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Summary of 2015 and 2016 State-of-the-Fleet Assessments of Cathodic Protection Systems

Summary of 2015 and 2016 State-of-the-Fleet Assessments of Cathodic Protection Systems

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ABSTRACT

To reduce and minimize corrosion of buried systems, structures, and components at nuclear power plants, original plant designs often incorporated cathodic protection systems. The performance effectiveness, maintenance practices, and management of these cathodic protection systems have been observed to vary throughout the industry and since the original commissioning of the systems. As buried pipe has garnered increased attention over the life of commercial nuclear power plants, so has the health of cathodic protection systems in maintaining those assets.

To gain an improved understanding of the condition and health of cathodic protection systems throughout the industry fleet, individual site assessments were conducted across eight commercial nuclear power plants in 2015 and 2016. The objectives of these assessments were to evaluate the design, operation, maintenance, and management practices at each. The observed strengths, deficiencies, and recommendations that are summarized in this report can be used to benchmark utility best practices regarding cathodic protection.

Keywords

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PRIMARY AUDIENCE: Engineers responsible for the design, operation, maintenance, and/or management of cathodic protection (CP) systems at commercial nuclear power plants.

SECONDARY AUDIENCE: Engineers and program owners responsible for management of buried piping and tanks.

KEY RESEARCH QUESTIONS

- What is the overall condition of CP systems within the nuclear utility fleet?
- What lessons learned and best practices might be observed and shared for the benefit of the industry, based on individual site assessments of CP systems?
- What gaps exist regarding training and/or guidance on the design, operation, maintenance, or management of CP systems?

RESEARCH OVERVIEW

Over the course of 2015 and 2016, eight nuclear power plants in North America volunteered to host site-specific assessments of their respective CP systems. Each participant received its own assessment report detailing various strengths, deficiencies, and recommendations for improvement. The results of all eight have been combined and summarized to identify utility best practices, capture lessons learned, and identify any gaps in industry guidance and training. Information gathered from the assessments have also been summarized in a manner to provide effective benchmarking resources for the industry as a whole.

KEY FINDINGS

- Engineers are typically receiving or planning to receive CP-specific training in accordance with industry best practices to assist in their daily duties.
- There exists significant variance in CP data sets that are trended, as well as the time periods and manner in which they are trended.
- One site incorporated steps for engineering review of data, subsequent rectifier adjustments, and final verification of adequate effectiveness into the annual CP effectiveness survey procedure. Such a practice was shown to lead to work management efficiencies and ultimately improved CP effectiveness by implementing necessary changes prior to closing out the annual survey work order. This also eliminated time delays otherwise associated with initiating new work orders.
- Plant procedures and programmatic documents did not always clearly and easily identify the represented system/component, safety classification, material type, and acceptance criteria for each identified test point in the annual survey list. Inclusion of such information in a common place (such as a survey procedure) can lead to improved understanding of the protection levels of various critical versus non-critical assets.

- Benefits of installing remote monitoring units for rectifiers were observed at one site to include the following:
  - Elimination of periodic (typically bimonthly) maintenance tasks and personnel resources associated with manually recording rectifier data
  - Implementation of automated data trending software to reduce engineering administrative tasks
  - Engineers receiving automated alerts for equipment malfunction. This leads to less time associated with identifying equipment failures and implementing repairs and to improving rectifier availability calculations based on known failure dates and times

WHY THIS MATTERS

The results of the eight individual cathodic protection site assessments, when combined and summarized, provide CP and buried pipe engineers with a benchmarking resource related to the design, operation, maintenance, and management aspects of CP systems. The best practices and lessons learned identified through this project can be captured for consideration by CP and buried pipe engineers as a potential means of improving their respective asset management programs and plans.

HOW TO APPLY RESULTS

CP and buried pipe engineers can use the information from site-specific assessments described in Section 4 and summarized in Section 5 to capture lessons learned regarding programmatic strengths, deficiencies, and recommendations for improvement. Appendix A provides a series of tables describing how the volunteer sites assessed in 2015 and 2016 align among one another on various topics. These tables can be used as a quick benchmarking reference for sites to determine where they individually align with industry peers.

LEARNING AND ENGAGEMENT OPPORTUNITIES

The EPRI Cathodic Protection Users Group (CPUG) holds annual meetings and periodic webcasts intended to provide a forum for discussion, development, and communication of information on the operation, maintenance, and testing of cathodic protection systems.

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INTRODUCTION

In order to reduce and minimize corrosion of buried systems, structures, and components at nuclear power plants, original plant designs often incorporated cathodic protection (CP) systems. However, the performance effectiveness, maintenance practices, and management of these CP systems have been observed to vary throughout the industry and since original commissioning of the systems. As buried pipe has garnered increased attention over the life of commercial nuclear power plants, as has the health of cathodic protection systems in maintaining those assets. Periodic assessments of a CP system can be 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 electrical generating power plants (including nuclear power plants), the buried piping is often commonly grounded to a copper grounding grid for personnel protection in the case of a faulted main generator. This results in significant current requirements on the cathodic protection system; thus impressed current systems are most commonly used to provide protection to buried steel piping, storage tanks, piles, and intake structures 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 [1]. NACE International Publication 41013 provides a state-of-the-art report for external corrosion, assessment, and control of corrosion for buried piping systems in NPPs [2].

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 ground beds. 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 ground bed.

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 electrical 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[3] 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.
3. At least 100 mV of cathodic polarization. Measurement of either the decay or development 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.

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 [3] 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 [4], 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 License Renewal Interim Staff Guidance LR-ISG-2015-01 [5], 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 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 [5]. 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) (0.025 mm per year) [5]. These alternative criteria are also referenced for consideration in the special conditions section of NACE SP0169-2013 [3]; where polarized instant-off potentials less negative than -850 mV (CSE) might be sufficient in uniformly high-resistivity, well-aerated, and well-drained soil.

- Per NACE SP0169-2013 [3], criteria that have been documented for stainless steel piping include:
  - At least 100 mV of cathodic polarization between the structure and a stable reference electrode contacting the electrolyte. Measurement of either the decay or development of polarization is acceptable to satisfy this criterion.
  - A polarized (instant-OFF) potential of at least -450 mV, or more negative, relative to a copper/copper sulfate reference electrode in neutral or alkaline conditions. In acid conditions, the protection potential should be determined by testing.

When dissimilar metals are encountered, NACE SP0169-2013 [3] 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 always known at NPPs because the potential of the structure (buried piping and tanks) was often 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" [6], which is also attached to this report. 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 NPP sites in 2015 and four NPP sites in 2016. Additional assessments are planned to occur in 2017. Information obtained from the plant-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 ASSESSMENTS

3.1 Selection Criteria

Host sites for the 2015 and 2016 assessments were selected based on the following criteria from amongst those sites and engineers who expressed interest in participating:

- Differences in utility owner/operator
- Size of CP system (e.g., number of rectifiers, anode beds, annual test point measurements)
- Type of CP system (e.g., galvanic versus impressed current, linear/distributed/shallow bed/deep bed anode systems)
- Variety of systems, structures, and materials receiving protection (e.g., piping, tanks, intake structures)
- System upgrade/refurbishment history

Based on these inputs and responses, eight NPP sites were selected which would allow outside assessment of their CP systems. The identity of each NPP participant has been kept anonymous, with the following identifiers used to distinguish them:

- Host sites for the 2015 assessments are designated as: NPP - α, NPP - β, NPP - γ and NPP – δ.
- Host sites for the 2016 assessments are designated as: NPP - ε, NPP - ζ, NPP - η and NPP - θ.

3.2 CP Self-Assessments

In order to facilitate consistent assessments for each participant, the EPRI Cathodic Protection Users Group (CPUG) Position Paper No. 03, “Guidance for the Development of a Cathodic Protection Self-Assessment Plan” [6] was used as a basis for the assessment plan. The field questionnaire utilized in the performance of the assessment is included as an attachment to 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
- Reviewing performance history of equipment and overall system effectiveness
- Reviewing site procedures, administrative controls, and guidance documents
- Reviewing of training, qualifications, and experience of individuals associated with CP (e.g., CP and buried pipe engineers, backups, and maintenance and technicians)

- Reviewing past and future plans for upgrades and refurbishments
- Interviews with cathodic protection and/or buried pipe engineers, and electrical maintenance personnel
- Identifying areas where additional plant guidance is needed for CP
- Assessment of utility strengths, deficiencies, and recommendations

This technical report classifies results of the assessments into Deficiencies, Recommendations and Strengths for each site.

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.

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.

Lastly, 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.

4
ASSESSMENT OBSERVATIONS

A summary of observations made during visits to the four NPP sites in 2015 can be found in the EPRI technical update 3002007627 “2015 State-of-the-Fleet Assessment of Cathodic Protection Systems” [7]. This technical report includes the results of the four site assessments performed in 2016 and a summary of findings for all eight sites.

4.1 NPP - ε

4.1.1 System Overview

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

- Assets receiving CP: Various safety-related and nonsafety-related piping systems, above grade storage tank bottoms, intake structures, weirs, cofferdams and retaining walls.
- CP system type: The primary CP system for the buried and immersed assets consists of impressed current CP using distributed, surface, linear and deep well anode beds. Galvanic (zinc) anodes are also used to protect the submerged surfaces of weir 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: There are no permanent test stations for monitoring CP system effectiveness by original design.
- 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 polarized (instant off) potential of at least 850 mV relative to a copper-copper sulfate electrode (CSE).

4.1.2 Assessment Summary

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

- The overall system at NPP - ε 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 (NACE CP Level 2 certified), understands the responsibilities associated with the system, and has stability and leadership in the system. In addition, the plant technicians performing annual surveys of the CP system are adequately qualified (NACE CP Level 1 certified).

  A description of various NACE Training Courses, including definitions of CP level certifications can be found through NACE International (http://nace.org/Training-and-Education/Courses-by-Program/).

- 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” [1]. The rectifier DC output is monitored at 1-2 month intervals and the data is trended by the system engineer. A qualified CP Vendor is used for design, installation, and to provide recommendations for annual adjustment of the rectifiers.
- By original design, there are no permanently installed test stations, coupons, or reference electrodes.
- At the time of the assessment, more than half of the original rectifiers have been replaced with new rectifiers equipped with integral GPS current interrupters.

4.1.3 Deficiencies

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

- It does not appear that test stations for CP system monitoring were incorporated during initial plant construction. As a result, all potential measurements (~600) are taken at grade level during the annual survey. Grade-level readings may not necessarily accurately represent the true pipe-to-soil potential at pipe depths. Furthermore, since the precise location of the potential measurements at grade can vary from year to year, they do not provide consistency for repeat measurements and accurate trending of data.
- NPP - ε contains an aluminum-based alloy buried pipe material. Although the percentage of aluminum in the alloy is small (6.0-8.0%), aluminum is considered an amphoteric material and can experience corrosion in high pH environments. Annual survey reports indicate many instant-off potentials in excess of -1200mV, which can result in the build-up of alkali (high pH) environments at the metal substrate.

  In the absence of any procedurally specified over-protection guidance for this piping, consideration should be given to utilizing the upper limit guideline of -1200 mV (CSE) “instant-off”, in accordance with ISO-15589-1, “Petroleum, Petrochemical and Natural Gas Industries – Cathodic Protection of Pipeline Systems – Part 1: On-Land Pipelines” [4], and NACE SP0169-2013 “Control of External Corrosion on Underground or Submerged Metallic Piping Systems” [3].

4.1.4 Recommendations

Based on the observations made during this assessment, the following Recommendations are outlined as a means of potentially improving system performance, corrosion protection, and programmatic management or oversight:

- In general, the annual survey reports do not define which buried piping systems are being evaluated at each test point. In order to ensure that an optimum level of CP is being maintained for each piping system and structure, site procedures and assessment reports could be modified to include the structure or system, material, minimum protection criteria, and overprotection guidelines for each test point.

- Installation of new coupon test stations and/or electrical resistance (ER) probes at critical locations inside the plant area, such as in congested areas and locations where pipes enter a foundation wall or vault, would provide additional data on cathodic protection effectiveness in areas that constitute high susceptibility to under-protection.
- NPP - ε has a considerable amount of pre-stressed concrete cylinder pipe (PCCP). According to NACE SP0100-2014, 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 [8].

  Many of the instant-off potentials taken during the recent annual survey of the PCCP exceed this upper limit guideline. Additional rectifier balancing is required to more evenly distribute the current to this buried piping.
- NPP - ε does not currently monitor individual anode current readings as part of the annual CP survey for each system. Measuring and trending individual anode current readings can be useful in evaluating system performance and can be used to determine which anodes are depleted so replacement and/or repairs can be scheduled [15].
- More precise locations (possibly using GPS coordinates for test points) should be incorporated into the annual survey procedure(s) for repeatability in positioning the reference electrodes each year.
- The procedures and annual survey reports do not indicate where the structure connection is made for the structure-to-soil potential measurement. This is especially important for potential surveys on long lengths of pipe, remote from the plant, where ground connection points are separated by a significant distance. In such cases, proper field technique is important to ensure accurate interpretation of the data. Additional information on proper surveying techniques can be found in industry literature and used to revise site procedures and documentation practices [9].
- Permanent reference electrodes were not installed beneath the aboveground storage tank (AST) bottoms. The annual surveys account for tank-to-soil potentials taken around the perimeter using a portable copper-copper sulfate reference electrode (CSE). However, potential readings around the perimeter of ASTs do not provide accurate measurement of the protection levels at the center of the tank bottom.

  In order to obtain more accurate information on the degree of protection at the center of the tank bottom, consideration should be given to implementing means of obtaining additional potential measurements across the tank bottom [19]. Guidance regarding cathodic protection, corrosion monitoring, and obtaining potential measurements of above ground storage tanks can be found in EPRI report 3002000596 “Cathodic Protection Application and Maintenance Guide, Volume 2: Plant Structures and Equipment” [1].

4.1.5 Strengths

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

- There is strong system ownership at NPP - ε. The current system engineer is experienced, qualified (NACE CP Level 2 certified), understands the responsibilities associated with the system, and has stability and leadership in the position. Furthermore, the system engineer has developed a multi-year action plan that is periodically reviewed and approved by site management to incrementally upgrade various parts of the CP system.
- The plant technicians performing annual surveys are NACE CP Level 1 certified. The system engineer has proposed and gained site management support of a multi-year action plan for electrical maintenance technicians to take and obtain NACE CP Level 1 certification each year. This plan results in an effective time-staggered approach to ensuring all technicians obtain appropriate CP training, while reducing contracted resources.
- NPP - ε is planning to purchase test stations that incorporate CP coupons, native coupons, permanent reference electrodes and ER probes. These test stations will be placed in inventory and can be used opportunistically for installation in future pipe excavations.
- Each of the new rectifiers at NPP - ε incorporates a built-in GPS current interrupter. Plans are in place to ensure that all new and replacement rectifiers will have GPS current interruption capabilities by the end of 2017. This helps ensure that all power supplies can be interrupted simultaneously, which will facilitate accurate measurement of the instant-off potential.
- The work process/procedures at NPP - ε allows for rectifier adjustments to be performed under the annual survey work order prior to close-out. As a result, adjustments are generally made to the system in a timely manner, which appears to contribute to limited and reduced equipment out-of-service time.
- The CP system engineer has demonstrated an active role and level of involvement in managing the system, engaging site management on issues, and obtaining management and other system stakeholder support and sponsorship in correcting identified deficiencies in a timely manner (as evident by rectifier trending history).

4.2 NPP – ζ

4.2.1 System Overview

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

- Assets receiving CP: Various safety-related and nonsafety-related piping systems.
- CP system type for buried assets: Distributed impressed current anode beds.
- When was the system installed: The majority of the system was installed during initial plant construction, however several upgrades of the anode system were completed in 2007 and 2010.

- Test stations: Although there are no test stations with permanently installed reference electrodes or coupons, there are approximately 290 test wells for monitoring the structure-to-soil potential using a portable copper-copper sulfate electrode CSE.
- Pipe backfill material: The buried piping is typically backfilled in a well-graded compacted 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:

- There is strong system ownership at NPP - ζ. The current system engineer has taken and passed the NACE CP Level 2 course. The engineer has approximately six years of experience in CP and understands the responsibilities associated with the system.
- Although there are no test stations with permanently installed reference electrodes or coupons at NPP - ζ, there are approximately 290 test wells for monitoring the structure-to-soil potential. Based on the results of the 2015 annual survey, approximately 83% of the potentials meet or exceed the -850 mV polarized instant-off criterion.
- In general, the CP system at NPP - ζ is consistent with the testing and maintenance practices outlined in EPRI report 3002000596 “Cathodic Protection Application and Maintenance Guide, Volume 1: Buried Piping”. The DC output (Volts and Amps) of the rectifiers is monitored monthly and the data is trended by the system engineer. The annual surveys are presently being performed by plant maintenance electricians using the existing test procedures. All field testing is under the direct supervision of the system engineer. After the test data is reviewed by the system engineer, the rectifier DC outputs are adjusted if necessary to improve protection levels.

4.2.3 Deficiencies

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

- There are no test stations with permanent reference electrodes and/or coupons at NPP - ζ. Instead, performance testing is based on using test wells in which a portable CSE is placed inside a plastic casing that extends 18” (45 cm) below grade. Although the test wells provide consistency for repeat measurements and accurate trending of data, the potential readings at the base of the test wells may be mixed potentials that are dominated by other structures, such as copper grounding, and may not be representative of the true pipe-to-soil potential at pipe depth.
- Based on review of the design drawings, there does not appear to be any dedicated test wells or permanently installed reference electrodes for three safety-related fuel oil storage tanks. Therefore, the protection levels on the buried fuel oil tanks are not well-known.

- There is an extensive amount of deeply buried carbon steel safety-related piping (underdrain system) that does not appear to have any designated cathodic protection system and/or designated test wells or permanent reference electrodes. Although there are distributed anodes in the general vicinity of the underdrain system, the levels of protection on this piping system is not known.
- NPP - ζ use electrical maintenance technicians to perform the annual survey of the CP system. The electrical maintenance technicians have standard site training and receive on-the-job training from the system engineer, but are not NACE certified. As stated in EPRI CPUG Position Paper No. 02, "Qualification Guidelines for Personnel Performing Activities Associated with Nuclear Power Plant Cathodic Protection Systems," it is recommended that personnel involved in taking annual survey readings have a minimum certification as a NACE CP1 Tester [13].
- During the annual survey, portable current interrupters are placed in the output of the rectifiers; however the interrupters are "non-synchronizeable". As a result, the accuracy of the instant-off potentials that are being measured during the annual surveys should be validated.

4.2.4 Recommendations

Based on the observations made during this assessment, the following Recommendations are outlined as a means of potentially improving system performance, corrosion protection, and programmatic management or oversight:

- Additional performance testing of the plant's diesel fuel oil tanks would assist in determining the level of CP being afforded to these structures. The testing can consist of drilling small ½" (1.25 cm) diameter holes over the tanks (at the middle and both ends of each tank) through the asphalt until soil is encountered. The holes could then be filled with water and on and instant-off potentials taken while interrupting the influencing rectifiers.

  Additional guidelines regarding the design, installation and testing of CP systems for buried storage tanks can be found in NACE SP0285-2011 "External Corrosion Control of Underground Storage Tanks Systems by Cathodic Protection" [10] and EPRI report 3002000596 "Cathodic Protection Application and Maintenance Guide, Volume 2: Plant Structures and Equipment" [1].
- Obtaining additional structure-to-soil potential measurements over the underdrain system piping, in remote areas of the plant, during future annual surveys might be considered in an effort to evaluate the level of CP afforded to this safety-related system. Identification and review of the procurement specification or design basis document for the CP system may provide additional information regarding the original intent to provide protection to the underdrain system.

- In order to validate proper synchronization of rectifier interrupters and the accuracy of the instant-off potential measurements, data loggers (with waveform capabilities) and stationary reference electrodes at test wells in the areas being tested can be installed during future annual surveys. The oscilloscopic DC waveform patterns of the structure-to-soil potential can be observed on a daily basis to ensure all interrupters are synchronized and that no voltage spikes exist in the off potential waveform, which otherwise could result in erroneous instant-off data.

  Guidelines for validating synchronization of interrupters can be found in NACE Standard TM0497-2012 “Measurement Techniques Related to Criteria for Cathodic Protection on Underground or Submerged Metallic Piping Systems” [11] and NACE SP0207-2007 “Performing Close-Interval Potential Surveys and DC Surface Potential Gradient Surveys on Buried or Submerged Metallic Pipelines” [12].

- Many of the areas with inadequate CP on the buried piping are a result of broken anode header cables. Consider using methods such as “conductive” pipe and cable locators, which consist of a transmitter and receiver wand, to locate breaks in the anode header cables and restore equipment to proper working order [1].

- Consider having the maintenance electricians who are responsible for performing the annual survey of the CP system become NACE CP Level 1 certified (Cathodic Protection Tester), as outlined in EPRI CPUG Position Paper No. 02, “Qualification Guidelines for Personnel Performing Activities Associated with Nuclear Power Plant Cathodic Protection Systems” [13].

4.2.5 Strengths

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

- There is strong program ownership at NPP - ζ. The current system engineer has taken and passed the NACE CP Level 2 course (Cathodic Protection Technician), has approximately six years of experience in CP, and understands the responsibilities associated with the program.

- NPP - ζ has recently (within last 10 years) initiated a project to replace all consumed and depleted anodes, with the exception of 10 that are inaccessible. Based on the anode current trending data, these newer anode wells should have an extended life expectancy.

- CP has been in place since initial construction of the plant and is providing beneficial corrosion control to buried piping at the plant. As a result, no external corrosion pitting or loss of section has been observed during past buried pipe inspections. Furthermore, no leaks have been reported as a result of external corrosion either.

4.3 NPP - η

4.3.1 System Overview

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

- Assets receiving CP: Various safety-related and nonsafety-related piping systems, underground storage tanks, and above ground storage tanks.
- CP system type: The system for the buried assets consists of impressed current systems using deep and surface anode ground beds.
- When was the system installed: The initial CP system was installed during original plant construction. A major retrofit consisting of rectifier and anode bed replacements was completed in 2015/2016.
- Test stations: There are 71 test stations with permanent reference electrodes that were installed during original plant construction, however ten (10) of the reference electrodes are considered unstable.
- Pipe backfill material: Native backfill and engineered fill.
- Acceptance criteria: The primary acceptance criteria being used is a negative polarized “instant-off” potential of at least 850 mV (CSE). A minimum of 100 mV of cathodic polarization will possibly be used on piping outside of the protected area not influenced by copper grounding.

4.3.2 Assessment Summary

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

- The system has undergone a significant recent upgrade, including the installation of numerous shallow and deep anode ground beds and 29 new replacement rectifiers. Each rectifier is equipped with an integral GPS current interrupter and remote monitoring capabilities.
- A close interval survey (CIS) performed in 2016 indicated that approximately 80% of plant piping and structures are adequately protected. A post-installation/ upgrade survey of the system indicated that approximately 98% of the potential measurements taken at existing test points exceed the -850 mV polarized instant-off criterion (discrediting those test points with permanent reference electrodes determined to be non-functional).
- There is strong system ownership at NPP - η. The primary system engineer is NACE CP Level 2 certified, and the back-up system engineer (previous primary system engineer) is NACE CP Level 1 Certified.

- Due to the recent upgrade of the CP system, procedural revisions are recommended to improve system assessment and monitoring capabilities.
- Various piping systems classified as either safety-related, within the scope of the industry Buried Piping Integrity Initiative (NEI 09-14), and/or within the scope of License Renewal currently have no designated test stations or permanent reference electrodes to facilitate collection of CP data. Surface potential readings using portable reference electrodes above these piping systems are also not incorporated into the annual survey, resulting in no CP data collected on these important systems.

4.3.3 Deficiencies

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

- A significant portion of a make-up pipeline (which is approximately 5-miles long) is receiving inadequate CP.
- Cathodic protection effectiveness is not known for certain safety-related buried carbon steel piping systems, as there are no permanently installed reference electrodes or grade-level readings directed to be taken during annual CP surveys.
- A buried gasoline storage tank and associated piping were originally designed to be protected by two sacrificial anodes. No structure-to-soil potential data is available for this system, despite its environmentally sensitive contents. Without proper electrical isolation of these components from the rest of the station structures, these anodes may be providing limited protection, if not already consumed.

4.3.4 Recommendations

Based on the observations made during this assessment, the following Recommendations are outlined as a means of potentially improving system performance, corrosion protection, and programmatic management or oversight:

- In general, the annual survey reports at NPP - η do not define which buried piping systems are being evaluated at the individual test points. To promote improved monitoring, trending, and evaluation of results, procedures and assessment reports could be modified to include the structure, system and material being assessed at each test point, as well as the protection criteria and upper limit overprotection guidelines. These changes would assist in maintaining the optimum level of CP being provided for each piping system and structure.

  Additional classification of the test points and the piping they represent may further assist in reporting CP effectiveness on the following discrete risk-based populations:

  – % of test points indicating adequate protection for safety-related piping

  – % of test points indicating adequate protection for piping within the scope of the industry's Buried Piping Integrity Initiative (NEI 09-14)

  – % of test points indicating adequate protection for piping within the scope of License Renewal

  – % of test points indicating adequate protection for other/non safety-related/power-production related piping

- Installation of new coupon test stations and/or electrical resistance (ER) probes at critical locations inside the plant area, such as in congested areas and locations where pipes enter a foundation wall or vault, could provide additional data on cathodic protection effectiveness in areas that constitute high susceptibility to under-protection. Test stations may consist of native (isolated) coupons, CP coupons, and permanent (stationary) copper-copper sulfate reference electrodes.

  Maintaining an inventory of test stations, coupons, and permanent reference electrodes can also facilitate installation of such devices during excavations that opportunistically uncover adjacent buried piping. This can be an effective method of expanding the extent of CP knowledge on various buried piping systems.

- Consider having the maintenance electricians who are responsible for performing the annual survey of the CP system become NACE CP Level 1 certified (Cathodic Protection Tester), as outlined in EPRI CPUG Position Paper No. 2, “Qualification Guidelines for Personnel Performing Activities Associated with Nuclear Power Plant Cathodic Protection Systems” [13].
- In accordance with EPRI report 3002000596 “Cathodic Protection Application and Maintenance Guide, Volume 1: Buried Piping,” periodic performance (3-years) of a CIS can provide valuable information regarding the state of CP, such as on long lengths of remote piping (e.g., water make-up pipelines) [1].
- In general, increased communication between the CP system engineer and buried pipe (BP) owner has been shown to be beneficial in regards to cross-discipline understanding of corrosion, cathodic protection, test stations, piping repairs, integrity digs, pipe modifications, excavations, and external coatings. It is recommended that these cross-discipline discussions and interactions continue between the CP system engineer and BP program owner to maintain the asset integrity strategy at NPP - η.
- To provide accuracy and consistency during annual surveys, consideration should be given to using a field data PC for collecting structure-to-soil potential measurements. These instruments can be used to collect CIS data, observe interruption waveforms, and can be set to precisely measure and record the true instant-off potential, thereby reducing technician error and judgment during annual surveys. Techniques for collecting structure-to-soil potential measurements can be found in NACE TM0497-2012 “Measurement Techniques Related to Criteria for Cathodic Protection on Underground or Submerged Metallic Piping Systems” [11].
- Currently, there are no dedicated anodes or test stations associated with three buried storage tanks. These tanks appear to have been installed subsequent to original construction, and therefore not included in the original design of the CP system. Due to the content of fluids contained within these tanks (e.g., fuel oil and environmentally sensitive), it is recommended that the degree of cathodic protection potentially being afforded to these tanks be assessed during future annual surveys.

4.3.5 Strengths

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

- There is strong program ownership at NPP - η. The current system engineer has taken and passed the NACE CP Level 2 course (Cathodic Protection Technician), has approximately 2.5 years of experience in CP, and understands the responsibilities associated with the program.
- The back-up system engineer is the former primary system engineer for CP, and is NACE CP Level 1 certified. This level of training is in accordance with EPRI CPUG Position Paper No. 2, "Qualification Guidelines for Personnel Performing Activities Associated with Nuclear Power Plant Cathodic Protection System" [13].
- During 2015-2016, NPP - η initiated a project to upgrade the existing CP system for buried piping and tanks. As a result, a high level of protection is now being afforded to these structures. Approximately 98% of the structure-to-soil potentials measured at permanent reference cells during the most recent (2016) survey now meet the NACE -850mV (CSE) polarized instant-off potential criterion. Approximately 80% of the plant piping was shown to meet that same criteria during a close interval survey (CIS) in 2016 as well, as measured by surface level readings.

  In accordance with the 'Green', 'White', 'Yellow', and 'Red' classification categories presented in CPUG Position Paper No. 1, "Cathodic Protection Performance Parameters" regarding cathodic protection effectiveness, these levels of protection are synonymous with a 'White' to 'Green' classification [14].
- The upgrade project also consisted of installing numerous new rectifiers, each equipped with a remote monitoring system complete with integral GPS current interrupter. Implementation of the remote monitoring system has significantly reduced the amount of time necessary for the system engineer to administratively track/trend CP data, versus manually entering data. It has also allowed for quicker identification of equipment issues and necessary repairs and adjustments, while also improving resolution of rectifier availability trending for system performance indicators and license renewal commitments.

4.4 NPP - θ

4.4.1 System Overview

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

- Assets receiving CP: Various safety-related and nonsafety-related piping systems, eight buried emergency diesel fuel oil tanks and associated transfer piping.
- CP system type: The CP system for the buried assets consists of impressed current systems using distributed anode ground beds.
- When was the system installed: The entire system was installed during initial construction of the plant and has not been upgraded.

- Test stations: All of test station sites use permanent zinc electrodes, with portable copper-copper sulfate electrodes (CSE) used to take supplementary surface readings.
- Pipe backfill material: Cementitious fill.
- Acceptance criteria: The acceptance criteria being used is a polarized "instant-off" potential of at least -850 mV (CSE) or +250 mV (Zinc).

4.4.2 Assessment Summary

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

- There is strong organizational support at NPP - θ. Although the system engineer has only owned the system for approximately six months, there are plans to send the system engineer and back-up to multi-day CP specific training by the end of the year. The corporate engineer responsible for cathodic protection has been actively involved in developing new procedures to provide additional guidance on monitoring and trending of the CP systems, as well as hosting peer calls with CP engineers throughout the utility's fleet.
- The CP system at NPP - θ has never been upgraded. There are 22 rectifiers at NPP – θ. One rectifier has been offline for approximately five years. Approximately 10% of the anodes are considered deficient and require replacement.
- There are approximately 47 test stations at NPP - θ. Each test station is equipped with one or two permanent Zinc reference electrodes that are used for monitoring the effectiveness of the CP systems. These electrodes were installed at pipe depth during initial plant construction. However, the accuracy of the zinc reference electrodes is not known, as the potential of zinc may drift over time and become unstable.
- The majority of buried piping at NPP - θ is coated with an asphaltic coating or coal tar enamel with felt wrap. All of the buried piping and diesel fuel oil tanks at NPP - θ are embedded in a cementitious backfill that was installed at the time of construction. The cementitious backfill will provide additional corrosion protection to the buried piping and tanks because of its high alkalinity.
- Consideration should be given to obtaining additional samples of the cementitious fill from future buried pipe excavations and testing it for resistivity, pH, and other chemical species such as chlorides, sulfates and sulfides. This data could potentially be used to support alternative criteria for CP based on high soil resistivity.

4.4.3 Deficiencies

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

- One rectifier has been out of service for approximately five years. The apparent cause is a 480 VAC power supply failure. This system provides protection to safety-related piping at the plant.
- Corrective actions from the 2015 annual survey were never rolled into work orders and the work executed. This included rectifier adjustments for over and under-protected areas, repair and return of a defective rectifier to service, and investigating the causes and repair of numerous non-functioning anodes (estimated ~10% of the total system).

- With regards to the emergency diesel fuel oil storage and transfer system:
  - Design drawings do not indicate any anodes specifically intended for the protection of the supply and return fuel oil piping.
  - Design drawings do not indicate any permanent reference electrodes for the supply and return fuel oil piping, nor are there any surface level readings taken during annual surveys to assess this piping.
  - Design drawings indicate there are only two permanently installed zinc reference electrodes amongst the eight buried storage tanks.

  As a result, it cannot be fully and adequately determined whether all safety-related emergency diesel fuel oil storage tanks and associated piping are receiving sufficient protection.

4.4.4 Recommendations

Based on the observations made during this assessment, the following Recommendations are outlined as a means of potentially improving system performance, corrosion protection, and programmatic management or oversight:

- Recommended corrective actions from the last annual survey report were observed to have been entered into the site's corrective action program but never been rolled into work orders and the work executed. It is recommended that these actions be combined with any findings from the forthcoming annual survey and further evaluated by the system engineer for implementation.
- Recommendations to perform rectifier adjustments due to over or under protected areas are typically entered into the corrective action program, where a new work order(s) would be generated to address the issue. This process was observed to result in delays in performing the adjustments, or in some cases, long deferrals or even no implementation. Modifying the existing preventive maintenance task and associated work order to include a step for the CP system engineer to review the results of the annual survey and direct subsequent rectifier adjustment may offer opportunities to make such adjustments prior to closing out the existing work order, thereby improving the time to implement such recommendations.

- To promote improved monitoring, trending, and evaluation of annual survey data, the following changes could be implemented:
  - Update the CP trending spreadsheet to identify the associated rectifier, reference electrode, and protected system, structure, or component (SSC) for each test point reading.
  - Identify the protected SSC for each test point as either safety-related, nonsafety-related, within the scope of license renewal, with the scope of the industry's Buried Piping Integrity Initiative (NEI 09-14), etc. to facilitate effectiveness reporting on the different pipe groupings. This is consistent with EPRI CPUG Position Paper No. 1, "Cathodic Protection Performance Parameters" [14].
  - Modify effectiveness reporting strategies to include trending of individual test points over time in order to identify any consistently under-protected areas that are at an increased risk of degradation. This can be used to prioritize areas for excavation, when necessary, for condition assessment as part of the buried pipe asset management strategy.
- In order to understand the extent of CP protection being provided to eight safety-related buried fuel oil storage tanks and associated transfer piping, the system engineer should consider obtaining additional potential measurements. While potential measurements at pipe and tank depth may be challenged due to the presence of flowable cementitious fill, additional surface level measurements could be obtained by drilling ½" (1.25 cm) diameter holes through the asphalt over the pipelines and tanks until native soil is reached, filling those holes with water, and taking pipe-to-soil potential readings.
- In order to verify the accuracy and stability of the permanent zinc reference electrodes, additional actions should be considered as part of future annual surveys. The comparison of values taken between a permanent zinc and portable copper-copper sulfate reference electrode can be trended and analyzed by the CP engineer as one means of determining the accuracy and stability of the zinc reference electrodes over time.
- Installation of test stations with permanent (stationary) copper-copper sulfate reference electrodes at critical locations inside the plant area, such as in congested areas and locations where pipes enter a foundation wall or vault, could provide additional data on CP effectiveness in areas that constitute high susceptibility to under-protection. Reference electrodes could be installed at pipe depth inside the flowable fill material or in the soil adjacent to the flowable fill.
- Despite the majority of plant piping being embedded in cementitious fill, maintaining a limited inventory of test stations and permanent reference electrodes would facilitate installation of such devices during excavations that opportunistically uncover buried piping. This can be an effective method of expanding the extent of CP knowledge on various buried piping systems and structures. Guidelines regarding the design, installation and use of test stations for buried piping in nuclear power plants can be found in EPRI report 3002000596 "Cathodic Protection Application and Maintenance Guide, Volume 1: Buried Piping" [1].

- The system engineer should consider discontinuing turning rectifiers off and taking depolarized potential measurements during the annual survey. The depolarized potential that is being measured is a mixed potential consisting of several different metals and does not represent the true open circuit potential of the carbon steel piping. Therefore, these potentials should not be used as a base reading for polarization development (e.g., using the 100mV polarization CP criterion).
- A number of anodes were noted to have little to no current output. It is recommended that the system engineer trend anode currents and rectifier outputs to assess anode deterioration and end of life [15]. This includes reviewing historical data over the last 10-15 years. This data can then be used to prioritize anode bed replacements.
- In general, increased communication between the CP system engineer and buried pipe (BP) owner has been shown to be beneficial in regards to cross-discipline understanding of corrosion, cathodic protection, test stations, piping repairs, integrity digs, pipe modifications, excavations, and external coatings. It is recommended that these cross-discipline discussions and interactions continue between the CP system engineer and BP program owner to maintain the asset integrity strategy at NPP - θ.

4.4.5 Strengths

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

- Although the system engineer has only owned the system for approximately six months, there is strong organizational support to obtain proper CP training, as evidenced by plans to send the system engineer and backup to a multi-day CP specific training by the end of the year.
- There exists strong organizational support in the form of a corporate CP engineer, including periodic fleet peer calls.
- All of the buried piping and tanks at NPP - θ are embedded in a cementitious backfill, providing additional corrosion protection to the coated steel structures due to its high alkalinity (high pH).
- The combined effects of the cementitious backfill, protective coatings applied to buried piping and tanks, and the application of CP has resulted in no observed leaks of critical assets due to external surface corrosion over the life of the plant thus far.
- There is strong procedural guidance in place for CP governance/oversight. Upon implementation, this will ensure proper CP parameters are monitored and trended and will facilitate good turnover to any new system engineers that may subsequently inherit the system.

5
SUMMARY

Appendix A of this report provides a tabular summary, by category, of the various observations found at the eight participating NPP sites. These include:

- Table A-1 “CP System/Program Engineer”
- Table A-2 “Monitoring and Maintenance”
- Table A-3 “System Design and Operating Details”
- Table A-4 “CP Criteria and System Performance Details”
- Table A-5 “System/Programmatic Details – Administrative”

The following provides a summary of observations from the 2015/2016 State-of-Fleet CP assessments that were carried out at the eight participating plants.

General Observations:

1. The CP systems at the eight 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” [1]. All eight plants have plans in place to improve the design, monitoring, and operation of their systems.
2. In general, there is strong system ownership at the eight 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” [13], or plans are in place to obtain standard industry training and qualifications.

Technical and Programmatic Considerations:

1. Personnel Performing Annual Surveys

   Five of the nuclear power plants assessed 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 experienced and certified CP engineers and technicians can assist in the identification of maintenance deficiencies and expert recommendations for improvement of the systems. This is particularly important if the system engineer or plant representative has not received adequate technical training in CP or is new to their position.

Three plants assessed were using in-house electrical maintenance technicians under the supervision of a qualified CP engineer to conduct annual surveys. One of those plants utilized a vendor for review of data and providing recommendations for system adjustments while attempting to rebalance the system following recent upgrades.

Based on EPRI CPUG Position Paper No. 02, "Qualification Guidelines for Personnel Performing Activities Associated with Nuclear Power Plant Cathodic Protection Systems" [13], personnel who are responsible for performing annual surveys of the CP system and performing significant rectifier repairs and adjustments should be at least NACE CP Level 1 certified (Cathodic Protection Tester).

2. Monitoring and Trending

   Based on the eight plants assessed throughout 2015 and 2016, it was observed that there exists significant variance in the parameters that are monitored and trended. This is further depicted in Table A-5, "System/Programmatic Details – Administrative," of Appendix A. Specifically, most plants monitored and trended similar parameters, however, either the total scope of parameters were not consistent, and/or the frequency over which the parameter was trended was variable. Frequency of monitoring and trending in the table should be read as: *(Frequency at which the parameter is monitored and/or reported)/(Time period over which the parameter is trended)*.

   Guidance on managing cathodic protection systems can be found in EPRI Report 3002002949, "Recommendations for Managing an Effective Cathodic Protection System," including potential parameters to be monitored and trended, and analysis of trends [15].

3. 100mV polarization criteria

   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. In general, when applying the 100 mV polarization criterion, the open-circuit potential of the material of interest (e.g., carbon steel piping) is used as a baseline for calculating the amount of polarization development. Unfortunately, the open-circuit potential of the buried piping at nuclear power plants is typically not known, as it was not measured prior to connection of the copper grounding grid. At some plants, depolarized potential surveys have been used as a baseline for calculating the amount of polarization development. However, these potentials represent mixed potentials that are typically more electro-positive (less negative) than carbon steel by itself.

   One solution to more accurately evaluate the use of the 100 mV polarization development criterion is through the use of "native" coupons. Native coupons that are constructed of the same material as the buried piping being evaluated can represent the true open-circuit potential of the piping. As a result, they may be used for establishing a baseline potential by material type which can be used for calculating the amount of polarization development. A sufficient number of coupon test stations with native coupons should be installed at nuclear power plants in order to establish a baseline of native potentials throughout the site.

4. Over-Protection

   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 [8], 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.

5. Alternative Acceptance Criteria

   Various industry standards and guidance exists related to the use of alternative acceptance criteria for evaluating cathodic protection effectiveness.

   For example, the U.S. Nuclear Regulatory Commission (NRC), in the License Renewal Interim Staff Guidance LR-ISG-2015-01 [5], has provided guidance on use of alterative acceptance criteria for CP of buried piping and tanks at nuclear power plants going through license renewal. For buried steel pipe, the acceptance criteria for CP is -850 mV relative to a copper-copper sulfate electrode (CSE), instant off. Alternatives to the -850 mV instant-off criterion for steel piping are also given. These include:

   – 100 mV minimum polarization
   – -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, and
   – -650 mV (CSE) instant-off structure-to-soil potential where the soil resistivity is greater than 100,000 ohm-cm.
   – Verify that less than 1 mil per year (mpy) (0.025 mm per year) loss of material. Loss of material rates in excess of 1 mpy (0.025 mm per year) may be acceptable if an engineering evaluation demonstrates that the corrosion rate would not result in a loss of intended function prior to the end of the period of extended operation.

   Recommendations are provided by the NRC to verify these alternative acceptance criteria through the use of electrical resistance (ER) probes to confirm that the corrosion rate is less than 1 mpy (0.025 mm per year).

   These alternative criteria are also referenced for consideration in the Special Conditions of NACE SP0169-2013 [3]; where it states that in uniformly high-resistivity, well-aerated and well-drained soil, polarized potentials less negative than -850 mV (CSE) may be sufficient.

   Obtaining soil samples (or cementitious fill samples) during opportunistic and planned excavations of buried piping and testing them for resistivity, pH and other chemical species such as chlorides, sulfates and sulfides can lead to a better understanding of soil/cementitious fill conditions and corrosivity, particularly when consolidated into a single document.

Furthermore, this data may also be used to help support the use of alternative criteria for CP (i.e., -650 mV or -750 mV instant off). If so done, the resistivity, pH and chemical species data can be stored in a common database for quick reference to facilitate a holistic approach to evaluating backfill material corrosivity.

Guidelines regarding the collection and testing of soil samples can be found in EPRI report 3002005294 “Soil Sampling and Testing Methods to Evaluate the Corrosivity of the Environment for Buried Piping and Tanks at Nuclear Power Plants” [16]. Test methods for measuring the resistivity of concrete are referenced in EPRI report 3002003090 “Technology Innovation: Corrosion Mitigation of Conventionally Reinforced Concrete Structures” [17].

6. Annual Survey Consistency

   – To provide accuracy and consistency during annual surveys, consideration should be given to using a portable field data PC for collecting structure-to-soil potential measurements. These instruments can be used to collect close interval survey (CIS) data, observe interruption waveforms, and can be set to precisely measure and record the true instant-off potential, thereby reducing operator error and judgment and providing consistency during annual surveys. Techniques for collecting structure-to-soil potential measurements can be found in NACE TM0497-2012 “Measurement Techniques Related to Criteria for Cathodic Protection on Underground or Submerged Metallic Piping Systems” [11].

   – 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. Use of global positioning system (GPS) coordinates is another alternative to improving consistency in the location of test points each year.

7. Reference Cell Accuracy

   Older copper-copper sulfate permanent reference electrodes (CSE) that were installed during initial plant construction may be subject to leaching and dry-out, which can adversely affect their accuracy. Similarly, the potential of permanently installed zinc reference electrodes may drift over time and become unstable.

   Therefore, consideration should be given to periodically testing and assessing the accuracy of older (e.g., greater than 20 years of age) permanent reference electrodes. This can be done by placing a portable reference electrode above the permanent one, and analyzing and trending the voltage drop between the two cells.

8. Test point coverage

   Cathodic protection effectiveness is assessed based on a sampling at discretely measured points of interest. The design and installation of new and supplemental test points and 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 improve CP assessment capabilities at locations that constitute high consequences of pipe failure or high susceptibility to under-protection. Test stations may consist of native (isolated) coupons, CP coupons, permanent (stationary) copper-copper sulfate reference electrodes and electrical resistance (ER) probes.

In addition, maintaining an inventory of test stations, coupons, and permanent reference electrodes can facilitate installation of such devices during excavations that opportunistically uncover adjacent buried piping. This can be a more effective and efficient method of expanding the extent of CP knowledge on various buried piping systems.

Guidelines regarding the design, installation, and use of test stations for buried piping in nuclear power plants can be found in EPRI report 3002000596 "Cathodic Protection Application and Maintenance Guide, Volume 1: Buried Piping" [1].

Recommendations:

1. Improvements to Annual Survey Reporting

   The annual survey reports for the NPPs assessed did not consistently define which buried piping systems were being evaluated at the individual test points. To promote improved monitoring, trending, and evaluation of results, procedures and assessment reports could be modified to include:

   – Identity of the system, structure, or component (SSC) being assessed at the test point

   – Material type of the SSC

   – Over-protection and under-protection criteria (or guidance, as applicable)

   – Additional classification of the test points and the piping they represent. This may further assist in reporting CP effectiveness on the following discrete risk-based populations, as an example:

     o % of test points indicating adequate protection for safety-related piping

     o % of test points indicating adequate protection for piping within the scope of the industry's Buried Piping Integrity Initiative (NEI 09-14)

     o % of test points indicating adequate protection for piping within the scope of License Renewal

     o % of test points indicating adequate protection for other/non safety-related/power-production related piping

   These changes can assist in maintaining the optimum level of CP being provided for each piping system and structure.

2. Timeliness of CP System Adjustments

   At several plants, recommendations to perform rectifier adjustments due to over or under protected areas are documented in the vendor supplied report and subsequently entered into the corrective action program. A new work order(s) is typically generated to address the issue, but follows a standard work-planning process timeline (e.g., 20-weeks). This process can result in delays in performing the necessary adjustments, or in some observed cases, long deferrals or even no implementation at all.

   Based on the observation at one of the sites assessed, modifying the existing preventive maintenance (PM) task and/or associated work order may offer opportunities to improve the time to implement such recommendations and adjustments. Specifically, PM or work order packages could include separate steps for the CP system engineer to review results of the annual survey, as well for rectifier adjustments to be made, in order to ensure the system is properly functioning and effective prior to closing out the annual survey work order. This would thereby reduce the amount of time the system is left in an otherwise ineffective state.

3. Rectifier Remote Monitoring Units

   The use of rectifier remote monitoring units (RMUs) and synchronized current interruption was observed to 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" 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. Communication can be provided by cellular or satellite networks. Based on observations at one plant that had already installed RMUs, RMUs can:

   – Reduce the amount of time required for the system engineer to manually track/trend CP data by using automated software associated with the RMUs.
   – Alert the engineer to equipment and performance issues, allowing repairs and adjustments to be implemented quicker.
   – Improve resolution of rectifier availability trending for system performance indicators and license renewal commitments. RMU's allow the engineer to identify when a system failure occurs and calculate exactly how long the rectifier was out of service for; as opposed to having to assume it was out of service since the last time it was inspected.

6
POTENTIAL FUTURE RESEARCH AND DEVELOPMENT

Based on the results of this study, the following areas represent potential opportunities for further research and investigation:

- The development and/or use of improved cathodic protection software may assist industry members in improving:
  - Consistency of monitored and trended CP related parameters.
  - Data management and configuration control capabilities (as opposed to use of spreadsheets) for monitored and trended parameters.
  - Ability to forecast remaining life, including proactive equipment replacement, for CP system components such as anodes and rectifiers.

  EPRI's BPWORKS™ is software that enables data management and risk-ranking of buried and underground piping, and includes features capable of assisting in monitoring/trending of CP data [18]. However, additional revisions would be required to address many of the CP parameters and trending practices observed at plants that participated in the 2015 and 2016 assessments (See Appendix A, Table A-5).

- Although EPRI Report 3002000596 "Cathodic Protection Application and Maintenance Guide, Volume 1: Buried Piping" [1] provides details regarding the use and application of different types of test stations for buried piping at NPPs, many of the plant personnel involved in CP at NPPs assessed in 2015 and 2016 indicated a desire for additional guidance related to the design, installation and testing considerations for permanently installed devices, such as CP coupons and electrical resistance probes, in order to facilitate greater installation and use of such devices.
- Program engineers at various sites that did not have remote monitoring capabilities of rectifiers indicated that cyber-security considerations have posed a barrier to implementation at their respective sites. Additional research targeting the development of guidelines for navigating cyber-security rules with respect to CP remote monitoring units may be of value to assist with ease of installation at nuclear power plants.
- Development of cathodic protection training materials, in addition to those described below, could be beneficial, specifically as it relates to new engineers inheriting the CP system or program.

  EPRI currently offers a multi-day training class, "CP101: Training for the Cathodic Protection System Owner," on an annual basis. Other organizations, such as NACE International, formerly National Association of Corrosion Engineers, also offer a variety of in-depth cathodic protection training classes.

As a general practice, many nuclear power plant engineers are required to undergo multi-day or multi-week classes on a variety of nuclear power plant systems as part of initial training and on-boarding requirements at their sites. However, cathodic protection is not typically included due to its smaller size and safety significance designation. Therefore, a gap exists between the time a new engineer inherits the CP system and when they might be able to attend formal multi-day training classes; sometimes in excess of 12-months.

Introductory level training material, such as in the form of a computer based training (CBT) module, could assist those engineers new to the position in understanding and performing their responsibilities for the system, until more formal training can be taken. The training could address aspects such as:

– What is premise of cathodic protection, and how does it work?

– Why is it important?

– What are the basic components and designs?

– What are the essential parameters that should be periodically monitored, and at what frequency?

– How to interpret annual survey reports, including key parameters and details to look at.

– What general regulatory considerations exist that the engineer should be made aware of, and where to look for site-specific requirements?

7
REFERENCES

1. EPRI Report 3002000596 “Cathodic Protection Application and Maintenance Guide, Volume 1: Buried Piping and Volume 2: Plant Structures and Equipment” dated July 31, 2013 (EPRI, Palo Alto, CA).
2. NACE Publication 41013 “State-of-the-Art Report: External Corrosion, Assessment, and Control of Buried Piping Systems in Nuclear Power Plants” (NACE International: Houston, TX).
3. NACE International SP0169-2013 “Control of External Corrosion on Underground or Submerged Metallic Piping Systems” (NACE International: Houston, TX).
4. International Organization for Standardization (ISO) in Standard 15589-1 “Petroleum, Petrochemical, and Natural Gas Industries – Cathodic Protection of Pipeline Systems – Part 1: On-Land Pipelines” (ISO: Geneva, Switzerland).
5. 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).
6. EPRI CPUG Position Paper No. 03, “Guidance for the Development of a Cathodic Protection Self-Assessment Plan”, dated March, 2015 (EPRI, Palo Alto, CA).
7. EPRI Technical Update 3002007627 “2015 State-of-the-Fleet Assessment of Cathodic Protection Systems”, dated June, 2016 (EPRI, Palo Alto, CA).
8. NACE International SP0100-2014 “Cathodic Protection to Control Corrosion of Concrete Pressure Pipelines and Mortar-Coated Steel Pipelines for Water or Waste Water Service” (NACE International: Houston, TX).
9. Holtsbaum, W. B., “Cathodic Protection Survey Procedures”, NACE International, 2009.
10. NACE International SP0285-2011 “External Corrosion Control of Underground Storage Tank Systems by Cathodic Protection” (NACE International: Houston, TX).
11. NACE International Standard TM0497-2012 “Measurement Techniques Related to Criteria for Cathodic Protection on Underground or Submerged Metallic Piping Systems” (NACE International: Houston, TX).
12. 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).
13. 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).

14. EPRI CPUG Position Paper No. 01, “Cathodic Protection Performance Parameters”, dated October, 2013 (EPRI, Palo Alto, CA).
15. EPRI Report 3002002949, “Recommendations for Managing an Effective Cathodic Protection System”, dated November, 2014 (EPRI, Palo Alto, CA).
16. EPRI Report 3002005294, “Soil Sampling and Testing Methods to Evaluate the Corrosivity of the Environment for Buried Piping and Tanks at Nuclear Power Plants”, dated November 6, 2015 (EPRI, Palo Alto, CA).
17. EPRI Report 3002003090, “Technology Innovation: Corrosion Mitigation of Conventionally Reinforced Concrete Structures”, dated December, 2014 (EPRI, Palo Alto, CA).
18. EPRI *BPWORKS (Data Management and Risk Ranking of Buried Piping Systems Version 2.2,* EPRI, Palo Alto, CA: November 2014. 3002003087
19. NACE International SP0193-2016 “Application of Cathodic Protection to Control External Corrosion of Carbon Steel On-Grade Storage Tank Bottoms” (NACE International: Houston, TX)

A
BENCHMARK OBSERVATIONS

The following tables presented within this Appendix are intended to be used as a benchmarking resource for cathodic protection system /program engineers. The tables provide a study of how the various volunteer plants compare to one another based on the identified metrics, but also provides an opportunity for an individual plant to compare itself to.

The data contained within the tables was obtained during the course of on-site assessments, and in some cases where data was absent, requested retroactively of the volunteer sites during creation of the tables. Unless otherwise noted (e.g., an asterisk), the data is representative of the assessed parameter at the time of the assessment; not at the time of publishing this report. Fields which have been marked “N/A” indicates data was either not available or provided, or, the parameter is not applicable to the assessed plant.

Table A-1
CP System/Program Engineer

	NPP - α	NPP - β	NPP - γ	NPP - δ	NPP - ε	NPP - ζ	NPP - η	NPP - θ
CP System ownership	System Engineer	Buried Pipe Engineer	System Engineer	System Engineer	System Engineer	System Engineer	System Engineer	System Engineer
Years of CP Experience	3 years	N/A	<1 year	1.5 years at current site	<18 months at current site; 4 years of prior CP experience	6 years of experience at current site	3 years at current site	< 1 year
CP Qualifications (e.g., EPRI CP101, NACE CP1, CP2, CP3, CP4, etc.)	EPRI CP 101	None at this time; plans are in place for the engineer to take NACE CP1 and CP2	EPRI CP 101	Current System Engineer has not taken any formal training at this time. * The former, and now back-up, Engineer has taken NACE CP2, but is not certified	NACE CP1 and CP2 certified	Engineer has passed NACE CP2 exam, but is not certified	NACE CP2 certified	Plans in place for Engineer and Back-up Engineer to attend multi-day CP training at end of 2016
NACE Member	Yes	No	Yes	Yes	Yes	Yes	Yes	No
Number of Systems/Programs owned	10 Systems	3 Programs*	6 Systems	7 Systems*	13 Systems	12-17 Systems	11 Systems	3-5 Systems
Estimated % of time normally dedicated to CP	10%*	33%*	10%	10%	10%	5%	5%	20%
Is there a Back-up CP Owner in place?	No	Yes	Yes	Yes	No	Yes	Yes	Yes
Number of CP Owners over the last 5 years?	2	1	3	3	2	1	2	3
Is corporate support available for CP?	No	Yes	No	No	No	No	No	Yes

Table A-2
Monitoring and Maintenance

	NPP - α	NPP - β	NPP - γ	NPP - δ	NPP - ε	NPP - ζ	NPP - η	NPP - θ
Who takes annual survey readings: Vendor or Site Personnel?	Vendor	Vendor	Vendor	Vendor	Station Performance Technicians	Electrical Maintenance Dept.	Electrical Maintenance Dept.	Vendor
Who checks rectifier operation and obtains readings?	Vendor	Vendor	Operations	System Engineer	Electrical Maintenance Department	Electrical Maintenance Department	System Engineer monitors the rectifier status using the remote monitoring system	Electrical Maintenance Department
Who maintains the system?	Vendor/Maintenance Department	Vendor/Maintenance Department	Vendor/Electrical Maintenance Department	Vendor/Electrical Maintenance Department	Electrical Maintenance Department	Electrical Maintenance Department	Electrical Maintenance Department	Electrical Maintenance Department
Who reviews annual survey data and prepares report?	Vendor (NACE CP3 and CP4) reviews data and prepares report; System Engineer reviews data and report	Vendor (NACE CP1 and CP2) reviews data and prepares report; Buried Pipe Engineer reviews data and report	Vendor (NACE CP4) reviews data and prepares report; System Engineer reviews data and report	Vendor (NACE CP3 and CP4) reviews data and prepares report; System Engineer reviews data and report	Vendor (NACE CP3 and CP4) reviews data and prepares report; System Engineer reviews data and report	System Engineer (NACE CP2) reviews data and provides recommendations for rectifier adjustments	System Engineer (NACE CP2) reviews data and provides recommendations for rectifier adjustments	Vendor reviews data and prepares report; System Engineer reviews data and report
Training/qualifications of CP Technician/ Maintenance Electrician?	Vendor technicians are NACE CP2 and CP3	Vendor technicians are NACE CP1 and CP2	Vendor technicians are NACE CP1	Vendor technicians are NACE CP1	Plant Performance Technicians are NACE CP1	Electrical Maintenance Technicians have standard site training; On-the-job training from CP System Engineer	Electrical Maintenance Technicians have standard site training; On-the-job training from CP System Engineer	Site Standard electrical maintenance training.
Frequency of rectifier readings	Monthly	Yearly	Weekly	Once every 2-3 months	2 Months	Monthly	Rectifiers are being monitored continuously using the remote monitoring system	Monthly
System performance testing (months)	12-months	12-months	12-months	12-months	12-months	12-months	12-months	12-months
Has a rectifier influence survey ever been performed?	No	N/A	Yes, 2012.	No	No	No	No	No
Close interval survey (CIS) performed?	Yes. one-time pseudo CIS was performed on select piping system only	Yes, CIS is performed on portions of select piping systems	Yes, a pseudo CIS was performed in 2012	No	Pseudo CIS performed on buried piping outside of the Protected Area	No	CIS performed on all buried piping as part of CP system upgrade	No
CIS frequency?	Not Applicable	2 Years	Not Applicable	Not Applicable	Annually as part of system performance testing	Not Applicable	Currently not recurring. Considering CIS at 3-5 year intervals on buried piping outside of the Protected Area	Not Applicable

Table A-3
System Design and Operating Details

	NPP - α	NPP - β	NPP - γ	NPP - δ	NPP - ε	NPP - ζ	NPP - η	NPP - θ
Type of CP System:	Impressed Current and galvanic anodes	Impressed Current and galvanic anodes	Impressed Current	Impressed Current	Impressed Current	Impressed Current	Impressed Current	Impressed Current
CP System installed as part of original plant design, or retrofit?	Included in Original Design	Included in Original Design	Retrofit	Included in Original Design	Included in Original Design	Included in Original Design	Included in Original Design	Included in Original Design
When was system last refurbished?	Rectifier and anode bed replacements are in-progress (2005-2016)	N/A	New rectifiers and anodes installed in 2010	New rectifiers and anode beds were installed in 2005-2007	Rectifier replacements/upgrades and new anode beds are currently being performed in phases	Anodes replaced in 2008 and 2010	Rectifiers and anodes replaced in 2015-2016	No Refurbishment
What structures have dedicated CP by design (e.g., buried pipe, buried tanks, condenser water boxes, intake structures, etc.)	- Buried Piping - Buried Tanks - Internal surfaces of Fire Protection aboveground storage tank - Aboveground Storage Tank bottoms - Cooling Tower Basins (galvanic) - Containment Base Mat	- Buried Piping	- Buried Piping - Internal surfaces of Fire Protection aboveground storage tank	- Buried Piping - Buried Tanks - Aboveground tank internal surface	- Buried Piping - Buried Tanks - Intake Structures - Traveling Screens - Trash Racks	- Buried Piping - Buried Tanks	- Buried Piping - Buried Tanks - Aboveground Storage Tank bottoms	- Buried Piping - Buried Tanks - Condenser Water Boxes
Number of rectifiers?	138 total	4 total	4 for buried piping 2 for water tank interiors	23 for buried piping 1 for water tank interior	28 for buried piping 20 for intake structures	9 total	29 total	22 for buried piping 24 for condensers
Number and type of anode beds?	366 deep anode beds	Galvanic: distributed magnesium anodes; Impressed Current: 4 distributed anode beds for buried piping under turbine building slabs	4 distributed anode beds for buried piping and tanks	23 semi-deep anode ground beds	Distributed, surface, linear, and deep anode ground beds	9 distributed anode beds for buried piping and tanks	25 Deep anode beds and 12 surface anode ground beds	>350 distributed anodes
Total DC Amps:	~2,200-2,300 Amps (2015)	Impressed current: ~24 Amps (2014) Galvanic: N/A	~230-240 Amps (2015)	~130-140 Amps (2014) ~160 Amps (2015)*	~280-290 Amps for buried piping (2015); ~190-200 Amps for intake structures (2015)	~150-160 Amps (2016)	~600 Amps (2016)	~77 Amps (2015)
Number of test stations?	258 test stations 578 test points (or test wells)	91 test stations, some with permanent reference electrodes and galvanic anode test lead wires	9 test stations 70 test points (or test wells)	15 test stations 34 test points (or test wells)	No permanent test stations ~587 potential measurements taken at grade	No permanent test stations ~290 test points (or test wells)	71 test stations ~170 test points Surface readings additionally taken at some test stations	47 test stations ~82 test points Surface readings additionally taken at some test stations

Table A-3 (continued)
System Design and Operating Details

	NPP - α	NPP - β	NPP - γ	NPP - δ	NPP - ε	NPP - ζ	NPP - η	NPP - θ
Are permanent reference electrodes installed at pipe depth?	No	Yes, but not at all test points	Yes, but not at all test points	Yes, but not at all test points	No	No	Yes	Yes
Are ER probes and/or corrosion coupons installed?	No	No	No	No	No	No	No	No
Remote monitoring installed on rectifiers?	In-progress*	No	No	No	No	No	Yes	No
Integral GPS Current Interrupters installed on rectifiers?	In-progress*	No	No	No	Yes	No	Yes	No
Have soil samples been taken to assess corrosivity?	Yes	Yes	Yes	No	Yes	No	Yes	Yes
Is the buried piping above, below, or at groundwater elevation?	Above	Above and below	Above and below	Above	Above and below	Above	Above and below	Above

Table A-4
CP Criteria and System Performance

	NPP – α	NPP – β	NPP – γ	NPP – δ	NPP – ε	NPP – ζ	NPP – η	NPP – θ
Rectifier Availability	85% (2014) 80% (2016)*	(Not Reported)	92% (2015)*	86% (2015)*	95% (2015)	(Not Reported)	97% (2016)	90% (2016)
Are “instant-off” potentials being measured?	No, however a modification is in place to install remote monitoring with integral GPS current interrupters at all rectifiers	Yes, galvanic anode wires are disconnected at test stations and instant-off potentials are measured	Yes, portable GPS current interrupters are installed during annual surveys	Yes, portable GPS current interrupters are installed during annual surveys	Yes, each rectifier is equipped with an integral GPS current interrupter	Yes, portable current interrupters are installed in each rectifier during annual surveys	Yes, each rectifier is equipped with a remote monitoring unit and integral GPS current interrupter	Yes, rectifiers have temporary pulse generators installed to interrupt current at rectifiers in the near proximity to each test station.
CP acceptance criteria used	-850mV “ON” potential	-850mV “instant-off” potential 100mV of polarization	-850mV “instant-off” potential 100mV of polarization	-850mV “instant-off” potential	-850mV: CS, SS, Cast Iron, Aluminum-Alloy, PCCP 100mV: None	-850mV “instant-off” potential 100mV of polarization	-850mV “instant-off” criterion for the majority of piping; and will possibly use the 100mV polarization criterion for piping outside the PA in remote areas	-850mV “instant-off” for CSE, and 0.25V for Zinc
Over protection guideline used	-1200 mV “ON” potential for PCCP -1500 mV “ON” potential for other materials	None	-1200 mV “instant-off”	None	None proceduralized; over-protection evaluated case-by-case	None proceduralized, over-protection evaluated case-by-case	-1200 mV “instant-off”	-1200mV “instant-off”
% of Test Points/Test Stations Meeting CP Acceptance Criteria	**2014:** -850mV ON potential: 60% of total **2016 (update)*:** -850mV ON potential: 55% of total	**2014:** -850mV I-OFF Potential: <10% of total	**2014:** -850mV I-OFF: 49% of total -850mV I-OFF OR 100mV shift: 80% of total **2016 (update)*:** -850mV I-OFF: 56% of total -850mV I-OFF OR 100mV shift: 92% of total	**2014:** -850mV I-OFF: 42% of total **2015 (update)*:** -850mV I-OFF: 33% of total	**2015:** -850mV I-OFF: ~80% of total	**2015:** Safety-related Test Points: 100mV shift: 100% -850mV I-OFF: 85% Nonsafety-related Test Points: 100mV shift: 87.5% -850mV I-OFF: 82%	**2016:** -850mV I-OFF: 98% of total	**2015:** -850mV I-OFF: 80% of total
CP Effectiveness, per CPUG Position Paper #1	Red	Red	Red	Red	White/Yellow	White (Safety-Related)/Green (Nonsafety-Related)	Green	White/Yellow

Table A-5
System/Programmatic Details - Administrative

	NPP - α	NPP - β	NPP - γ	NPP - δ	NPP - ε	NPP - ζ	NPP - η	NPP - θ
System Health Report for CP	Yes	CP is managed as part of the buried pipe program, see below	Yes	No	No	Yes	Yes	No
Do the performance indicators align with EPRI CPUG Position Paper #1?	Yes, partially	No	No	No	No	No	Yes	No
Which, if any, CP parameters are trended over time?	- Rectifier voltage and current outputs (monthly/annually)	N/A	- Rectifier voltage and current outputs (weekly/multi-year basis)	- Rectifier voltage and current outputs (monthly/multi-year basis)	- Rectifier voltage and current outputs (bi-monthly/annually)	- Rectifier voltage and current outputs (monthly/annually)	- Rectifier voltage and current outputs (continuously/multi-year basis)	- Rectifier voltage and current outputs (monthly/multi-year basis)
(reporting frequency/trending period)	- Rectifier availability (monthly/multi-year basis)	N/A	- Rectifier availability (quarterly/rolling 12-month monitoring period)	- Rectifier availability (monthly/annual basis)	- Rectifier availability (monthly/annually and annually/multi-year basis)	N/A	- Rectifier availability (continuously/multi-year rolling average)	- Rectifier availability (monthly/annually and annually/multi-year basis)
	- Individual pipe-to-soil potentials (annually/ multi-year basis)	N/A	- Individual pipe-to-soil potentials (annually/ multi-year basis)	N/A	- Individual pipe-to-soil potentials (annually/ multi-year basis)	- Individual pipe-to-soil potentials (annually/ multi-year basis)	- Individual pipe-to-soil potentials (annually/ multi-year basis)	- Recent procedure changes will direct individual pipe-to-soil potentials (annually/ multi-year basis)
	- Individual anode current output (annually/multi-year basis)	N/A	- Pipe-to-soil potentials as a subset of test points (quarterly/ multi-year basis)	N/A	N/A	- Rectifier individual circuit voltage and current (monthly/ annually)	- Individual anode current output (annually/multi-year basis)	N/A
	- Total system current output (monthly/ annually)	N/A	- Rectifier efficiency, as a function of AC Input to DC output (annually/ multi-year basis)	N/A	- Total system current output (monthly/ annually)	N/A	N/A	N/A
Is there a CP System Notebook?	Yes	Yes	Yes	No	Yes	Yes	Yes	Yes
Is there a CP System Design Basis Document?	Yes	Yes	No	No	Yes	No	Yes	Yes

Table A-5 (continued)
System/Programmatic Details - Administrative

	NPP - α	NPP - β	NPP - γ	NPP - δ	NPP - ε	NPP - ζ	NPP - η	NPP - θ
CP factored into Buried Pipe Health Report/Performance Indicator?	Yes, includes: - Overall CP system health report status/color	Yes, included as part of indirect inspection indicator	Yes, includes: - Rectifier availability - System effectiveness - CP material condition - Timeliness of maintenance - PM schedule adherence	No	Yes, includes: - System effectiveness	No	Yes, includes: - Overall CP system health report status/color	Yes, includes: - Rectifier availability - System effectiveness
Is the CP System Safety-related, have Tech Spec Implications, or within the scope of Maintenance Rule?	Yes –Tech Specification implications for emergency diesel fuel oil system only. CP system not scoped into Maintenance Rule.	N/A	No	No	No	Yes – Maintenance Rule	No	No

***Note:** Annotated data represents that which was collected and/or reported subsequent to the performance of the original assessment (i.e., during development of this report [2016])

Export Control Restrictions

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