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2015 State-of-the-Fleet Assessment of Cathodic Protection Systems

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PRODUCT DESCRIPTION

Cathodic protection (CP) is used to prevent and/or arrest corrosion of assets found at nuclear power plants (NPPs). Many asset management plans at NPPs include CP systems, however, the design, operation, and maintenance of these systems can vary significantly. This project summarizes strengths, deficiencies, and recommendations for improvement related to the CP system health or status based on the results of four site assessments performed in 2015, and may be used as a resource for system or programmatic benchmarking.

Background

Cathodic protection has been shown to inhibit corrosion of buried piping, tanks, and other metallic structures that are subjected to electrolytic corrosion. Nuclear power plants that have successfully implemented CP technology have experienced a reduction in the frequency of maintenance on buried piping, tanks, and other below-grade structures, as well as a reduction in leaks in these buried pressure retaining components. Periodic assessments of the CP system status or health are useful to determine the effectiveness of the system in controlling corrosion, comparing data with expected values, and providing recommendations for future monitoring and maintenance, upgrades, and/or improvements to the CP system performance.

Objective

The objective of this project was to perform an assessment of the overall program status or health of CP systems at four pre-selected nuclear power plant sites. CPUG Position Paper No. 03, “Guidance for the Development of a Cathodic Protection Self-Assessment Plan”, March 2015, was utilized during the performance of these assessments [1]. Information obtained from the self-assessments will be used to:

- Identify gaps in industry guidance and training
- Identify utility strengths, deficiencies, and recommendations
- Identify CP designs and equipment that provide enhanced technical benefits
- Identify areas where additional research and development (R&D) are needed

Approach

The approach for this project included performing the following tasks:

- Survey and identify utility plant members to learn which sites were potential candidates for CP assessments in 2015. Based on the survey results, identify four NPP sites which would allow participation in the self-assessment.
- Review the design basis for the system, as-built drawings, operating data, maintenance history, vendor reports and programmatic aspects of the CP system. This was followed by a walk-down of the plant to determine the layout of the system, equipment details, and structures receiving protection.
- Participate in the development of a CP self-assessment plan.
- Provide a detailed assessment report of findings that is specific to and intended for each site.
- Provide a final EPRI Technical Report that summarizes the results of the project for all participating plants that maintains anonymity of the host sites.

Results

Assessments were conducted at four sites, with detailed assessment reports provided to each individual site. The results of the assessments included the identification of various strengths, deficiencies, and recommendations for system or programmatic improvements. These observations are intended to improve system and programmatic effectiveness at each site, while providing the industry fleet with a benchmark of lessons learned from which to draw from in considering their own cathodic protection systems. Finally, these assessments have identified gaps in industry guidance and training, as well as potential opportunities for additional research and development (R&D).

Applications, Value, and Use

The scope of this document includes self-assessments of cathodic protection systems for buried piping, buried storage tanks, and other structures at nuclear power plants. This document can used as a benchmarking resource by the industry fleet of plants to potentially improve cathodic protection system performance.

Keywords

Anode
Asset management
Buried pipe
Corrosion
Cathodic protection
Rectifier
Test station

ABSTRACT

Cathodic Protection has been shown to inhibit corrosion of buried piping, tanks and other metallic structures that are subjected to electrolytic corrosion. Nuclear Power Plants that have successfully implemented CP technology have experienced a reduction in the frequency of maintenance to buried piping, tanks and other below-grade structures, as well as a reduction in leaks of these buried pressure retaining components. Site assessments of the CP system status or health were conducted to evaluate the design, operation, and maintenance practices at nuclear power plants. The observed strengths, deficiencies, and recommendations are summarized and can be used to benchmark utility best practices regarding cathodic protection. This update provides the results of four plant assessments performed in 2015.

EXECUTIVE SUMMARY

The 2015 State-of-the-Fleet Assessment of Cathodic Protection (CP) Systems project involved an assessment of the cathodic protection status at four (4) NPP sites in North America. Each participating plant was issued an assessment report that identified certain site-specific strengths, deficiencies, and recommendations. Information obtained from all four (4) self-assessments was used to assess consistency in design, operation, maintenance, and performance evaluation criteria of the cathodic protection systems at the various sites. Results from the 2015 CP assessments, in addition to future planned assessments, will be used to identify gaps in industry guidance and training, utility strengths, deficiencies, and recommendations for improvement, CP designs and equipment that provide enhanced technical benefits, and areas for additional follow-up research and development.

The results of the four (4) assessments conducted in 2015 indicate that the CP systems at the four (4) nuclear power plants are generally consistent with the system design, installation practices, periodic testing and inspection, and preventive maintenance practices outlined in EPRI report 3002000596, "Cathodic Protection Application and Maintenance Guide, Volume 1: Buried Piping, and Volume 2: Plant Structures & Equipment" [2]. Based on the 2015 assessments, the following observations were made:

Strengths

- In general, the system engineer or designated plant representative has (or anticipates soon having) CP technical training in accordance with the recommendations given in EPRI Cathodic Protection Users Group (CPUG) Paper No. 2 "Qualification Guidelines for Personnel Performing Activities Associated with Nuclear Power Plant Cathodic Protection Systems" [3].
- All of the plants assessed use a qualified corrosion engineer and/or certified technicians to perform annual surveys, monitor, test, trouble-shoot and maintain the CP systems. Use of CP certified and experienced individuals can better assist in the identification of maintenance deficiencies associated with the system and providing of recommendations for improvement.

Deficiencies

- Some rectifiers were observed to have malfunctioned or were operating at extremely high voltages (i.e., >100 Volts DC) at the time of the assessments. Rectifiers with high voltages may pose step-touch potential hazards. Retrofitting existing rectifiers to incorporate personnel safety features may be difficult, however, when ordering new rectifiers, plants may wish consider specifying additional safety features. Malfunctioning and out of service rectifiers also results in decreased levels of protection provided to buried assets, including potentially safety-related components.
- It was identified that the acceptance criteria used to assess CP effectiveness at discrete test locations for each site are in alignment with those criteria identified in NACE International (formerly the National Association of Corrosion Engineers) Standard Practice SP0169-2013 [4]. However, of the three primary criteria identified in the standard (-850mV ON, -850mV OFF, and 100mV polarization), precautions exist regarding the use and application of

the -850mV ON and 100mV polarization criteria. During the assessments, technical justification to support the use of these two acceptance criteria, given these precautions, were not identified. As such, reliance on these criteria to evaluate the effectiveness of CP being provided may not yield entirely accurate conclusions.

Recommendations

- Since cathodic protection effectiveness is assessed based on a sampling of the effectiveness at discrete points of interest, the design and installation of new supplemental test stations at critical locations, such as in areas along safety-related pipes and structures, or where pipes enter foundation walls or underground vaults, can lead to improved corrosion understanding at locations that constitute high consequences of pipe failure or high susceptibility to under-protection. Installation of additional test stations during planned and opportunistic pipeline excavations is considered a beneficial practice, as it provides the opportunity to improve cathodic protection data collection and assessment capabilities.
- The use of rectifier remote monitoring units and synchronized current interruption may lead to improved monitoring, trending, and data acquisition capabilities. Synchronized current interruption capability of rectifiers, such as by Global Positioning System (GPS) current interpreters, allow for the simultaneous current interruption of all rectifiers so that "instant-off" polarized potential readings are not influenced by any other operating rectifiers. Remote monitoring units offer the ability to track and trend rectifier parameters, such as voltage and amperage, remotely and without the need to send technicians into the field. Some can also offer the ability to notify the user when there are problems with the rectifier unit, improving time for repair completion and return to service.
- Collection and analysis of soil data taken during excavations of buried piping can promote a better understanding of the soil conditions and site-specific corrosivity conditions, particularly when the data is consolidated into a single document. This data can also be used to help support alternative criteria for CP

CONTENTS

1
INTRODUCTION

Cathodic protection (CP) has been shown to inhibit corrosion of buried piping, tanks, and other buried metallic structures that are susceptible to electrolytic corrosion. Nuclear Power Plants (NPPs) that have successfully implemented CP technology have experienced a reduction in the frequency of maintenance to the buried assets and a reduction in leaks. Periodic assessments of a CP system are useful to determine the effectiveness of the system in controlling corrosion, comparing data with expected values, and providing recommendations for future monitoring and maintenance, upgrades and/or improvements to the CP system performance.

1.1 Cathodic Protection

Cathodic protection is a widely used technique to control corrosion of a metal surface exposed to an electrolyte (soil or water). In theory, CP is defined as the reduction of corrosion by making the metal a cathode in an electrochemical cell. Cathodic protection can be accomplished by applying a direct current to a structure from a rectifier (e.g., an impressed current CP system) or by connecting a structure to a sacrificial (or galvanic) anode. In nuclear power plants, because of the significant current requirements, impressed current systems are most commonly used to provide protection to buried steel piping, storage tanks, piles, intake structures and condenser water boxes from corrosion. EPRI report 3002000596 “Cathodic Protection Application and Maintenance Guide, Volume 1: Buried Piping” provides guidelines for the design, installation, testing, monitoring and maintenance of CP systems for corrosion control of buried piping at NPPs, and Volume 2: Plant Structures and Equipment provides guidelines for CP in condensers, heat exchangers, reinforced concrete structures, intakes, steel pilings, buried storage tanks, above ground storage tanks and meteorological tower guy anchors [2]. NACE International Item No. 24252 provides a state-of-the-art report for external corrosion, assessment, and control of corrosion for buried piping systems in NPPs [5].

With CP, direct current is forced through the electrolyte (soil, water or concrete) and onto the surface of the structure being protected. This direct current shifts the potential of the structure in the active (negative) direction, resulting in a reduction of the corrosion rate of the metal. When the amount of current is adjusted properly, it will reduce the corrosion current discharging from the structure to a negligible level, and there will be a net current flow onto the structure surface. When the correct amount of current is applied and distributed to the structure, the entire surface of the structure will become a cathode and corrosion will be controlled or reduced to an acceptable level.

1.1.1 Impressed Current Systems

Impressed current CP makes use of an outside power source (rectifier) which is used to deliver direct current through the electrolyte to the surface of the structure from an anode material. The anode beds may consist of distributed anodes, semi-deep anode wells and/or deep anode groundbeds. The rectifier converts alternating current (AC) to direct current (DC). Rectifiers are usually provided with the means for varying the DC output voltage, in small increments, over a reasonably wide range. With the impressed current method, direct current is forced to flow from the anode material, through the electrolyte and onto the surface of the structure being protected. The rectifier system negative cable provides the return path for the current. The system negative cable is connected directly to the piping, tank or station ground that is electrically continuous with the structure.

Anodes consist of inert materials with low consumption rates, such as mixed metal oxide (MMO) coated titanium, high silicon cast iron, or graphite. The anodes are typically encapsulated in a low resistivity carbonaceous backfill (coke breeze). The coke breeze, which is a refined conductive coal product, is used to lower the contact resistance with the earth and increase the life of the anode groundbed.

Impressed current systems are the most commonly used method for CP at nuclear power plants because of the significant current requirements and longer life expectancy that can be expected from the anode materials. A typical impressed current system may consist of the following components:

- Inert anodes
- Carbonaceous backfill that encapsulates the anodes
- DC power source (rectifier)
- Interconnecting cables
- Structure connection
- Anode junction box (complete with current measuring shunts)

Various types of rectifiers are available for CP including: manual voltage control, constant current and potential controlled rectifiers. Manual voltage control rectifiers require adjustment of the transformer taps to change the DC output over a relatively large range. This type of rectifier is considered a conventional rectifier and is commonly used in the pipeline and nuclear power industry. Remote monitoring and GPS synchronized current interruption of the rectifier output may also be considered if communication features are deemed acceptable by plant cyber-security.

1.1.2 Galvanic Anode Systems

Galvanic anodes for cathodic protection consist of magnesium, zinc or aluminum. The two galvanic anodes that are commonly used for buried piping in soil environments are magnesium and zinc, with magnesium being the most prevalent for galvanic protection of buried metallic structures in soil.

Galvanic anodes are available in various sizes and weights. The anodes are typically prepackaged in a gypsum, bentonite and sodium sulfate backfill. The backfill is used to absorb moisture from the surrounding soil and lower the anode to-earth resistance. Because of self-passivating effects, zinc anodes are better suited for use in soils with lower soil resistivity (i.e., less than 1,500 ohm-cm), whereas magnesium anodes may be used in soils with higher resistivity.

With the galvanic type of protection, the anode material is consumed or sacrificed in the process. For buried structures, it is common practice to design the galvanic anode system for a 10 to 15 year service life. After the anodes have been consumed and the protective levels on the structure have decreased, the anodes will require replacement. Galvanic anodes will also suffer from self-corrosion. The ratio of metal expended while producing useful CP current to the total metal is termed anode efficiency. Magnesium has a lower efficiency and will tend to self-consume more quickly compared to zinc.

Galvanic anodes may be directly connected to the pipe or installed with lead wires (or header cables) that are connected to the structure (pipe) through a test station. A test station with test lead wires that are connected directly to the pipe is the preferred method of installing galvanic anodes because it allows the operator to disconnect the anodes for testing and trouble shooting. A shunt may also be installed in the test station to allow measurement of the anode current. Galvanic anodes may also be installed in open excavations and can be used for discrete “hot spot” protection of buried pipe. The components of a galvanic anode system may include:

- Galvanic anode
- Interconnecting cable
- Test station

The main benefit of galvanic anodes is that they are relatively inexpensive; less complicated than the impressed current method and require minimal maintenance after they are installed.
Under normal circumstances, the current available from galvanic anodes is limited. For this reason, CP by galvanic anodes normally is used where the current required for protection is relatively small (typically less than 1 ampere). Similarly the driving voltage between the pipe steel and galvanic anode is limited. Therefore, the contact resistance (resistance-to-earth) must be low enough for the anodes to discharge a useful amount of current. Normally, piping systems that are protected with galvanic anodes systems are well coated and fitted with insulating devices; otherwise the current will tend to flow to other structures. Insulating devices include dielectric unions, insulating flange kits and insulating spools that are designed to electrically isolate the protected piping from station ground. Under these conditions the current demand for CP will be relatively low and the galvanic anode system can be expected to protect a substantial length of pipe. However, if the insulating devices are electrically shorted or are not effectively incorporated into the piping system design, the galvanic anodes will consume rapidly and protection levels will be compromised. For this reason they are not commonly used for the protection of buried piping in nuclear power plants.

1.1.3 Test Stations

Test stations are used to evaluate the effectiveness of the CP systems so that the structure-to-soil potential can be measured and consistently monitored over time. Test stations are typically installed at a sufficient number of locations to provide a representative assessment of the potential measurements that are used to gauge the CP system performance. Test stations may include test points, test wells, soil access points, coupon test stations and electrical resistance (ER) probes. ER probes are used to measure the corrosion rate by monitoring the change in cross sectional resistance of a buried conductor over time. Some test stations may include permanent reference electrodes that are buried adjacent to the structure. Coupon test stations can be incorporated at critical locations to facilitate additional monitoring. Coupon test stations may have a polarized carbon steel coupon that is connected to the structure receiving CP (i.e., CP Coupon), and a free corroding steel coupon that is electrically isolated (i.e., Native Coupon). Each coupon consists of a bare carbon steel specimen of known surface area that is exposed to the soil. The polarized CP coupon allows connection to the CP system on the structure, thus simulating a similar-sized bare area of the structure's surface, such as a holiday in the coating. The CP coupon may be disconnected from the circuit during functional testing using a micro-switch, and its "instant-off" potential measured with a reference electrode. A second, freely corroding Native Coupon is used to measure the free-corrosion (native) potential of the structure in the open-circuit condition. The Native Coupon potential is measured using a reference electrode and its potential may represent the static or open-circuit potential of the carbon steel. This potential can be used as a base reading when the 100 mV polarization development criterion is used for determining CP system effectiveness. If possible, the coupons and ER probes should be installed above the pipe or adjacent to the pipe and in the same backfill as the pipe, so as to simulate the same environmental conditions to which the pipe is exposed.

1.1.4 Criteria for Effective CP

The criteria for effective CP of steel and gray or ductile-iron piping systems according to NACE SP0169-2013 [4] can be summarized as follows:

1. A current applied (ON) potential of at least -850 mV, or more negative, relative to a saturated copper/copper sulfate reference electrode. Voltage drops in the earth and metallic circuit must be considered in the measurement.
2. A polarized (instant-OFF) potential of at least -850 mV, or more negative, relative to a copper/copper sulfate reference electrode, or
3. At least 100 mV of cathodic polarization. Measurement of either the development or decay of polarization is acceptable to satisfy this criterion. In a mixed metal environment, adequate protection is achieved based on at least 100 mV of cathodic polarization of the most anodic material in the system.

NACE Task Group (TG) 491 is also developing a standard for CP of buried piping at NPPs. One of the proposed criteria in this standard is based on demonstrating that a corrosion rate of 0.025 mm/yr (1 mil per year) or less has been achieved on all piping protected by the CP system.

Special conditions regarding interpretation of data include:

- Structure-to-soil potentials are typically measured with respect to a calibrated copper-copper sulfate reference electrode (CSE) and are negative (-) in value, unless reported otherwise.
- Voltage drops other than those across the structure-to-electrolyte boundary must be considered for valid interpretation of the potential measurements. These voltage drops are a result of current flow through the electrolyte (soil, water and/or concrete) and are generally referred to as ohmic or voltage (IR) drops. IR drops are more prevalent in the vicinity of an anode well and generally increase with increasing soil resistivity and operating voltage of the rectifier. When a CP system is de-energized, the pipe-to-soil potential undergoes an instantaneous positive shift as a result of elimination of the IR voltage drop error in the soil. For bare or poorly coated structures, IR drops can be reduced by placing the reference electrode as close as possible to the structure, such as inside the reference tube of a test

station. To overcome this IR drop error, all influencing current sources (rectifiers) should be interrupted simultaneously to enable measurement of the true instant-off "polarized" potential. The "instant-off" polarized potential is used as a basis for determining the effectiveness of a system in meeting criteria for CP. The difference between the "on" and "off" potential indicates the magnitude of the IR drop error when measurement is made with the protective current applied.

- Under certain conditions, excessive amounts of CP current to a coated pipeline may damage the coating through a process called cathodic disbondment. Cathodic protection reactions result in the formation of hydroxyl ions (OH-) on the pipeline surface, which increases the pH. If the polarized potential is sufficiently negative, hydrogen can evolve in the form of gas on the surface of the structure being protected (the cathode). Although the amount of hydrogen evolution is considered to be small, the increase in pH at the pipeline/coating interface can result in cathodic disbondment of the protective coating. Nevertheless, a high level of alkalinity at a flaw in the pipeline coating is not necessarily an undesirable condition, as this is an indicator that the protective hydroxyl ion film has formed at the cathode surface. In general, tape wrap coatings are considered to be more susceptible to cathodic disbondment. NACE SP0169-2013 [4] includes guidance that the use of excessive polarized potentials should be avoided; however, it does not establish a specific upper limit as an acceptance criterion for the performance of CP systems. As discussed in the International Organization for Standardization (ISO) Standard 15589-1 [6], potentials more negative than -1200mV (CSE) may lead to coating damage due to high pH and/or hydrogen production at the substrate surface. As such, this maximum "instant-off" potential of -1200 mV (CSE) is recognized as a "guideline" for over protection in the pipeline industry. Furthermore, the U.S. Nuclear Regulatory Commission (NRC) in the recent License Renewal Interim Staff Guidance LR-ISG-2015-01 [7] has relocated this critical instant-off potential [-1200 mV (CSE)] to a recommendation within the "preventive actions" program to allow plants going through license renewal to have more flexibility in balancing the performance of the CP systems. "On" potentials with the CP system operating may have voltage (IR) drop error in the reading and therefore are not considered in the upper limit guideline.
- The NRC, in the recent License Renewal Interim Staff Guidance LR-ISG-2015-01, has also given "Alternative Cathodic Protection Acceptance Criteria" for buried piping and tanks at nuclear power plants going through license renewal. These include:
  - -750 mV (CSE) instant-off structure-to-soil potential where the soil resistivity is greater than 10,000 ohm-cm to less than 100,000 ohm-cm
  - -650 mV (CSE) instant-off structure-to-soil potential where the soil resistivity is greater than 100,000 ohm-cm.

  A recommendation is provided by the NRC in the LR-ISG-2015-01 document to verify the alternative acceptance criteria through the use of electrical resistance (ER) probes to confirm that the corrosion rate is less than 1 mil per year (mpy). These alternative criteria are also referenced for consideration in the special conditions section of NACE SP0169-2013 [4]; where polarized instant-off potentials less negative than -850 mV (CSE) might be sufficient in uniformly high-resistivity, well-aerated, and well-drained soil.

When dissimilar metals are encountered, NACE SP0169-2013 [4] recommends maintaining a negative voltage between all pipe surfaces and a stable reference electrode sufficient for the protection of the most anodic metal in the system. Since the buried carbon steel and stainless steel piping systems at NPPs are almost always connected to station ground (copper grounding grid) and the reinforcing steel in concrete foundations, the most anodic metal in the couple would be considered carbon steel. Unfortunately, the native potential of the pipe is not known at NPPs because the potential of the structure (buried piping and tanks) was not measured prior to connecting to the grounding grid. Depolarization surveys should not be used as the basis for the native potential as the depolarized potentials are mixed potentials that include the more noble copper grounding and reinforcing steel component. However, native coupons at coupon test stations can be used for this purpose. Therefore it would follow that the "native" carbon steel coupon at test stations can be used as a basis for establishing the static (open-circuit) potential of carbon steel, so application of the 100 mV cathodic polarization development criterion can be applied to the most anodic metal in the couple (i.e., carbon steel).

2
OBJECTIVES

The objective of the plant assessment is to determine the overall program status or health of the CP system. The assessment for this project included using the guidelines provided in CPUG Position Paper No. 03, "Guidance for the Development of a Cathodic Protection Self-Assessment Plan" [1]. The intent of this project was to identify and benchmark strengths, deficiencies, and recommendations for improvements for the CP systems of NPPs. This was achieved by conducting CP assessments at four (4) NPP sites in 2015. Additional assessments are planned to occur in 2016. Information obtained from the self-assessments will be used to:

- Identify gaps in industry guidance and training
- Identify utility strengths, deficiencies, and recommendations
- Identify CP designs and equipment that provide enhanced technical benefits
- Identify areas where additional research and development (R&D) are needed

The primary focus of this project is CP of buried piping at NPP sites; although assessment of CP systems for other structures such as buried storage tanks, above ground storage tanks, intake structures, condenser water boxes, and reinforced concrete structures was also considered.

3
PLANT VISITS

3.1 Selection Criteria

The first task of this project was to identify NPP sites to perform the CP assessments. This task involved correspondence with the various NPP sites where CP was currently being used to protect assets. Based on this correspondence, four (4) potential NPP sites were selected which would allow outside assessment of their CP systems.

Each NPP site participating in the 2015 assessments will remain anonymous. Host sites are designated as: NPP - α, NPP - β, NPP - γ and NPP - δ.

3.2 CP Self-Assessments

This task included conducting a CP assessment at four (4) NPPs identified in Task 1 above. The assessments included:

- Coordination with participating plants to conduct site assessments.
- Participation in the development of a CP assessment plan. The Cathodic Protection Users Group (CPUG) Position Paper No. 03 [1] was used as a basis for the assessment plan. The self-assessment field questionnaire contained within this position paper, and utilized throughout the assessments, is included in Appendix A of this report.

Each assessment included a review of the technical and programmatic aspects of the system, followed by a walk-down of the plant to determine the system layout, buried structures receiving protection, and equipment details. The assessment included information relative to:

- Identifying the piping, tanks, and other structures being protected by the CP system
- Implementing effective CP for intended piping and equipment at the NPP site
- Identifying areas where additional plant guidance is needed for CP
- Identifying areas where additional training is needed
- Identifying utility strengths, deficiencies, and recommendations
- Identifying CP designs and/or equipment that provide enhanced technical benefits

Providing a site-specific assessment report which is submitted to each host NPP participating in this project

4
OBSERVATIONS MADE DURING VISITS

The following provides a summary of the results of the assessments performed in 2015 at the four (4) host sites. Assessment of each of the four (4) sites consists of the identification of site-specific Strengths, Deficiencies, and Recommendations. Site Strengths are observations of system aspects and programmatic practices which can be beneficial to the long-term operation, maintenance, evaluation ability, and overall health of the CP system, in order to maximize system effectiveness. Deficiencies are observations of system performance challenges, component corrosion protection issues, or system or programmatic aspects which may impair CP system effectiveness or evaluation thereof. Lastly, Recommendations are provided related to improvements in the design, operation, and maintenance of the CP system, as well as programmatic changes. These recommendations can lead to improved CP system and corrosion protection effectiveness.

4.1 NPP - α

4.1.1 System Overview

The following is a general overview of the CP system at NPP - α:

- ***Assets receiving CP***: Various safety-related and nonsafety-related piping systems such as condensate, chemical waste, circulating water, fire protection, station blackout, service gas, oily waste, secondary chemical control, chemical and volume control, condensate storage and transfer, plant cooling water, diesel fuel oil, liquid radwaste, essential spray pond lines, various piping systems that transport gas, spent fuel storage structures, submerged cooling tower basins, and various buried and above grade storage tank systems.
- ***CP system type:*** The primary CP system for the buried assets consists of impressed current CP using distributed and deep well anode beds. Galvanic (magnesium) anodes are also used to protect the submerged surfaces of reinforced concrete structures.
- ***When was the system installed:*** The majority of the CP system was installed during initial plant construction, however several upgrades to the system have been completed since then.
- ***Test stations***: The majority of test station sites use soil access tubes (for portable reference electrode placement). Several test stations also have permanent reference electrodes and coupons.
- ***Pipe backfill material:*** Native backfill and engineered fill in the protected area zones.
- ***Acceptance criteria:*** The primary acceptance criterion currently being used is a negative (cathodic) potential of at least 850 mV (CSE) with CP applied.

4.1.2 Assessment Summary

During the course of the assessment, the following key observations were made:

- The overall system at NPP - α is effectively managed, organized, and has maintained a high level of performance over recent years.
- There is strong system ownership. The current system engineer is experienced, qualified, understands the responsibilities associated with the system, and has stability and leadership in the system.
- In general, the system is consistent with the system design, installation practices, and periodic testing, inspection, and preventive maintenance practices outlined in EPRI report 3002000596 "Cathodic Protection Application and Maintenance Guide, Volume 1: Buried Piping, and Volume 2: Plant Structures and Equipment" [2]. Recommendations and considerations have been offered to assist in addressing those primary gaps in consistency.
- The planned implementation of a rectifier remote monitoring/interruption modification is intended to improve the overall CP system performance. This modification, when complete, will facilitate improved monitoring of the rectifier DC output, allow for synchronized current interruption of all rectifiers so that polarized instant-off potentials can be obtained, allow for immediate identification of power failures, and improve time for repair and/or replacement of rectifier deficiencies.

4.1.3 Deficiencies

Deficiencies observed in the CP system health or status at NPP - α include the following:

- Based on the most recent system health report, approximately 52% to 61% of the test points at the site meet criteria for CP for the various units. In accordance with the 'Green', 'White', 'Yellow', and 'Red' classification categories presented in CPUG Position Paper No. 1, "Cathodic Protection Performance Parameters" [8] regarding cathodic protection effectiveness, this level of protection is synonymous with a 'Yellow' and 'Red' classification.
- Since there are multiple rectifiers with no provision for interruption, the criterion used for CP at NPP - α is an "on" potential measurement with current applied. The "on" potential does not consider IR voltage drop in the earth, other than comparing potential readings at test stations with those taken in excavations next to the pipe. Use of the "on" potential without consideration of the IR voltage drop error may result in non-conservative evaluations of effectiveness, as these potentials may not represent the true level of protection.
- Due to a malfunction of the AC power supply to a significant number of rectifier systems, there is no CP provided to a large quantity of critical piping. This malfunction is a result of internal shorting of the AC power wiring to the rigid galvanized steel conduits.
- Based on review of the most recent system health report, a significant number of CP test stations could not be located in the field, which significantly reduces system monitoring capabilities. As part of the ongoing annual survey, an attempt is being made to locate the missing test stations so they can be repaired or replaced. If the test stations cannot be located, consideration might be given to using coupon test stations and/or ER probes at critical locations.

- Much of the ductile iron fire protection piping is discontinuous as a result of bonding straps that have failed across the bell and spigot joints. The discontinuous sections of pipe are subject to stray current corrosion, which has resulted in numerous leaks. Although some of the fire protection lines have been replaced with non-metallic piping, additional resources are still required to replace the remaining piping and/or bonding straps.

4.1.4 Recommendations

Based on the observations made during this assessment, the following Recommendations are offered in regards to system and programmatic improvements:

- Based on visual observations, it was noted that some of the vent pipes at anode wellheads were buried in soil and not properly venting to atmosphere. It is recommended that all vent pipes in deep wells extend above grade and curve downwards. It is also recommended that the end of the vent pipes be screened to prevent insect entry. This will prevent future clogging of the vent pipes, allow gases to escape into the atmosphere, and reduce the potential for "gas blockage" of the anode wells.
- CP assessment capabilities can be expanded through the installation of new supplemental test stations, with permanent reference electrodes and test lead wires, during opportunistic and planned buried piping excavations.
- During annual CP surveys, only current-applied "on" potentials are being measured at the test stations. As such, the IR voltage drop is not being considered in the potential measurements, as suggested in NACE SP0169-2013 [4]. A polarized instant-off potential is necessary to properly evaluate the effectiveness of the system in meeting criteria for CP. GPS synchronized current interrupters can be installed in each rectifier to allow for measurement of the instant-off potential.
- Permanent copper-copper sulfate reference electrodes were installed beneath the majority of the aboveground storage tank bottoms. The majority of these reference electrodes are no longer functional and potential measurements of the tank bottoms can only be made from remote test locations. The placement of the reference electrode at the rim of each tank may yield erroneous results because of potential gradients created in the soil as a result of current discharge from the distributed anodes. Therefore, potential measurements taken closer to the center of each tank, and at other areas directly under the tank, would yield more accurate information regarding cathodic protection levels. Additional guidance regarding potential measurements under tanks can be found in EPRI Report 3002000596, "Cathodic Protection Application and Maintenance Guide, Volume 2: Plant Structures and Equipment" [2].
- The site has pre-stressed concrete cylinder pipe (PCCP) which is under cathodic protection. Based on review of various test reports, Class 3 pre-stressing wire was used in the manufacture of the PCCP, which has a design minimum tensile strength of 262 ksi (1,806 MPa). According to NACE SP0100-2014 [9], if high-strength steels (>100 ksi [690 MPa]) are used for pre-stressing wire, care should be taken to ensure that the instant-off potential is not more negative than -1000 mV (CSE) to avoid hydrogen embrittlement. The embrittlement of high strength steels by atomic hydrogen involves the ingress of hydrogen into the steel, causing a loss in ductility and load-bearing capacity, which could result in potential cracking and catastrophic brittle failure at stresses below the yield stress of the pre-stressing wire. Consideration should be given to additional monitoring of these pipelines.

This can be achieved by installation of additional test stations and a close interval survey (CIS) conducted over the PCCP piping, at no more than three year intervals, to help assess CP conditions and prevent overprotection. Ideally, the survey should be an interrupted survey so that "on" and "instant-off" potentials are captured. If performed prior to the interrupter and remote monitoring modification, a rectifier influence survey can be conducted to determine which rectifiers influence each section of piping. Portable synchronized current interrupters should be installed in the influencing power supplies so that "instant-off" potentials can be obtained. Care should be taken when analyzing the CIS potential data as copper grounding and other structures in close proximity to the buried piping can influence the test results. Additional guidance on conducting close-interval potential surveys can be found in NACE SP0207-2007 [10].

- Many of the existing test stations are missing, covered, or have been removed. As part of the ongoing annual survey, an attempt is being made to locate the missing test stations so they can be repaired or replaced. When installing new test stations, consideration should be given to using coupon test stations and/or electrical resistance (ER) probes at critical piping locations in order to collect additional information regarding cathodic protection effectiveness. Additional guidance regarding the design and installation of test stations, including coupons and electrical resistance probes, can be found in EPRI Report 3002000596, "Cathodic Protection Application and Maintenance Guide, Volume 1: Buried Piping" [2] and NACE SP0169-2013 [4].
- An AC power supply malfunction for an entire Motor Control Center (MCC) cubicle has resulted in a lack of corrosion protection to many critical piping systems. AC power supply should be restored, with the goal of providing 100% operation to all rectifier systems, in order to continue providing cathodic protection to all intended piping systems.
- Several rectifier enclosures were inspected during the CP assessment. A program is in place to replace old and malfunctioned rectifiers with standard air cooled manual voltage control units. Additional personnel safety features for the rectifiers are available, such as:
  - Tap-switch adjustment (allows safe adjustment of rectifier DC output without using link bars)
  - Dead front fuse holders (allows safe removal and insertion of fuses)
  - Plastic safety barriers (clear polycarbonate sheets) to cover exposed AC and DC components located on front panel of rectifier
- Regular anode well replacement occurs at the site. The anodes being used during the deep well replacements are graphite. Some of the anode wells are now being replaced in less than ten (10) years. Additional life may be realized by using titanium based anodes with a mixed metal oxide (MMO) catalyst.

4.1.5 Strengths

Based on the results of the assessment, the following Strengths were observed:

- There is strong system ownership. The current system engineer is experienced, qualified, understands the responsibilities associated with the system, and has stability and leadership in the system.
- NPP - α utilizes a qualified corrosion engineer and certified technicians to perform annual surveys, monitor, test, trouble-shoot and maintain the CP systems. A NACE CP Level 4 (CP Specialist) engineer reviews all CP data and is responsible for developing the annual survey reports. The primary site representative is a NACE CP Level 3 certified technologist (CP Technologist). This level of commitment helps provide continuity and experience for the future health the CP system, particularly when considering the relative size of the system.

4.2 NPP – β

4.2.1 System Overview

The following is a general overview of the CP system at NPP - β:

- ***Assets receiving CP:*** Various safety-related and nonsafety-related piping systems, including low pressure service water, emergency coolant injection, service air, instrument air, diesel generator fuel oil, fire protection, condenser cooling water, hydrogen supply, and trash removal sumps.
- ***CP system type for buried assets:*** Galvanic (magnesium) anodes and distributed impressed current anode systems.
- ***When was the system installed:*** The majority of the system was installed during initial plant construction, however, CP has also been installed on new and replacement piping systems.
- ***Test stations:*** The majority of test station sites use permanent reference electrodes.
- ***Pipe backfill material:*** Native backfill and engineered fill.
- ***Acceptance criteria:*** The primary acceptance criterion being used is a negative polarized “instant-off” potential of at least 850 mV (CSE).

4.2.2 Assessment Summary

During the course of the assessment, the following key observations were made:

- The buried piping engineer at NPP ─ β serves as the engineer who is responsible for CP at the site. The buried piping engineer has limited training and experience in CP; however, plans are in place for the engineer to attend a NACE CP Level 2 (CP Technician) course. This level of training is consistent with training recommendations for cathodic protection system engineers, as outlined in EPRI CPUG Position Paper No. 02 [3].
- NPP ─ β is reported to have soils that have moderate to high soil resistivities, high pH, and low concentrations of chemical species. These parameters are considered to help reduce the tendency towards external corrosion for carbon steel materials [11]. However, pitting corrosion was previously reported on a safety-related pipe that prompted a modification for replacement. The pitting corrosion was observed below the water table, such that other similar areas may also be at risk.
- The impressed current CP systems installed during initial construction for the low pressure service water supply lines were only recently energized. Many of the anode circuits associated with these systems have high resistance, possibly due to failed splices and/or broken cables. Unfortunately, many of the distributed anodes for these systems are installed beneath a turbine building slab where accessibility for repair is difficult.
- The design basis for the galvanic anode system required electrical isolation of the buried piping through the design and installation of insulating flanges with polarization cells at the pipe extremities. Although insulating flanges were installed in the buried piping when the plant was constructed, the majority of the piping is electrically shorted to station ground, which is resulting in a much greater current demand than the sacrificial anodes are capable of providing. In addition, many of the sacrificial anodes and impressed current systems are ineffective or are fully depleted. Based on review of the annual survey reports, the system has insufficient levels of CP to adequately meet NACE SP0169-2013 [4] criteria.

4.2.3 Deficiencies

Deficiencies observed in the CP system health or status at NPP - β include the following:

- The intent of the initial CP system design at NPP ─ β was to have CP on isolated sections of buried piping, protected by galvanic anodes. Electrical isolation was to be accomplished through the use of insulating flanges that are installed in the piping at the building entry points. With the exception of two lines that are electrically isolated, the buried piping is inadvertently shorted to station ground and, therefore, the majority of insulating flanges are ineffective. As a result of this shorted condition, a significant portion of the protective current from the anode systems will tend to flow to other structures that are not intended for CP, such as the copper grounding grid and reinforcing steel in the concrete foundations. This has resulted in a much higher current demand for CP, premature depletion of the galvanic anodes, and a lower level of protection to the buried piping.

- Based on review of the 2014 annual survey data from the indirect inspection report, it would appear that CP is minimal or non-existent on the majority of non-isolated piping. Specifically, approximately 90% of the test stations have pipe-to-soil potentials that reportedly do not meet the -850 mV (CSE) polarized instant-off potential criterion as defined in NACE SP0169-2013 [4]. In accordance with the ‘Green’, ‘White’, ‘Yellow’, and ‘Red’ classification categories presented in CPUG Position Paper No. 1, “Cathodic Protection Performance Parameters” [8] regarding cathodic protection effectiveness, this level of protection is synonymous with a ‘Red’ classification.
- NPP ─ β has experienced pitting corrosion on an emergency service water line below the water table, such that other areas of active corrosion may be of concern.
- An impressed current cathodic protection system was designed and installed to protect the low pressure service water system as part of the original design of the plant. The rectifiers providing protection for these lines, installed during initial construction of the plant, were only recently energized. Therefore, there was a significant period of time when the impressed current systems were not operating.
- The measurement of the pipe-to-soil potentials is currently being performed annually at the test stations by a qualified CP Vendor. The potentials are measured with reference to a portable copper-copper sulfate electrode (CSE) that is placed at grade near the test station and/or a permanent reference CSE that is buried next to the piping near the test station. The portable electrodes are typically placed at grade in a crack or opening in the asphalt and the contact area is wetted with water to reduce the contact resistance. As a result, in certain areas, the potential at grade may be a mixed potential that is dominated by other structures, such as copper grounding, and may not be representative of the true pipe-to-soil potential at pipe depth. Furthermore, since these readings are taken in cracks in the asphalt, they do not provide consistency for repeat measurement locations and trending of data.
- Some of the test stations have permanent copper-copper sulfate reference electrodes that were installed at pipe depth during initial construction of the plant. These older permanent electrodes, which consist of gel-type electrolytes, can have limited life due to leaching, dry-out, and contamination of the electrode from diffusion across the membrane interface. Therefore, the data obtained using these older permanent reference electrodes may contain some degree of error and not represent the true pipe-to-soil potentials.

4.2.4 Recommendations

Based on the observations made during this assessment, the following Recommendations are offered in regards to system and programmatic improvements:

- Installation of permanent test wells and/or soil access points through the asphalt at all test station sites would provide improved consistency and accuracy for pipe-to-soil potential readings.
- Installation of new coupon test stations and/or electrical resistance (ER) probes in critical areas, such as in congested areas or where pipes enter a foundation wall or underground vault, would provide additional data on cathodic protection effectiveness in areas that constitute high susceptibility to under-protection. In addition, whenever a buried pipe is exposed, consider installing a test station and permanent reference electrode, as this can be an effective way to expand CP effectiveness assessment capabilities. Additional guidance regarding the design and use of test stations for corrosion monitoring and cathodic protection can be found in EPRI report 3002000596 "Cathodic Protection Application and Maintenance Guide, Volume 1: Buried Piping" [2] and NACE SP0169-2013 [4].
- Although plans are in place for the replacement of the four (4) rectifiers in 2016, further assessment of the performance of the distributed anode impressed current circuits for all four (4) systems may be warranted, as 13 of 16 circuits appear to have high anode-to-earth resistance values. Anode circuits with open or high anode circuit resistance can have limited or no benefit to the buried piping. EPRI Report 3002000596 [2] provides additional details regarding troubleshooting of impressed current and galvanic anode cathodic protection systems.
- Soil chemical analysis, resistivity, and pH measurements are being performed at all direct inspections of buried piping. However, the data is not organized or consolidated into one document. Consolidating soil data into a common location or document can facilitate improved site soil condition and corrosivity assessments.
- A plan is in place to replace depleted magnesium anodes throughout the site. However, since the majority of plant piping is shorted to station ground, the amount of replacement anodes will need to exceed the original system design due to the additional metal structures that now require protection. Another alternative would be to consider an impressed current system, particularly for the systems that are safety-related or contain hazardous or licensed materials (e.g., tritium).
- Since the majority of buried piping is essentially shorted to station ground, the polarization cells that have been installed across the insulating joints to mitigate AC power surges have limited or no effect and, therefore, testing and reporting of these devices in annual survey reports may be of limited value. Some of the piping systems have above grade insulating flanges at the building entrance points. Solid-state decoupling device are one means to provide DC current isolation and AC grounding at these insulating flanges.
- When designing and installing a new galvanic anode system, EPRI report 3002000596, "Cathodic Protection Application and Maintenance Guide – Volume 1" [2] recommends having all anode leads connected to header cables that are in-turn connected to the pipe through test leads at test stations. Additionally, shunts may be installed in the test stations for measuring the galvanic anode current. This will help facilitate functional testing to determine system effectiveness.

4.2.5 Strengths

Based on the results of the assessment, the following Strengths were observed:

- Although the buried piping system engineer has limited formal training in CP, the plant is committed and plans are in place for the engineer to obtain NACE CP Level 2 (CP Technician) certification. This level of training is consistent with training recommendations for cathodic protection system engineers, as outlined in EPRI CPUG Position Paper No. 02 [3].
- Although not performed historically, NPP - β is now performing annual surveys of the galvanic anode CP systems, which is in line with EPRI guidelines [2] and industry standards [4] for monitoring and maintenance of these systems.
- NPP - β utilizes certified CP testers and technicians to perform annual surveys and provide consultation regarding corrosion and CP. NACE CP Level 1 (CP Tester) and Level 2 engineers collect and analyze the data, and are responsible for developing the annual survey reports. This level of commitment helps ensure that CP data is being collected and analyzed by certified individuals knowledgeable in cathodic protection.

4.3 NPP - γ

4.3.1 System Overview

The following is a general overview of the CP system at NPP - γ:

- ***Assets receiving CP:*** Various safety-related and nonsafety-related piping systems, including Service Water, Standby Gas Treatment, Circulating Water, fire water, water wells, and the interior submerged surfaces of elevated water storage tanks.
- ***CP system type:*** The system for the buried assets consists of impressed current systems using distributed anode groundbeds.
- ***When was the system installed:*** The initial CP system was installed as a retrofit after the plant was constructed and was later abandoned. The existing system was installed in 2010 as part of a major CP system upgrade project at the plant.
- ***Test stations:*** Test station sites use both permanent and portable reference electrodes.
- ***Pipe backfill material:*** Native backfill and engineered fill.
- ***Acceptance criteria:*** The acceptance criteria being used is a negative polarized “instant-off” potential of at least 850 mV (CSE) and a minimum of 100 mV of cathodic polarization.

4.3.2 Assessment Summary

During the course of the assessment, the following key observations were made:

- There is strong system ownership. The current system engineer is qualified, understands the responsibilities associated with the system, and has undergone training and mentoring from the previous system engineer.
- In general, the CP system at NPP - γ is consistent with the testing and maintenance practices outlined in EPRI report 3002000596 "Cathodic Protection Application and Maintenance Guide, Volume 1: Buried Piping" [2].
- Although CP is not written into the license requirements for NPP - γ, there is strong evidence to support its continued long-term use based on soil samples obtained during buried piping excavations which indicate a greater degree of corrosivity.

4.3.3 Deficiencies

Deficiencies observed in the CP system health or status at NPP - γ include the following:

- As part of the annual survey, the majority of pipe-to-soil potentials are measured at test points using a portable copper-copper sulfate reference electrode that is placed at grade near the test point. The portable reference electrodes are typically placed in a crack or opening in the asphalt or concrete. As a result, in certain areas, the potential at grade may be a mixed potential that is dominated by other structures or components, such as copper grounding, and may not be representative of the true pipe-to-soil potential at pipe depth. Furthermore, since these readings are taken in openings in the asphalt or concrete, they do not provide consistency for repeat measurement locations and trending of data.
- Some of the test stations have permanent copper-copper sulfate reference electrodes that are installed at pipe depth. Some of these were installed in the early 1990s when the original CP system was installed. These older permanent electrodes typically consist of gel-type electrolytes and can have limited life due to leaching, dry-out, and can become contaminated due to diffusion across the membrane interface. Therefore, the data obtained using these older permanent reference electrodes may contain some degree of error and not represent the true pipe-to-soil potentials.
- Although a high amount of CP values have been reported to meet the 100 mV polarization criterion during assessment surveys, caution must be exercised when evaluating CP effectiveness based on this criterion. This is due, in part, to the fact that depolarized potential surveys are used as the basis for calculating the amount of polarization development. When buried piping is connected to, and electrically continuous with, the station grounding grid, a depolarization potential survey represents the potential of the mixed metal system, not just that of the buried piping material of interest. As a result, comparison of the instant-off potentials to the depolarization potential of the entire system does not necessarily ensure that the most anodic material in the system, often carbon steel piping, has achieved 100 mV of polarization. Therefore, this can lead to mis-interpretation of the degree of cathodic protection effectiveness.

- Only 49% of the potential measurements taken at test points during the 2015 annual survey exceed the -850 mV polarized instant-off criterion. In accordance with the ‘Green’, ‘White’, ‘Yellow’, and ‘Red’ classification categories presented in CPUG Position Paper No. 1, “Cathodic Protection Performance Parameters” [8] regarding cathodic protection effectiveness, this level of protection is synonymous with a ‘Red’ classification.
- There is presently no CP system for the two (2) buried diesel fuel oil tanks and associated piping at this site. Pitting corrosion has been previously observed at coating holidays of safety-related piping and tanks, suggesting corrosion may be of concern in the absence of adequate cathodic protection.

4.3.4 Recommendations

Based on the observations made during this assessment, the following Recommendations are offered in regards to system and programmatic improvements:

- Based on the safety significance of two (2) diesel fuel oil tanks and associated piping, and previous history of pitting type corrosion observed on previous buried assets, a distributed anode cathodic protection system would be beneficial to the mitigation of corrosion for these components. Additional guidance on evaluating the need to install or upgrade a cathodic protection system can be found in EPRI Report 3002005067, “Evaluation for Installing or Upgrading Cathodic Protection,” [12] and additional guidance on the design and application of cathodic protection systems for buried piping and tanks can be found in EPRI Report 3002000596, “Cathodic Protection Application and Maintenance Guide” [2].
- The 2014 annual survey report recommended that two (2) new deep-anode groundbeds, complete with a common rectifier, be installed to restore protective levels to all associated plant piping and metallic structures. Based on the relatively shallow depth of bedrock, installation of semi-deep anodes down to the depth of bedrock may result in improved protection levels [2].
- Installation of permanent test wells and/or soil access points through the asphalt at all test station sites would provide improved consistency and accuracy for pipe-to-soil potential readings.
- When performing annual surveys, obtaining a greater number of potential measurements over critical piping systems and buried diesel fuel oil tanks would enhance the level of understanding related to cathodic protection effectiveness in these areas.
- Installation of new coupon test stations and/or electrical resistance (ER) probes in critical areas, such as in congested areas or where pipes enter a foundation wall or underground vault, would provide additional data on cathodic protection effectiveness in areas that constitute high susceptibility to under-protection. At the two (2) buried diesel fuel oil tanks, installation of soil access points at the extremities of each tank would provide beneficial information regarding CP effectiveness of the tanks. In addition, whenever a buried pipe is exposed, consider installing a test station and permanent reference electrode, as this can be an effective way to expand CP effectiveness assessment capabilities. Additional guidance regarding the design and use of test stations for corrosion monitoring and cathodic protection can be found in EPRI report 3002000596 “Cathodic Protection Application and Maintenance Guide, Volume 1: Buried Piping” [2] and NACE SP0169-2013 [4].

- It was noted in a 2015 annual survey report that only 49% of the potential measurements taken at test points exceeded the -850 mV polarized instant-off criterion for CP and that 89% of the readings exceed the 100 mV polarization development criterion. An area potential and earth current survey was also performed in 2012. The report stated that adequate protection using the 100 mV criterion was present in 98% of the grids; however some of the readings in the grid may have been taken directly over anode beds, which could provide misleading results [13]. Caution should be exercised when evaluating this data for purposes of determining CP effectiveness due to the effects of the mixed metal environment.
- A depolarized potential survey was used as a basis for calculating the degree of polarization on the buried piping so that the 100 mV polarization criterion could be used. Since buried piping is often connected the copper grounding grid at nuclear power plants, depolarization potential surveys provide mixed metal potentials. As discussed in NACE SP0169-2013 [4], when electrically continuous dissimilar metals (i.e., mixed metals) are encountered, 100 mV of polarization should be achieved relative to the native potential of the most anodic material in the system. One method to more accurately assess the 100 mV polarization development for carbon steel piping at nuclear power plants is through the installation of "native" carbon steel coupons. Additional guidance regarding the design and use of test station coupons can be found in EPRI report 3002000596 "Cathodic Protection Application and Maintenance Guide, Volume 1: Buried Piping" [2] and NACE SP0104-2014 [14].
- Data from the annual 2015 survey report indicates that two (2) rectifiers for the interior surfaces of water storage tanks are operating at a low current output. The rectifiers are reported to be electronic potential-controlled rectifiers. The system is designed to automatically monitor and adjust the DC output required for CP using a permanent reference electrode that is suspended in the water (electrolyte) inside the tank, while preventing under-protection or over-protection of the coating surface. Based on the low current readings observed, this system may not be properly functioning and would benefit from further investigation by CP knowledgeable and qualified individuals.
- Two (2) remote anode groundbeds were designed and installed at NPP - γ during the early 1990s. These were subsequently abandoned due to maintenance problems related to numerous breaks in the positive (+) DC cables. It may be possible to re-utilize these anode groundbeds if the anode cables can be located and tested to determine if there is acceptable resistance.

4.3.5 Strengths

Based on the results of the assessment, the following Strengths were observed:

- There is strong system ownership. The current system engineer understands the responsibilities associated with the system, has stability and leadership in the system, and has taken EPRI CP101, "Training for the Cathodic Protection System Owner", consistent with the training recommendations presented in EPRI CPUG Position Paper No. 02 [3].
- The anodes that are installed at NPP - γ consist of mixed metal oxide (MMO) anodes. These anodes are relatively inert and can be operated at relatively high current densities with very low consumption rates [2]. Based on analysis of the annual survey report data, all of the MMO anodes are operating at appropriate current output levels. This will optimize the expected life of the anode groundbeds.

- NPP - γ utilizes a qualified corrosion engineer and certified technicians to perform annual surveys, monitor, test, and trouble-shoot the CP systems. Use of CP certified and experienced individuals can better assist in the identification of maintenance deficiencies associated with the system and providing of recommendations for improvement. This level of commitment is essential for larger systems and provides continuity and experience for the future health of the system.
- This site has a coordinated effort between the CP owner(s) and Operations to check rectifiers weekly and potentials at test stations on a quarterly basis. The quick response that follows allows for mitigation/remediation of existing or pending problems.

4.4 NPP – δ

4.4.1 System Overview

The following is a general overview of the CP system at NPP - δ:

- ***Assets receiving CP:*** Emergency service water piping, residual heat removal service water piping, buried diesel fuel storage tanks and piping, chlorine/acid piping, buried oily waste tank, and the interior submerged surfaces of the elevated clarified water storage tank.
- ***CP system type:*** The CP system for the buried assets consists of impressed current systems using semi-deep anode groundbeds.
- ***When was the system installed:*** The majority of the existing system was installed in 2005 as part of a major CP system upgrade project at the plant.
- ***Test stations:*** The majority of test station sites use permanent reference electrodes and/or test leads.
- ***Pipe backfill material:*** Flowable-fill.
- ***Acceptance criteria:*** The acceptance criteria being used is a negative polarized "instant-off" potential of at least 850 mV (CSE) and a minimum of 100 mV of cathodic polarization.

4.4.2 Assessment Summary

Based upon the assessment, the following key observations were made:

- There is strong system ownership. The current system engineer has taken the NACE CP2 - Cathodic Protection Technician course and the future system engineer intends to take formal training in accordance with training recommendation outlined in EPRI CPUG Position Paper No. 02 [3] for cathodic protection system engineers.
- While rectifiers are intended to be monitored on a monthly basis, monthly monitoring does not always occur.
- The buried pipe engineer at the site believes all of the buried piping is embedded in a flowable-fill that was installed at the time of construction. Flowable-fill is a cementitious backfill with high water-cement ratio that provides additional corrosion protection to the buried metallic structures because of its high pH (high alkalinity). The buried pipe engineer also reported that no external corrosion has been observed on any of the buried piping during excavations and inspections.

4.4.3 Deficiencies

Deficiencies observed in the CP system health or status at NPP - δ include the following:

- Only 35% of the potential measurements taken at test points and test stations during the 2014 annual survey exceed the -850 mV polarized instant-off criterion for CP. In accordance with the ‘Green’, ‘White’, ‘Yellow’, and ‘Red’ classification categories presented in CPUG Position Paper No. 1, “Cathodic Protection Performance Parameters” [8] regarding cathodic protection effectiveness, this level of protection is synonymous with a ‘Red’ classification.
- Buried diesel fuel oil tanks and associated piping at NPP - δ are not fully protected from corrosion per NACE RP0285-95 [15]. These tanks receive only partial protection from near-by semi-deep anode wells.
- The CP system for the interior of an elevated water storage tank was found not operating. An inspection conducted in 2015 indicated zero current output from the rectifier. The system has now been inoperative for several years and the rectifier AC breaker has been turned off.
- Many of the semi-deep anode wells have high anode-to-earth resistance, which is restricting current delivery to the buried tanks and piping from the rectifier systems. According to the well drilling logs from the CP system upgrade project, many of the semi-deep anodes are installed in a bedrock material. Bedrock is not an ideal environment for installing anode groundbeds due to its high resistivity, which can result in high rectifier voltages and/or lower levels of provided protection [2]. Ideally, anode beds should be installed in a lower resistivity soil backfill or ground formation.

4.4.4 Recommendations

Based on the observations made during this assessment, the following Recommendations are offered in regards to system and programmatic improvements:

- The design and installation of a distributed anode CP system for buried diesel fuel oil tanks and associated piping would help mitigate corrosion to safety-related and/or components carrying environmentally hazardous materials.
- Installation of new coupon test stations and/or electrical resistance (ER) probes in critical areas, such as in congested areas, along safety-related pipes, or where pipes enter a foundation wall or underground vault, would provide additional data on cathodic protection effectiveness in areas that constitute high consequences of pipe failure or high susceptibility to under-protection. In addition, whenever a buried pipe is exposed, consider installing a test station and permanent reference electrode, as this can be an effective way to expand CP effectiveness assessment capabilities. Additional guidance regarding the design and use of test stations for corrosion monitoring and cathodic protection can be found in EPRI report 3002000596 “Cathodic Protection Application and Maintenance Guide, Volume 1: Buried Piping” [2] and NACE SP0169-2013 [4].

- Based on the review of cathodic protection trending data, rectifiers are operating at relatively high voltages and anode resistance values are also reported as relatively high. High rectifier voltages can contribute to a phenomenon known as anode groundbed “dry-out,” where the high voltage will tend to increase electro-osmosis (i.e., driving water away from the anode). This high anode bed resistance reduces the current delivery supplied from the rectifiers and ultimately results in lower levels of protection provided to the buried assets. This condition is further discussed in EPRI Report 3002000596 [2], as well as the concept that water can be added to the groundbed to reduce the anode-to-earth resistance. Water could be added using a vent pipe, if present, or even a prototype irrigation system.
- When performing annual surveys, obtaining a greater number of potential measurements over critical piping systems and buried diesel fuel oil tanks would enhance the level of understanding related to cathodic protection effectiveness in these areas. Furthermore, in areas of asphalt or concrete, consider drilling small diameter holes through the surface to gain access to the underlying soil in order to obtain more accurate and consistent data.
- Many of the rectifiers are operating at high voltage outputs. These high voltages may pose step touch potential hazards. Since retrofitting existing rectifiers to incorporate personnel safety features may be difficult, the following options might be considered when ordering new rectifiers:
  - Tap-switch adjustment (allows safe adjustment of rectifier DC output without using link bars).
  - Dead front fuse holders (allows safe removal and insertion of fuses).
  - Plastic safety barriers (clear polycarbonate sheets) to cover exposed AC and DC components located on front panel of the rectifier.
  - Interruption ports to allow safe connection of portable current interrupters, or consider specifying integral GPS current interrupters with the relay inserted in the AC input.

  Additional information regarding safe rectifier design can be found in the Canadian Association of Petroleum Producers (CAPP) Publication No. 2009-0019 “Impressed Current Cathodic Protection Rectifier Design-for-Safety Guideline” [16].
- NPP - δ reports both the -850 mV instant-off criterion, as well as the 100 mV polarization criterion, when assessing cathodic protection effectiveness. It was noted in the 2015 annual survey report that only 35% of the potential measurements taken at test stations and test points exceed the -850 mV (instant-off criterion), but approximately 70% of the readings exceed the 100 mV polarization criterion. The 100 mV polarization criterion is determined based on the original native potentials taken at the test stations, before CP was applied at this site. Since the carbon steel buried piping is electrically continuous and connected to the station grounding grid, these native potentials will represent the potentials of the entire mixed metal system of components, not necessarily the native potential exclusive to only the material of construction for the component of interest (e.g., carbon steel buried piping). Therefore, without the use of installed native coupons, the use of the 100 mV polarization shift criterion may not accurately reflect the true degree of polarization for buried steel

components and, furthermore, may potentially lead to misinterpreting the extent of adequate CP effectiveness being reported. Additional guidance regarding the design and installation of test stations, including test (native) coupons, can be found in EPRI report 3002000596 “Cathodic Protection Application and Maintenance Guide, Volume 1: Buried Piping” [2] and NACE SP0169-2013 [4].

- Due to the high rectifier voltages, portable rectifier current interrupters have not been able to be used during performance of annuals surveys. Instead, the rectifiers have been manually interrupted in order to obtain instant-off polarized potentials. Without the ability to simultaneously interrupt all rectifier current output, some of the instant-off potentials may be partially affected by current being supplied by operating rectifiers. Therefore, these instant-off readings may not be true IR voltage free potentials. To accurately measure the polarized instant-off potential for the buried piping and tanks at NPP - δ, the use of synchronized current interrupters may be necessary, unless it can be proven through a rectifier influence survey that no overlapping current is evident at the test stations and test points where the potentials are being measured.
- NACE SP0169-2013 [4] includes guidance that when a pipeline is buried in dry or aerated high-resistivity soil, values less negative than the -850mV criteria in this standard may be sufficient. It would follow that the flowable-fill backfill may fall into this category. Therefore, the flowable-fill could be tested for resistivity at all buried pipe excavations to help support use of an alternative criteria for CP effectiveness.

4.4.5 Strengths

Based on the results of the assessment, the following Strengths were observed:

- There is strong system ownership. The current system engineer has taken NACE CP2 training and is in the process of transitioning the system responsibilities to a new engineer. The new system engineer will benefit from the guidance and mentorship of the current system engineer, while also intending to take formalized CP training consistent with EPRI CPUG Position Paper No. 02 [3].
- The anodes that are installed at NPP - δ consist of mixed metal oxide (MMO) anodes. These anodes are relatively inert and can be operated at relatively high current densities with very low consumption rates [2]. Based on analysis of the annual survey report data, all of the MMO anodes are operating at appropriate current output levels. This will optimize expected life of the anode groundbeds.
- NPP - δ utilizes a certified corrosion engineer and technicians to perform annual surveys, monitor, test, and trouble-shoot the CP systems. The use of certified and experienced individuals helps ensure that CP data is being properly collected and analyzed to assist in the identification of maintenance and performance deficiencies.

5 SUMMARY

The following provides a summary of observations from the 2015 CP assessments that were carried out at the four (4) participating plants.

1. The CP systems at the four (4) nuclear power plants generally exhibit consistency with the system design, installation practices, periodic testing, inspection and preventive maintenance practices outlined in EPRI report 3002000596 “Cathodic Protection Application and Maintenance Guide, Volume 1: Buried Piping, and Volume 2: Plant Structures and Equipment” [2]. All four (4) plants have plans in place to improve the design, monitoring, and operation of their systems. Recommendations and considerations have been offered to assist in addressing those identified inconsistencies.
2. In general, there is strong system ownership at the four (4) nuclear power plants. The current system engineer or responsible plant representative understands the responsibilities associated with the system and has stability and leadership in the system. Site engineers responsible for the CP system either meet the qualification recommendations in EPRI CPUG Position Paper No. 2 “Qualification Guidelines for Personnel Performing Activities Associated with Nuclear Power Plant Cathodic Protection Systems” [3], or plans are in place to obtain the recommended training and qualifications.
3. Each of the four (4) nuclear power plant sites use the services of a third-party qualified corrosion engineer and / or certified technicians to perform annual surveys, monitor, test, trouble-shoot, and maintain the CP systems. Use of CP certified and experienced individuals can better assist in the identification of maintenance deficiencies associated with the system and providing of recommendations for improvement. Entering these recommendations for improvement into the site’s corrective action program can be an effective means to document and track opportunities for improvement to the CP system and overall performance. This is particularly important if the system engineer or plant representative has not received adequate technical training on CP or is new to their position.
4. Caution should be exercised when applying the 100 mV polarization development criterion for CP of buried piping at nuclear power plants due to the presence of mixed metal environments at most NPP sites. In general, when applying the 100 mV polarization criterion, the open-circuit potential of the material of interest (e.g., carbon steel piping) is typically used as a baseline for calculating the amount of polarization development. Unfortunately, the open-circuit potential of individual buried piping material types at nuclear power plants is typically not known, as it was not measured prior to connection of the copper grounding grid. Depolarized potential surveys are sometimes used by nuclear power plants as a baseline for calculating the amount of polarization development, however, the results of depolarization surveys are mixed potentials of various metals. These mixed potentials are typically more electro-positive (less negative) than carbon steel by itself. One solution to more accurately evaluate the 100 mV polarization development is through the use of “native” coupons. Native coupons can be constructed of the same material as buried piping and represent the true open-circuit potential of the piping. As a result, they may be used for

establishing a baseline potential for the material type when calculating the amount of polarization development. A sufficient number of coupon test stations with native coupons (freely corroding carbon steel coupons) can be installed at nuclear power plants in order to establish a baseline of native potentials.

5. Increased communication between the Buried Pipe and CP Engineers, where applicable, as well as increased cross discipline training or understanding between the two subject matters can be beneficial to improving asset management. If not already in place, development of a CP System Notebook that includes all references to the station's CP system design, industry standards, and all existing and future work regarding corrosion of buried structures and cathodic protection at the plant would also be beneficial for both engineers.
6. Sites with pre-stressed concrete cylinder pipe (PCCP) may be susceptible to hydrogen embrittlement of the pre-stressing wires if the CP system is operated at too high of a level in the area of these pipelines. The embrittlement of high strength steels by atomic hydrogen involves the ingress of hydrogen into the steel, causing a loss in ductility and load-bearing capacity, which could result in potential cracking and catastrophic brittle failure at stresses below the yield stress of the pre-stressing wire. According to NACE SP0100-2014 [9], if high-strength steels (>100 ksi [690 MPa]) are used for pre-stressing wire, care should be taken to ensure that the instant-off potential is not more negative than -1000 mV (CSE) to avoid hydrogen embrittlement. Class 3 pre-stressing wire, which has previously been used in the manufacture of PCCP, would fall into this category.
7. Soil chemical analysis, resistivity, and pH measurements taken from soil samples during opportunistic and planned excavations of buried piping can lead to a better understanding of soil conditions and corrosivity, particularly when consolidated into a single document. This data may also be used to help support the use of alternative effectiveness evaluation criteria for CP.

In addition to the above observations, the following considerations are also offered in regards to equipment improvements. These considerations are further discussed in EPRI Report 3002000596 "Cathodic Protection Application and Maintenance Guide, Volume 1: Buried Piping" [2].

1. The use of rectifier remote monitoring units and synchronized current interruption may lead to improved monitoring, trending, and data acquisition capabilities. Synchronized current interruption capability of rectifiers, such as by Global Positioning System (GPS) current interpreters, allow for the simultaneous current interruption of all rectifiers so that "instant-off" polarized potentials readings are not influenced by any other operating rectifiers. Remote monitoring units offer the ability to track and trend rectifier parameters, such as voltage and amperage, remotely and without the need to send technicians into the field. Some units can also offer the ability to notify the user when there are problems with the rectifier unit, improving time for repair completion and return to service.
2. Cathodic protection effectiveness is assessed based on a sampling at discretely measured points of interest. The design and installation of new supplemental test stations at critical locations, such as in areas along safety-related pipes and structures, or where pipes enter foundation walls or underground vaults, would improve CP assessment capabilities at locations that constitute high consequences of pipe failure or high susceptibility to under-protection. Test stations may consist of permanent reference electrodes, coupons, and/or electrical resistance (ER) probes that are used for measuring corrosion rates. Additionally,

the accuracy of older permanent copper-copper sulfate reference electrodes (>20 years in age) may be subject to leaching and dry-out, which can adversely affect their accuracy.

3. Installation of permanent test wells and/or soil access points at test station sites, especially in areas of asphalt and concrete, can improve consistency in measurement location and accuracy of pipe-to-soil potential readings when taken at grade.
4. While there are two common types of cathodic protection systems, impressed current and galvanic anode systems, galvanic anodes are best suited for CP of well coated piping systems that are fitted with insulating devices [2]. The insulating devices will electrically isolate the buried piping from station ground and limit the current demand for CP. However, if the insulating devices are shorted or are not effectively incorporated into the piping system design, the galvanic anodes can be consumed rapidly and protection levels can be compromised.
5. When ordering new rectifiers, plants may wish to consider the following personnel safety options:
   a. Tap-switch adjustment (allows safe adjustment of rectifier DC output without using link bars).
   b. Dead front fuse holders (allows safe removal and insertion of fuses).
   c. Plastic safety barriers (clear polycarbonate sheets) to cover exposed AC and DC components located on front panel of the rectifier.
   d. Interruption ports to allow safe connection of portable current interrupters, or consider specifying integral GPS current interrupters with the relay inserted in the AC input.

6
REFERENCES

1. EPRI CPUG Position Paper No. 03, “Guidance for the Development of a Cathodic Protection Self-Assessment Plan”, dated March, 2015 (EPRI, Palo Alto, CA).
2. *Cathodic Protection Application and Maintenance Guide: Volume 1: Buried Piping. EPRI*, Palo Alto, CA: 2013. 3002000596 Volume 1.
3. EPRI CPUG Position Paper No. 02, “Qualification Guidelines for Personnel Performing Activities Associated with Nuclear Power Plant Cathodic Protection Systems”, dated October, 2013 (EPRI, Palo Alto, CA).
4. NACE International SP0169-2013 “Control of External Corrosion on Underground or Submerged Metallic Piping Systems” (NACE International: Houston, TX).
5. NACE International Item No. 24252 “State-of-the-Art: External Corrosion, Assessment and Control of Buried Piping Systems in Nuclear Power Plants” (NACE International: Houston, TX).
6. International Organization for Standardization (ISO) in Standard 15589-1 “Petroleum and Natural Gas Industries – Cathodic Protection of Pipeline Transportation Systems – Part 1: On-Line Pipelines” (ISO: Geneva, Switzerland).
7. License Renewal Interim Staff Guidance LR-ISG-2015-01 “Changes to Buried and Underground Piping and Tank Recommendations” (U.S. Nuclear Regulatory Commission: Washington, DC).
8. EPRI CPUG Position Paper No. 1, “Cathodic Protection Performance Parameters”, dated October, 2013 (EPRI, Palo Alto, CA)
9. NACE International SP0100-2014 “Cathodic Protection to Control Corrosion of Concrete Pressure Pipelines and Mortar-Coated Steel Pipelines for Water and Waste Water Service” (NACE International: Houston, TX).
10. NACE International SP0207-2007 “Performing Close-Interval Potential Surveys and DC Surface Potential Gradient Surveys on Buried or Submerged Metallic Pipelines” (NACE International: Houston, TX).
11. *Soil Sampling and Testing Methods to Evaluate the Corrosivity of the Environment for Buried Piping and Tanks at Nuclear Power Plants.* EPRI, Palo Alto, CA: 2015. 3002005294.
12. *Evaluation for Installing or Upgrading Cathodic Protection Systems: A Guide for Cathodic Protection for Buried Piping and Tanks.* EPRI, Palo Alto, CA: 2015. 3002005067.
13. *Recommendations for Managing an Effective Cathodic Protection System*. EPRI, Palo Alto, CA: 2014. 3002002949
14. NACE International SP0104-2014, The Use of Coupons for Cathodic Protection Monitoring Applications” (NACE International: Houston, TX).

15. NACE International RP0285-95 “Corrosion Control of Underground Storage Tank Systems by Cathodic Protection” NACE International: Houston, TX).
16. “Canadian Association of Petroleum Producers (CAPP) Publication Number 2009–0019 Impressed Current Cathodic Protection Rectifier Design-for-Safety Guideline,” dated October, 2009 (CAPP: Calgary, Alberta).

A
SELF-ASSESSMENT POSITION PAPER

Self-Assessment Field Questionnaire – GENERAL

#	Description	Yes	No	Unk	N/A	Comments
A1	Does the CP system or program (herein called Program for simplicity) identify any/all applicable codes of record?					
A2	Does the Program appropriately reference appropriate industry documents?					
A3	Does the Program appropriately reference license requirements?					
A4	Does the Program define key personnel?					

Self-Assessment Field Questionnaire – RECORDS and REPORTS

#	Description	Yes	No	Unk	N/A	Comments
B1	Does the Program identify the responsible personnel who will prepare applicable installation, repair, and/or replacement forms?					
B2	Do the Program requirements indicate that applicable records and reports be maintained for replacements?					
B3	Does the Program outline considerations for the preparation of a relief request for temporary repairs?					
B4	Does the program require identification of the applicable procedure used to install, repair, and/or replace the item?					
B5	Does the Program require an analysis of the intended life of the item when that life is less than the remainder of the design life of the item being cathodically protected?					
B6	Does the CP system have design or other site drawings with pending changes? Are they being updated in accordance with site procedures?					

Self-Assessment Field Questionnaire – DESIGN AND COVERAGE

#	Description	Yes	No	Unk	N/A	Comments
C1	Are all buried piping (BP) and structures which are to receive CP identified?					
C2	Are the safety significance of the different BP systems and structures known? If so, please identify the BP and structures and indicate the approximate percent of BP and tanks which are: • Safety-related • Fire protection • Contain licensed • Environmentally sensitive materials • High risk as identified by the plant risk ranking evaluation have CP.					
C3	According to your site specifications, is CP available and being adequately applied to critical piping located under structures (e.g., tanks, turbine buildings)?					
C4	Is there CP for other lines and underground storage tanks which are important to power production and safety?					
C5	Are there plant areas that require higher levels of CP that are above generally accepted levels (reasons may include: MIC, organic acids, or dissolved gases in soil)? Are these conditions documented in the design basis or subsequent evaluations with specific areas and/or limits of applicability defined?					
C6	Is there CP on building structures that are showing signs of degradation?					
C7	Is there CP on PCCP and/or bar wrapped pipe? Are the PCCP pipe sections bonded? Identify the type (class) of the prestressing if known.					
C8	Have the current demands for grounding associated with metal fencing and reinforced concrete foundations been considered in the CP design?					

#	Description	Yes	No	Unk	N/A	Comments
C9	Is adequate CP being applied at critical locations such as pipe-to-building and pipe-to-tunnel penetration areas?					
C10	Is CP current being delivered to tank interiors using the tank content as the electrolyte?					
C11	Is there CP for intake structures (e.g., traveling screens, sheet pilings, and trash racks)?					
C12	Is there CP for the main condenser? (internal CP)					
C13	Is there CP for the Closed Cooling Water Heat Exchanger (or similar systems)? (internal CP)					
C14	Is there CP for submerged components?					
C15	How are rectifier and CP test leads being attached to the pipe?					
C16	Do you have documented criteria for under/overprotection of your SSC?					
C17	How is criteria established (e.g., per component, per area, or general site conditions)? Are criteria documented in the design basis or approved evaluation?					

Self-Assessment Field Questionnaire – TEST STATIONS

#	Description	Yes	No	Unk	N/A	Comments
D1	Who selected locations for the test stations? Were they NACE certified; if so, to what level?					
D2	How many test stations are there and are locations of the test stations documented? Do you know where you are effectively measuring in relation to area?					
D3	Do design drawings show locations of test stations and permanent reference electrodes?					
D4	Based on percentage, how many test stations are functional?					

#	Description	Yes	No	Unk	N/A	Comments
D5	How many test stations meet NACE criteria for pipe-to-soil potential?					
D6	Are any test stations located in security exclusion or high radiation areas?					
D7	Do you know what area of influence is being measured with the test stations?					
D8	Are there indications of overprotection (i.e., instant-off potentials more negative than -1,200 mV (CSE)?					
D9	Do design drawings show locations of test stations and permanent reference electrodes?					
D10	Is data from the test stations being monitored? If so, at what frequency is the monitoring?					
D11	Are there test points and/or test coupons at the following? • Locations close to the grounding grid • Building and vault penetrations • Heavily congested areas • Pipes that are deeply buried • Pipe crossings • Locations under roads and paved areas • Water crossings • High consequence of failure locations • Pipes with low structural margins or known to have corrosion problems					
D11	Are test stations being installed at all digs? If so, • Are reference cells only or reference cells plus pipe test leads being used? • Do test leads require a modification? • Are corrosion coupons being installed?					

#	Description	Yes	No	Unk	N/A	Comments
D12	How many corrosion coupons are there? • Are the locations known? • How many are functional? • How often are corrosion readings being taken? • Are the corrosion readings being reviewed with the Buried Pipe Program Owner(s)?					

Self-Assessment Field Questionnaire – IMPRESSED CURRENT SYSTEM

#	Description	Yes	No	Unk	N/A	Comments
E1	How many rectifiers are present and are functional? How many are currently meeting voltage and current criteria?					
E2	Can all rectifiers be interrupted (explain if automatic, manual, and/or remotely)? If not, how is IR drop being compensated for in the measured pipe-to-soil potentials?					
E3	How many times were the rectifiers monitored in the last twelve (12) months?					
E4	Is there a procedure for rectifier reading and maintenance?					
E5	Is there remote monitoring of rectifiers?					
E6	Who reviews the rectifier readings? How often are the readings reviewed?					
E7	What is the estimated remaining life of the anodes? Have funds been budgeted to replace them when depleted?					
E8	Are rectifier readings being compared to set-points and resulting pipe-to-soil potentials? Are set points evaluated for adjustment based upon pipe-to-soil potentials? By whom?					
E9	Are impressed current systems targeting submerged intake structures? Where are they located and what technology do they use?					

Self-Assessment Field Questionnaire – PASSIVE SYSTEM

#	Description	Yes	No	Unk	N/A	Comments
F1	How many junction boxes for passive (galvanic) systems are present and fully operational?					
F2	Are insulating joints installed to isolate the structure or component which is receiving passive protection?					
F3	What type(s) of galvanic anodes are used? Are galvanic anodes used for primary or supplemental protection of buried and/or submerged components?					
F4	How often are junction boxes inspected for anode current output and structure-to-soil potential?					
F5	Is the passive system checked following digs in the area (line tracing, anode currents, etc.)? If so, how soon is the system check after the dig?					
F6	What is the estimated remaining life of the galvanic anodes? Have funds been budgeted to replace them when depleted?					

Self-Assessment Field Questionnaire – RESPONSIBILITIES, TRAINING, AND QUALIFICATIONS

#	Description	Yes	No	Unk	N/A	Comments
G1	Is the CP System or Program Owner and Backup CP Owner clearly identified? How many years of experience does the CP System Owner have in this role?					
G2	Is the CP System Owner and Backup System Owner qualified per CPUG Position Paper No. 2?					
G3	How many CP System Owners have there been in the last five (5) years? How many CP System Owners have there been in the last five (5) years?					

#	Description	Yes	No	Unk	N/A	Comments
G4	Is there a process in place to provide training and qualification of CP personnel (e.g., tester, technician, Owner, etc.)? If so, please summarize the process for each type of CP personnel. Is the previous CP System Owner available to provide knowledge transfer and mentoring?					
G5	Are persons taking rectifier readings and maintaining them qualified per CPUG Position Paper No. 2?					
G6	Is an appropriate amount of time available to the CP System/Program owner (and Backup Owner) to effectively manage the Program? How many systems and/or programs are these individuals responsible?					
G7	Are persons repairing and adjusting rectifiers qualified per CPUG Position Paper No. 2?					
G8	Is the person reviewing the rectifier readings qualified per CPUG Position Paper No. 2?					
G9	Are the qualifications of persons performing close interval surveys (CIS) qualified per CPUG Position Paper No. 2?					
G10	What are the qualifications of the individuals who have designed or modified the CP systems on site (e.g., NACE CP3 or CP4 qualification)?					

Self-Assessment Field Questionnaire – ADJUSTMENT AND MAINTENANCE

#	Description	Yes	No	Unk	N/A	Comments
H1	What is the average expected work-process lead time for voltage or current adjustments of rectifiers?					
H2	What is the average expected work-process lead time for repairs to CP system (broken wires, rectifiers, etc.)?					
H3	Have all outstanding maintenance and repair items been scheduled and/or budgeted?					

#	Description	Yes	No	Unk	N/A	Comments
H4	Have any of the outstanding maintenance and repair items been deferred? Why were they deferred?					
H5	How long is the system monitored after large-scale projects?					
H6	How do you determine if there are broken wires in the CP system?					
H7	Are the above maintenance tasks performed by qualified site, vendor, or project personnel?					

Self-Assessment Field Questionnaire – ANNUAL SURVEYS

#	Description	Yes	No	Unk	N/A	Comments
I1	When was the last annual survey performed (this may include CIS or similar)?					
I2	How are the structure-to-soil potentials being measured/evaluated at tank centers?					
I3	How are the pipe-to-soil potentials being measured under buildings, roadways, foundations, or other obstructions?					
I4	When necessary, are component internals being evaluated in submerged conditions?					
I5	Is the survey being performed at the same time each year and under similar weather and soil conditions? Is the survey performed by the same group and/or vendor?					
I6	Are the results of the survey being reviewed by station personnel? Are actions being taken to correctly identify deficiencies and implement enhancements? Is this part of the preventive maintenance program for the station?					
I7	Does the annual survey include spot adjustments and instant off potential readings?					

#	Description	Yes	No	Unk	N/A	Comments
I8	Does the annual survey include investigation and/or troubleshooting of adverse conditions?					
I9	Does the annual survey report include recommendations for further evaluation and/or repair?					

Self-Assessment Field Questionnaire – CLOSE INTERVAL SURVEYS

#	Description	Yes	No	Unk	N/A	Comments
J1	When was the last CIS performed? Is the data compared and aligned with previous CIS results? Was a "native" condition evaluation performed?					
J2	Did the CIS include all in-scope piping or was it limited to a discrete area?					
J2	Were areas identified where the pipe-to-soil potentials could not be accurately determined? Have such areas been identified for the addition of test stations? Have schedule and modification plans been established to add the test stations?					
J3	Were areas of significant coating damage identified?					
J4	Were there areas identified where the pipe-to-soil potentials are not meeting CP criteria?					
J5	Did any of the CIS findings contradict or refine previous annual survey results and/or recommendations?					

Self-Assessment Field Questionnaire – DOCUMENTATION

#	Description	Yes	No	Unk	N/A	Comments
K1	Is there a CP Design Basis document? Does it match up with other programs (e.g., BP)? Is it scheduled for regular review and potential revision?					
K2	Is there a CP Health Report? • Are the performance parameters consistent with CPUG Position Paper No. 1? (If not, please list the parameters.) • What is the frequency of reporting? • When was it last reviewed by management? • Is the report shared with the BP owner/engineer? • Are there qualification requirements for the preparers of the report? • Does the report identify any adverse conditions and does this agree with other results being reported?					
K3	Are there accurate plant drawings in the record system that contain: • Anode locations; • Ground grid; • Pipe leads; • Rectifiers; • Test stations; and/or • Junction boxes?					
K4	Are the CP design calculations included in the plant record system? Are all CP components and modifications included?					
K5	Are the records of annual survey and previous peer assessment included in the plant record system?					
K6	Are CP maintenance records included in the plant record system?					

#	Description	Yes	No	Unk	N/A	Comments
K7	Is there a CP System Notebook? If so, does it contain the following? • CP System drawings • CP design calculations • CP performance evaluations • BP inspection results • Annual survey records • Close interval survey records • CP maintenance records • Operating Experience (OE) reviews					

Self-Assessment Field Questionnaire – AREAS-FOR-IMPROVEMENTS AND FINDINGS

#	Description	Yes	No	Unk	N/A	Comments
L1	Are there any outstanding AFIs on the CP system? Were these self-identified or from external sources? If external, who identified the AFIs?					
L2	Are there any outstanding PDs on the CP system? Were these self-identified or from external sources? If external, who identified the PDs?					
L3	Are there any outstanding findings from the last CP Self-Assessment?					
L4	Are there any outstanding CP related findings from the NRC Phase 2 / NEI 09-14 Inspection?					
L5	When was the last self-assessment?					
L6	Does the CP Owner review relevant industry OE and/or participate in fleet status calls (e.g., BP, corrosion, CP, etc.)? Are reviews, dispositions, and/or actions tracked?					

Self-Assessment Field Questionnaire – INTERFACING

#	Description	Yes	No	Unk	N/A	Comments
M1	Is the CP System Owner part of the BP team? If not, is there regular communication between the CP and BP Owners?					
M2	How are needs for additional test stations, anodes, and/or other upgrades being communicated to the BP Program Owner and to the plant design group?					
M3	How are coating issues being communicated to/from the BP Program owner?					
M4	How are coating issues being communicated to/from the Coating Specialist for the site?					
M5	Are CP maintenance priorities effectively communicated and understood by the work-management department?					
M6	Are CP maintenance priorities effectively communicated and understood by the maintenance department?					
M7	Are CP maintenance priorities effectively communicated and understood by plant management?					
M8	Are CP maintenance and repair issues properly documented in work requests, plant reviews, funding forecasting, etc.?					

Self-Assessment Field Questionnaire – POST-ASSESSMENT INTERVIEW

#	Description	Yes	No	Unk	N/A	Comments
N1	Are there new areas which have been identified as needing attention? If yes, what areas have been identified and have they been properly reported within the self-assessment documents?					
N2	Do you observe areas which were previously identified as needing attention? If yes, what areas and corrective action were performed on these areas? If yes, were these areas previously closed-out?					

N3	Have previous self-assessments improved the overall CP-system performance? If yes, how?					
N4	Are there actions which should be taken by CP management and leadership which should be taken to improve system performance? If yes, what?					

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