should be used for testing when any other method is not conclusive.

B-1.5.2 Testing Methods.

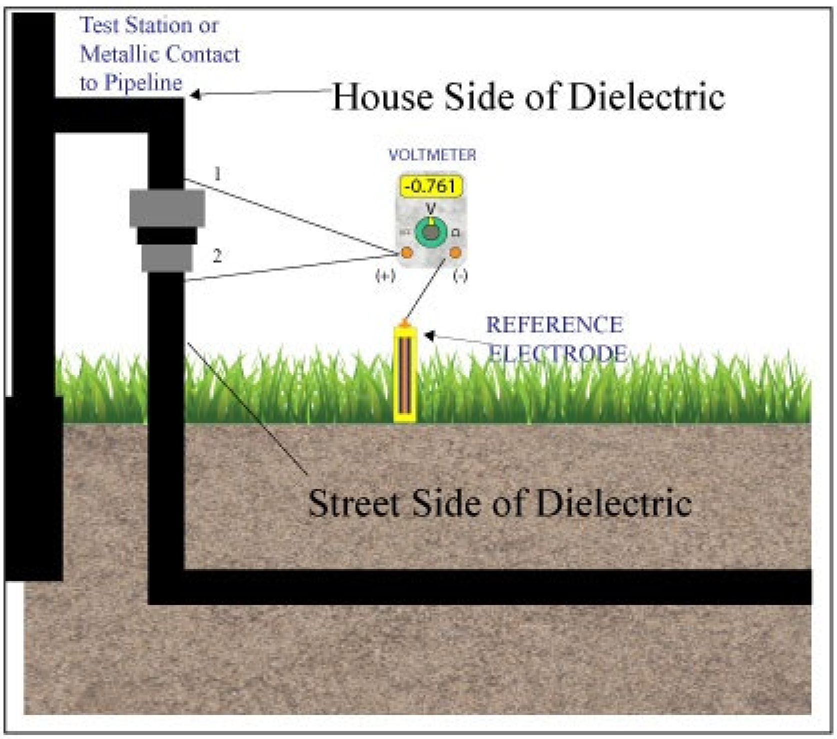
The preferred method to determine if a dielectric may be shorted is by potential testing. This method provides an immediate indication if the dielectric is not shorted and, at the same time, provides valuable potential data. If this method indicates that the dielectric may be shorted, other methods of verification are required. The radio frequency tester (insulated flange tester) should be used when a shorted condition is indicated by potential measurements. The pipe locator and the power supply methods of verification may be used to test installed dielectrics. The pipe locator method (paragraph B-1.5.3) can determine that an installed dielectric is bad but does not give conclusive evidence if the test indicates that the dielectric is good. The power supply method, which can determine that an installed dielectric is good, does not give conclusive evidence if the test indicates that an installed dielectric is bad.

CAUTION
Do not use an ohmmeter to measure resistance of an installed dielectric. If the dielectric is good, current flows through the meter and damage could result. If the current damages the meter, the measurement does not give a valid resistance value.

B-1.5.3 Testing for a Shorted Dielectric.

Take a potential measurement of both sides of the installed dielectric by changing only the structure connection, without moving the saturated copper/copper sulfate reference electrode. See Figure B-1.

Figure B-1 Testing for a Shorted Dielectric



B-1.5.3.1 Significantly Different Potential Measurements.

If the two potential measurements are significantly different (over 10 mV), the dielectric is good. The street side of the dielectric, under normal conditions (with CP), should be at a potential more negative than –0.85 volts DC, and the house side of the dielectric should be between approximately –0.15 and –0.45 volts DC (a difference of between 400 and 700 mV). If the dielectric is good and the house side of the dielectric has a potential more negative than expected, another shorted dielectric in the area should be suspected, and further investigation is required (for example, if the house side potential reading is over –0.65 volts DC, with a street side potential the same or more negative).

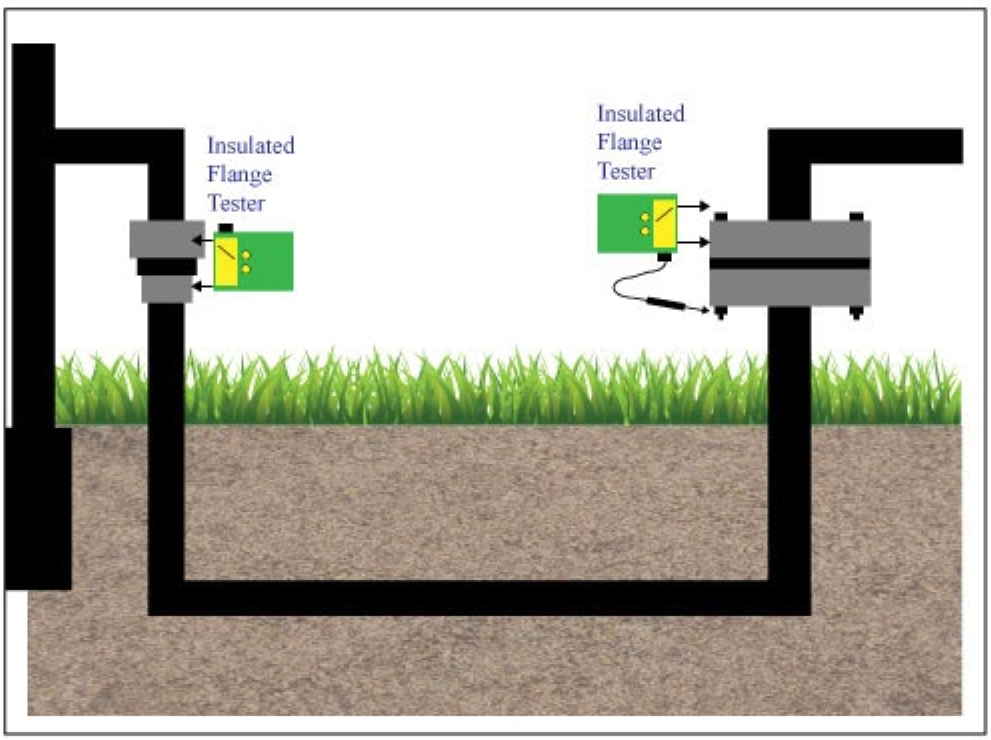
B-1.5.3.2 Not Significantly Different Potential Measurements.

The dielectric may be shorted and additional testing is required if the two potential measurements are not significantly different (under 10 mV). The preferred method is to use a radio frequency tester (insulated flange tester) to test that specific dielectric (paragraph B-1.5.2). Other possible methods that may or may not be conclusive include using the pipe locator method (paragraph B-1.5.3) or the impressed test current method (paragraph B-1.5.4).

B-1.5.4 Using a Radio Frequency Tester.

This method is the most accurate and conclusive method of testing a dielectric. Turn the insulated flange tester test switch to "zero," turn the control knob on, and zero the needle indicator. Turn the test switch to "test" and, without turning the control knob, test the dielectric. See Figure B-2.

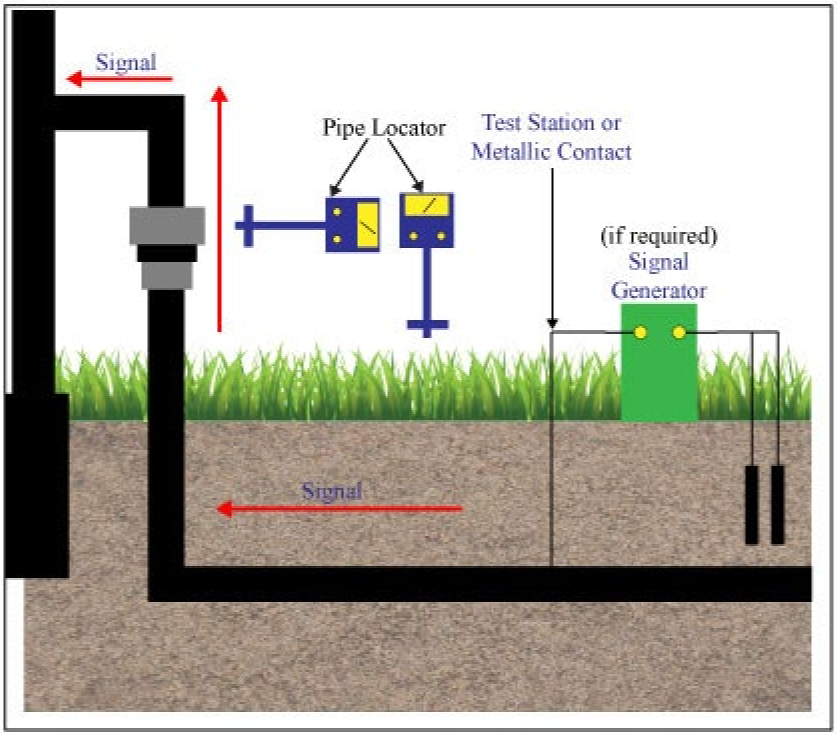
Figure B-2 Testing an Installed Dielectric with Insulated Flange Tester



B-1.5.5 Using a Pipe Locator.

Using two different types of pipe locators may indicate that a dielectric is bad. One uses a short wavelength signal (paragraph B-1.5.3.2), and one uses the signal from an impressed current system (60-cycle "noise"—this method can only be used on impressed current systems with a single-phase rectifier) (paragraph B-1.5.3.1). These methods give a rapid indication if the dielectric is shorted but may not be conclusive. See Figure B-3.

Figure B-3 Testing for Shorted Dielectric with Impressed Test Current



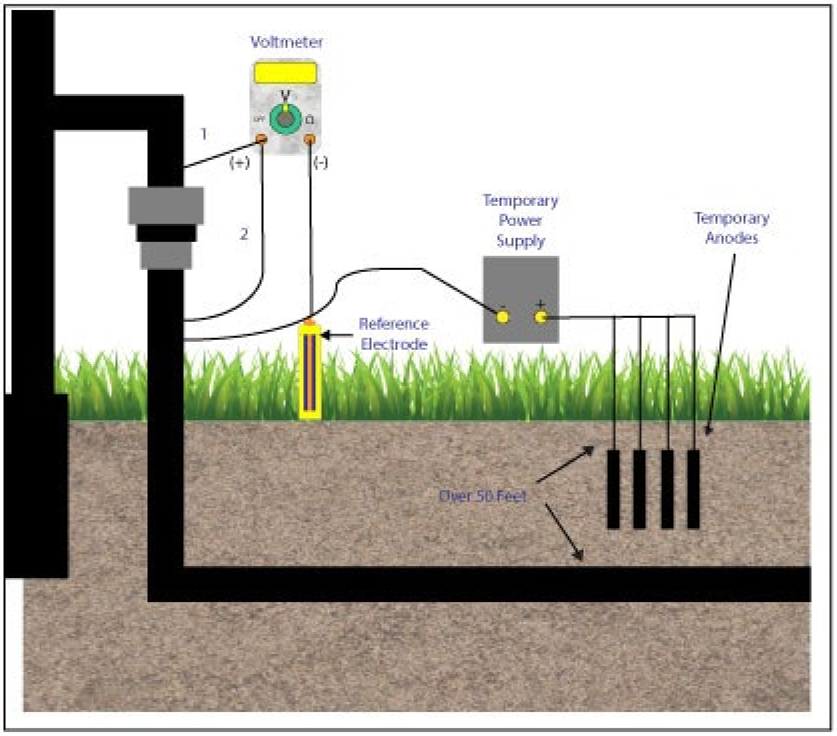
B-1.5.5.1 Pipe Horn, Model FDAC200.

The Pipe Horn, Model FDAC200, detects the signal from a single-phase rectifier. With the impressed current system on, this locator can be used to follow the underground pipeline. If a dielectric is shorted and the current is sufficient, the locator follows the signal across the dielectric. Consequently, if the signal is followed through the dielectric, that dielectric is bad. If no signal can be followed, verify with the insulated flange tester (paragraph B-1.5.2).

B-1.5.5.2 Short Wavelength Pipe Locator.

A short wavelength pipe locator, using a direct connection, detects the signal from a signal generator. To obtain a strong signal, ensure that a good metallic connection is made, a good battery is installed in the signal generator, and, most importantly, that the signal generator has a good, low-resistant ground. This locator can then be used to follow the underground pipeline. If a dielectric is shorted, and the signal is sufficient, the locator follows the signal across the dielectric. Consequently, if the signal is followed through the dielectric, that dielectric is bad. If no signal can be followed, verify with the insulated flange tester (paragraph B-1.5.2). See Figure B-4.

Figure B-4 Testing for Shorted Dielectric with Power Supply



B-1.5.6 Using a Temporary Ground to Impress Test Current.

Use a temporary ground to impress test current to the street side of the dielectric, or, if possible, merely increase the current level of the existing system. Note that the temporary ground should be installed where the current distributes to the location being tested. Repeat the potential measurement of both structures. If the potential of the house side of the dielectric remains approximately the same or changes in a positive direction (less negative) when the potential of the street side of the dielectric changes in a negative direction, they are not shorted. If both potential measurements change in a more negative direction as current is increased, the two structures are shorted together.

B-2 TROUBLESHOOTING IMPRESSED CURRENT SYSTEMS.

B-2.1 Common Problems.

The following section lists how to troubleshoot common problems associated with ICCP systems.

B-2.2 Zero Output Current.

The following lists the possible causes and troubleshooting steps for the condition when there is zero output current and slight increase in output voltage. Historical data indicate that output has remained relatively constant for a long period of time.

B-2.2.1 Troubleshooting Broken Anode Lead (Header Cable).

- With power OFF, disconnect anode lead(s) at P4.
- Connect P4 (positive terminal) to an alternative isolated metallic structure (isolated from structure being tested; if doubt exists, measure continuity to structure lead), such as a metal culvert or fence, or install temporary ground rods.
- For a short period of time, turn power ON and note AC (paragraph B-2.7). One of two conditions exists: either current is now present (changed) or it is not present (not changed).

Note: If the structure being tested is the inside of a water tank or tower, and the lack of water does not allow current flow (no electrolyte), fill the tank and then retest.

- If current exists, the anode lead is broken or the anodes have failed (proceed to paragraph B-2.13).
- If no current exists, the structure lead may be broken (see next section).

B-2.2.2 Troubleshooting Broken Structure Lead.

- The temporary or alternative anode should be connected to terminal P4 as described in previous section.
- With power OFF, disconnect structure lead at N4.
- Connect N4 (negative terminal) to alternative isolated metallic structure (isolated from structure being tested; if doubt exists, measure continuity to structure lead), such as a metal culvert or fence, or install temporary ground rods.
- For a short period of time, turn power ON and note AC. One of two conditions exists: either current is now present (changed) or it is not present (not changed).
- If current still does not exist (not changed), the temporary anode bed is not sufficient. Supplement the temporary anode bed, and then perform steps in paragraph B-2.8.
- If current is present (changed), the structure connection is broken. Use the fault detector and cable locator connected directly to the structure lead at N4 to trace the structure lead from the rectifier toward the structure. This can be extremely difficult in some cases.
- An alternative method is to locate the first structure connection (from drawings, markers, or induction methods). Excavate to the structure and measure continuity back to the rectifier using a CP multi-combination meter continuity check circuit.
- Use the fault detector and cable locator connected directly to the structure lead to trace the lead from the structure toward the rectifier. If this is still unsuccessful, replace the structure lead from the rectifier to the structure.

Note: When using the direct connection method, it is essential to have a low-resistance, isolated ground for the fault detector or cable locator to put strong locator signals on the cable under test.

B-2.3 Zero Output Current and Maximum Output Voltage.

The following lists the possible causes and troubleshooting steps for the condition when there is zero output current and maximum output voltage. Historical data show that system voltage increased several times and output current decreased slowly at first, then faster as time progressed.

B-2.3.1 Troubleshooting Failed Anode Bed.

- Determine from records if there is sufficient anode material to attempt locating and repairing the fault.
- Calculate current and time to amp-years.
- Compare that calculation to the weight of the installed anodes and the weight loss of the anode material. This indicates if the anodes are expended or have significant life remaining. Another indicator is that if there is a gradual failure over a period of time, the anodes have failed. See paragraph B-2.13 for further direction.

B-2.4 Zero Output Current and/or Zero or Minimal Output Voltage.

The following lists the possible causes and troubleshooting steps for the condition when there is zero output current and/or zero or minimal output voltage. No historical data are immediately available.

B-2.4.1 Troubleshooting Loss of AC Power.

- Check all fuses and measure AC voltage input to the rectifier.
- With power OFF, remove all fuses at the rectifier and any fusible disconnect.
- Measure the continuity of fuses with a handheld multimeter. Set scale to ohms; measure resistance of each fuse. Corrosion on fuse end caps or fuse holders also causes loss of voltage.
- Replace any fuse with measurable resistance, or clean and reinstall fuses if corrosion is found.
- If a disconnect exists, measure the AC voltage with a handheld multimeter on the AC volts scale.
- Measure the voltage on the rectifier side of the disconnect. If a disconnect does not exist, measure the AC voltage from the circuit breaker of the rectifier with a handheld multimeter on AC volts scale.
- For 110/120 V, single-phase rectifiers, turn power to the rectifier OFF, open cabinet, and connect meter to A3 (output of circuit breaker) and

ground (cabinet). Turn power to the rectifier ON and the rectifier circuit breaker ON; measure voltage from the rectifier circuit breaker.

- For 220/240 V, single-phase rectifiers, use the same procedures, but connect meter to A4 and (instead of cabinet ground) the output side of the circuit breaker on the second power lead.
- If voltage is present, either the transformer or the connections inside the rectifier are faulty (proceed to paragraph B-2.14).
- If voltage is not present, there is a loss of AC power to the rectifier.
- Measure the AC voltage to the circuit breaker of the rectifier with a handheld multimeter on the AC volts scale.
- For 110/120 V, single-phase rectifiers, turn power to the rectifier OFF, open cabinet, and connect meter to A1 and A4. Turn power to the rectifier ON; measure voltage to rectifier.
- For 220/240 V, single-phase rectifiers, use the same procedures, but connect meter to A4 and input side of the circuit breaker (A1) on the second power lead.
- If voltage is not present, proceed to paragraph B-2.15.
- If voltage is present, replace circuit breaker or fuse.
- Verify the circuit breaker has not tripped or fuse has not blown.
- If properly operating, measure the AC voltage from the circuit breaker or fuse where power is supplied to the rectifier with a handheld multimeter on the AC volts scale.
- For 110/120 V, single-phase systems, open the circuit breaker panel or fuse panel and connect meter to the output of circuit breaker or the output side of the fuse and ground or neutral bar.
- For 220/240 V, single-phase systems, use the same procedures, but connect the meter to the output lugs of the circuit breakers or the output side of the fuses.
- If voltage is present, locate the break in the power feed from that point to the rectifier circuit breaker (or rectifier fusible disconnect, whichever was last tested).
- If voltage is not present, measure the AC voltage to the circuit breaker or fuse supplying power to the rectifier with a handheld multimeter on the AC volts scale.
- For 110/120 V, single-phase systems, open the circuit breaker panel or fuse panel and connect the meter to the main lugs of the circuit breaker panel or the input side of the fuses and ground.
- For 220/240 V, single-phase systems, use the same procedures, but check individual lugs separately.

- If voltage is not present, locate the circuit breaker panel or transformer supplying power to the panel and apply the applicable procedures in paragraph B-2.15.
- If voltage is present, replace the circuit breaker or fuses.

B-2.4.2 Troubleshoot Defective Meters.

- This symptom indicates defective diodes/selenium plates or improper AC input.
- To troubleshoot AC input to the stacks, measure the AC voltage input to the stacks of the rectifier with a handheld multimeter on the AC volts scale.
- Measure voltage from F6 to C6 (tap bars). One of two conditions may exist: voltage may be near zero or near normal.
- If voltage is near zero, there is a loss of AC power to the rectifier, bad fuses or circuit breakers, or a bad transformer (or connections) in the rectifier.
- Check all fuses and measure AC voltage input to the rectifier. With power OFF, remove all fuses at the rectifier and any fusible disconnect.
- Measure the continuity of fuses with a handheld multimeter. Set scale to ohms; measure resistance of each fuse.
- Corrosion on fuse end caps or fuse holders also causes loss of voltage.
- Replace any fuse with measurable resistance, or clean and reinstall fuses if corrosion is found.
- If disconnect exists, measure the AC voltage with a handheld multimeter on the AC volts scale.
- Measure the voltage on the rectifier side of the disconnect.
- If disconnect does not exist, measure the AC voltage from the circuit breaker of the rectifier with a handheld multimeter on AC volts scale.
- For 110/120 V, single-phase rectifiers, turn power to the rectifier OFF, open cabinet, and connect meter to A3 (output of circuit breaker) and ground (cabinet). Turn power to the rectifier ON and the rectifier circuit breaker ON; measure voltage from the rectifier circuit breaker.
- For 220/240 V, single-phase rectifiers, use the same procedures, but connect meter to A4 and (instead of cabinet ground) the output side of the circuit breaker on the second power lead.
- If voltage is present, either the transformer or the connections inside the rectifier are faulty (proceed to paragraph B-2.14).

- If voltage is not present, there is a loss of AC power to the rectifier. Measure the AC voltage to the circuit breaker of the rectifier with a handheld multimeter on the AC volts scale.
- For 110/120 V, single-phase rectifiers, turn power to the rectifier OFF, open cabinet, and connect meter to A1 and A4. Turn power to the rectifier ON; measure voltage to rectifier.
- For 220/240 V, single-phase rectifiers, use the same procedures, but connect meter to A4 and input side of the circuit breaker (A1) on the second power lead.
- If voltage is not present, proceed to paragraph B-2.15; if voltage is present, replace circuit breaker or fuse.
- If voltage is near normal, there are faulty diodes/selenium plates or bad connections inside the rectifier. Check the diodes/selenium plates of the rectifier with a handheld multimeter on the diode check scale.
- With power OFF, remove the tap bars or shorting wires and the anode lead (P4) and/or the structure lead (N4).
- Check the diode/selenium plate sets by connecting one test lead to N4 and the other to F6 (diode 3), then to C6 (diode 4). Both should beep or not beep.
- Reverse test leads and repeat connections. The beep should be opposite (both should not beep or beep). Repeat the test using P4 instead of N4 to test diodes/selenium plate sets (diodes 1 and 2).

Note: An ohms scale may be used. A good diode has very high resistance in one direction and low resistance in the other direction.

- With power OFF, check for loose connections from F6 to F7, C6 to C7, P1 to P2, P2 to P4, and N1 through N4, and continuity of all wires between those points.
- Repair or replace loose connections and replace damaged or broken wires, if possible. If no problems are found, replace the stacks.
- If the rectifier does not have taps, proceed to paragraph B-2.6; if that test is normal, the rectifier must be removed from the cabinet for checkout.
- Refer to specific rectifier manual to troubleshoot the diodes/selenium plates and the transformer.
- For general reference, see paragraph B-2.12 for the stacks and paragraph B-2.14 for the transformer.
- If the current is normal and a rectifier ammeter reading is significantly different, either the shunt, the connections, or the ammeter is/are faulty. Measure DC with a handheld multimeter connected in series and with the meter on the DC amps scale.

- Disconnect anode header cable at P4 and measure current from P4 to anode lead.
- Compare the measured current value to the current value taken in paragraph B-2.7. If values are significantly different, replace the shunt. If values are the same, the current is normal, the rectifier ammeter reads normal, and structure potentials are still significantly changed from normal, there may be a change in the protected structure.
- If the protected structure is isolated, check all dielectrics and repair or replace faulty ones.
- If the protected structure is not isolated, check for additions to the protected structure or new structures in the area that are continuous with the protected structure, increase current to protect larger structure(s), isolate other structure(s), or install additional impressed current system(s) as required.

WARNING
AC voltage is still present inside the rectifier with the rectifier circuit breaker or power switch OFF. To prevent possible injury or death, employ electrical safety practices for working with live circuits when needlepoint leads are used with power ON.

- With power OFF, check for loose connections from N2 through N9, including any press-to-test switches or buttons, and continuity of all wires between those points. This requires disconnection of AC power from the rectifier cabinet and possibly removal of the rectifier from the cabinet. Note that loose connections are characterized by heat, discoloration of the connection, and melted insulation.
- Repair or replace loose connections and replace damaged or broken wires or proceed to the next step.
- With power OFF, remove ammeter from rectifier. This requires disconnection of AC power from the rectifier cabinet and possibly removal of the rectifier from the cabinet.
- Disconnect one end of the resistors on reverse side of meter.
- Measure the resistance of the resistors with a handheld multimeter on the ohms scale and compare to the value of the resistor (if no resistors are present, replace meter).
- Replace resistor or meter as required.

B-2.4.3 Troubleshoot Broken Anode or Structure Leads.

- With power OFF, disconnect anode lead(s) at P4.

- Connect P4 (positive terminal) to an alternative isolated metallic structure (isolated from structure being tested; if doubt exists, measure continuity to structure lead), such as a metal culvert or fence, or install temporary ground rods.
- For a short period of time, turn power ON and note AC (paragraph B-2.7). One of two conditions exists: either current is now present (changed) or it is not present (not changed).

Note: If the structure being tested is the inside of a water tank or tower and the lack of water does not allow current flow (no electrolyte), fill the tank and then retest.

- If current is present, the anode lead is broken or the anodes have failed. Before a great deal of time is expended troubleshooting an anode bed, it should be determined from records if there is sufficient anode material to attempt locating and repairing the fault. Generally, if the current and time is calculated to amp-years, comparing that number to the weight of the installed anodes and the weight loss of the anode material indicates if the anodes are expended or have significant life remaining.
- Another indicator is that if a gradual failure occurred over a period of time, the anodes have failed. If the failure was sudden, a cable break can be expected. If failed anodes are found, replace the anode bed.
- If a broken anode lead is found, repair the cable. The first step to locating the break is to find the location of any excavations that have occurred in the area of the anode cable. There are two methods of troubleshooting anode beds, depending upon whether all anodes have failed (no current) or some (or most) of the anodes have failed.
- If one or more anodes are functioning, the best method is first to locate the functioning anodes, then an anode bed gradient graph to isolate and locate the problem.

Note: If separate anode lead wires in a junction box were installed, use these to measure the anode current and determine the functioning anodes.

- Perform a CIS over the anode bed. For the purpose of troubleshooting, you may adjust the rectifier to the highest voltage setting that would not result in coating damage to the structure to allow easier location of the anodes.
- Measure the potentials over the anodes with a handheld multimeter on the volts DC scale. With power ON, connect the positive lead of the multimeter to the structure lead (N4) of the rectifier.
- Using a saturated copper/copper sulfate reference cell connected to the negative lead of the multimeter, locate the point of highest voltage on the surface of the ground (directly over an anode).
- Repeat by locating all operational anodes.
- Mark each anode found and compare to system drawings.

- Starting in a straight line 10 feet (3 meters) from the first anode, perform a potential test every 2 feet (0.6 meters) over the entire length of the anode bed to a point 10 feet (3 meters) past where the last anode is (or is supposed to be) located.
- Using graph paper and using vertical lines to represent the measured potentials and horizontal lines to represent the 2-foot (0.6-meter) intervals, graph all readings. This shows the condition of all anodes and indicates if a broken header cable (anode lead) or failed anodes exist. It shows a broken cable between functional and non-functional anodes. If anodes are failing, the gradients peak differently or the gradients fall, then rise intermittently.
- If no anodes are operational, use the fault detector and cable locator connected directly to the anode cable P4 to trace the anode lead from the rectifier toward the anode bed. This can be extremely difficult in some cases.
- An alternative method is to locate the first anode (from drawings, markers, or induction methods).
- Excavate to the first anode and measure continuity back to the rectifier using a CP multi-combination meter continuity check circuit.
- Use the fault detector and cable locator connected directly to the anode to trace the anode lead from the anode toward the rectifier.
- If this is still unsuccessful, replace the anode lead from the rectifier to the anode.

Note: When using the direct connection method, it is essential to have a low-resistance, isolated ground for the fault detector or cable locator to allow a strong locator signal on the cable under test.

- If no current exists, the structure lead may be broken.
- The temporary or alternative anode should remain connected to terminal P4 as described in paragraph B-2.8.
- With power OFF, disconnect structure lead at N4.
- Connect N4 (negative terminal) to an alternative isolated metallic structure (isolated from structure being tested; if doubt exists, measure continuity to structure lead), such as a metal culvert or fence, or install temporary ground rods.
- For a short period of time, turn power ON and note AC. One of two conditions exists: either current is now present (changed) or it is not present (not changed).
- If current still does not exist (not changed), the temporary anode bed is not sufficient. Supplement the temporary anode bed, then perform the steps in paragraph B-2.8.

- If current is present, the structure connection is broken. Use the fault detector and cable locator connected directly to the structure lead at N4 to trace the structure lead from the rectifier toward the structure. This can be extremely difficult in some cases.
- An alternative method is to locate the first structure connection (from drawings, markers, or induction methods).
- Excavate to the structure and measure continuity back to the rectifier using a CP multi-combination meter continuity check circuit.
- Use the fault detector and cable locator connected directly to the structure lead to trace the lead from the structure toward the rectifier.
- If this is still unsuccessful, replace the structure lead from the rectifier to the structure.

Note: When using the direct connection method, it is essential to have a low-resistance, isolated ground for the fault detector or cable locator to put strong locator signals on the cable under test.

- The temporary or alternative anode should remain connected to terminal P4 as described in paragraph B-2.8.
- With power OFF, disconnect structure lead at N4.
- Connect N4 (negative terminal) to an alternative isolated metallic structure (isolated from structure being tested; if doubt exists, measure continuity to structure lead), such as a metal culvert or fence, or install temporary ground rods.
- For a short period of time, turn power ON and note AC. One of two conditions exists: either current is now present (changed) or it is not present (not changed).
- If the current is present, the structure connection is broken. Use the fault detector and cable locator connected directly to the structure lead at N4 to trace the structure lead from the rectifier toward the structure. This can be extremely difficult in some cases.
- An alternative method is to locate the first structure connection (from drawings, markers, or induction methods).
- Excavate to the structure and measure continuity back to the rectifier using a CP multi-combination meter continuity check circuit.
- Use the fault detector and cable locator connected directly to the structure lead to trace the lead from the structure toward the rectifier.
- If this is still unsuccessful, replace the structure lead from the rectifier to the structure.

Note: When using the direct connection method, it is essential to have a low-resistance, isolated ground for the fault detector or cable locator to put strong locator signals on the cable under test.

- If current still does not exist (not changed), the temporary anode bed is not sufficient. Supplement the temporary anode bed, then repeat paragraph B-2.8.

B-2.4.4 Troubleshoot Blown Fuses or Tripped Circuit Breakers.

- Check all fuses and measure AC voltage input to the rectifier.
- With power OFF, remove all fuses at the rectifier and any fusible disconnect.
- Measure the continuity of fuses with a handheld multimeter. Set scale to ohms; measure resistance of each fuse.
- Corrosion on fuse end caps or fuse holders also causes loss of voltage.
- Replace any fuse with measurable resistance, or clean and reinstall fuses if corrosion is found.
- If a disconnect exists, measure the AC voltage with a handheld multimeter on the AC volts scale. Measure the voltage on the rectifier side of the disconnect.
- If a disconnect does not exist, measure the AC voltage from the circuit breaker of the rectifier with a handheld multimeter on AC volts scale.
- For 110/120 V, single-phase rectifiers, turn power to the rectifier OFF, open cabinet, and connect meter to A3 (output of circuit breaker) and ground (cabinet). Turn power to the rectifier ON and the rectifier circuit breaker ON; measure voltage from the rectifier circuit breaker.
- For 220/240 V, single-phase rectifiers, use the same procedures, but connect meter to A4 and (instead of cabinet ground) the output side of the circuit breaker on the second power lead.
- If voltage is present, either the transformer or the connections inside the rectifier are faulty (proceed to paragraph B-2.14).
- If voltage is not present, there is a loss of AC power to the rectifier. Measure the AC voltage to the circuit breaker of the rectifier with a handheld multimeter on the AC volts scale.
- For 110/120 V, single-phase rectifiers, turn power to the rectifier OFF, open cabinet, and connect meter to A1 and A4. Turn power to the rectifier ON; measure voltage to rectifier.
- If voltage is present, locate the break in the power feed from that point to the rectifier circuit breaker (or rectifier fusible disconnect, whichever was last tested).
- If voltage is not present, measure the AC voltage to the circuit breaker or fuse supplying power to the rectifier with a handheld multimeter on the AC volts scale.

- For 110/120 V, single-phase systems, open the circuit breaker panel or fuse panel and connect the meter to the main lugs of the circuit breaker panel or the input side of the fuses and ground.
- For 220/240 V, single-phase systems, use the same procedures, but check individual lugs separately. If voltage is not present, locate the circuit breaker panel or transformer supplying power to the panel and apply the applicable procedures in paragraph B-2.15; if voltage is present, replace the circuit breaker or fuses.

B-2.4.5 Troubleshoot Loose or Bad Wire Connections.

- Check the diodes/selenium plates of the rectifier with a handheld multimeter on the diode check scale. With power OFF, remove the tap bars or shorting wires and the anode lead (P4) and/or the structure lead (N4).
- Check the diode/selenium plate sets by connecting one test lead to N4 and the other to F6 (diode 3), then to C6 (diode 4). Both should beep or not beep.
- Reverse test leads and repeat connections. The beep should be opposite (both should not beep or beep).
- Repeat the test using P4 instead of N4 to test diodes/selenium plate sets (diodes 1 and 2).

Note: An ohms scale may be used. A good diode has very high resistance in one direction and low resistance in the other direction.

- With power OFF, check for loose connections from F6 to F7, C6 to C7, P1 to P2, P2 to P4, and N1 through N4, and check continuity of all wires between those points. Repair or replace loose connections and replace damaged or broken wires, if possible. If no problems are found, replace the stacks.
- Before a great deal of time is expended troubleshooting an anode bed, it should be determined from records if there is sufficient anode material to attempt locating and repairing the fault. Generally, if the current and time are calculated to amp-years, comparing that number to the weight of the installed anodes and the weight loss of the anode material indicates if the anodes are expended or have significant life remaining. Another indicator is that if a gradual failure occurred over a period of time, the anodes have failed. If the failure was sudden, a cable break can be expected.
- If failed anodes are found, replace the anode bed.
- If a broken anode lead is found, repair the cable. The first step to locating the break is to find the location of any excavations that have occurred in the area of the anode cable.

- There are two methods of troubleshooting anode beds, depending upon whether all anodes have failed (no current), or some (or most) of the anodes have failed. If one or more anodes are functioning, the best method is first to locate the functioning anodes, then an anode bed gradient graph to isolate and locate the problem.

Note: If separate anode lead wires in a junction box were installed, use these to measure the anode current and determine the functioning anodes.

- Perform a CIS over the anode bed. For the purpose of troubleshooting, you may adjust the rectifier to the highest voltage setting that would not result in coating damage to the structure to allow easier location of the anodes.
- Measure the potentials over the anodes with a handheld multimeter on the volts DC scale.
- With power ON, connect the positive lead of the multimeter to the structure lead (N4) of the rectifier.
- Using a saturated copper/copper sulfate reference cell connected to the negative lead of the multimeter, locate the point of highest voltage on the surface of the ground (directly over an anode).
- Repeat by locating all operational anodes.
- Mark each anode found and compare to system drawings. Starting in a straight line 10 feet (3 meters) from the first anode, perform a potential test every 2 feet (0.6 meters) over the entire length of the anode bed to a point 10 feet (3 meters) past where the last anode is (or is supposed to be) located.
- Using graph paper and using vertical lines to represent the measured potentials and horizontal lines to represent the 2-foot (0.6-meter) intervals, graph all readings. This shows the condition of all anodes and indicates if a broken header cable (anode lead) or failed anodes exist. It shows a broken cable between functional and non-functional anodes. If anodes are failing, the gradients peak differently or the gradients fall, and then rise intermittently.
- If no anodes are operational, use the fault detector and cable locator connected directly to the anode cable P4 to trace the anode lead from the rectifier toward the anode bed. This can be extremely difficult in some cases.
- An alternative method is to locate the first anode (from drawings, markers, or induction methods).
- Excavate to the first anode and measure continuity back to the rectifier using a CP multi-combination meter continuity check circuit.
- Use the fault detector and cable locator connected directly to the anode to trace the anode lead from the anode toward the rectifier.

- If this is still unsuccessful, replace the anode lead from the rectifier to the anode.

Note: When using the direct connection method, it is essential to have a low-resistance, isolated ground for the fault detector or cable locator that allows a strong locator signal on the cable under test.

B-2.5 Rectifier Voltage Is Half of Normal.

The following lists possible causes and troubleshooting steps for the condition when the rectifier voltage is about half of normal. Rectifier output is required to be turned up to regain proper amount of current.

B-2.5.1 Troubleshoot Lightning or Other Power Surges.

- Check all fuses and measure AC voltage input to the rectifier. With power OFF, remove all fuses at the rectifier and any fusible disconnect.
- Measure the continuity of fuses with a handheld multimeter. Set scale to ohms; measure resistance of each fuse.
- Corrosion on fuse end caps or fuse holders also causes loss of voltage.
- Replace any fuse with measurable resistance, or clean and reinstall fuses if corrosion is found.
- If a disconnect exists, measure the AC voltage with a handheld multimeter on the AC volts scale. Measure the voltage on the rectifier side of the disconnect.
- If a disconnect does not exist, measure the AC voltage from the circuit breaker of the rectifier with a handheld multimeter on the AC volts scale.
- For 110/120 V, single-phase rectifiers, turn power to the rectifier OFF, open cabinet, and connect meter to A3 (output of circuit breaker) and ground (cabinet). Turn power to the rectifier ON and the rectifier circuit breaker ON; measure voltage from the rectifier circuit breaker.
- For 220/240 V, single-phase rectifiers, use the same procedures, but connect meter to A4 and (instead of cabinet ground) the output side of the circuit breaker on the second power lead.
- If voltage is present, then either the transformer or the connections inside the rectifier are faulty (proceed to paragraph B-2.15).
- If voltage is not present, then there may be loss of AC power to the rectifier. Measure the AC voltage to the circuit breaker of the rectifier with a handheld multimeter on the AC volts scale.
- For 110/120 V, single-phase rectifiers, turn power to the rectifier OFF, open cabinet, and connect meter to A1 and A4. Turn power to the rectifier ON; measure voltage to rectifier.

- For 220/240 V, single-phase rectifiers, use the same procedures, but connect meter to A4 and input side of the circuit breaker (A1) on the second power lead.
- If voltage is present, replace circuit breaker or fuse.
- If voltage to the rectifier is not present, measure the AC voltage from the circuit breaker or fuse where power is supplied to the rectifier with a handheld multimeter on the AC volts scale.
- For 110/120 V, single-phase systems, open the circuit breaker panel or fuse panel and connect meter to the output of circuit breaker or the output side of the fuse and ground or neutral bar.
- For 220/240 V, single-phase systems, use the same procedures, but connect the meter to the output lugs of the circuit breakers or the output side of the fuses.
- If voltage is present, locate the break in the power feed from that point to the rectifier circuit breaker (or rectifier fusible disconnect, whichever was last tested).
- If voltage is not present, measure the AC voltage to the circuit breaker or fuse supplying power to the rectifier with a handheld multimeter on the AC volts scale.
- For 110/120 V, single-phase systems, open the circuit breaker panel or fuse panel and connect the meter to the main lugs of the circuit breaker panel or the input side of the fuses and ground.
- For 220/240 V, single-phase systems, use the same procedures, but check individual lugs separately. If voltage is not present, locate the circuit breaker panel or transformer supplying power to the panel and repeat paragraph B-2.15; if voltage is present, replace the circuit breaker or fuses.

B-2.5.2 Troubleshoot Sudden Decrease in Soil Resistivity Due to Long Period of Heavy Rain.

- Check all fuses and measure AC voltage input to the rectifier. With power OFF, remove all fuses at the rectifier and any fusible disconnect.
- Measure the continuity of fuses with a handheld multimeter. Set scale to ohms; measure resistance of each fuse. Corrosion on fuse end caps or fuse holders also causes loss of voltage.
- Replace any fuse with measurable resistance, or clean and reinstall fuses if corrosion is found.
- If disconnect exists, measure the AC voltage with a handheld multimeter on the AC volts scale.
- Measure the voltage on the rectifier side of the disconnect.

- If disconnect does not exist, measure the AC voltage from the circuit breaker of the rectifier with a handheld multimeter on AC volts scale.
- For 110/120 V, single-phase rectifiers, turn power to the rectifier OFF, open cabinet, and connect meter to A3 (output of circuit breaker) and ground (cabinet). Turn power to the rectifier ON and the rectifier circuit breaker ON; measure voltage from the rectifier circuit breaker.
- For 220/240 V, single-phase rectifiers, use the same procedures, but connect meter to A4 and (instead of cabinet ground) the output side of the circuit breaker on the second power lead.
- If voltage is present, either the transformer or the connections inside the rectifier are faulty (proceed to paragraph B-2.15).
- If voltage is not present, there is a loss of AC power to the rectifier. Measure the AC voltage to the circuit breaker of the rectifier with a handheld multimeter on the AC volts scale.
- For 110/120 V, single-phase rectifiers, turn power to the rectifier OFF, open cabinet, and connect meter to A1 and A4. Turn power to the rectifier ON; measure voltage to rectifier.
- For 220/240 V, single-phase rectifiers, use the same procedures, but connect meter to A4 and input side of the circuit breaker (A1) on the second power lead. If voltage is not present, proceed to paragraph B-2.15; if voltage is present, replace circuit breaker or fuse.

B-2.6 Rectifier Output Is Decreased.

The following lists the causes and troubleshooting steps for the condition when the rectifier output is decreased but the voltage is near normal.

B-2.6.1 Troubleshoot Rectifier Is Half Waving and One of the Diodes or Selenium Plates Burned Out.

- Measure the DC voltage output of the rectifier with a handheld multimeter. With power ON and scale on volts DC, measure voltage from N4 to P4 (see Figure B-6). One of three conditions may exist: voltage may be near zero (proceed to paragraph B-2.7.1), near half of normal (proceed to paragraph B-2.7.2), or near normal (proceed to paragraph B-2.7.3).
- With power OFF, check for loose connections from P2 to P3, N2 and N5 through N7, including any press-to-test switches or buttons, and continuity of all wires between those points. This requires disconnecting AC power from the rectifier cabinet and possibly removal of the rectifier from the cabinet. Note that loose connections are characterized by heat, discoloration of the connection, and melted insulation.
- Repair or replace loose connections and replace damaged or broken wires. If problems are not found, proceed with paragraph B-2.7.3.

- With power OFF, remove voltmeter from rectifier. This requires disconnecting AC power from the rectifier cabinet and possibly removal of the rectifier from the cabinet.
- Disconnect one end of the resistors on reverse side of meter.
- Measure the resistance of the resistors with a handheld multimeter on the ohms scale and compare to the value of the resistor (if no resistors are present, replace meter).
- Replace resistor or meter as required.

B-2.6.2 Troubleshoot Failure of Some Anodes or Anode Leads When Soil Is Dried Out (Increased Resistivity).

- Measure the DC output of the rectifier with a handheld multimeter on the mV scale. Measure mV from N2 to N3. Multiply the indicated reading by the appropriate multiplication factor (see Figure B-7).
- One of three conditions may exist:

a. The current may be near zero, indicating a break in the anode lead, failed anodes, or a break in the structure lead (proceed to paragraph B-2.8.1).

b. The current may be near half of normal, indicating a defective diode/selenium plate; a break in the header cable between anodes; or, if there are multiple anode leads, loss of one anode lead or anode bed. Measure the DC voltage output of the rectifier with a handheld multimeter on the volts DC scale. Measure the voltage from N4 to P4. If voltage is also half of normal, proceed to paragraph B-2.13 to troubleshoot the diodes/selenium plates. If voltage is normal, proceed to paragraph B-2.14 to troubleshoot the anode bed.

c. The current may be near normal. Proceed to paragraph B-2.8.3 for detailed instructions.

WARNING

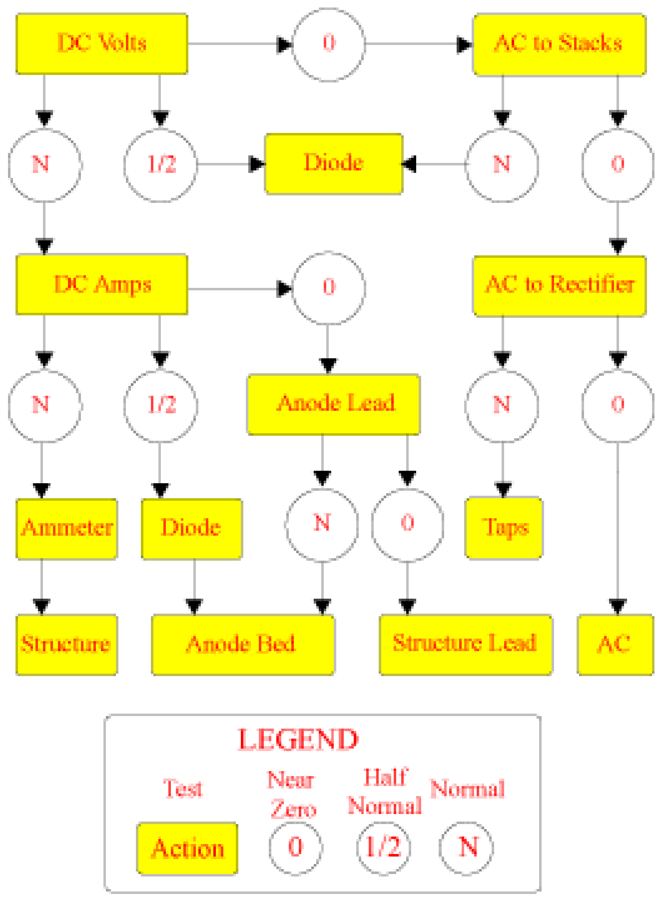
All connections should be made with alligator clip leads with the rectifier circuit breaker or power switch OFF. To prevent possible injury or death, employ electrical safety practices for working with live circuits when needlepoint leads are used with power ON.

The starting point for all impressed current systems troubleshooting is at the rectifier. Indications of all problems are present at this location. The greatest aids to troubleshooting are historical data and drawings of the system. Usually, the fault may be isolated and then verified by testing. There are sufficient test points on the face plate of the rectifier to isolate the faulty component. Figure B-5 depicts the troubleshooting block diagram.

WARNING
AC voltage is still present inside the rectifier with the rectifier circuit breaker or power switch OFF. All connections inside the rectifier cabinet should be made with alligator clip leads connected with the power to the rectifier OFF. To prevent possible injury or death, employ electrical safety practices for working with live circuits when needlepoint leads are used with power ON.

WARNING
For Navy projects, when conducting work on or near circuits, energized lines, or parts of equipment operating at or above 50 V, utilize work practices identified in OPNAV P-45-117-6-98.

Figure B-5 Troubleshooting Block Diagram

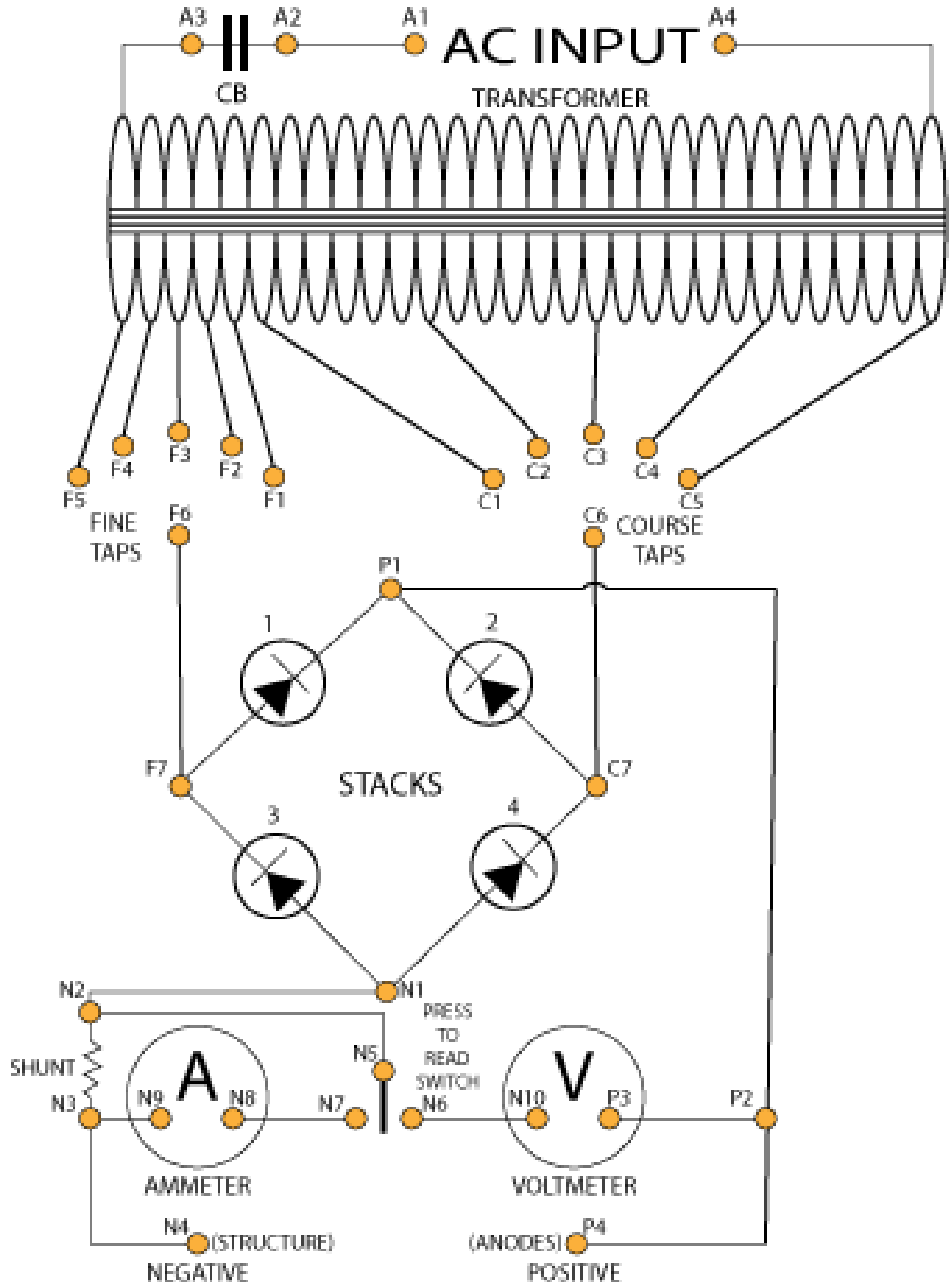


B-2.7 DC Voltage.

Measure the DC voltage output of the rectifier with a handheld multimeter. With the power ON and the scale on volts DC, measure voltage from N4 to P4 (see Figure B-6). One of three conditions may exist: voltage may be near zero (proceed to paragraph B-2.7.1), near half of normal (proceed to paragraph B-2.7.2), or near normal (proceed to paragraph B-2.7.3).

- With power OFF, check for loose connections from P2 to P3, N2 and N5 through N7, including any press-to-test switches or buttons, and continuity of all wires between those points. This requires disconnection of AC power from the rectifier cabinet and possibly removal of the rectifier from the cabinet. Note that loose connections are characterized by heat, discoloration of the connection, and melted insulation. Repair or replace loose connections and replace damaged or broken wires. If problems are not found, proceed to paragraph B-2.7.3.
- With power OFF, remove voltmeter from rectifier. This requires disconnection of AC power from the rectifier cabinet and possibly removal of the rectifier from the cabinet. Disconnect one end of the resistors on reverse side of meter. Measure the resistance of the resistors with a handheld multimeter on the ohms scale and compare to the value of the resistor (if no resistors are present, replace meter). Replace resistor or meter as required.

Figure B-6 Typical Rectifier Wiring Diagram



B-2.7.1 No DC Voltage.

No DC voltage indicates that one of the components in the rectifier is faulty or there has been a loss of AC power (proceed to paragraph B-2.11).

B-2.7.2 Half the Normal Voltage Output.

This case indicates defective diodes/selenium plates or improper AC input. Proceed to paragraph B-2.11 to check the AC input to the stacks and paragraph B-2.13 to troubleshoot the diodes/selenium plates.

B-2.7.3 Normal DC Voltage.

This case indicates a break in the anode lead, failed anodes, or a break in the structure lead (proceed to paragraph B-2.10). If the voltage is normal and the rectifier voltmeter reads significantly different, the connections or the voltmeter are faulty (proceed to paragraph B-2.10).

B-2.8 DC Current.

Measure the DC current output of the rectifier with a handheld multimeter on the mV scale. Measure the mV from N2 to N3 across the shunt resistor. Multiply the indicated reading by the appropriate multiplication factor. See Figure B-7. One of three conditions may exist: the current may be near zero (proceed to paragraph B-2.8.1), near half of normal (proceed to paragraph B-2.8.2), or near normal (proceed to paragraph B-2.8.3).

Figure B-7 Shunt Multiplication Factors

SHUNT SIZE		MEASURE	X	FACTOR	=	AMPS
50 mV	100A	___mV	X	2	=	___A
50 mV	75A	___mV	X	1.5	=	___A
50 mV	50A	___mV	X	1	=	___A
50 mV	45A	___mV	X	.9	=	___A
50 mV	40A	___mV	X	.8	=	___A
50 mV	35A	___mV	X	.7	=	___A
50 mV	30A	___mV	X	.6	=	___A
50 mV	25A	___mV	X	.5	=	___A
50 mV	20A	___mV	X	.4	=	___A
50 mV	15A	___mV	X	.3	=	___A
50 mV	10A	___mV	X	.2	=	___A
50 mV	5A	___mV	X	.1	=	___A
a mV	b A	___mV	X	$\frac{bA}{amV}$	=	___A

B-2.8.1 Normal DC Voltage with Near Zero Current.

This condition indicates a break in the anode lead, failed anodes, or a break in the structure lead (proceed to paragraphs B-2.9 and B-2.10).

B-2.8.2 Half the Normal Current Output.

This condition indicates either a defective diode/selenium plate; a break in the header cable between anodes; or, if there are multiple anode leads, loss of one anode lead or anode bed. Measure the DC voltage output of the rectifier with a handheld multimeter on the volts DC scale. Measure the voltage from N4 to P4. If voltage is also half of normal, proceed to paragraph B-2.13 to troubleshoot the diodes/selenium plates. If voltage is normal, proceed to paragraph B-2.12 to troubleshoot the anode bed.

B-2.8.3 Current Is Normal and Rectifier Ammeter Reads Differently.

If the current is normal and a rectifier ammeter reading is significantly different, then the shunt, the connections, or the ammeter is faulty (proceed to paragraph B-2.8.3.a)). If the current is normal, the rectifier ammeter reads normal, and structure potentials are still significantly changed from normal, proceed to paragraph B-2.8.3.d).

a. Measure DC with a handheld multimeter connected in series and with the meter on the DC amps scale. Disconnect anode header cable at P4 and measure current from P4 to anode lead. Compare the measured current value to the current value taken in paragraph B-2.7. If values are significantly different, replace the shunt. If values are the same, proceed to paragraph B-2.8.3.d).

WARNING
AC voltage is still present inside the rectifier with the rectifier circuit breaker or power switch OFF. All connections should be made with alligator clip leads with the rectifier circuit breaker or power switch OFF. To prevent possible injury or death, employ electrical safety practices for working with live circuits when needlepoint leads are used with power ON.

WARNING
For Navy projects, when conducting work on or near circuits, energized lines, or parts of equipment operating at or above 50 V, utilize work practices identified in OPNAV P-45-117-6-98.

b. With power OFF, check for loose connections from N2 through N9, including any press-to-test switches or buttons, and continuity of all wires between those points. This requires disconnection of AC power from the rectifier cabinet and possibly removal of the rectifier from the cabinet. Note that loose connections are characterized by heat, discoloration of the connection, and melted insulation. Repair or replace loose connections and replace damaged or broken wires. If problems are not found, proceed to paragraph B-2.8.3.c).

c. With power OFF, remove ammeter from rectifier. This requires disconnection of AC power from the rectifier cabinet and possibly removal of the rectifier from the cabinet. Disconnect one end of the resistors on reverse side of meter. Measure the resistance of the resistors with a handheld multimeter on the ohms scale and compare to the value of the resistor (if no resistors are present, replace meter). Replace resistor or meter as required.

d. Normal current values accompanied by loss of potential shifts indicate a change in the protected structure. If the protected structure is isolated, all dielectrics and repair or replace faulty ones. If the protected structure is not isolated, check for additions to the protected structure or n check ew structures in the area that are continuous with the protected structure, increase current to protect larger structure(s), isolate other structure(s), or install additional impressed current system(s) as required.

B-2.9 Anode Lead Wires.

With power OFF, disconnect anode lead(s) at P4. Connect P4 (positive terminal) to an alternative isolated metallic structure (isolated from structure being tested; if doubt exists, measure continuity to structure lead), such as a metal culvert or fence, or install temporary ground rods. For a short period of time, turn power ON and note AC. One of two conditions exists: either current is now present (changed) or it is not present (not changed).

Note: If the structure being tested is the inside of a water tank or tower, and the lack of water does not allow current flow (no electrolyte), fill the tank and then retest.

B-2.9.1 Current Is Present.

If current exists, the anode lead is broken or the anodes have failed (proceed to paragraph B-2.14).

B-2.9.2 Current Is Not Present.

If no current exists, the structure lead may be broken (proceed to paragraph B-2.10).

B-2.10 Structure Lead.

For this test, the temporary or alternative anode should remain connected to terminal P4. With power OFF, disconnect structure lead at N4. Connect N4 (negative terminal) to an alternative isolated metallic structure (isolated from structure being tested; if doubt exists, measure continuity to structure lead), such as a metal culvert or fence, or install temporary ground rods. For a short period of time, turn power ON and note AC. One of two conditions exists: either current is now present (changed) (proceed to paragraph

B-2.9.1) or it is not present (not changed). If current still does not exist (not changed), the temporary anode bed is not sufficient. Supplement the temporary anode bed, then repeat paragraph B-2.8.

B-2.10.1 Structure Connection Broken.

Since current is now present, the structure connection is broken. Use the fault detector and cable locator, connected directly to the structure lead at N4, to trace the structure lead from the rectifier toward the structure. This can be extremely difficult in some cases. An alternative method is to locate the first structure connection (from drawings, markers, or induction methods). Excavate to the structure and measure continuity back to the rectifier using a CP multi-combination meter continuity check circuit. Use the fault detector and cable locator, connected directly to the structure lead, to trace the lead from the structure toward the rectifier. If this is still unsuccessful, replace the structure lead from the rectifier to the structure.

Note: When using the direct connection method, it is essential to have a low-resistance isolated ground for the fault detector or cable locator to put strong locator signals on the cable under test.

If current still does not exist (not changed), the temporary anode bed is not sufficient. Supplement the temporary anode bed, then repeat paragraph B-2.8.

B-2.11 AC Voltage to Stacks.

Measure the AC voltage input to the stacks of the rectifier with a handheld multimeter on the AC volts scale. Measure voltage from F6 to C6 (tap bars). One of two conditions may exist: voltage may be near zero (proceed to paragraph B-2.11.1) or near normal (proceed to paragraph B-2.11.2).

B-2.11.1 Voltage Near Zero.

This indicates loss of AC power to the rectifier, bad fuses or circuit breakers, or a bad transformer (or connections) in the rectifier (proceed to paragraph B-2.12).

B-2.11.2 Voltage Near Normal.

This indicates faulty diodes/selenium plates or bad connections inside the rectifier (proceed to paragraph B-2.13). If the rectifier does not have taps, proceed to paragraph B-2.12; if that test is normal, the rectifier must be removed from the cabinet for checkout. Refer to specific rectifier manual to troubleshoot the diodes/selenium plates and the transformer. For general reference, see paragraph B-2.13 for the stacks and paragraph B-2.14 for the transformer.

B-2.12 Fuses.

Check all fuses and measure AC voltage input to the rectifier. With power OFF, remove all fuses at the rectifier and any fusible disconnect. Measure the continuity of fuses with a handheld multimeter. Set scale to ohms; measure resistance of each fuse. Corrosion on fuse end caps or fuse holders also causes loss of voltage. Replace any fuse with measurable resistance, or clean and reinstall fuses if corrosion is found. If a disconnect exists, measure the AC voltage with a handheld multimeter on the AC volts scale. Measure the voltage on the rectifier side of the disconnect. If a disconnect does not exist, measure the AC voltage from the circuit breaker of the rectifier with a handheld multimeter on AC volts scale. For 110/120 V, single-phase rectifiers, turn power to the rectifier OFF, open cabinet, and connect meter to A3 (output of circuit breaker) and ground (cabinet). Turn power to the rectifier ON and the rectifier circuit breaker ON; measure voltage from the rectifier circuit breaker. For 220/240 V, single-phase rectifiers, use the same procedures, but connect meter to A4 and (instead of cabinet ground) the output side of the circuit breaker on the second power lead (not shown on drawing). If voltage is present, proceed to paragraph B-2.12.1. If voltage is not present, proceed to paragraph B-2.12.2.

B-2.12.1 Voltage Is Present.

This indicates that either the transformer or the connections inside the rectifier are faulty (proceed to paragraph B-2.15).

B-2.12.2 Voltage Is Not Present.

This indicates loss of AC power to the rectifier. Measure the AC voltage to the circuit breaker of the rectifier with a handheld multimeter on the AC volts scale.

- For 110/120 V, single-phase rectifiers, turn power to the rectifier OFF, open cabinet, and connect meter to A1 and A4. Turn power to the rectifier ON; measure voltage to rectifier.
- For 220/240 V, single-phase rectifiers, use the same procedures, but connect meter to A4 and input side of the circuit breaker (A1) on the second power lead.

If voltage is not present, proceed to paragraph B-2.16; if voltage is present, replace circuit breaker or fuse.

B-2.13 Diodes.

Check the diodes/selenium plates of the rectifier with a handheld multimeter on the diode check scale. With power OFF, remove the tap bars or shorting wires and the anode lead (P4) and/or the structure lead (N4). Check the diode/selenium plate sets by connecting one test lead to N4 and the other to F6 (diode 3), then to C6 (diode 4). Both should beep or not beep. Reverse test leads and repeat connections. The beep should be opposite (both should either not beep or beep). Repeat the test using P4 instead of N4 to test diodes/selenium plate sets (diodes 1 and 2).

Note: An ohms scale may be used. A good diode has very high resistance in one direction and low resistance in the other direction.

With power OFF, check for loose connections from F6 to F7, C6 to C7, P1 to P2, P2 to P4, and N1 through N4, and continuity of all wires between those points. Repair or replace loose connections and replace damaged or broken wires, if possible. If no problems are found, replace the stacks.

B-2.14 Anode Bed.

Before a great deal of time is expended troubleshooting an anode bed, it should be determined from records if there is sufficient anode material to attempt locating and repairing the fault. Generally, if the current and time are calculated to amp-years, comparing that number to the weight of the installed anodes and the weight loss of the anode material indicates if the anodes are expended or have significant life remaining. Another indicator is that if a gradual failure occurred over a period of time, the anodes have failed. If the failure was sudden, a cable break can be expected. If failed anodes are found, replace the anode bed. If a broken anode lead is found, repair the cable. The first step to locating the break is to find the location of any excavations that have occurred in the area of the anode cable. There are two methods of troubleshooting anode beds, depending upon whether all anodes have failed (no current) or some (or most) of the anodes have failed. If one or more anodes are functioning, see paragraph B-2.14.2. If no anodes are functioning, see paragraph B-2.14.3.

If one or more anodes are functioning, the best method is first to locate the functioning anodes, then an anode bed gradient graph to isolate and locate the problem.

Note: If separate anode lead wires in a junction box were installed, use these to measure the anode current and determine the functioning anodes.

B-2.14.1 Linear Anode ICCP Systems.

These systems are commonly used to protect long line structures, such as pipelines. This is usually the most economical choice when the pipeline due to poor or aged coating requires a continuous and close coupled current. This type of anode bed is used to protect pipelines with poor coating and can be installed up to several miles along a pipeline. The distance from the structure is normally 5 to 10 feet (1.5 to 3 meters). In most cases, the anode is installed with a separate header cable to minimize voltage drop. Mixed metal oxide (MMO) anodes or polymer anodes are typically used for this type of installation.

B-2.14.1.1 Mixed Metal Oxide Anodes.

MMO anodes exhibit favorable design life characteristics while providing current at very high density levels. The oxide film is not susceptible to rapid deterioration due to anode acid generation, rippled DC, or half wave rectification, as is common with other precious metal anodes. The composition of the anode consists of a titanium rod, wire, tube, or expanded mesh with the oxide film baked on the base metal. In oxygen evolution environments, such as soils, the oxide consists of ruthenium crystals and titanium halide salts in an aqueous solution that is applied like paint on the base metal and baked at 400ºC to 800ºC, forming a rutile oxide. Normally, titanium experiences physical breakdown around 10 V, but the oxide film is so highly conductive (10^{-5} ohm-cm resistivity) that the current, which takes the path of least resistance, is discharged from the oxide rather than the base metal, even with a rectifier voltage of 90 V in soils. This contrasts with the insulating titanium dioxide film that naturally forms on the surface of bare titanium. When the MMO film has been consumed, the insulating titanium dioxide film covers the anode and does not allow current to discharge unless the applied voltage is greater than 10 V in seawater or 50 to 70 V in fresh water.

The anode life is based on the thickness of the oxide film. Typical thicknesses result in a 30- to 50-year anode life.

Anodes in soil or mud should be backfilled with fine, low-resistance, calcined petroleum coke breeze for maximum life and performance. Consumption rates range from 0.5 milligrams per amp-year in seawater to 5 milligrams per amp-year in coke breeze, fresh water, and sea mud. As with any anode, the connection must be constructed to be moisture proof, watertight, and have no more than 0.001 ohms of resistance.

B-2.14.2 Close Interval Survey.

Perform a CIS over the anode bed. For the purpose of troubleshooting, adjust the rectifier to the highest voltage setting that would not result in coating damage to the structure to allow easier location of the anodes. Measure the potentials over the anodes with a handheld multimeter on the volts DC scale. With power ON, connect the positive lead of the multimeter to the structure lead (N4) of the rectifier. Using a saturated copper/copper sulfate reference cell connected to the negative lead of the multimeter, locate the point of highest voltage on the surface of the ground (directly over an anode). Repeat by locating all operational anodes. Mark each anode found and compare to system drawings. Starting in a straight line 10 feet (3 meters) from the first anode, perform a potential test every 2 feet (0.6 meters) over the entire length of the anode bed to a point 10 feet (3 meters) past where the last anode is (or is supposed to be) located. Using graph paper and using vertical lines to represent the measured potentials and horizontal lines to represent the 2-foot (0.6-meter) intervals, graph all readings. This shows the condition of all anodes and indicates if a broken header cable (anode lead) or failed anodes exist. It shows a broken cable between functional and non-functional anodes. If anodes are failing, the gradients peak differently, or the gradients fall and then rise intermittently.

B-2.14.3 Anodes Are Non-operational.

If no anodes are operational, use the fault detector and cable locator connected directly to the anode cable P4 to trace the anode lead from the rectifier toward the anode bed. This can be extremely difficult in some cases. An alternative method is to locate the first anode (from drawings, markers, or induction methods). Excavate to the first anode and measure continuity back to the rectifier using a CP multi-combination meter continuity check circuit. Use the fault detector and cable locator, connected directly to the anode, to trace the anode lead from the anode toward the rectifier. If this is still unsuccessful, replace the anode lead from the rectifier to the anode.

Note: When using the direct connection method, it is essential to have a low-resistance, isolated ground for the fault detector or cable locator in order to allow a strong locator signal on the cable under test.

B-2.15 Rectifier Taps.

Measure the AC voltage on the taps of the rectifier with a handheld multimeter on the AC volts scale. Remove the tap bars or shorting wires. Measure the voltage from F5 to F4, F4 to F3, F3 to F2, F2 to F1, and F1 to C1. All readings should be approximately the same. Measure the voltage from C5 to C4, C4 to C3, C3 to C2, and C2 to C1. All readings should be approximately the same. Any lead that tests differently must be checked for connection (proceed to paragraph B-2.15.1).

Note: On some rectifiers, F1 to C1 may be a unique voltage.

B-2.15.1 With Power Off.

Note: Loose connections are characterized by heat, discoloration of the connection, and melted insulation.

- Check for loose connections from F1 through F5 and C1 through C5, including any tap bar or shorting wire, and continuity of all wires between those points. Repair or replace loose connections and replace damaged or broken wires, if possible. If only one tap is inoperative, a different tap setting may be operational, and testing reveals functioning taps. If replacement of wire is not possible, replace the transformer. If no problems are found, proceed with the next step.
- Check for loose connections from A2 through A4 and continuity of all wires between those points. Repair or replace loose connections and replace damaged or broken wires, if possible. If replacement of wire is not possible, replace the transformer.

Note: Checkout of transformers or pole fuses requires personnel certified for work on high-voltage lines and proper equipment beyond the scope of these procedures.

B-2.16 Rectifier Input Voltage.

First, verify that the circuit breaker has not tripped or the fuse has not blown. If properly operating, measure the AC voltage from the circuit breaker or fuse where power is supplied to the rectifier with a handheld multimeter on the AC volts scale. For 110/120 V, single-phase systems, open the circuit breaker panel or fuse panel and connect meter to the output of circuit breaker or the output side of the fuse and ground or neutral bar. For 220/240 V, single-phase systems, use the same procedures, but connect the meter to the output lugs of the circuit breakers or the output side of the fuses.

If voltage is present, locate the break in the power feed from that point to the rectifier circuit breaker (or rectifier fusible disconnect, whichever was last tested).

If voltage is not present, measure the AC voltage to the circuit breaker or fuse supplying power to the rectifier with a handheld multimeter on the AC volts scale.

- For 110/120 V, single-phase systems, open the circuit breaker panel or fuse panel and connect the meter to the main lugs of the circuit breaker panel or the input side of the fuses and ground.
- For 220/240 V, single-phase systems, use the same procedures, but check individual lugs separately. If voltage is not present, locate the circuit breaker panel or transformer supplying power to the panel and repeat paragraph B-2.15; if voltage is present, replace the circuit breaker or fuses.

WARNING
AC voltage is still present inside the rectifier with the rectifier circuit breaker or power switch OFF. All connections should be made with alligator clip leads with the rectifier circuit breaker or power switch OFF. To prevent possible injury or death, employ electrical safety practices for working with live circuits when needlepoint leads are used with power ON.

WARNING
For Navy projects, when conducting work on or near circuits, energized lines, or parts of equipment operating at or above 50 V, utilize work practices identified in OPNAV P-45-117-6-98.

APPENDIX C SERVICE-SPECIFIC GUIDANCE

C-1 ARMY.

C-1.1 If Required.

C-2 AIR FORCE.

C-2.1 Sample Base Corrosion Control Operating Instructions.

C-2.1.1 Purpose.

The following sections outline responsibilities and procedures required to establish and conduct a continuing and recurring Corrosion Control Program for Sample Air Force Base (AFB), XX.

C-2.1.2 Criteria.

This UFM is applicable to all Civil Engineering Squadron personnel involved, directly or indirectly, in the development and maintenance of an effective Corrosion Control Program.

C-2.1.3 Responsibility.

C-2.1.3.1 AFCEC.

AFCEC has overall responsibility for the Air Force Facility and Infrastructure Corrosion Control Program. AFCEC is responsible for the functional adequacy of Air Force new construction.

C-2.1.3.2 Base Engineering.

Base Engineering with AFCEC consultation is responsible for its Corrosion Control Program and ensures it develops, establishes, and maintains Infrastructure Systems that ensure an effective comprehensive Corrosion Control Program with personnel adequately trained to carry out their responsibilities.

Base Engineering must establish and maintain a Corrosion Control Program for each activity within the squadron at Sample AFB. The Chief of the Engineering Flight and the Chief of Operations Flight work together to assign the Base Corrosion Control Engineer (BCCE). They also appoint a Base Industrial Water Treatment Engineer and a Base Protective Coatings Engineer as required. The Chief of Operations appoints the CP and industrial water treatment craftsmen in consultation with the Chief of Infrastructure Systems.

C-2.1.3.3 BCCE.

The BCCE is responsible for the overall management of the base Corrosion Control Program and coordinates this program with the Chief of Operations Flight, Chief of

Operations Engineering Element, Chief of Infrastructure Support Element, CP craftsmen, industrial water treatment craftsmen, protective coatings personnel, and other appropriate functions within the operations flight. The BCCE establishes and chairs a Base Corrosion Control committee that meets at least quarterly. Minimum participants are: (1) Chief of Operations, (2) Chief of Operations Engineering, (3) Chief of Infrastructure Systems, (4) Lead craftsmen in Mechanical, Electrical, Structural, and Sanitation, (5) Lead planner, and (6) Others as appropriate.

C-2.1.3.4 Engineering Construction Management.

Engineering Construction Management and/or Service Contract personnel monitor every phase of coatings operations to include Simplified Acquisition of Base Engineering Resources (SABER) contract and general contract operations. For all other corrosion work, whether contract or in-house, this office provides the coatings test equipment and expertise to evaluate work and investigate coating failures.

C-2.1.4 Reference.

See AFI 32-1054, Attachment 1, for directives and guidance that have an impact on corrosion control engineering.

C-2.1.5 Work Procedures.

C-2.1.5.1 Operations/Engineering.

- The Civil Engineer (CE) appoints, by letter, a Corrosion Control Engineer with the advice of the Chief of Engineering, Chief of Operations, and Chief of Operations Engineering.
- Chief of Operations and/or Engineering assigns corrosion control duties to the engineer appointed by the CE and ensures the appointee receives adequate training to carry out these responsibilities (see AFI 32-1054).
- Chief of Operations appoints at least 2 CP craftsmen and other corrosion control craftsmen from the appropriate shops as he or she deems necessary to facilitate corrosion control duties. Personnel involved in corrosion control duties should receive adequate training on an annual basis and be appointed in writing. A file containing a current roster of corrosion control personnel is in the Operations Branch and contains training status and training program information. Send updated copies of appointment letters for corrosion control duties to the BCCE.

C-2.1.5.2 BCCE.

The BCCE manages the overall Engineering Squadron Corrosion Control Program. This includes the following tasks:

- Develop program and management procedures.
- Review engineering drawings and specifications developed under base direction for adequacy of corrosion control.

- Review engineering drawings for Military Construction (MILCON) projects for adequacy of corrosion control.
- Maintain base corrosion control records.
- Retain logs compiled by appropriate shops to be collected at the end of the calendar year. CP craftsmen shall retain and log readings on the appropriate forms during the year and forward to the BCCE at the end of the calendar year.
- Review corrosion records monthly.
- Complete a CIS every 5 years.
- Include requirements and criteria of AFI 32-1054 in the Corrosion Control Program.
- Establish a CP system master plan and show all installed rectifiers, ground beds, test stations, and anodes. Update the maps to show any modifications made on the systems. Indicate the location of neighboring structures.
- Conduct an annual CP performance survey with qualified CP craftsmen; accomplish by contract if capability is not available with shop. This includes:
  - Taking S/E potential measurements on all pipelines (building gas service risers), both sides of isolating insulation, hydrant outlets in petroleum, oil, and lubricant (POL) systems, and surface and underground tanks.
  - Internally inspecting water storage tanks.
  - Updating the Cathodic Protection Annual Performance Booklet.
  - Updating the CP program record.
  - Determining actions required to provide complete protection and preparing maintenance action sheets.
- Ensure the necessary corrosion tests and system examinations are performed on boiler water.
- Ensure the treatment equipment is adequate and working for cooling water.
- Investigate all reported leaks and corrosion failures, determine cause of failure and corrective action required to prevent recurrence. Do not restrict viewpoint to fluid-carrying systems or high-value steel structures, expand to include other items, such as metal roofing and flashing, that leak and cause water damage to structures and contents.
- Maintain data on corrosion failures and record each location where an underground failure occurs on a base layout map.

- Analyze data for patterns that indicate major problem areas.
- Assist Operations in procuring proper CP test equipment.
- Assist Engineering in procuring necessary paint inspection equipment.
- Assist other corrosion control craftsmen in procuring leak detection equipment, test instruments, chemical treatment equipment, and consumables as necessary to conduct an effective Corrosion Control Program.
- Perform life cycle cost analysis of corrosion control measures.
- Arrange for technical assistance as required through AFCEC.
- Call corrosion control committee meetings, establish agenda items, and ensure coordination of all corrosion control activities through this committee.

C-2.1.5.3 CP Craftsmen.

CP craftsmen perform tests consisting primarily of electrical measurements to indicate the condition of system components. Maintenance duties include:

- Performing rectifier checks for current and voltage output, meter function, proper operation, and adjustment to maintain the current required (as recorded at the last annual survey) for adequate protection.
- Conducting S/E potential measurements at the four test points established by annual surveys of impressed current systems.
- Conducting S/E potential measurements and current output of anode systems, and the addition of anodes as required for complete protection.
- Performing minor system repairs.
- Submitting maintenance requirements for major work.
- Entering operational data in appropriate logs and forwarding to the BCCE for filing and maintenance.
- Conducting an annual CP survey under the BCCE. Accomplish by contract if capability is not available with shop.
- Procuring and retaining custody of instruments authorized and required in routine maintenance of installed CP systems.

C-2.1.5.4 Engineering Construction Management.

Engineering Construction Management and/or Service Contract personnel keep every phase of coating operations under surveillance. This includes:

- Recording coating type, thickness, and bonding.
- Checking the above items against specifications.

- Checking surface preparation prior to coating application.
- Documenting subsequent coating performance.
- Reporting any damage found during inspections.
- Assuring repair of reported damage by recommended methods.
- Procuring and retaining custody of test equipment necessary for inspection (film thickness gauges, blasting standards, holiday detector, and paint test kit).
- Coordinating requirements for coating operations with the BCCE, SABER contractor, service contractor and general contractors as required, ensuring adequate corrosion control operations.
- Forwarding all test data to the BCCE for filing and retention.

C-2.1.5.5 Corrosion Control Craftsmen.

Corrosion control craftsmen perform tasks necessary to accomplish corrosion control to the maximum extent possible in their areas of responsibility. The following areas may require a corrosion control craftsman.

C-2.1.5.6 Potable Water Systems.

Potable water systems and treatment corrosion control craftsman will (OPR: Infrastructure Systems Element):

- Perform raw analysis every 3 years; accomplish by contract if capability is not available with shop.
- Record treatment performed daily on AF Form 1461, Water Utility Operating Log.
- Determine and record consumption monthly.
- Maintain water treatment logs in Facility 62515, Water and Waste Building, for review by the BCCE.
- Use AF Form 1687, Leak/Failure Data Record, as appropriate, and forward to the BCCE.
- Monitor water distribution systems’ pressure meters hourly to determine possible water leaks.

C-2.1.5.7 Boiler Water Systems and Treatment.

Boiler water systems and treatment corrosion control craftsmen will (OPR: Facility System Elements):

- Maintain complete records of boiler water treatment daily on AF Form 1459, Water Treatment Operating Log for Steam and Hot Water Boilers. This includes internal treatment with chemicals and external treatment with deaerators, softeners, and decarbonators.

- Test make-up water, quantity, and quality monthly.
- Check for leaks in steam valves, flanges, and unions in boiler plants daily.
- Test heat exchangers for leaks monthly.
- Check pressure and temperature of deaerating heater daily.
- Determine conductivity of return condensate daily at a minimum; hourly for large plants.
- Have condensate corrosion tests performed monthly.
- Test ion exchanger output quality daily at a minimum; more often if required.
- Check mechanical rooms with hot water heat exchangers for signs of corrosion problems semiannually.
- Check all tanks annually.
- Check boiler plant piping systems daily.
- Use AF 1687, Leak/Failure Data Record, as appropriate, and forward to the BCCE.
- Procure and retain custody of test equipment necessary for corrosion control testing of boiler water systems.

C-2.1.5.8 Cooling Water Systems and Treatment.

Cooling water systems and treatment corrosion control craftsmen will (OPR: Facility System Elements):

- Maintain complete records of cooling water treatment as required. Use AF Form 1457, Water Treatment Operating Log for Cooling Tower Systems at a minimum. Maintain these records in the shop for review by the BCCE.
- Check cooling towers for algae and scale buildup monthly.
- Together with the BCCE, ensure monthly that treatment equipment is adequate and is working.
- Calculate cycles of concentration and maintain according to survey recommendations monthly.
- Procure and retain custody of test equipment necessary for corrosion control testing of cooling water systems.
- Use AF Form 1687, Leak/Failure Data Record, as appropriate, and forward to the BCCE.

C-2.1.5.9 Water Distribution Systems.

Water distribution systems corrosion control craftsmen will (OPR: Infrastructure Systems Element):

- Perform leak/failure inspections as required. Notify the BCCE of leaks and failures in the water distribution systems.
- Use AF Form 1687, Leak/Failure Data Record, for all leaks detected in the water distribution systems and forward to the BCCE.
- Coordinate with the water systems and treatment corrosion control craftsmen (Water & Waste) on possible water distribution leaks.
- Procure and retain custody of test equipment necessary for leak detection in the water distribution system.

C-2.1.5.10 Protective Coating Corrosion Control.

Protective coating corrosion control is normally accomplished by Service Contract (OPR: Operations Engineering):

- Update painting records as required.
- Report any damage found to the BCCE for subsequent repair or recommendations.
- Ensure Service Contractor applies suitable coatings to the structure and environment and ensure compatibility with previously applied coatings and other protective methods, such as CP.
- Together with the BCCE, inspect coatings on all high-cost steel structures semiannually.
- Coordinate closely with Operations Engineering to ensure compliance.
- Use AF Form 1687, Leak/Failure Data Record, an appropriate, and forward to the BCCE.

C-2.1.5.11 POL/JP4 Distribution Systems.

POL/JP4 distribution systems corrosion control craftsmen will (OPR: Infrastructure Systems Element):

- Perform leak/failure inspections as required. Notify the BCCE of leaks and failures in the POL/JP4 distribution systems.
- Use AF Form 1687, Leaks/Failure Data Record, for all leaks detected in the POL/JP4 distribution systems and forward to the BCCE.
- Procure and retain custody of test equipment necessary for leak detection in the POL/JP4 distribution systems.

C-2.1.6 Record Procedures.

Maintain the following records to support the Corrosion Control Program at Sample AFB as indicated.

C-2.1.6.1 Personnel Files.

Operations Flight and the BCCE maintain a current roster of corrosion control craftsmen. File contains training status and training program information.

C-2.1.6.2 Equipment Information.

BCCE maintains a list of corrosion control equipment with operational status. File contains the following information:

- Manufacturers' data on installed equipment.
- Lists of repair parts.
- Names and addresses on sources and parts.
- Current price lists.
- Repair, operating, and maintenance instructions.

C-2.1.6.3 System Information.

BCCE maintains files on water treatment systems, CP installations, protective coatings, and all other systems of corrosion control. File includes the following information:

- Standard design and construction specifications.
- Cross-reference listing of projects containing corrosion control.
- Shop and as-built drawings updated to show modifications.
- Cathodic Protection Program Records Booklet.
- Cathodic Protection Annual Performance.

C-2.1.6.4 Failure Records.

BCCE maintains records of corrosion control damage and facility failures. Forward to the BCCE the AF Form 1687, Leak/Failure Data Record, after completion by the appropriate corrosion control craftsmen. The BCCE further investigates the failure as appropriate. The BCCE indicates the location of the leak or failure on the base layout map. The BCCE records the corrective maintenance, repair, or applied corrosion control measures, including costs. Distribution of this form is one copy to each of the following:

- BCCE's record.
- Facility jacket.
- Cathodic Protection Annual Performance Booklet.
- AFCEC corrosion control Subject Matter Expert (SME).

C-2.1.6.5 Survey Records.

The BCCE maintains a continuous and current file of corrosion survey results and recommendations. These records contain the following information:

- Corrosion analysis team surveys, recommendations, and implementation plans.
- Architecture - Engineering (A-E) surveys and recommendations.
- Water and gas leak surveys.
- AF Form 1688, Annual Cathodic Protection Performance Survey.

C-2.1.6.6 Test Results.

The BCCE maintains records of test data and results. This file contains the following information:

- Boiler water analysis.
- Corrosion tester/coupon reports.
- Interference testing record sheets.
- Area of Influence Test Worksheet, using a modified AF Form 1688, Annual Cathodic Protection Performance Survey.
- AF Form 1689, Water Tank Calibration (for tank interiors).

C-2.1.6.7 Operational Logs.

The BCCE periodically reviews all operational logs. Distribute the following logs as indicated:

- The Non-Commissioned Officer in Charger (NCOIC), Water and Fuels Systems Maintenance, completes AF Form 1461, Water Utility Operating Log, and maintains it in Building 417. Upon request from BCCE, the NCOIC forwards a copy for review.
- The CP craftsman completes AF Form 491, Cathodic Protection Operating Log for Impressed Current System, and AF Form 1686, Cathodic Protection Operating Log for Sacrificial Anode System, and forwards copies to the BCCE for inclusion in the CP facility jacket folder and the Cathodic Protection Annual Performance Booklet.
- Heating, ventilation, and air conditioning (HVAC) boiler water systems and treatment corrosion control craftsman completes AF Form 1459, Water Treatment Operation Log for Steam and Hot Water, and forwards a copy to the BCCE.
- The cooling water systems and treatment corrosion control craftsman forwards one copy of all records maintained by their function to the BCCE.

C-2.1.6.8 Equipment Maintenance.

Maintain equipment maintenance records and maintenance action sheets (MASs) according to AFI 32-1001, *Operations Management*. Keep a copy of the AF Form 1841, *Maintenance Action Sheet*, in the facility jacket folder for corrosion control activities.

C-2.1.6.9 Cost Records.

The BCCE maintains continuous records. This file includes the following information:

- Failure costs from AF Form 1687, *Leak/Failure Data Record*.
- All other corrosion control costs, to include projects containing corrosion control measures. These costs include initial installations, recurring maintenance, and surveys. It is especially important to include all repairs by replacement projects and work orders to historically record the life cycle costs of the base infrastructure.

C-2.1.6.10 Requirements and Management Plans.

The BCCE includes corrosion control items for each system and component to minimize system life cycle costs.

C-2.2 Air Force Forms.

C-2.2.1 Form 491.

Entries on AF Form 491 must be made on a monthly basis. No readings of the S/E potentials are to be taken where the electrode is in contact with frozen ground. Readings are to be made with the authorized meters only (see note under item 10 of instructions). See Tables C-1 and C-2 for form items and specific instructions for completing each item. See Figures C-1 and C-2 for completed example forms.

Table C-1 Form 491 Item Descriptions

Item	Name	Description
1	Installations	Enter the official name and location of the installation (i.e., ROBINS AFB, GA). Do not abbreviate or use unit designations.
2	Year	Enter calendar year.
3	Protected Structure	Enter the name of the protected structure and its number as shown on United States Air Force (USAF) Real Property Report (RCS: HAF-PRES(SA)7115) as “Water Tank 603” or “Gas piping system family housing.”
4	Rectifier Number	Enter the number of the rectifier as assigned by the corrosion engineer. Numbers are consecutive starting with number 1 and are conspicuously shown on the rectifier.
5	Rectifier Data (from nameplate)	• **Manufacturer:** Enter full name and address of manufacturer. • **Model Number:** Enter model number as shown on nameplate. • **Serial Number:** Enter serial number as shown on nameplate. • **AC Rated Capacity:** Enter AC voltage and phase. • **DC Rated Capacity:** Enter DC voltage and amperage. • **Date Installed:** Enter date installed. This information is to be obtained from the BCCE. Where no detailed information is available, estimate and enter approximate date.
6	Ground Bed Data	• **Anode Material:** Enter the name of the material and alloy designation, if known, as “graphite,” “aluminum 3003,” or “high-silicon cast iron.” • **Size of Anode:** Enter the dimensions or the standard size designation as 1½" x 60" or 3" x 60." • **Number of Anodes:** Enter number of anodes. • **Type of Backfill:** Enter the type of backfill used around the anodes as “coke breeze” or “natural soil.” • **Date Installed:** Enter the date when the anode bed was installed.

Item	Name	Description
7	Location Reference Drawing Number	Enter the location of rectifier and test stations as recorded on the drawings. Enter the number of the drawing and the sheet number for easy reference.
8	Current Required	Enter the amount of current needed to give complete protection and the date such determination was made.
9	Location and Description	Enter a brief description of the location of the rectifier and test points in order to easily find them, as “west leg of tower,” “pole 468-1,” or “300 feet east of the side entrance of building 1450.” The test points indicated here and in items 10H through 10K for recording values are the same test points.
10	Operating Record	See Table C-2.
***Signature:** Each monthly log must be signed by the cathodic protection technician (CPT) and the BCCE before submission to higher headquarters.		

Table C-2 Form 491 Item 10 Operating Record

Name	Description
A	Enter the month tests are performed.
B	Enter the date of the month.
C* & E*	Enter the as found (before any adjustments are made) DC voltage in Column C and the DC current in column E.
D* & F*	If required, adjust the DC voltage level until the DC current is equal to or greater than the current requirement (item 8) and enter the as adjusted DC voltage in column D and DC current in column F.
G	The corrosion engineer must compute the circuit resistance using Ohm's Law and enter the value in column G. $$Resistance = \frac{Adjusted\ Voltage}{Adjusted\ Amperage}$$
H	Test point 1 (referred to as "maximum potential area") must be determined using data obtained from the annual performance survey. This point is located closest to the ground bed and is to be taken over the structure in that area. Enter this value in column H. Care must be taken to read the correct polarity.
I-K	Test points 2, 3, and 4 are the lowest potential points of the protected structure being protected by the rectifier. These test points must be determined using data obtained from the annual performance survey. They are subject to change as directed by the corrosion engineer. Enter the values found for the appropriate points.
L	State whether soil is wet, moist, dry, or powdery. **Note:** For the testing of S/E potentials, only authorized multimeters and potentiometers are used. For S/E potential readings, the potentiometer circuit must be used. If the ground is frozen, do not take readings and state so in column L by entering "GF."
*Columns C through F are readings of DC voltage and DC current only. Readings must be taken with handheld calibrated meters, not rectifier meters.	

Figure C-1 Sample Completed Form 491 (Front)

CATHODIC PROTECTION OPERATING LOG FOR IMPRESSED CURRENT SYSTEM

1. INSTALLATION: Tyndall AFB, FL	2. YEAR: 2018
3. PROTECTED STRUCTURE: Underground Gas Distribution, Base Housing	4. RECTIFIER NUMBER: 3

5. RECTIFIER DATA (From Nameplate)	6. GROUND BED DATA
A. MANUFACTURER: Universal	A. ANODE MATERIAL: HSCI
B. MODEL NUMBER: ASAI	B. SIZE OF ANODE: 2.9" x 84" (3884Z)
C. SERIAL NUMBER: 980427	C. NUMBER OF ANODES: 12
D. AC RATED CAPACITY: 120/240V 14/7A	D. TYPE OF BACKFILL: Loresco DW-1
E. DC RATED CAPACITY: 60V 28A	E. DATE INSTALLED (YYYY MM DD): 1998 04 16 — 7. LOCATION (REFERENCE DRAWING NO.: 473 Sheet 3

8. CURRENT REQUIRED		9. OPERATING RECORD (Complete on three month intervals)
DATE	ADJUSTED CURRENT (AMPS)	RECTIFIER: Felix Lake Dr S of Prime Beef Rd
2017 04 12	16.4	TEST POINT 1: Youth Center Regulator
2017 06 15	16.55	TEST POINT 2: T/S Andrews Loop @ S Bullard Cr
		TEST POINT 3: T/S Hackney Ct
		TEST POINT 4: T/S Eagle Dr + Phantom St

OPERATING RECORD

10. MONTH A	DAY B	RECTIFIER VOLTS AS FOUND C	RECTIFIER VOLTS AS ADJUSTED D	RECTIFIER AMPS AS FOUND E	RECTIFIER AMPS AS ADJUSTED F	CIRCUIT RESISTANCE G	TEST POTENTIAL TEST POINTS (Volts) 1 H	2 I	3 J	4 K	SOIL CONDITION L	INITIALS OF TECHNICIAN M
JAN	14	34.7		16.71		2.08	-1.482	-1.217	-1.040	-.979	Moist	NCP
FEB	20	34.8		16.64		2.10	-1.447	-1.211	-1.033	-.970	Dry	NCP
MAR	17	34.8		16.60		2.10	-1.460	-1.301	-1.011	-.962	Dry	GF
APR	20	36.2	34.9	9.41	17.11	2.04	-1.412	-1.229	-1.001	-.955	Wet	NCP
MAY	15	35.0		16.77		2.09	-1.441	-1.241	-1.004	-.947	Moist	GF
JUN	15	34.8		16.55		2.10	-1.437	-1.246	-.999	-.939	Dry	GF
JUL	22	35.0		16.60		2.11	-1.411	-1.217	-.988	-.927	Dry	NCP
AUG	18	36.2	41.1	14.80	16.9	2.43	-1.404	-1.201	-.977	-.918	Wet	GF
SEP	12	41.3		16.65		2.48	-1.441	-1.197	-.974	-.909	Wet	GF
OCT	18	41.4		16.54		2.50	-1.462	-1.202	-.982	-.898	Moist	NCP
NOV	14	41.1	46.2	16.31	18.26	2.53	-1.455	-1.124	-.991	-.894	Dry	NCP
DEC	4	46.1		18.25		2.53	-1.450	-1.201	-.982	-.910	Dry	NCP

SIGNATURE OF CATHODIC PROTECTION TECH	DATE (YYYY MM DD)	SIGNATURE OF BASE CORROSION ENGINEER	DATE (YYYY MM DD)
George Freeman	2018 12 04	Marshall J Monroe, P.E.	2018 12 07

AF IMT 491, JAN 81, V2 PREVIOUS EDITION IS OBSOLETE

Figure C-2 Sample Completed Form 491 (Back)

REMARKS (Date and Initials)	CORRECTIVE ACTION (Date and Initials)
20 April 2018 NCP	Current dropped, troubleshooting determined bad Diode, replaced stacks.
15 June 2018 NCP	Cleaned rectifier cabinet and tightened connections.
18 August 2018 GF	Performed anode bed CIS, one failed anode, adjusted rectifier to meet current requirement.
14 Nov 2018 NCP	Current dropped below the current requirement, adjusted rectifier up one fine.

SIGNATURE OF CORROSION ENGINEER	DATE (YYYY MM DD)
Michael J. Monroe, P.E.	2018 12 07

AF IMT 491, JAN 81, V2 (Reverse)

C-2.2.2 Form 1686.

Entries on AF Form 1686 are made biannually or more often if required by the parent command. No readings of the S/E potentials are to be taken where the ground is frozen. Readings are to be made with the authorized meters only. See Tables C-3 and C-4 for items and descriptions. Figures C-3 and C-4 depict examples of a completed form.

Table C-3 Form 1686 Items and Descriptions

Item	Name	Description
1	Installations	Enter the name of the protected structure and its number as shown on USAF Real Property Report (RCS: HAF-PRE(SA)7115), such as "Underground Gas Pipeline Capehart Hsg Nr 220."
2	Year	Enter calendar year.
3	Protected Structure	Enter the name of the protected structure and its number as shown on USAF Real Property Report (RCS: HAF-PRE(SA)7115), such as "Underground Gas Pipeline Capehart Hsg Nr 220."
4	Test Station Number	Enter the number of the test station where the reading of the potential is to be taken. Test stations should be numbered consecutively starting with number 1 for the entire base.
5	System Data	• **Number of Anodes:** From record, find the number of existing anodes on this system and enter it on the form. Also, note under remarks on back of form if any new anodes were installed during the last year and how many. • **Number of Test Stations:** Enter here the total number of test stations for this piping system. List the test stations by number.
6	Anode Data	• **Type:** Enter the name of the anode, trade name, its manufacturer, and the name of the material, as "magnesium H-1" or "zinc." • **Size:** Enter the dimensions or the standard size designations as "2" by 5' long" or "17 lbs.," or "32 lbs." • **Type of Backfill:** Enter the type of backfill used around the anodes as "prepackaged," "bentonite," "coke breeze," or "none." • **Location:** Enter a brief description of the location of the anode so that it can be located easily, as "gas line 50' W to 10' N of building 2263." • **Date Installed:** Enter date of installation. This date is supplied by the corrosion engineer. Where no detailed information is available, estimate and enter the approximate date.
7	Operating Record	See Table C-4.
***Signature:** Each log must be signed by the CPT and the BCCE before submission to higher headquarters.		

Table C-4 Form 1686 Item 7 Operating Record

Column	Description
A	Enter the month tests are performed.
B	Enter the date of the month of the survey.
C	S/E Potentials At Test Station (Volts). This reading is usually taken at the test station(s) of the system. Where no test stations are installed, readings must be taken at point as directed by the corrosion engineer. Enter the value found in column C.
D	S/E Potential Between Anodes (Volts). This is the potential-to-ground of the structure halfway between two anodes (or the most remote point of a structure from the anode protecting it). It is important to know how far the protection of an anode extends. Enter the value in column D.
E	Anode-to-Soil (Volts). This reading represents the open-circuit voltage of the anode with the structure (load) disconnected. Enter the reading in Column E.
F	Anode-to-Structure (Milliamps). Connect the milliamp meter between the structure and anode at the test station and enter the value in column F.
G	Soil Conditions. State whether soil is wet, moist, dry, or powdery. The condition of soil is approximately 1 foot below surface. If the ground is frozen, do not take readings and so state by entering “GF.”
H	Initials of Technician. The initials of the CPT must be shown in this column.

Figure C-3 Sample Completed Form 1686 (Front)

CATHODIC PROTECTION OPERATING LOG FOR SACRIFICIAL ANODE SYSTEM

1. INSTALLATION Keesler AFB, MS	2. YEAR 2018
3. PROTECTED STRUCTURE Underground Hospital Oxygen Pipeline	4. TEST STATION NUMBER 27
5. SYSTEMS DATA	6. ANODE DATA
A. NUMBER OF ANODES 4	A. TYPE High Potential Magnesium (20D2)
B. NUMBER OF TEST STATIONS 1	B. SIZE 2 3/4" x 3 3/4" x 59 3/4"
	C. TYPE OF BACKFILL Gypsum/Bentonite/Sodium Sulfate
	D. LOCATION DESCRIPTION NE Corner by Mechanical Room
	E. DATE INSTALLED April 1981

7. OPERATING RECORD (Complete on three month intervals)

MONTH A	DAY B	STRUCTURE TO SOIL/WATER (Volts) C	REMOTE STRUCTURE TO SOIL/WATER (Volts) D	ANODE TO SOIL/WATER (Volts) E	ANODE TO STRUCTURE (Milliamps) F	SOIL CONDITION G	INITIALS OF TECHNICIAN H
JAN							
FEB							
MAR	15	-1.029	-.991	-1.748	27	Moist	LRS
APR							
MAY							
JUN							
JUL							
AUG							
SEP	16	-1.017	-.985	-1.729	24	Dry	LRS
OCT							
NOV							
DEC							

SIGNATURE OF CATHODIC PROTECTION TECHNICIAN	DATE (YYYY MM DD)	SIGNATURE OF BASE CORROSION ENGINEER	DATE (YYYY MM DD)
Lauren R Smith	20181210	Sanford Mason PE	20181214

AF FORM 1686, JAN 81 (EF-V2)

Figure C-4 Sample Completed Form 1686 (Back)

REMARKS (Date and Initials)	CORRECTIVE ACTION (Date and Initials)
15 Mar 2018 LRS	Cleaned wires and replaced split bolt during Semi Annual Inspection.
16 Sept 2018 LRS	Annual Survey Completed.

SIGNATURE OF CORROSION ENGINEER		DATE (YYYY MM DD)
Sanford Mason P.E		2018 12 14

AF FORM 1686, JAN 81 (EF-V2)

C-2.2.3 Form 1687.

Table C-5 lists the items and descriptions for Form 1687. See Figures C-5 and C-6 for completed example forms.

Table C-5 Form 1687 Items and Descriptions

Item	Description
Report Control Symbol	N/A
Installation	Enter the official name and location of the installation, such as “Fairchild AFB, WA.” DO NOT ABBREVIATE OR USE UNIT DESIGNATIONS, SUCH AS “FAFB.”
Facility Number	Enter the number of the facility, such as “Building 1376”or “Water Tank 904.”
Area/Specific Location	Enter the area, such as “North side of building 1376, 50' west of the fire hydrant.”
Drawing Number	Show drawing number of the map upon which this leak is located for the purpose of recording installation leak history.
Fluid Transported or Stored	Mark (x) in the block for the type of fluid or fill in the other (specify) block with the appropriate name of the fluid.
Average Temperature of Fluid	Enter average temperature in degrees Fahrenheit (°F).
Date	Enter the date of the structure (i.e., pipe, valve, or tank) installation.
Design Life	Enter the number of years (life expectancy) of the structure.
Type and Location of Storage Facility or Transport	Mark (x) in the appropriate block or fill in the other (specify) block for those not listed.
Date Leak/Failure Discovered	Enter the appropriate date, in day, month, and year format, such as “1 Feb 98.”
Size/Diameter	Enter the size of the storage facility or transport, such as “6"” or “500-gallon capacity.”
Line or Tank Depth	Enter the depth of the corroded structure.
Cause of Failure	Mark (x) in the appropriate block or enter the information in the block for other (specify).
Metal(s) and/or Substrate Affected	Write in the appropriate type of metal or substrate.
Specific Action Taken to Repair Leak	Write in the specific action taken to make repairs and identify the specific area(s) affected on the drawing.
*Cathodic Protection	Mark (x) if applicable.
Type System	Mark (x) in the appropriate block.

Item	Description
Protective Coatings	Mark (x) if applicable.
Coatings System Used	Specify the type of coating and/or wrap used if applicable.
Industrial Water Treatment	Mark (x) if applicable.
Type System	Mark (x) in the appropriate block.
As Found Condition	Describe the condition of the structure when the problem was discovered.
As Left Condition	Describe the work accomplished to repair the structure.
Specific Action Taken to Repair Cause of Leak or Failure	Describe the measures taken to prevent a reoccurrence of this problem.
Signatures	The form must be signed by the CPT and the BCCE before submitting to a higher authority.
*Second page – corrosion engineer directs.	

Figure C-5 Sample Completed Form 1687 (Front)

LEAK/FAILURE DATA RECORD
RESOURCE ADVOCACY/CORROSION CONTROL METRIC

Report Control Symbol: N/A

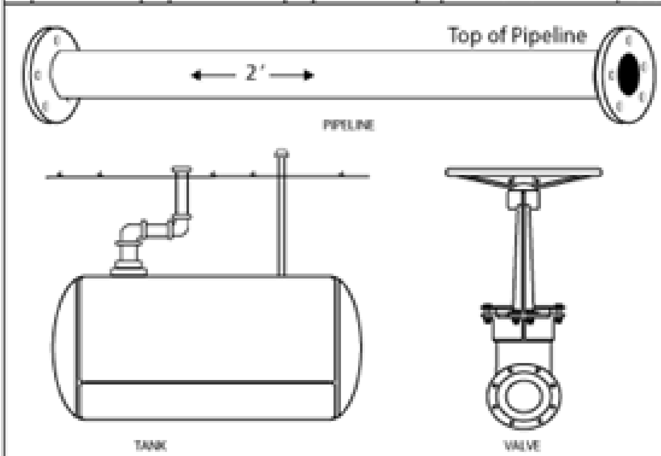
INSTALLATION	FACILITY NUMBER	AREA/SPECIFIC LOCATION	DRAWING NUMER
Maxwell AFB, AL	PH 1054	240' E Riser	G1731

FLUID TRANSPORTED OR STORED: WATER; HOT WATER; STEAM; CONDENSATE; CHILLED WATER; NATURAL GAS; X FUEL; OTHER (Specify)

AVERAGE TEMP OF FLUID (Degrees Fahrenheit): 64°
DATE INSTALLED (YYYYMMDD): March 1981
DESIGN LIFE: 30 Years

TYPE AND LOCATION OF STORAGE FACILITY OR TRANSPORT: TANK; X PIPE; VALVE; OTHER (Specify); ABOVE GROUND; BURIED; SUBMERGED; OTHER (Specify)

DATE LEAK/FAILURE DISCOVERED: 14 May 2018
SIZE/DIAMETER: 4"
LINE OR TANK DEPTH: 3' 4"



CAUSE OF FAILURE (Contact Corrosion Specialist per O.I.)
MECHANICAL: IMPROPER INSTALLATION; STRESS; X OTHER (Specify) Excavation Damage
CORROSION: EXTERNAL (Cathodic Protection & Coatings); INTERNAL (Industrial Water Treatments & Coatings)

METAL(S) AND/OR SUBSTRATE BEING AFFECTED (Specify): Top of Steel Pipeline

SPECIFIC ACTION TAKEN TO REPAIR LEAK (Include troubleshooting, repair, and/or replacement.): 2' section cut out and new piece welded in & coated with epoxy.

SIGNATURE OF INITIAL EVALUATOR	DATE	DATE RECORD RECEIVED BY CORROSION ENGINEER	INITIALS OF ENGINEER
Marcus Whaley	14 May 2018	15 May 2018	MJR

AF IMT 1687, JAN 98 (EF-V1)

Figure C-6 Sample Completed Form 1687 (Back)

CORROSION ENGINEER DIRECTS:

X CATHODIC PROTECTION

TYPE SYSTEM ("X" one)

☐ GALVANIC ☒ IMPRESSED CURRENT ☐ NONE

X PROTECTIVE COATINGS

COATING SYSTEM USED (Specify)

Fusion Bonded Epoxy

☐ INDUSTRIAL WATER TREATMENT N/A

TYPE SYSTEM ("X" one)

☐ HEATING ☐ COOLING

SYSTEM TREATMENT (Specify)

AS FOUND CONDITION (Describe specifics.)

Deep scratch 2' in length with puncture on East side.
No corrosion found.

AS LEFT CONDITION (Describe specifics.)

New pipe welded in, x-ray completed, recoated with epoxy, allowed to cure for 24 hours, inspected with high voltage holiday detector with 2 minor repairs.

SPECIFIC ACTION TAKEN TO REPAIR CAUSE OF LEAK OR FAILURE

Review Digging Permit Location Procedures & have personnel on-site during excavations in areas of pipelines.

COST

1801512

JOB ORDER/WORK ORDER NO.

$ 12,450.00

SIGNATURE OF SPECIALIST *Bill Regan* DATE 16 May 2018

SIGNATURE OF CORROSION ENGINEER *Sanford R Monroe P.E.* DATE 22 May 2018

AF FORM 1687, JAN 98, (EF-V1) (REVERSE)

C-2.2.4 Form 1688.

Figure C-7 depicts an example of a completed Form 1688.

Figure C-7 Sample Completed Form 1688

ANNUAL CATHODIC PROTECTION PERFORMANCE SURVEY

DATE (YYYYMMDD): 2018 08 12

[X] IMPRESSED CURRENT SYSTEMS
[ ] SACRIFICIAL ANODE SYSTEMS

INSPECTOR: Roger Mason

RECTIFIER NO.: 7

ANODE TEST STATION: N/A

LOCATION: Sabre Dr. @ 7th St.

RECTIFIER SETTING — DC VOLTS: 22.8; DC AMPS: 7.43

PROTECTED STRUCTURE: U/G Gas Distribution

NO.	TEST STATION LOCATION	ON(1)(2)	OFF(1)	REMARKS
1	@ Rectifier	-2.711	-1.218	
2	2712 Sabre Dr.	-1.812	-1.147	
3	Sabre Dr. + 11th St.	-1.772	-1.140	
4	1480 E. 11th St.	-1.624	-1.121	
5	Mitchell Dr. + 11th St.	-1.552	-1.108	
6	2284 E. 11th St.	-1.509	-1.049	
7	Mitchell Dr. Reg. Stat.	-1.447	-1.023	
8	Mitchell Dr. Reg. Stat.	-.410	-4.27	Dielectric house side
9	Bldg #1472	-1.202	-.992	
10	Bldg # 1570	-1.191	-.984	Back of Mech. Room
11	4th St. at Market Ave.	-1.219	-.992	
12	4th St. at Beach Blvd.	-1.227	-1.019	
13	Beach Blvd. at Main St.	-1.241	-1.108	
14	2912 Beach Blvd.	-1.221	-1.119	
15	Beach Elementary	-1.240	-1.122	(reg.)
16	Beach Elementary	-.272	-.289	Dielectric house side
17	4750 Beach Blvd.	-1.118	-.917	
18	Oscar Dr. at 9th St.	-1.107	-.923	
19	3218 Oscar Dr.	-1.121	-.974	
20	Oscar Reg. Stat	-1.202	-1.109	
21	Oscar Reg. Stat	-.243	-.243	Dielectric house side
22	2280 Oscar Dr.	-1.191	-1.011	
23	Farley Dr. + Oscar Dr.	-1.172	-1.101	

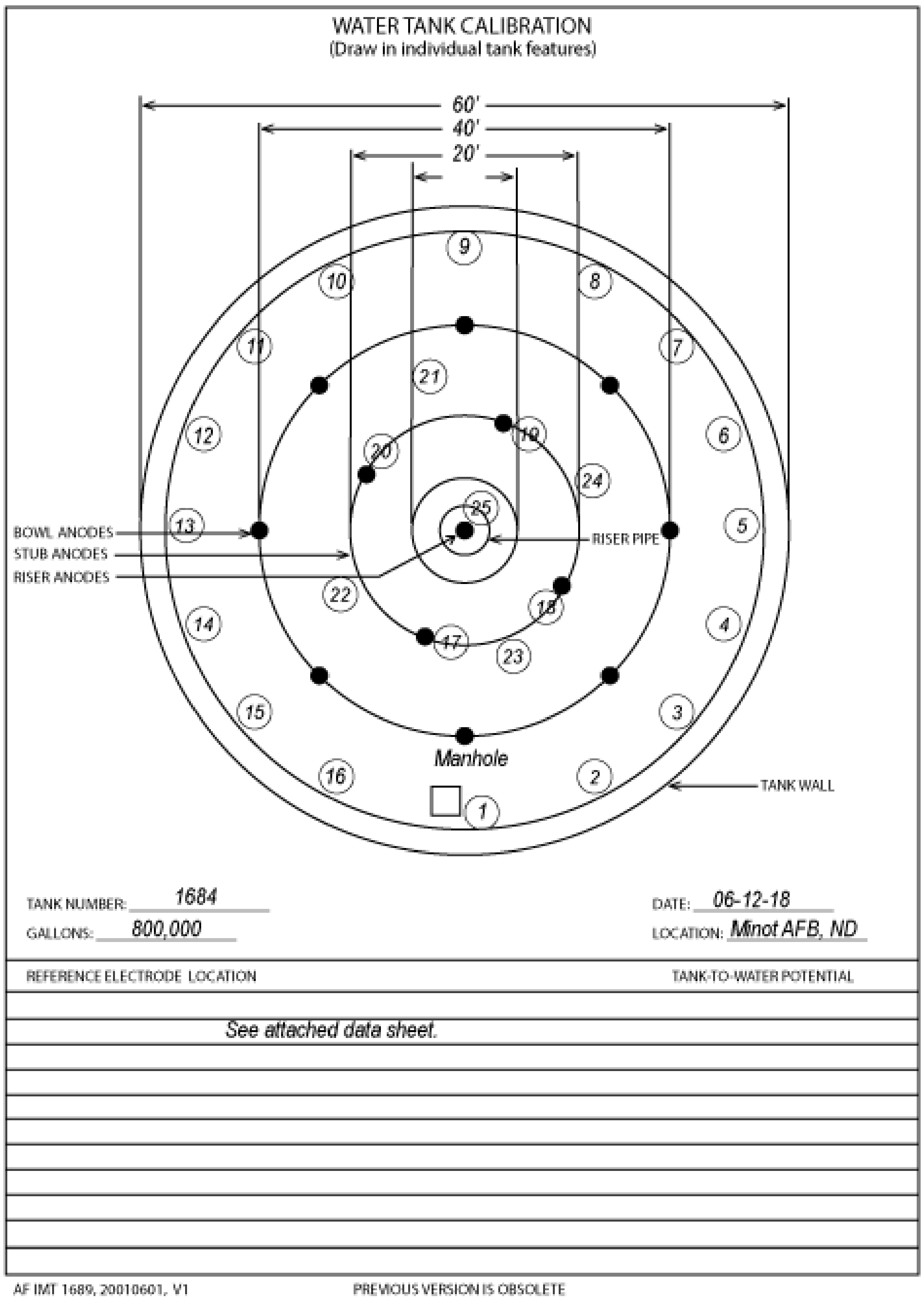
(1) Structure to electrolyte potentials in volts to a copper-copper sulfate electrode.
(2) For sacrificial anode systems, enter reading here.

AF IMT 1688, 19850201, V3 PREVIOUS EDITION WILL BE USED.

C-2.2.5 Form 1689.

Figure C-8 depicts an example of a completed Form 1689, used to record data for water tank calibration. Because the form does not include adequate space to record I.O. potential data, it is recommended to record the data in a separate spreadsheet document, as depicted in Figure C-9.

Figure C-8 Sample Completed Form 1689



WATER TANK CALIBRATION
(Draw in individual tank features)

TANK NUMBER: 1684

GALLONS: 800,000

DATE: 06-12-18

LOCATION: Minot AFB, ND

REFERENCE ELECTRODE LOCATION	TANK-TO-WATER POTENTIAL
See attached data sheet.	

AF IMT 1689, 20010601, V1 PREVIOUS VERSION IS OBSOLETE

Figure C-9 Sample Completed Data Sheet for Form 1689

SAMPLE EXCEL SPREADSHEET FOR ON/I.O. POTENTIAL DATA FOR WATER TANK CALIBRATION

	ON (TOP)	I.O (TOP)	ON (MIDDLE)	I.O (MIDDLE)	ON (BOTTOM)	I.O (BOTTOM)
1	-1.220	-1.114	-1.278	-1.202	-1.257	-1.191
2	-1.232	-1.211	-1.319	-1.223	-1.268	-1.197
3	-1.237	-1.214	-1.337	-1.202	-1.266	-1.212
4	-1.254	-1.221	-1.355	-1.227	-1.292	-1.214
5	-1.227	-1.207	-1.307	-1.194	-1.283	-1.207
6	-1.208	-1.199	-1.266	-1.136	-1.256	-1.191
7	-1.244	-1.140	-1.250	-1.130	-1.240	-1.184
8	-1.273	-1.186	-1.314	-1.154	-1.287	-1.193
9	-1.294	-1.205	-1.344	-1.169	-1.312	-1.212
10	-1.303	-1.233	-1.447	-1.174	-1.372	-1.231
11	-1.284	-1.211	-1.388	-1.152	-1.348	-1.223
12	-1.288	-1.220	-1.360	-1.140	-1.312	-1.209
13	-1.260	-1.200	-1.291	-1.119	-1.273	-1.172
14	-1.251	-1.193	-1.279	-1.108	-1.260	-1.163
15	-1.255	-1.198	-1.312	-1.144	-1.292	-1.181
16	-1.303	-1.221	-1.376	-1.201	-1.337	-1.199
17					-1.372	-1.202
18					-1.384	-1.210
19					-1.419	-1.227
20					-1.404	-1.221
21					-1.322	-1.208
22					-1.327	-1.210
23					-1.331	-1.212
24					-1.309	-1.197
RISER						
	ON (TOP)	I.O (TOP)	ON (COLUMN 2)	I.O (COLUMN 2)	ON (COLUMN 3)	I.O (COLUMN 3)
25	-1.414	-1.220	-1.527	-1.202	-1.519	-1.200
3′	-1.472	-1.231	-1.662	-1.214	-1.412	-1.191
3′	-1.577	-1.221	-1.513	-1.199	-1.332	-1.104
3′	-1.626	-1.227	-1.499	-1.192		
3′	-1.505	-1.216	-1.592	-1.195		
3′	-1.412	-1.191	-1.488	-1.187		
3′	-1.622	-1.212	-1.499	-1.189		
3′	-1.525	-1.210	-1.620	-1.212		
3′	-1.418	-1.191	-1.512	-1.197		
3′	-1.720	-1.222	-1.552	-1.199		
3′	-1.417	-1.190	-1.571	-1.201		
3′	-1.488	-1.191	-1.498	-1.188		
3′	-1.620	-1.207	-1.412	-1.174		
3′	-1.595	-1.202	-1.527	-1.182		
3′	-1.472	-1.191	-1.612	-1.211		
3′	-1.712	-1.209	-1.592	-1.204		
3′	-1.520	-1.204	-1.487	-1.192		
3′	-1.572	-1.205	-1.606	-1.217		

C-2.3 Annual Performance Booklet.

The annual survey should be a hard cover, three-ring binder, and only one copy of the Cathodic Protection Annual Performance Booklet should be prepared. The booklet must be completed by 1 February following the year of survey for review and kept for review by any higher headquarters personnel.

The binder contains basic information and the annual survey data. Table C-6 lists the order of this information.

Table C-6 Annual Performance Booklet Binder Information

Tab	Tab Title	Description
A	Title Page	List the base, type of survey, date survey was completed, and the names of the corrosion engineer and the CPT.
B	Index	
C	General Description	Describe in detail and in numerical order what the CP systems on the base consist of: impressed current or galvanic, sacrificial anode system; how many systems installed and for which utilities or structures, such as: water distribution systems, gas distribution systems, POL, heating, and storage tanks. Add information on type of metal used in mains and service lines, types of coatings, when installed, and by whom.
D	Summary of Survey Analysis and Actions Required	Describe in detail reasons or probable reasons for either high- or low-potential measurements. Describe actions needed to provide protective potentials, estimated costs, and completion dates.
E	Base Cathodic Protection Operation and Maintenance Procedures	Provide a copy of the CP operations and maintenance procedures.
F	Cathodic Protection Program Record	Provide a copy of the CP program record. This record must be updated yearly, as necessary. It must have its individual data sheets, showing location of test points by building number or other landmarks. Maximum and minimum test points as required by AF Form 491 must be identified, such as 7h, 7i, 7j, 7k, for rectifier number 7.
G	Maintenance Action Sheet	

Tab	Tab Title	Description
H	Leak/Failure Data Records	Complete and provide one copy of AF Form 1687 for each failure that was caused by corrosion during the preceding year. This record must be kept on all systems without regard to the application of CP.
I	Master Plan Tab G-8	A copy of Tab G-8 of the master plan must be included.
J	Cathodic Protection Operating Logs	The operating logs from the preceding year must be included for each system.
K	Equipment	This tab should be used to list all CP equipment on hand and the condition of equipment.
L	Annual Performance Survey Data	All survey data must be provided, including areas that are resurveyed after rectifier adjustments are made. Each system as listed in the program record (Tab F) must have its individual data sheets, showing location of test points by building number or other landmarks. Maximum and minimum test points as required by AF Form 491 must be identified, such as 7h, 7i, 7j, 7k, for rectifier number 7.
M	Sketches and Drawings	A sketch must be provided for each underground tank system indicating location of tank and where readings were taken. Include any additional drawings that will assist in the evaluation of the survey data.
N	Personnel Roster	Provide a list of names and grades of the corrosion engineer and CPT, along with a description of their training in CP and along with the date received.

C-3 NAVY.

C-3.1 Naval Shore Facilities Corrosion Control Report.

C-3.1.1 Introduction.

The annual cost of corrosion within the Navy shore establishment is estimated to exceed $10 million, and facilities and equipment with a plant value of over $60 million are at risk of failure due to corrosion. Corrosion of Navy facilities is a common and serious problem and must be addressed to ensure their safe and economical operation. Corrosion impacts shore facilities in many more ways and to a far greater degree than regularly considered:

- Costly system repairs and replacements.
- Downtime and disruption of service.
- Expensive loss of product.
- Environmental and safety hazards.
- Decreased system capacities.
- Adverse impacts on operational readiness.

Action to control corrosion and to repair corrosion damage is among the most frequent reasons for performing maintenance on our facilities. By formulating and executing a facility corrosion protection plan, system life is extended and operational costs are reduced. It is important that we obtain maximum benefit from our facilities by applying corrosion control measures as lessening amounts of funds are available for maintaining and repairing facilities to meet critical mission requirements.

It is important to consider corrosion control during the design and construction of new facilities or the repair/replacement of existing facilities. In most cases, it is less costly to eliminate causes of corrosion and include corrosion control measures during the design and construction phase than to correct the problem after construction is complete.

C-3.1.2 Corrosion Control Program.

Corrosion control **is** considered as an integral part of the design, construction, operation, and maintenance of all facilities under the cognizance of Naval Facilities Engineering and Expeditionary Warfare Center (NAVFAC EXWC). POL systems, waterfront structures, utility systems, and antenna systems have been found to be the most critical facilities in terms of a combination of risk from corrosion, the need to provide a continuity of direct fleet support, and the cost effectiveness of utilizing appropriate corrosion control systems.

Corrosion control systems are planned, designed, installed, monitored, and maintained for:

- All POL liquid fuel pipelines and storage facilities in accordance with the provisions of Code of Federal Regulations (CFR) Title 49 Chapter 1, Part 195, Transportation of Liquids by Pipeline and CFR Title 40 Chapter 1, Part 112, Oil Pollution Prevention.
- All natural gas pipelines in accordance with the provisions of CFR Title 49 Chapter 1, Part 192, Transportation of Natural and Other Gas by Pipeline.
- All steel underground storage tank systems in accordance with CFR 40 Part 280, Technical Standards and Corrective Action for Owners and Operators of Underground Storage Tanks, or more stringent state/local regulations as applicable.
- All buried or submerged metallic shore facilities in which the electrolyte (soil or water) resistivities are below 10,000 ohm-cm at the installation depth at any point along the installation.
- Other facilities as indicated in NAVFACENGCOM letter 11012 04C/cmm of 31 May 1994, Cathodic Protection Systems, Interim Technical Guidance.
- Overseas activities should comply with the requirements of the DoD Overseas Environmental Baseline Guidance Document and applicable area governing standards.

NAVFACENGCOM letter 11012 04C/cmm of 31 May 1994, Cathodic Protection Systems, Interim Technical Guidance describes the policy in more detail. For any questions on the policy, please contact your Engineering Field Division (EFD) CP program manager or the NAVFACENGCOM Cathodic Protection Technical Expert at the Naval Facilities Engineering Service Center (NFESC).

C-3.1.3 Corrosion Control.

The corrosion control systems described below are those most commonly used on shore facilities.

C-3.1.3.1 Protective Coatings.

Coatings provide protection to a variety of substrates (e.g., metals, wood, concrete) by forming a barrier to the surrounding environment. The continuing integrity of this barrier film is necessary for continuing protection.

C-3.1.3.2 Cathodic Protection.

Metal structures (including rebar), buried or immersed in electrolyte (e.g., soil, water, concrete), can be cathodically protected from external corrosion. This method of protection, normally used in conjunction with coatings, is achieved by transferring the corrosion to other cheaper “anode” materials that are sacrificed to protect the structure. The two basic types of CP systems are “sacrificial (galvanic) anode” and “impressed current.” All CP systems require periodic maintenance and adjustment to ensure system integrity and continuous control of corrosion.

C-3.1.3.3 Other Methods.

Other corrosion control methods include:

- Proper design techniques to eliminate conditions conducive to corrosion (e.g., contact of dissimilar metals).
- Selection of materials resistant to the particular environment.
- Use of chemical inhibitors or treatments in a closed system.

C-3.1.4 NAVFACENGCOM Headquarters.

NAVFACENGCOM Headquarters establishes policy, provides oversight, and provides budget guidance.

C-3.1.5 CP System Reporting.

Figures C-10, C-11 and C-12 are sample report forms. Similar report forms having the test data described below may be substituted. Contact the cognizant EFD for more information on CP system reporting, special report form requirements, and approval of substitute report forms.

- Structure-to-electrode potential readings generally shall be recorded quarterly, but no less than annually.
- Rectifier settings and outputs generally shall be recorded no less than bimonthly.

Figure C-10 Cathodic Protection Installation Report

UFC 3-570-06
JANUARY 31 2003

CATHODIC PROTECTION INSTALLATION REPORT

ACTIVITY: ______________________________ DATE: ______________

IMPRESSED CURRENT SYSTEM

Location of Rectifier				
Identification Number				
Structure(s) Protected				
Reference Drawing Number(s) Showing CP System				
Anode Description	Type:	Quantity:	Size: dia. X long	
Rectifier Manufacturer				
Rectifier Rated Capacity				
A.C. Input	Amps:	Volts:	Phases:	Cycles: Hz
D.C. Output	Amps:	Volts:		
Date Unit Turned On				
Number of Test Stations				
System Maintained By				

SACRIFICIAL SYSTEM

Location of Sacrificial Anodes				
Structure(s) Protected				
Reference Drawing Number(s) Showing CP System				
Anode Description	Type:	Quantity:	Weight:	Size:
Date Unit Turned On				
Number of Test Stations				
System Maintained By				

Notes:
1. Submit a one-time report for each impressed current rectifier.
2. Submit a one-time report for each structure protected by a sacrifical anode system.
3. Report CP installations within three months of installation. Attach initial test data information.

Figure C-11 CP Quarterly Structure-to-Electrode Potential Report

UFC 3-570-06
JANUARY 31 2003

CATHODIC PROTECTION

QUARTERLY STRUCTURE-TO-ELECTRODE POTENTIAL REPORT

ACTIVITY:	PERIOD ENDING
CP SYSTEM ID:	

TS NO.	LOCATION OR IDENTIFICATION	S/E (VOLT)	SHUNT			INSPECTOR	DATE	REMARKS*
			MV	RES	MA			

* IDENTIFY TEST ELECTRODE IF OTHER THAN COPPER SULFATE

SHEET _____ OF ______

Figure C-12 Cathodic Protection Rectifier Report

UFC 3-570-06
JANUARY 31 2003

CATHODIC PROTECTION RECTIFIER REPORT

ACTIVITY:					PERIOD ENDING:	
DESCRIPTION OF SYSTEMS PROTECTED:						
RECTIFIER ID NO. & LOCATION:						
RECTIFIER MANUFACTURER:				RECTIFIER TYPE:		
MODEL NO.:			SERIAL NO.:			
RECTIFIER RATED CAPACITY						
AC INPUT	AMPS	VOLTS		PHASE		AMP CYCLES
DC OUTPUT	AMPS	VOLTS		SHUNT SIZE:	MV	
ANODE MATERIAL	TYPE:	QTY:	WT:	SIZE:	DIA. X	LONG
DATE TURNED ON:						

MONTHLY READINGS

RECTIFIER AC SETTING		DC OUTPUT		CHECKED BY	DATE	REMARKS

APPENDIX D TRAINING AND CERTIFICATION

D-1 INTRODUCTION.

All personnel assigned to CP duties must receive initial, annual, and/or refresher training and/or required certifications. This training should equip personnel with the ability to apply NACE criteria to determine the effectiveness of applied CP and the ability to troubleshoot the CP system if inoperative. Applicable personnel may require specialized training for protective coatings, industrial waste treatment, and/or for design and construction projects.

D-2 SOURCES.

CorrDefense is a DoD web site for the Office of Corrosion Policy and Oversight and is operated and maintained by the Logistics Management Institute. CorrDefense offers technical papers, key corrosion documentation, briefs by academia, Government, and Industry, and links to training opportunities. These resources can be accessed at www.corrdefense.org.

Association for Materials Protection and Performance (AAMP / NACE International®) – AAMP is a professional organization for corrosion control offering CP training opportunities. For more information on available courses and upcoming seminars providing training opportunities, see https://www.ampp.org/home.

AAMP Education & Certification
Phone: 1-800-797-6223
https://www.ampp.org/education

Center for Professional Advancement
Contact: General Information
P.O. Box H
East Brunswick, NJ 08816-0257
Phone: Comm (201) 613-4500

JA Electronics
13715 North Promenade Boulevard
Stafford, TX 77477
Phone: (281) 879-9903
www.jaelectronics.com

- Rectifier Maintenance Course, 2 to 4 days

Heath Consultants
9030 Monroe Road
Houston, TX 77061
Phone: Comm (713) 844-1300
info@heathus.com
http://heathus.com

- Pipe and Cable Locating Seminar

Institute of Corrosion
Barratt House
Suite S3, Kingsthorpe Road
Northampton
NN2 6EZ UK
Phone: Comm + 44 (0)1604 438222
admin@icorr.org
www.icorr.org

- The Institute of Corrosion provides online and classroom corrosion and CP training in the areas of Coating Inspector, Cathodic Protection Technician, and Pipelines Coating Inspector. Registration for these courses may be done at https://www.icorr.org/training-qualifications/.

M.C. Miller Training Course
1580 US Highway 1
Sebastian, FL 32956
Phone: (772) 388-8588
sales@mcmiller.com
www.mcmiller.com

- Cathodic Protection Corrosion Software & Datalogger Course, 4 days
- Cathodic Protection Tester Training & Certification Program, 3 days

Oklahoma University Corrosion Control Course
College of Professional and Continuing Studies
University of Oklahoma
1700 Asp Avenue
Norman, OK 73037-0001
Phone: Comm (405) 325-3136

- Annual Course, 3 days

Puckorius & Associates, Inc.
7828 West 90th Avenue
Westminster, CO 80021
Phone: Comm (303) 674-9897

- Boiler Water Treatment, 2 days
- Cooling Water Treatment, 3 days
- Cooling Water Treatment for Utility Power Stations, 3 days

Purdue University Annual Corrosion Short Courses
Purdue University
Division of Conferences
Stewart Center, Room 116
128 Memorial Mall
West Lafayette, IN 47907
Phone: Comm (866) 515-0023
John2145@purdue.edu
www.conf.purdue.edu/corrosion

- Basic Course
- Oil and Gas Section Course
- Water Section Course
- Power and Communications Section Course
- Special Topics Course

Technical Training School
366 TRS/TSIE
727 Missile Road
Sheppard AFB, TX 76311-5334
Phone: DSN 736-5847

- J3AZR3E051003, Cathodic Protection Course, 8 days

SSPC – The Society for Protective Coatings
800 Trumbull Drive
Pittsburgh, PA 15205, USA
Phone: 412.281.2331 Toll-free: 877.281.7772
www.sspc.org

Transportation Safety Institute
Joint Services Safety Division
P.O. Box 25082
6500 S. MacArthur Boulevard
Oklahoma City, OK 73125-5050
DSN 940-2880 Ext 4472
Comm: (405) 954-4472

- Course JS00425 Pipeline Corrosion Control 1
- Course JS00426 Pipeline Corrosion Control 2

West Virginia University
Appalachian Underground Corrosion Short Course
Contact: AUCSCP.O. Box 926
Morgantown, WV 26505
info@aucsc.com
https://www.aucsc.com/

WebCorr
1 Scotts Road #24-10
Shaw Centre, Singapore 228208
Phone: Comm (+65) 64916456

- WebCorr Corrosion Consulting Services provides online and classroom corrosion and CP training. Registration for these courses may be done at https://www.corrosionclinic.com/index.html.

Whole Building Design Guide Corrosion Prevention & Control (CPC) Source Overview

- https://www.wbdg.org/dod/cpc-source/corrosion-prevention-control-source-overview

APPENDIX E TYPES OF CORROSION

It is convenient to classify corrosion by the forms in which it manifests itself, the basis for this classification being the appearance of the corroded metal. Each form can be identified by visual observation, although, in some cases, magnification is required. Valuable information for the solution of a corrosion problem can often be obtained through careful observation of the corroded test specimens or failed equipment. Examination before cleaning is particularly desirable.

Some of the eight forms of corrosion are unique, but all of them are more or less interrelated. The eight forms are: (1) uniform, or general attack, (2) galvanic, or two-metal corrosion, (3) crevice corrosion, (4) pitting, (5) intergranular corrosion, (6) selective leaching, or parting, (7) erosion corrosion, and (8) stress corrosion. This listing is arbitrary but covers practically all corrosion failures and problems. The forms are not listed in any particular order of importance. Below, the eight forms of corrosion are discussed in terms of their characteristics, mechanisms, and preventive measures. Hydrogen damage, although not a form of corrosion, often occurs indirectly as a result of corrosive attack and is, therefore, included in this discussion.

E-1.1 Uniform Attack.

Uniform attack is the most common form of corrosion. It is normally characterized by a chemical or electrochemical reaction that proceeds uniformly over the entire exposed surface or over a large area. The metal becomes thinner and eventually fails. For example, a piece of steel or zinc immersed in dilute sulfuric acid normally dissolves at a uniform rate over its entire surface. A sheet iron roof shows essentially the same degree of rusting over its entire outside surface.

Uniform attack, or general overall corrosion, represents the greatest destruction of metal on a tonnage basis. This form of corrosion, however, is not of too great concern from the technical standpoint, because the life of equipment can be accurately estimated on the basis of comparatively simple tests. Merely immersing specimens in the fluid involved is often sufficient. Uniform attack can be prevented or reduced by (1) proper materials, including coatings, (2) inhibitors, or (3) cathodic protection.

E-1.2 Galvanic or Two-Metal Corrosion.

A potential difference usually exists between two dissimilar metals when they are immersed in a corrosive or conductive solution. If these metals are placed in contact (or otherwise electrically connected), this potential difference produces electron flow between them. Corrosion of the less corrosion-resistant metal is usually increased, and attack of the more resistant material is decreased, as compared with the behavior of these metals when they are not in contact. The less resistant metal becomes anodic and the more resistant metal becomes cathodic. Usually the cathode or cathodic metal corrodes very little or not at all in this type of couple. Because of the electric currents and dissimilar metals involved, this form of corrosion is called galvanic, or two-metal, corrosion. It is electrochemical corrosion, but we shall restrict the term galvanic to dissimilar-metal effects for purposes of clarity.

E-1.3 Crevice Corrosion.

Intense localized corrosion frequently occurs within crevices and other shielded areas on metal surfaces exposed to corrosives. This type of attack is usually associated with small volumes of stagnant solution caused by holes, gasket surfaces, lap joints, surface deposits, and crevices under bolt and rivet heads. As a result, this form of corrosion is called crevice corrosion or, sometimes, deposit or gasket corrosion.

E-1.4 Pitting.

Pitting is a form of extremely localized attack that results in holes in the metal. These holes may be small or large in diameter, but in most cases they are relatively small. Pits are sometimes isolated or so close together that they look like a rough surface. Generally a pit may be described as a cavity or hole with the surface diameter about the same as or less than the depth.

Pitting is one of the most destructive and insidious forms of corrosion. It causes equipment to fail because of perforation with only a small percent weight loss of the entire structure. It is often difficult to detect pits because of their small size and because the pits are often covered with corrosion products. In addition, it is difficult to measure quantitatively and compare the extent of pitting because of the varying depths and numbers of pits that may occur under identical conditions. Pitting is also difficult to predict by laboratory tests. Sometimes the pits require a long time—several months or a year—to show up in actual service. Pitting is particularly vicious because it is a localized and intense form of corrosion, and failures often occur with extreme suddenness.

E-1.5 Intergranular Corrosion.

Grain boundary effects are of little or no consequence in most applications or uses of metals. If a metal corrodes, uniform attack results since grain boundaries are usually only slightly more reactive than the matrix. However, under certain conditions, grain interfaces are very reactive and intergranular corrosion results. Localized attack at and adjacent to grain boundaries, with relatively little corrosion of the grains, is intergranular corrosion. The alloy disintegrates (grains fall out) and/or loses its strength.

Intergranular corrosion can be caused by impurities at the grain boundaries, enrichment of one of the alloying elements, or depletion of one of these elements in the grain-boundary areas. Small amounts of iron in aluminum, wherein the solubility of iron is low, have been shown to segregate in the grain boundaries and cause intergranular corrosion. It has been shown that, based on surface tension considerations, the zinc content of a brass is higher at the grain boundaries. Depletion of chromium in the grain-boundary regions results in intergranular corrosion of stainless steels.

E-1.6 Selective Leaching.

Selective leaching is the removal of one element from a solid alloy by corrosion processes. The most common example is the selective removal of zinc in brass alloys (dezincification). Similar processes occur in other alloy systems in which aluminum; iron, cobalt, chromium, and other elements are removed. Selective leaching is the general term to describe these processes, and its use precludes the creation of terms such as dealuminumification, decobaltification, etc. Parting is a metallurgical term that is sometimes applied, but selective leaching is preferred.

E-1.7 Erosion Corrosion.

Erosion corrosion is the acceleration or increase in rate of deterioration or attack on a metal because of relative movement between a corrosive fluid and the metal surface. Generally, this movement is quite rapid, and mechanical wear effects or abrasion are involved. Metal is removed from the surface as dissolved ions, or it forms solid corrosion products, which are mechanically swept from the metal surface. Sometimes, movement of the environment decreases corrosion, particularly when localized attack occurs under stagnant conditions; this is not erosion corrosion because deterioration is not increased.

Erosion corrosion is characterized in appearance by grooves, gullies, waves, rounded holes, and valleys and usually exhibits a directional pattern. In many cases, failures because of erosion corrosion occur in a relatively short time, and they are unexpected largely because evaluation corrosion tests were run under static conditions or because the erosion effects were not considered.

E-1.8 Stress-Corrosion Cracking.

Stress-corrosion cracking refers to cracking caused by the simultaneous presence of tensile stress and a specific corrosive medium. Many investigators have classified all cracking failures occurring in corrosive media as stress-corrosion cracking, including failures due to hydrogen embrittlement. However, these two types of cracking failures respond differently to environmental variables. To illustrate, cathodic protection is an effective method for preventing stress-corrosion cracking; whereas, it rapidly accelerates hydrogen-embrittlement effects. Hence, the importance of considering stress-corrosion cracking and hydrogen embrittlement as separate phenomena is obvious. For this reason, the two cracking phenomena are discussed separately in this chapter.

During stress-corrosion cracking, the metal or alloy is virtually unattacked over most of its surface, while fine cracks progress through it. This cracking phenomenon has serious consequences, since it can occur at stresses within the range of typical design stress. Exposure to boiling MgCl2 at 310°F (154°C) is shown to reduce the strength capability to approximately that available at 1200°F.

APPENDIX F GLOSSARY

F-1 ACRONYMS

AC	alternating current
ACVG	alternating current voltage gradient
AFCEC	Air Force Civil Engineer Center
ANSI	American National Standards Institute
API	American Petroleum Institute
ASTM	ASTM International (formerly American Society for Testing and Materials)
AWWA	American Water Works Association
BCCE	Base Corrosion Control Engineer
BIA	Bilateral Infrastructure Agreement
CIS	close-interval potential survey
CMP	Centrally Managed Program
CP	cathodic protection
DC	direct current
DCVG	direct current voltage gradient
DIPRA	Ductile Iron Pipe Research Association
DLA	Defense Logistics Agency
DoD	Department of Defense
DOT	Department of Transportation
EFD	Engineering Field Division
EPA	Environmental Protection Agency
GACP	galvanic anode cathodic protection
HCA	high consequence area
HNFA	Host Nation Funded Construction Agreement

HQUSACE	Headquarters U.S. Army Corps of Engineers
ICCP	impressed current cathodic protection
IEEE	Institute of Electrical and Electronic Engineers
IMP	Integrity Management Program
kWh	kilowatt hours
LRA	Local Reproduction Authorized
MILCON	Military Construction
NAVFAC	Naval Facilities
NAVFACENGCOM	Naval Facilities Engineering Command
NFESC	Naval Facilities Engineering Service Center
NFPA	National Fire Protection Association
NSF	National Sanitation Foundation
NOV	Notice of Violation
OSHA	Occupational Safety and Health Administration
POL	petroleum, oil, and lubricant
SABER	Simplified Acquisition of Base Engineering Resources
S/E	structure-to-electrolyte
SOFA	Status of Forces Agreement
STI	Steel Tank Institute
UFC	Unified Facilities Criteria
UFM	Unified Facilities Manual
UFS	Unified Facilities Supplement
WBDG	Whole Building Design Guide

F-2 DEFINITIONS

amphoteric metal: A metal that is susceptible to corrosion in both acid and alkaline environments.

anode: The electrode of an electrochemical cell at which oxidation occurs. (Electrons flow away from the anode in the external circuit. It is usually the electrode where corrosion occurs and metal ions enter solution.)

anode bed: One or more anodes installed—underground or submerged—for the purpose of supplying cathodic protection. It is often called a “ground bed.”

backfill: Material placed in a hole to fill the space around the anodes, vent pipe, and buried components of a cathodic protection system. For the purposes of this standard, “backfill” is also defined as the material (native or imported) used to fill a pipeline trench.

beta curve: A plot of dynamic (fluctuating) stray current or related proportional voltage (ordinate) versus the corresponding structure-to-electrolyte potentials at a selected location on the affected structure (abscissa). For the purposes of this standard, “beta curve” is defined as a correlation between the pipe-to-soil potential of the affected pipeline and the open-circuit potential between the affected pipeline and the stray current source.

cable: One conductor or multiple conductors insulated from one another.

casing: A metallic pipe (normally steel) installed to contain a pipe or piping.

cathode: The electrode of an electrochemical cell at which reduction is the principal reaction. (Electrons flow toward the cathode in the external circuit.)

cathodic disbondment: The destruction of adhesion between a coating and the coated surface caused by products of a cathodic reaction.

cathodic polarization: (1) The change of electrode potential caused by a cathodic current across the electrode/electrolyte interface; (2) a forced active (negative) shift in electrode potential. See *polarization*.

cathodic protection: A technique to reduce the corrosion of a metal surface by making that surface the cathode of an electrochemical cell.

cathodic protection criterion: Standard for assessment of the effectiveness of a cathodic protection system.

coating: (1) A liquid, liquefiable, or mastic composition that, after application to a surface, is converted into a solid protective, decorative, or functional adherent film; (2) (in a more general sense) a thin layer of solid material on a surface that provides improved protective, decorative, or functional properties. Coatings used in conjunction with cathodic protection are electrically isolating materials applied to the surface of the metallic structure that provide an adherent film that isolates the metallic structure from the surrounding electrolyte. The thickness and structure of the coating type vary according to the environment and application parameters.

coating disbondment: Loss of adhesion between a coating and the pipe surface.

coating system: The complete number of coats and type applied to a substrate in a predetermined order. (When used in a broader sense, surface preparation, pretreatments, dry film thickness, and manner of application are included.)

conductor: A material suitable for carrying an electric current. It can be bare or insulated.

continuity bond: A connection, usually metallic, that provides electrical continuity between structures that can conduct electricity.

correlation: (1) A causal, complementary, parallel, or reciprocal relationship, as by having corresponding characteristics. (2) (As used in Section 9) Simultaneous measurement of two dynamic (time-varying) parameters, e.g., voltage and current, presented in an X-Y plot to determine the relative relationship between the two parameters and whether the fluctuations over time are caused by one or more sources of stray current.

corrosion: The deterioration of a material, usually a metal, that results from a chemical or electrochemical reaction with its environment.

corrosion potential (Ecorr): The potential of a corroding surface in an electrolyte measured under open-circuit conditions relative to a reference electrode (also known as “electrochemical corrosion potential,” “free corrosion potential,” and “open-circuit potential”).

corrosion rate: The time rate of progress of corrosion. (It is typically expressed as mass loss per unit area per unit time, penetration per unit time.)

current applied potential: The half-cell potential of an electrode measured while protective current flows through the electrolyte environment, typically measured with respect to a reference electrode placed at the soil surface.

current density: The electric current to or from a unit area of an electrode surface.

diode: A bipolar semiconducting device having a low resistance in one direction and a high resistance in the other.

disbondment: The loss of adhesion between a coating and the substrate.

distributed-anode impressed current system: An impressed current anode configuration in which the anodes are “distributed” along the structure at relatively close intervals such that the structure is within each anode’s voltage gradient. This anode configuration causes the electrolyte around the structure to become positive with respect to remote earth.

electrical isolation: The condition of being electrically separated from other metallic structures or the environment.

electrical shielding: Preventing or diverting the cathodic protection current from its intended path.

electrical survey: Any technique that involves coordinated electrical measurements taken to provide a basis for deduction concerning a particular electrochemical condition relating to corrosion or corrosion control.

electrode: A material that conducts electrons and is used to establish contact with an electrolyte and through which current is transferred to or from an electrolyte.

electrolyte: A chemical substance containing ions that migrate in an electric field. For the purposes of this standard, “electrolyte” refers to the soil or liquid adjacent to and in contact with an underground or submerged metallic piping system, including the moisture and other chemicals contained therein.

electrolytically contacted pipeline casing: A casing that contains soil or water electrolyte in contact with both the casing and the carrier pipe.

electro-osmotic effect: Passage of a charged particle through a membrane under the influence of a voltage. Soil or coatings can act as the membrane.

empirical: Originating in or based on observation or experience.

foreign structure: Any metallic structure that is not intended as a part of a system under cathodic protection.

free corrosion potential: See *corrosion potential*.

galvanic anode: A metal that provides sacrificial protection to another metal that is more noble when electrically coupled in an electrolyte. This type of anode is the electron source in one type of cathodic protection.

galvanic series: A list of metals and alloys arranged according to their corrosion potentials in a given environment.

holiday: A discontinuity in a protective coating that exposes unprotected surface to the environment.

impressed current: An electric current supplied by a device employing a power source that is external to the electrode system. (An example is direct current for cathodic protection.)

in-line inspection: The inspection of a pipeline using an electronic instrument or tool that travels along the interior of the pipeline.

instant off potential: The polarized half-cell potential of an electrode taken immediately after the cathodic protection current is stopped, which closely approximates the potential without IR drop (i.e., the polarized potential) when the current was on.

interference: Any electrical disturbance on a metallic structure as a result of stray current.

interference bond: An intentional metallic connection between metallic systems in contact with a common electrolyte designed to control electrical current interchange between the systems.

IR drop: See *voltage drop*.

isolation: See *electrical isolation*.

line current: The direct current flowing in a pipeline.

linear anode impressed current system: An impressed current anode configuration in which a continuous anode is installed parallel to the structure such that the structure is within the anode voltage gradient.

long line current: Current through the earth between an anodic and a cathodic area that returns along an underground metallic structure (usually used only where the areas are separated by considerable distance and where the current results from concentration-cell action).

mechanical damage protection: Any material or equipment used to eliminate or minimize damage to the piping system (as might be caused from soil stresses and damage caused from rocks, debris, or other outside forces) without inhibiting or interfering with CP.

mechanical damage protection system: Consists of multiple processes and products to achieve protection for the piping and coating system.

mechanical shielding: Protective cover against mechanical damage. See *mechanical damage protection* and *mechanical damage protection system*.

microbiologically influenced corrosion (MIC): Corrosion affected by the presence or activity, or both, of micro-organisms.

mixed potential: A potential resulting from two or more electrochemical reactions occurring simultaneously on one metal surface.

nonadhered: Not bonded to the surface by chemical reaction or mechanical means.

nonshielding coating system: A coating system with a failure mode (e.g., loss of adhesion) that does not prevent distribution of cathodic protection current to the metal substrate.

oxidation: (1) Loss of electrons by a constituent of a chemical reaction; (2) Corrosion of a material that is exposed to an oxidizing gas at elevated temperatures.

pipe-to-electrolyte potential: See *structure-to-electrolyte potential*.

pipeline casing: See *casing*.

polarization: The change from the open-circuit potential as a result of current across the electrode/electrolyte interface.

polarized potential: (1) (general use) The potential across the electrode/electrolyte interface that is the sum of the corrosion potential and the applied polarization; (2) (cathodic protection use) The potential across the structure/electrolyte interface that is the sum of the corrosion potential and the cathodic polarization.

reduction: Gain of electrons by a constituent of a chemical reaction.

reference electrode: An electrode having a stable and reproducible potential, which is used in the measurement of other electrode potentials.

reverse current switch: A device that prevents the reversal of direct current through a metallic conductor.

shielding: (1) Protecting; protective cover against mechanical damage; (2) Preventing or diverting cathodic protection current from its natural path. For the purposes of this standard, see *electrical shielding* and *mechanical shielding*.

shorted pipeline casing: A casing that is in direct metallic contact with the carrier pipe.

sound engineering practices: Reasoning that exhibits or is based on thorough knowledge and experience, is logically valid, and has technically correct premises that demonstrate good judgment or sense in the application of science.

stray current: Current through paths other than the intended circuit.

stray-current corrosion: Corrosion resulting from stray current.

structure-to-electrolyte potential: The potential difference between the surface of a buried or submerged metallic structure and electrolyte that is measured with reference to an electrode in contact with the electrolyte.

telluric current: Current in the earth as a result of geomagnetic fluctuations.

unbonded: To have lost the ability to adhere to a surface to which it has been applied and has become disbonded or to have never been adhered (nonadhered) to a surface to which it has been applied.

voltage: An electromotive force or a difference in electrode potentials expressed in volts.

voltage drop: The voltage across a resistance when the current is applied in accordance with Ohm’s Law. This term is also referred to as “IR drop.”

weak acids: Acids that only partially dissociate to form hydrogen (H^+) ions at moderate concentrations.

wire: A slender rod or filament of drawn metal. In practice, the term is also used for smaller-gauge conductors.

APPENDIX G SUPPLEMENTAL REFERENCES

G-1 FEDERAL GOVERNMENT

CODE OF FEDERAL REGULATIONS

https://www.ecfr.gov/

29 CFR 1910, *Occupational Safety and Health Standards*

29 CFR 1915, *Occupational Safety and Health Standards for Shipyard Employment*

29 CFR 1926, *Safety and Health Regulations for Construction*

40 CFR 112, *Oil Pollution Prevention*

40 CFR 280, *Technical Standards and Corrective Action Requirements for Owners and Operators of Underground Storage Tanks (UST)*

49 CFR 192, *Transportation of Natural and Other Gas by Pipeline: Minimum Federal Safety Standards*

49 CFR 193, *Liquefied Natural Gas Facilities: Federal Safety Standards*

49 CFR 195, *Transportation of Hazardous Liquids by Pipeline*

Public Law 107-314, *Bob Stump National Defense Authorization Act for Fiscal Year 2003, Section 1067, "*Prevention and Mitigation of Corrosion of Military Equipment and Infrastructure*"*

DEPARTMENT OF DEFENSE (DOD)

DoD Corrosion Prevention and Control Planning Guidebook for Military Systems and Equipment, https://apps.dtic.mil/sti/pdfs/ADA606227.pdf

Department of Defense (DoD) Directive 4270.05, *Military Construction* https://www.esd.whs.mil/Directives/issuances/dodd/

DoD Instruction (DODI) 4715.05-G, *Overseas Environmental Baseline Guidance Document* https://www.esd.whs.mil/Directives/issuances/dodi/

DODI 5000.67, *Prevention and Mitigation of Corrosion on DoD Military Equipment and Infrastructure* https://www.esd.whs.mil/Directives/issuances/dodi/

MIL-DTL-18001L, *Detail Specification: Anodes, Sacrificial Zinc Alloy* https://everyspec.com/MIL-SPECS/MIL-SPECS-MIL-DTL/MIL-DTL-18001L_52572/

MIL-HDBK-1136/1, *Cathodic Protection Field Testing* https://www.wbdg.org/navy/criteria-manuals/mil-hdbk-1136-1

UNIFIED FACILITIES CRITERIA (UFC)

https://www.wbdg.org/dod/ufc

UFC 3-430-09, *Exterior Mechanical Utility Distribution*

UFC 3-440-05N, *Tropical Engineering*

UFC 3-460-01, *Design: Petroleum Fuel Facilities*

UFC 3-501-01, *Electrical Engineering*

UFC 3-575-01, *Lightning and Static Electricity Protection Systems*

UFM 3-230-02, *Operation and Maintenance: Water Supply Systems*

UFM 3-230-13, *Industrial Water Treatment Operation and Maintenance*

UFM 3-560-01, *Operation and Maintenance: Electrical Safety*

UFM 3-601-02, *Operation and Maintenance: Inspection, Testing and Maintenance of Fire Protection Systems*

UFM 4-150-07, *Waterfront Facilities: Operations and Maintenance*

UFS 3-190-06, *Protective Coatings and Paints*

UNIFIED FACILITIES GUIDE SPECIFICATIONS (UFGS)

https://www.wbdg.org/dod/ufgs

UFGS 26 42 13.00 20, Cathodic Protection by Galvanic Anodes

UFGS 26 42 14.00 10, *Cathodic Protection System (Sacrificial Anode)*

UFGS 26 42 15.00 10, *Cathodic Protection System (Steel Water Tanks)*

UFGS 26 42 17.00 10, *Cathodic Protection System (Impressed Current)*

UFGS 26 42 19.00 20, *Cathodic Protection by Impressed Current*

UFGS 26 42 22.00 20, *Cathodic Protection System for Steel Water Tanks*

ARMY

EM 1110-2-2704, *Cathodic Protection Systems for Civil Works Structures* https://www.publications.usace.army.mil/Portals/76/Publications/EngineerManuals/EM_1110-2-2704.pdf

ERDC/CERL TR-07-22, *Demonstration of Ice-Free Cathodic Protection Systems for Water Storage Tanks at Fort Drum* https://apps.dtic.mil/sti/html/tr/ADA534424/index.html

ERDC/CERL TR-07-26, *Cathodic Protection of Hot Water Tanks at Fort Sill* https://apps.dtic.mil/sti/tr/pdf/ADA503860.pdf

Engineer Technical Letter (ETL) 1110-3-474, *Cathodic Protection* https://standards.globalspec.com/std/933643/coe-etl-1110-3-474

Technical Manual (TM) 5-811-7, *Electrical Design, Cathodic Protection* https://armypubs.army.mil/ProductMaps/PubForm/TM_Admin.aspx

AIR FORCE

https://www.e-publishing.af.mil/

Air Force Civil Engineer Energy Savings Performance Contracts (ESPC) Playbook

Air Force Policy Directive 32-10, *Installations and Facilities*

Air Force Instruction (AFI) 20-114, *Air and Space Equipment Structural Management*

AFI 23-201, *Fuels Management*

AFI 32-1054, *Corrosion Control*

AFI 32-1065, *Grounding Systems*

AFI 32-1067, *Water and Fuel Systems*

AFI 32-7086, *Hazardous Materials Management*

AFI 33-360, *Publications and Forms Management*

Air Force Manual (AFMAN) 33-363, *Management of Records*

Air Force Technical Order (TO) 00-25-172, *Ground Servicing of Aircraft and Static Grounding/Bonding* *https://www.robins.af.mil/Portals/59/11%20Feb00-25-172.pdf*

Air Force TO 37-1-1, *General Operation and Inspection of Installed Fuel Storage and Dispensing Systems*

Air Force Form 491, *Cathodic Protection Operating Log for Impressed Current Systems* (Not LRA)

NAVY

MIL-HDBK 419A, *Grounding, Bonding, and Shielding for Electronic Equipment and Facilities Volume 1* https://www.wbdg.org/NAVFAC/DMMHNAV/hdbk419a_vol1.pdf

MIL-HDBK 1004/10, *Electrical Engineering Cathodic Protection* https://webstore.ansi.org/standards/dod/MILHDBK100410

NAVFACENGCOM letter 11012 04C/cmm of 1 April 1994, *Cathodic Protection Systems, Interim Technical Guidance* https://www.wbdg.org/navy/itg/fy94-01

OPNAV P-45-117-6-98, Electrical Safety Field Guide https://www.safety.marines.mil/Portals/92/Docs/Electrical_Safety_Field_Guide.pdf

G-2 INDUSTRY STANDARDS.

AAMP - ASSOCIATION FOR MATERIALS PROTECTION AND PERFORMANCE (NACE INTERNATIONAL®)

https://content.ampp.org/standards

An Introduction to Asset Corrosion Management in the Oil and Gas Industry, Second Edition

Cathodic Protection: Industrial Solutions for Protecting Against Corrosion

Cathodic Protection of Steel in Concrete and Masonry, Second Edition

Cathodic Protection Survey Procedures, Third Edition

CorrCompilations: CO_2 and H_2S Metal Loss Corrosion - 10 Year Review

CorrCompilations: Mechanism of CO_2 Corrosion, Volumes 1 & 2

Corrosion and Materials Selection: A Guide for Chemical and Petroleum Industries

Corrosion Basics: An Introduction, Third Edition

Corrosion Engineering

Crude Unit Corrosion Guide - A Complete How-To Guide, Third Edition

Field Guide for Investigating Internal Corrosion of Pipelines

Field Guide to Internal Corrosion Mitigation and Monitoring for Pipelines

Forms of Corrosion-Recognition and Prevention: NACE Handbook, Volume 1

Fusion-Bonded Epoxy (FBE): A Foundation for Pipeline Corrosion Protection

Galvanic Corrosion: A Practical Guide for Engineers, Second Edition

Corrosion Engineering Handbook, Second Edition

M27 External Corrosion Control for Infrastructure Sustainability, Third Edition

NACE Corrosion Engineer's Reference Guide, Fourth Edition

Oil and Gas Pipelines: Integrity and Safety Handbook

Peabody's Control of Pipeline Corrosion, Third Edition

Pipeline Coatings

Pitting and Crevice Corrosion

Preferential Weld Corrosion of Carbon Steels

Publication 05114-2014, *High-Voltage Direct Current Interference*

Publication 10B189-2014-SG, *Direct Current Operated Rail Transit Stray Current Mitigation*

Publication 1E100-2012, *Engineering Symbols Related to Cathodic Protection*

Publication 7L198-2009-SG, *Design of Galvanic Anode Cathodic Protection Systems for Offshore Structures*

Publication 01102-2002-SG, *State-of-the-Art Report: Criteria for Cathodic Protection of Prestressed Concrete Structures*

Publication 01105-2005-SG, *Sacrificial Cathodic Protection of Reinforced Concrete Elements - A State-of-the-Art Report*

Publication 01110-2010-SG, *Stray Current-Induced Corrosion in Reinforced and Prestressed Concrete Structures*

Publication 01210-2010-SG, *Cathodic Protection for Masonry Buildings Incorporating Structural Steel Frames*

Publication 05101-2002-SG, *State-of-the-Art Survey on Corrosion of Steel Piling in Soils*

Publication 05107-2007, *Report on Corrosion Probes in Soil or Concrete*

Publication 11100-2018, *Reference Electrodes for Atmospherically Exposed Reinforced Concrete Structures*

Publication 30105-2005, *Electrical Isolation/Continuity and Coating Issues for Offshore Pipeline Cathodic Protection Systems*

Publication 35108-2008-SG, *One Hundred Millivolt (mV) Cathodic Polarization Criterion*

Publication 35110-2010-SG, *AC Corrosion State-of-the-Art: Corrosion Rate, Mechanism, and Mitigation Requirements*

Publication 10A392-2018, *Effectiveness of Cathodic Protection on Thermally Insulated Underground Metallic Structures*

Standard Practice (SP) 0100-2019, *Cathodic Protection to Control External Corrosion of Concrete Pressure Pipelines and Mortar-Coated Steel Pipelines for Water or Wastewater Service*

SP0104-2014-SG, *The Use of Coupons for Cathodic Protection Monitoring Applications*

SP0107-2017, *Electrochemical Realkalization and Chloride Extraction for Reinforced Concrete*

SP0177-2014-SG, *Mitigation of Alternating Current and Lightning Effects on Metallic Structures and Corrosion Control Systems*

SP0186-2007, *Application of Cathodic Protection for External Surfaces of Steel Well Casings*

SP0193-2016-SG, *External Cathodic Protection of On-Grade Carbon Steel Storage Tank Bottoms*

SP0196-2015, *Galvanic Anode Cathodic Protection of Internal Submerged Surfaces of Steel Water Storage Tanks*

SP0207-2007-SG, *Performing Close-Interval Potential Surveys and DC Surface Potential Gradient Surveys on Buried or Submerged Metallic Pipelines*

SP0216-2016-SG, S*acrificial Cathodic Protection of Reinforcing Steel in Atmospherically Exposed Concrete Structures*

SP0285-2011-SG, *Corrosion Control of Underground Storage Tank Systems by Cathodic Protection*

SP0286-2007, *Electrical Isolation of Cathodically Protected Pipelines*

SP0290-2007, *Impressed Current Cathodic Protection of Reinforcing Steel in Atmospherically Exposed Concrete Structures*

SP0387-2014-SG, *Metallurgical and Inspection Requirements for Cast Galvanic Anodes for Offshore Applications*

SP0388-2018, *Impressed Current Cathodic Protection of Internal Submerged Surfaces of Carbon Steel Water Storage Tanks*

SP0408-2014, *Cathodic Protection of Reinforcing Steel in Buried or Submerged Concrete Structures*

SP0492-2016-SG, *Metallurgical and Inspection Requirements for Offshore Pipeline Bracelet Anodes*

SP0572-2007-SG, *Design, Installation, Operation, and Maintenance of Impressed Current Deep Anode Beds*

SP0575-2007-SG, *Internal Cathodic Protection (CP) Systems in Oil-Treating Vessels*

Pipeline CICS— *Stress Corrosion Cracking of Pipelines*

Test Method (TM) 0101-2012-SG, *Measurement Techniques Related to Criteria for Cathodic Protection of Underground Storage Tank Systems*

TM0102-2002, *Measurement of Protective Coating Electrical Conductance on Underground Pipelines*

TM0105-2018, *Evaluation of Coatings Containing Conductive Carbon Additives for Use as an Anode on Atmospherically Exposed Reinforced Concrete*

TM0108-2012-SG, *Testing of Catalyzed Titanium Anodes for Use in Soils or Natural Waters*

TM0109-2009-SG, *Aboveground Survey Techniques for the Evaluation of Underground Pipeline Coating Condition*

TM0190-2017-SG, *Impressed Current Laboratory Testing of Aluminum and Zinc Alloy Anodes*

TM0211-2011-SG, *Durability Test for Copper/Copper Sulfate Permanent Reference Electrodes for Direct Burial Applications*

TM0294-2016-SG, *Testing of Embeddable Impressed Current Anodes for Use in Cathodic Protection of Atmospherically Exposed Steel-Reinforced Concrete*

TM0497-2018-SG, *Measurement Techniques Related to Criteria for Cathodic Protection on Underground or Submerged Metallic Piping Systems*

AMERICAN WATER WORKS ASSOCIATION (AWWA)

https://www.awwa.org/

AWWA C105, *Polyethylene Encasement for Ductile-Iron Pipe Systems*

AWWA D104-17, *Automatically Controlled, Impressed-Current Cathodic Protection for the Interior of Steel Water Storage*

AWWA M42, *Steel Water Storage Tanks*

AMERICAN PETROLEUM INSTITUTE (API)

https://www.api.org/

API 570, *Piping Inspection Code: In-service Inspection, Repair, and Alteration of Piping Systems*

API Standard 650, *Welded Tanks for Oil Storage*

API Standard 653, *Tank Inspection, Repair, Alteration, and Reconstruction*

API RP 651, *Cathodic Protection of Aboveground Petroleum Storage Tanks*

ASTM INTERNATIONAL

https://www.astm.org/

ASTM G57-06, *Standard Test Method for Field Measurement of Soil Resistivity Using the Wenner Four-Electrode Method*

DUCTILE IRON PIPE RESEARCH ASSOCIATION (DIPRA)

https://dipra.org/

Corrosion Control: Polyethylene Encasement

Corrosion Control: Stray Current Effects on Ductile Iron Pipe

Corrosion Control: The Design Decision Model™ for Corrosion Control of Ductile Iron Pipe

INSTITUTE OF ELECTRICAL AND ELECTRONIC ENGINEERS (IEEE)

https://www.ieee.org/

C2, *National Electrical Safety Code*

NATIONAL FIRE PROTECTION ASSOCIATION (NFPA)

https://www.nfpa.org/

NFPA 70®, *National Electrical Code (NEC)*

NFPA 70B, *Recommended Practice for Electrical Equipment Maintenance*

NFPA 70E®, *Standard for Electrical Safety in the Workplace*

NATIONAL SANITATION FOUNDATION (NSF)

https://www.nsf.org/

NSF 61-2018, *Drinking Water System Components - Health Effects*

STEEL TANK INSTITUTE (STI)

https://stispfa.org/

STI-P3, *Specification and Manual for External Corrosion Protection of Underground Steel Storage Tanks*