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2017 State-of-the-Fleet Assessment of Cathodic Protection Systems

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2017 State-of-the-Fleet Assessment of Cathodic Protection Systems

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NOTE

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ABSTRACT

In order to minimize corrosion of buried systems, structures, and components at nuclear power plants (NPPs), original plant designs often incorporated cathodic protection (CP) systems. 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 NPPs, so has the health of CP systems in maintaining those assets.

In order to gain an improved understanding of the condition and health of CP systems throughout the industry fleet, individual site assessments were conducted across eleven commercial NPPs in 2015, 2016, and 2017. The objective of these assessments was to evaluate the design, operation, maintenance, and management practices at each. This specific report provides an overview of the assessments that were performed at three NPPs in 2017. The observed strengths, deficiencies, and recommendations are summarized within this report and can be used to benchmark utility best practices regarding CP. A summary of the 2015 and 2016 assessments can be found in Electric Power Research Institute reports 3002007627 and 3002010678, respectively.

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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 (NPPs).

SECONDARY AUDIENCE: Engineers/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

During 2017, three NPPs 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 the three assessments have since 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 has also been summarized in a manner that will provide effective benchmarking resources for the industry as a whole.

KEY FINDINGS

- CP engineers are typically receiving CP-specific training, in accordance with industry best practices, to assist in their daily duties.
- Significant variance exists in CP data sets that are trended, as well as the time periods and manner in which they are trended.
- One site incorporated steps into the annual CP effectiveness preventive maintenance task to have engineering review data results, direct subsequent rectifier adjustments, and perform final verification of adequate effectiveness. 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 sometimes associated with initiating new work orders.
- Significant variance exists in the extent of proceduralized guidance, parameters, and methods related to evaluating CP performance in the field. In one case, the plant lacked procedures related to performance of the annual effectiveness survey. The PM task and work order instructions specified that electrical maintenance would support the vendor, but no procedure that documented the equipment to be inspected or parameters to be monitored was provided; instead, the task relied heavily on vendor expertise. Development and use of more robust procedural guidance, even when work is performed by a contractor, can lead to consistency in the work performed and the parameters monitored from year to year; particularly if contractor changes occur.

EXECUTIVE SUMMARY

WHY THIS MATTERS

The results of the three individual CP site assessments in 2017, along with the eight previous assessments in 2015 (Electric Power Research Institute [EPRI] report 3002007627) and 2016 (EPRI report 3002010678), 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 detailing how the volunteer sites assessed in 2017 align on various topics. These tables can be used as a quick benchmarking reference for sites 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 CP systems. Gaps in knowledge and training identified through this user group are used to inform EPRI research imperatives and relative priorities.

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1 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, so 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 to be protected 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 (as opposed to sacrificial anode 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, intake structures, 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 via 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.

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) 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 Global Positioning System (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.

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 selfconsume 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 system 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, or
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.

Relevant international standards on cathodic protection include:

1. EN 12954, "Cathodic Protection of Buried or Immersed Structures"
2. EN 14505, "Cathodic Protection of Complex Structures"
3. ISO 15589-1, "Petroleum, petrochemical and natural gas industries – Cathodic protection of pipeline systems – Part 1: On-land pipelines"

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 assessments 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 three NPP sites 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 2017 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, three 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 2017 assessments are designated as: NPP-17-1, NPP-17-2 and NPP-17-3.

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 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]. A summary of observations made during visits to the eight NPP sites in 2015 and 2016 can be found in the EPRI technical report 3002010678, *2015 and 2016 State-of-the-Fleet Assessments of Cathodic Protection Systems* [8]. This report includes the results of the three site assessments performed in 2017.

4.1 NPP-17-1

4.1.1 System Overview

The following is a general overview of the CP system at NPP-17-1:

- Yard assets receiving CP: Various safety-related and nonsafety-related piping systems, and above grade storage tank bottoms.
- CP system type: The primary CP system for the buried assets consists of impressed current CP using deep anode and distributed (shallow) anode beds. There were seven (7) rectifiers, with ~340 amps of total current output, at the time of the assessment.
- When was the system installed: The majority of the CP system was installed during initial plant construction. A multi-year cathodic protection system upgrade project was under way at the time of the assessment. The upgrade will consist of approximately 51 additional distributed anode wells and four (4) additional rectifiers.
- Test stations: There are approximately 230 test points for monitoring the structure-to-soil potential. Included in the above are eleven (11) instrumented test stations with permanent reference electrodes, coupons, and ER probes that have been installed next to the buried piping in high risk areas throughout the plant.
- Pipe backfill material: A large portion of the safety-related buried piping is embedded in a low-strength cementitious backfill that provides additional corrosion protection because of its high alkalinity (high pH). Plant specifications also identify a controlled engineered backfill, adhering to state department of transportation standards for a certain gradation, for other buried piping.
- Acceptance criteria: The primary acceptance criterion currently being used is a negative polarized (instant-off) potential of at least 850 mV relative to a CSE.
- Non-yard assets receiving CP: A review of design documents and interviews with the CP system engineer indicated intake structures, main condenser(s), and cooling water exchangers are not cathodically protected.

4.1.2 Assessment Summary

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

- NPP-17-1 was in the process of implementing a sizeable CP system upgrade. The existing and original system was reliant upon multiple deep anode beds. Historically, this design did not provide adequate protection throughout the site. The recommended new design incorporates the use of shallow distributed anodes. This would appear to be a successful strategy to improve CP levels and provide a higher level of corrosion control to the buried piping throughout the plant. Prior to finalizing plans for future system upgrade phases, NPP-17-1 may want to consider the following activities:
  - Review all past buried pipe inspection reports for evidence of coating damage, external corrosion, and/or loss of material of the substrate to ensure they are addressed by the future planned activities.
  - Re-review CP surveys for areas of historically low potentials, but for where no new anodes are proposed.
  - In between upgrade installation phases, perform spot checks or even a close interval survey (CIS) over pipelines intended to be addressed by installation of new anodes, following their placement into service. If the desired objective is not achieved for whatever reason, adjustments to the design could potentially be incorporated into future phases prior to completion of the overall upgrade project.
- NPP-17-1 did not use specific procedures for conducting routine surveillance of rectifiers or performing annual surveys of their CP systems; rather relying on simple sets of work package instructions. Implementation of more detailed procedures would:
  - Better align with industry peers and EPRI's Technical Report 3002000596, *Cathodic Protection Application and Maintenance Guide, Volume 1: Buried Piping* [1],
  - Ensure consistency in the parameters monitored and inspected during the annual surveys, particularly as vendors of choice change from year to year,
  - Better document the scope of activities to be performed (e.g., components to be inspected and adverse conditions to be aware of), and
  - Hold vendors accountable to a standardized and set scope of work
- NPP-17-1 has installed several instrumented test stations and more are in the planning stage. Each instrumented test station consists of a permanently installed reference electrode, a CP and disconnected (native) coupon, and a polarized and disconnected ER probe. The data from these test stations can be used to provide valuable information regarding corrosion rate, coupon potential and pipe-to-soil potential, and can be used to help support the use of alternate criteria for CP.

4.1.3 Deficiencies

Deficiencies observed in the CP system health or status at NPP-17-1 include the following:

- There was no procedure for conducting the annual survey. NPP-17-1 relies upon outside vendor support in performing annual surveys to assess CP system effectiveness. The annual Preventive Maintenance task work order for the CP system annual survey provides only a minimal amount of work instruction for site electrical maintenance technicians to support the contractor during the survey. Absence of clearly defined procedures can result in:
  - Inconsistency and lack of specificity in the parameters (e.g., On/Instant-Off/Native potentials, and data specific to rectifiers, anodes, and anode beds) which are to be assessed and evaluated each year,
  - Inconsistency in the precise location for individual test point potential measurements taken at grade-level,
  - Inconsistency and lack of specificity in the components which are to be inspected for material condition, including documentation thereof,
  - Failure to ensure proper calibration of rectifier panel meters,
  - Variability in all of the above if/when NPP-17-1 undergoes changes in vendor-of-choice for annual surveys

  EPRI Report 3002000596, *Cathodic Protection Application and Maintenance Guide, Volume 1: Buried Piping* provides guidance and recommendations on inspecting, testing, and maintaining CP systems that can assist in developing more detailed procedural guidance and/or work instructions [1].

- The potential measurements at test points were measured with reference to a portable CSE that is placed at grade in a general area near the test station. A site wide schematic drawing exists identifying generic locations for test points, however, this schematic is not precise in identifying exact locations. Since the precise location for the potential measurements at test points are not recorded or identified in any procedure, this can lead to inconsistency for repeat measurements and accurate trending of data. Accuracy of the test point directly above the pipe of interest, as well as precision from year to year, is important as the potential at grade may be a mixed potential that is dominated by other structures, such as copper grounding, and may not be representative of the true pipe-to-soil potential at pipe depth.

  Recording the GPS coordinates (latitude and longitude) of each test point over the piping and using them to position the CSE at the same location would be beneficial to improve consistency in monitoring and trending from year to year. Sets of marked-up photographs specifying the precise location for measurements might also be included in a revised work package to improve precision year-to-year, while also assisting the CP technician in more quickly locating the area of interest.

- The employed methods of assessing potentials of above-ground storage tank bottoms are likely not accurate and indicative of the true potentials of the tank bottoms. Readings are generally taken at 4-directional locations around the perimeter of the tank, including in proximity to valve vaults for some locations. These readings may be highly influenced by the reinforced concrete ring foundation upon which the tanks reside on, as well as the reinforced concrete valve vaults.

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:

- External corrosion was observed on safety-related and nonsafety-related piping during a previous buried pipe integrity dig near a cooling tower. Surface potential readings in this area based on previous annual survey data indicated instant-off potentials below minimum acceptable levels for CP (i.e., between -380 mV to -700 mV). This area is heavily congested with multiple pipelines, cooling tower foundations, valve pits, security structures and fences, duct banks, and is adjacent to safety-related switchgear with the potential for electrical grounding components in the vicinity. A review of planned future anode placements as part of the CP system upgrade did not identify any plans for new anodes in this area. NPP-17-1 may wish to consider further investigating the extent of buried structures, including electrical grounding, additional historical protection levels, as well as current demands in this area to determine whether supplementary protection (i.e., additional anodes) would be beneficial as part of the upgrade process.
- As part of the commissioning process for the CP system upgrade, performance of a CIS, particularly along piping that is safety-related, within the scope of license renewal, or piping which contains hazardous material, would be beneficial to understanding new baseline cathodic protection conditions and any remaining areas of under-protection. As discussed in EPRI report 3002000596, *Cathodic Protection Application and Maintenance Guide, Volume 1: Buried Piping*, this process can be repeated on a frequency such as 3-years to improve trending and comparison of protection levels along the lengths of critical piping systems. NACE SP0207-2007 “Performing Close-Interval Potential Surveys and DC Surface Potential Gradient Surveys on Buried or Submerged Metallic Pipelines” provides procedures for performing close interval surveys on buried piping systems [9].
- It was observed that the model work order package for the annual survey included a step for the system engineer to review the results of the annual survey as part of closure of the annual work. Any vendor recommendations included in the annual survey report, however, are typically entered in the corrective action program and managed through a standard 20-week planning process.

  Revision of the annual survey work order to include an additional step to make rectifier adjustments based on recommendations within the report, prior to closure of the annual survey work order, can assist in expediting system adjustments and ensuring areas of the plant are not under or overprotected for extended periods of time. It was also observed that the results of the annual survey, including the vendor supplied report, have not previously been included in the annual survey work order records. Inclusion of the survey results, including vendor report, in the annual work package can be an effective means of ensuring the results are recorded, maintained, and easily retrievable for future needs; such as for historical trending or evaluating system design changes.

- Eleven (11) instrumented test stations have been installed throughout the plant, eleven (11) permanent reference electrodes have been installed during previous buried pipe inspections, and approximately five (5) additional concrete instrumented test stations have been proposed by a vendor as part of the CP system upgrade. It does not appear, however, that many of these instrumented test stations, or other permanently installed reference electrodes, have been installed adjacent to buried piping at building entrances.

  Piping in these areas may exhibit higher corrosion rates due to the prevalence of reinforcing steel and copper grounding near building foundations. These areas are often among the most difficult to cathodically protect. Furthermore, some of the recently installed test stations are in relatively remote areas of the plant next to non-safety related piping systems, such as fire protection. While these test stations provide valuable data on areas throughout the entire plant, future installations targeting areas adjacent to building structures and areas with heavy congestion of buried assets would provide an improved understanding of the protection levels in areas that constitute the highest risk of under-protection.

- The U.S. Nuclear Regulatory Commission (NRC) in the License Renewal Interim Staff Guidance LR-ISG-2015-01 has given acceptance criteria for CP of buried piping and tanks at nuclear power plants going through license renewal [5]. These alternative criteria are summarized in Section 1.1.4 of this report.

  Samples of the cementitious fill used at NPP-17-1 could alternatively be taken from future buried pipe excavations and tested for resistivity, pH, and other chemical species such as chloride ions, sulfates, and sulfides. This data could potentially then be used to support alternative criteria for CP (i.e., -650 or -750mV). Core samples from the cementitious fill could also be procured and tested for compressive strength to give an indication of the density and permeability of the material.

  Test methods for measuring the resistivity of concrete are referenced in EPRI report 3002003090, *Corrosion Mitigation of Conventionally Reinforced Concrete Structures* [10]. If so done, it is recommended that the resistivity and other chemical data be stored in a common database for quick reference to facilitate a holistic approach to evaluating backfill material corrosivity.

4.1.5 Strengths

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

- NPP-17-1 was in the process of implementing a sizeable CP system upgrade at the time of the assessment. The existing design consists of seven deep anode beds, which historically have not provided adequate CP throughout the site. As a result, a new approach is being pursued, consisting of supplemental distributed anodes in areas of high congestion and historically low protection.

  As part of the initial design work, the station directed considerable investigative work to be performed regarding subsurface geology. Furthermore, as part of the design, test wells were installed to provide valuable information, such as current requirement test data, soil conditions, depth to bedrock, and anode-to-earth resistance. This information and data will improve the chances of meeting with success and properly providing protection as part of the final implementation of the system.

- NPP-17-1 has installed several instrumented test stations, with more in the planning stages. These instrumented test stations consist of a permanently installed reference electrode, a polarized and disconnected coupon, and a polarized and disconnected electrical resistance probe. The data from these test stations can be used to provide valuable information regarding corrosion rate, coupon potential and pipe-to-soil potential, and can be used to help support the use of alternate criteria for CP.
- NPP-17-1 receives a high level of corporate support. The corporate/fleet engineer has implemented several beneficial practices, including:
  - Initiating periodic fleet calls to discuss industry and fleet operating experience.
  - Providing assistance with outside audits/inspections/evaluations associated with CP.
  - Developing reference materials, such as procedural guidance for managing the CP system and spreadsheet templates for consistent monitoring, trending, and reporting of CP parameters.

  Furthermore, the corporate organization has also previously allocated annual funds to each plant within the fleet to assist in performing minor maintenance, repairs, upgrades, and testing of the site-specific systems, at the discretion of the system-engineer. This represents a strong organizational level of understanding of the importance of CP and dedication towards successful performance of the system in controlling corrosion of the buried assets.

4.2 NPP-17-2

4.2.1 System Overview

The following is a general overview of the CP system at NPP-17-2:

- Yard assets receiving CP: Various safety-related piping systems, nonsafety-related piping systems, aboveground storage tanks (e.g., condensate storage), and buried diesel fuel oil storage tanks.
- CP system type for buried assets: Impressed current with distributed and deep anode beds. There are nine rectifiers for buried piping and tanks, with a capacity of ~ 266 amps.
- When was the system installed: The majority of the system was installed during initial plant construction.
- Test stations: There are approximately 128 test points for monitoring the structure-to-soil potential. Most of these test points require the use of a portable CSE that is placed at grade or inside a shallow test well. Seven (7) test points have permanently installed reference electrodes.

- Pipe backfill material: Engineered fill was used as the primary backfill around the buried piping and tanks.
- Acceptance criteria: Although the plant procedure still references 100 mV of polarization, the primary acceptance criterion being used is a negative polarized “instant-off” potential of at least 850 mV (CSE).
- Non-yard assets receiving CP: A review of design documents and interview with the CP system engineer indicated intake structures, main condenser(s), and cooling water exchangers are not cathodically protected.

4.2.2 Assessment Summary

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

- Based on a review of recent and historical CP system performance, as well design drawings for piping layout and distribution of anodes, the current operation and/or original design of the NPP-17-2 CP system may not be optimized to adequately protect all intended structures. Additional measures that may be taken to better assess this include:
  - System Balancing: This includes rectifier adjustments to maximize current output, as well as the possibility of disconnecting certain anodes to avoid over-protection in certain areas.
  - CP system conceptual design: A NACE certified CP Level 3 or 4 engineer could be engaged to reassess the CP system performance, piping layout, and anode layout to determine if a more optimal solution could be developed.
  - CP system design/installation: If a system re-design is determined to be necessary to obtain the levels of protection NPP-17-2 desires, this 3^{rd} phase would consist of installation of anodes, wires, junction boxes, rectifiers, and additional test stations. Start-up testing, re-assessment, and system commissioning would then follow.
- A number of procedural deficiencies were identified during the course of the assessment. These include:
  - The CP procedure directs either one or two influencing rectifiers be interrupted in order to obtain pipe-to-soil potentials at select test points on a quarterly basis. Based on a recent rectifier influence survey, additional rectifiers may be influencing such readings. Failure to interrupt all influencing current sources will result in IR error and inaccurate measurement of instant-off potentials.
  - Cathodic protection effectiveness criteria utilized in the procedure (i.e., 100mv polarization and -850mV current applied potential) have conditional statements associated with their use, as outlined in NACE SP0169-2013 [3]. Although procedural changes are forthcoming, these conditions have not been addressed as of the time of the assessment. Criteria such as the -850mV instant-off polarized potential is often a more conservative criterion for buried piping and structures in grounded mixed metal facilities, such as nuclear power plants.

4.2.3 Deficiencies

Deficiencies observed in the CP system health or status at NPP-17-2 include the following:

- The CP procedure for NPP-17-2 was reviewed during the on-site assessment and a number of issues were identified that could challenge adequately attaining data and evaluating CP system effectiveness.
  - Specified use of the 100 mV polarization criteria, without direction to consider the native potential of the most anodic metal in the mixed-metal coupling of structures.
  - Individual anode currents are specified only to be obtained for troubleshooting purposes, not necessarily for monitoring and trending system health over time.
  - While current can be calculated from data recorded (i.e., rectifier voltage and shunt resistance), as-found current measurements are not obtained nor compared to allowable values.
  - Portions of the annual survey measurements rely on evaluating CP effectiveness based on current-applied (ON) potentials, without consideration of the IR drop error that may be present.
- The buried diesel generator fuel oil tanks do not appear to have permanent reference electrodes buried near the mid-level and base of the tanks, and as such, the tank-to-soil potentials are only measured at or near grade. Adding permanent reference electrodes or test wells, that extend down to the mid-level and base of the tanks, would provide the benefit of determining the level of CP at these depths and be more representative of the tank itself (versus area potentials of adjacent structures potentially influencing the surface reading).
- The measurement of anode current was not part of the annual survey procedure at NPP-17-2. Measurement of anode currents during the annual survey can help ensure that the maximum rated anode current output is not exceeded. Trending of the individual anode current data can also be helpful as an indicator of consumption, failure, and/or remaining anode service life.
- EPRI CPUG Position Paper No. 2, "Qualification Guidelines for Personnel Performing Activities Associated with Nuclear Power Plant Cathodic Protection Systems," recommends that individuals involved in taking and obtaining potential readings and other CP data during the annual survey be certified as NACE CP1 (Cathodic Protection Tester) [11]. Individuals associated with reviewing and evaluating the annual survey data are recommended to be certified as a NACE CP2 (Cathodic Protection Technician). While NPP-17-2 occasionally utilizes 3rd party outside contractors to perform annual surveys, who are qualified and certified as stated above, the annual survey is often performed using plant CP procedures and internal personnel resources, without the above certification recommendations.
- While some common CP parameters were routinely monitored in accordance with plant procedures, none of these parameters were necessarily trended over time. Common types of trended data include:
  - Rectifier DC output (Volts and Amps)
  - Rectifier availability
  - Individual anode current outputs

- Ground bed circuit resistance
- Total system current output
- On and instant-off structure-to-soil potential measurements

Data trending can be accomplished through a variety of means, including spreadsheets and/or automated computer software (e.g., BPWORKS^{TM}) [12]. When the data is presented in a graphical format, observations can be made regarding CP system performance, anode consumption, and changes resulting from seasonal variations or other environmental conditions. Predictive analyses can also identify pending problems and is a useful tool for planning cathodic protection system upgrades and/or replacements.

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:

- Several procedural changes were recommended, including:
  - Eliminating use of the 100 mV polarization shift criterion, unless proper considerations are taken into account, as discussed in industry standards,
  - Measurement of individual anode currents during annual surveys, and
  - Eliminating use of the current-applied (ON) potential reading criterion, unless proper considerations are taken into account, as discussed in industry standards.
- Installation of permanent reference electrodes or test wells may help determine the level of CP more accurately (i.e., at-depth readings) on the buried diesel fuel oil tanks. Test wells should extend down to the mid-level and base of the tanks for optimum readings.
- NPP-17-2 uses a combination of in-house personnel and 3rd party contracted NACE CP1 (Cathodic Protection Tester) and CP2 (Cathodic Protection Technician) individuals to perform the annual survey from year-to-year. While established procedures are intended to direct the necessary activities to be performed during each annual survey, ensuring individuals performing the test are certified as NACE CP1 and CP2 (whether in-house personnel or contracted) can help ensure that all proper monitoring, testing, and inspection activities are performed in case of missing procedural guidance. The following annual survey activities are identified in the EPRI Cathodic Protection Application and Maintenance Guide, Volume 1 [1]:
  - Visual inspection of the system components,
  - Recording rectifier DC output values (voltage and current),
  - Recording rectifier tap settings,
  - Measuring individual anode currents in the anode lead junction boxes (using a shunt or clamp-on DC ammeter),
  - Interrupting all influencing rectifiers using GPS synchronized current interrupters,

  - Measuring on and instant-off potentials at test points and other locations as deemed necessary by the corrosion engineer,
  - Adjusting rectifier DC outputs as necessary,
  - Preparing a final report to include a description of the test procedures, rectifier DC output data, interruption cycles, interrupter sites, anode current measurements, anode-to-earth resistance data, structure-to-soil potential measurements at test points and other locations, with recommendations for future monitoring, upgrades, and/or improvements to the system performance.

- Based on the results of the 2016 annual survey, approximately 44% of assessed test points met or exceed the -850mV polarized instant-off potential criteria. Such performance can typically indicate either poor system performance, inadequate system design, or both. The first step in addressing such a problem consists of system balancing, followed potentially by system re-design and upgrade, and installation. Additional details regarding the design and installation of CP systems can be found in EPRI report 3002000596, *Cathodic Protection Application and Maintenance Guide* [1].

- Eight (8) of the nine rectifiers are from original plant construction and have been operating for over 30 years. Although these older rectifiers have been well maintained, operating experience has shown that rectifiers of such vintage can begin exhibiting increased numbers of failures; challenging overall system reliability. Given the age of these original rectifiers, it becomes increasingly important to trend rectifier performance (voltage and current output), rectifier availability (how often, as a percent of time, each and all rectifiers are supplying power within their normal operating band), as well as the number and frequency of equipment malfunctions. If and when NPP-17-2 elects to replace the original rectifiers, consideration might be given to the following functional and safety features:
  - Integral GPS current interrupters
  - Tap switch adjustment (allows adjustment of rectifier DC output using link bars)
  - Dead front fuse holders (allows safe removal and insertion of fuses)
  - Polycarbonate barriers to cover exposed DC components on the front panel of the rectifier
  - Remote monitoring (permit automated attainment of rectifier parameters, without having to send technicians into the field on a monthly basis).

- An improved understanding of site soil corrosivity, along with historical CP system performance, and results from direct evaluations, can promote a more holistic understanding of the overall corrosion threats to buried assets at NPP-17-2. As a result, NPP-17-2 may wish to consider collecting samples of backfill material during future pipe excavations and characterizing the individual soil parameters. Soil corrosivity testing may consist of moisture content, pH, resistivity, redox potential, chloride ion content, and sulfate ion content. The test results should be stored in a database to allow for future access and easy retrieval. Additional information regarding soil testing 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* [13].

- The site has a considerable amount of pre-stressed concrete cylinder pipe (PCCP) for the circulating water system. Per 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, measured against a CSE, to avoid hydrogen embrittlement [14]. 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. Although the type of pre-stressing wire for the circulating water PCCP could not be obtained during the site assessment, it is suggested that applicable pipe specifications be identified, strength of the pre-stressing wires determined, and actions taken as necessary to reduce over-protection.

4.2.5 Strengths

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

- Most of the test points are clearly identified and labeled in the field. This helps facilitate accurate repeat measurement of the structure-to-soil potential and trending of data.
- Test procedures clearly identify the system, structure, or component (SSC) intended to be assessed by each test point measurement. This allows for an improved understanding of the levels of protection relative to critical (safety-related, containing hazardous or licensed material) piping systems.

4.3 NPP-17-3

4.3.1 System Overview

The following is a general overview of the CP system at NPP-17-3:

- Yard assets receiving CP: Various safety-related and nonsafety-related piping systems, and above ground storage tanks.
- CP system type: The system for the buried assets consisted of impressed current systems using both distributed and linear anode ground beds. There were 19 active rectifiers, with a total system capacity of ~645 amps. A limited amount of piping was also electrically isolated and protected using a galvanic (magnesium) anode system.
- When was the system installed: The initial CP system was installed during original plant construction. A major retrofit consisting of linear anode beds (horizontal anode strings) was completed between approximately 2007-2012 inside the protected area (PA).
- Test stations: There were approximately 290 test points for monitoring the structure-to-soil potential. In addition, NPP-17-3 recently installed four (4) coupon test stations since 2015.

- Pipe backfill material: The primary backfill around the buried pipes was a granular crushed limestone.
- Acceptance criteria: The primary acceptance criteria used was a negative polarized "instant-off" potential of at least 850 mV (CSE). Alternative criteria, such as a minimum 100 mV of cathodic polarization where piping is not influenced by copper grounding, was also referenced in the plant manual.
- Non-yard assets receiving CP: A review of design documents and interview with the CP program engineer indicated intake structures, main condenser(s), and cooling water exchangers are not cathodically protected.

4.3.2 Assessment Summary

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

- There was strong system ownership at NPP-17-3. The current program owner was NACE CP Level 2 certified (Cathodic Protection Technician), had approximately three years of experience in CP, and embraced the responsibilities associated with the system. The program engineer was responsible for one other program at the plant and spent approximately 40% of his/her time on CP. This allows the engineer to dedicate more time to CP than industry peers, managing similar sized CP systems.
- Based on the 2016 effectiveness tracking report, approximately 79% of the total test points associated with piping that is within the scope of License Renewal (LR) met the -850mV instant-off polarization criterion as established in NACE SP0169-2013, Approximately 78% of the total test points associated with piping not within the scope of LR met the same criterion [3]. The level of protection realized at NPP-17-3 is attributed to the use of distributed anodes and linear anodes, which typically provide more uniform current distribution because of the closely coupled anodes and a higher level of protection compared to other systems. Areas of inadequate protection appear to be in congested areas where higher concentrations of copper grounding and reinforcing steel exist, beneath reinforced concrete floor slabs, at building foundation penetrations, and where anodes are depleted or inoperative.
- In general, the CP system at NPP-17-3 was consistent with the testing and maintenance practices outlined in EPRI report 3002000596, *Cathodic Protection Application and Maintenance Guide, Volume 1: Buried Piping* [1]. The DC output (Volts and Amps) of the rectifiers were monitored monthly and the data was trended by the program engineer. A qualified CP vendor was used to design and install supplemental CP, perform annual surveys of the system, review survey data, and provide status reports with recommendations for improving system performance.
- Discussions with the program engineer indicated that the vendor performing annuals surveys is permitted to make spot adjustments to rectifiers. This is an effective process for adjusting outputs and improving CP levels for under-protected and over-protected piping.

4.3.3 Deficiencies

Deficiencies observed in the CP system health or status at NPP-17-3 include the following:

- There did not appear to have been adequate turn-over of documentation and CP data from the previous program engineer to the current program engineer. Examples include:
  - During the assessment, there was limited documentation regarding the types of anodes that have been installed, their dimensions, and maximum current ratings (amps/anode for distributed anodes or amps/linear foot for linear anodes). NPP-17-3 may wish to reconsider making further adjustments to rectifier output until anode system design information can be identified so as to ensure maximum current ratings for individual anodes are not exceeded.
  - Historical data related to rectifier voltage and current readings, as well as past pipe-to-soil potentials, was observed to not have been turned over from the previous corporate engineer responsible for cathodic protection to the current site program engineer. Rather, the historical data was fortunately retained by a vendor and eventually forwarded to the site engineer.
- It does not appear that annual survey potentials for an above ground fuel oil storage tank are trended over time or included in the engineer's tracking spreadsheet.
  - The aboveground tanks program owner indicated that this tank may be a candidate for replacement in 2018 as part of a long-term asset management plan. In the event that this replacement does not occur, it may be helpful to trend the CP potentials of the tank to, a) understand the condition of the tank bottom, and b) potentially permit alternative inspection requirements (e.g., one-time inspection) of the tank bottom, in accordance with site-specific license renewal commitments.
  - In the event that the tank is replaced, and if the system design includes cathodic protection, it is recommended that EPRI Report 3002000596, *Cathodic Protection Application and Maintenance Guide* be reviewed to consider the anode system design and desired CP monitoring features to be included [1].

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:

- NPP-17-3 had a considerable amount of PCCP for the circulating water system. According to the Buried Pipe Engineer, some of the PCCP may be susceptible to hydrogen embrittlement and failure of the pre-stressing wires due to over-protection of cathodic protection [15]. According to NACE SP0100-2014, "Cathodic Protection to Control External Corrosion of Concrete Pressure Pipelines and Mortar-Coated Steel Pipelines for Water and Waste Water Service", 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 [14]. 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.

These PCCP lines were supposedly not bonded, such that this issue may not be as applicable. However, there are no test stations for these pipes which can permit monitoring and validation. Due to the lack of bonding, there also exists the possibility for stray current corrosion of isolated components, which may be caused by the adjacent impressed current anodes. Although NPP-17-3 is aware of these issues, care should be taken not to over drive anode beds in the immediate vicinity of the circulating water lines.

- The program engineer had developed a CP effectiveness tracking spreadsheet in order to trend the potentials of all test points over time. This spreadsheet is effective in identifying the structure associated with each test point, as well as whether or not that structure is within the scope of license renewal.
  - In addition to identifying test stations as being within or not within the scope of license renewal, it can also be useful to identify those test points which are associated with safety-related piping, piping that falls within the scope of the NEI 09-14 industry initiative on buried piping, or is piping that is critical to generation.

    As such, effectiveness can be reported out on these additional discrete populations, while also improving the level of understanding of the corrosion behavior on piping with the greatest risk to safety, environment, and generation.
    - The mechanism and nomenclature for identifying test point locations was not intuitive nor precise. NPP-17-3 has historically relied on ‘tribal knowledge’ of the corporate CP engineer, a commonly used vendor, and now the current site CP program owner for where these individual test points are precisely located, as well as translating the meaning of the location description.

      Reliance on ‘tribal knowledge’ of test point locations and description nomenclature presents certain inherent risks to the execution of the annual survey in circumstances such as CP program engineer turnover/unavailability and/or changes in vendor personnel. The following improvements to location identification are offered:
      - Record and document GPS coordinates of each test point. This would provide the most precise, and potentially quickest, method of re-identifying test points and obtaining readings; potentially reducing the time it takes to perform the survey.
      - Mark-up a series of yard drawings, potentially as a CAD overlay of the drawing, to identify the test point number and location within the yard.
      - Include within the tracking spreadsheet and spreadsheet used by the vendor for performing the annual survey, a plant drawing reference, along with grid location, for where the test point can be found relative to the plant layout.
      - Expand the description of the location, with less abbreviations, to enable someone less familiar with the nomenclature to more easily discern the exact location.

- A review of site documentation identified a system functional description, including the type, size, and quantity of anodes used in the original design of the CP system. However, no documentation could be identified for the maximum current rating for these anodes. Likewise, no documentation could be identified at the time of the assessment related to the type, size, weight, and maximum ratings for anodes installed after original construction. This information can be helpful in evaluating and forecasting remaining life of the anodes, particularly in comparison to historical trending data. It also helps ensure that rectifier adjustments do not result in exceeding maximum specified anode current ratings.

4.3.5 Strengths

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

- There was strong program ownership. The current program engineer was experienced, qualified, embraced the responsibilities associated with the program, and had stability and leadership in the program.
- NPP-17-3 has developed detailed and thorough programmatic documents (e.g., CP Program Manual and CP program basis document) for the CP program. Specifically, a Cathodic Protection Program Manual has been developed which includes the following key elements:
  - List of all rectifiers
  - List of all preventive maintenance tasks associated with CP
  - Description of cathodic protection key concepts and types of systems (e.g., impressed vs galvanic)
  - Identification of parameters to be monitored and trended
  - Description of types of surveys (annual survey, close-interval survey, area potential earth current, etc.)
  - Description of License Renewal implementation guidance
  - Description of corrosion rate monitoring devices
  - Overview of work control process
  - Overview of industry interfaces (e.g., EPRI, NACE, vendors, etc.)
  - Definitions of common CP terms

  This level of programmatic guidance provides a superior resource to educate new program owners in the event of turnover, as well as for purposes of communicating with management.

A cathodic protection conduct manual for the CP program has also been developed and includes the following key elements.

– Extensive list of personnel responsibilities

– List of qualification requirements of various individuals involved in CP (in accordance with EPRI CPUG Position Paper No. 2, "Qualification Guidelines for Personnel Performing Activities Associated with Nuclear Power Plant Cathodic Protection Systems") [11]

– Well-defined listing of various acceptance criteria, including license renewal implications

- NPP-17-3 had captured, reviewed, and incorporated industry operating experience relative to the potential for failure of high-strength pre-stressing wire in PCCP due to hydrogen embrittlement and over-protection by CP. While the PCCP circulating water lines at NPP-17-3 are not intended to be protected, and the joints are not bonded and are discontinuous, NPP-17-3 had proactively elected to investigate the condition of the PCCP to ensure adequate margin exists. This demonstrates successful incorporation and consideration of industry operating experience.

- The CP system inside the plant area included a number of linear anode beds (horizontal anode strings) that were reportedly installed between 2007 and 2012 as a retrofit. Some of these anode strings were reportedly installed using the horizontal directional drilling (HDD) method. Although the type of anode and current rating (amps/linear foot) is not known, linear anodes will typically provide more uniform current distribution, lower anode-to-earth resistance, and lower current density for CP compared to other systems, and as such are well suited for the buried piping inside the protected area (PA).

- Several lines at NPP-17-3 were designed with galvanic anodes using pre-packaged 17-lb (7.7 kg) high potential magnesium anodes. The anodes are connected to the piping through above grade test stations. The piping is fitted with above grade insulating flanges at the supply and receiving ends. The insulating flanges were designed with zinc grounding cells. Zinc grounding cells provide low resistance across the insulating joints, without loss of effective cathodic protection current. They act as an open circuit to DC and a low resistance path for AC and lightning surges, thus reducing the danger of shock, arcing, and burning of the insulating joints. In this manner, the bare copper grounding is not competing with the piping for CP current. Installation of these devices will also allow effective use of indirect survey techniques that can be used to locate coating flaws and corrosion activity on buried piping. External connection of the anode lead wires to pipe test leads at the test stations allows for measurement of the anode current and instant-off potential. As an alternative to zinc grounding cells, CP and pipe designers may also wish to consider using solid-state de-coupling devices across insulating joints.

  Plants installing new piping systems may wish to consider using galvanic anodes with insulating flanges that are fitted with zinc grounding cells and/or DC de-coupling devices, as this type of design can provide effective CP at a fraction of the total current demand compared to grounded piping with impressed current technology.

5
SUMMARY

Appendix A of this report provides a tabular summary, by category, of the various observations found at the three 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”, and
- Table A-5 “System/Programmatic Details – Administrative”

The following provides a summary of observations from the 2017 State-of-Fleet CP assessments that were carried out at the three participating plants.

General Observations:

1. The CP systems assessed at the three nuclear power plants in 2017 generally exhibited 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 & Equipment* [1]. All three plants had plans in place to improve the design, monitoring, and operation of their systems.
2. All three site engineers met the qualification recommendations in EPRI CPUG Position Paper No. 2 “Qualification Guidelines for Personnel Performing Activities Associated with Nuclear Power Plant Cathodic Protection Systems” [11].

Technical and Programmatic Considerations:

1. Personnel Performing Annual Surveys

   The three 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.

   One of the plants assessed periodically uses in-house electrical maintenance technicians under the supervision of the system engineer to conduct annual surveys. However, these technicians have not received any formal CP training and receive only basic site training regarding electrical maintenance. Based on EPRI CPUG Position Paper No. 02, “Qualification Guidelines for Personnel Performing Activities Associated with Nuclear

Power Plant Cathodic Protection Systems" [11], 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 three plants that were assessed in 2017, 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. Generically, the following differences were observed:

   – At one plant, a new corporate CP guidance document had just been implemented around the time of the assessment which identified many of the parameters (and frequencies) that are to be monitored/trended. However, there was no clearly defined field procedure(s) capturing which parameters are to be monitored during the annual survey by the vendor. A trending spreadsheet template developed by corporate was beginning to be used by the engineer to trend data over time, however, it was not obvious at the time of the assessment which data was previously formally trended.

   – One plant had clearly defined procedures for which parameters are to be monitored, however, the captured data was not being trended over time in any spreadsheet or software.

   – One plant had clearly defined procedures for which parameters were to be monitored during various maintenance tasks. The CP data recorded was also being effectively trended via a spreadsheet.

   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 [16].

3. Effectiveness Reporting

   None of the three sites assessed in 2017 reported CP effectiveness in the same manner.

   – One site reported effectiveness based on the number of test points meeting station criteria out of all test points assessed for the given year

   – One site did not report on effectiveness in any manner

   – One site reported effectiveness primarily based on two distinction populations; percent of test points meeting station criteria that are associated with piping that is within the scope of license renewal, and percent of test points meeting station criteria that are associated with piping that is not within the scope of license renewal (annually)

4. 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, or other dissimilar metals. 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. If used, a sufficient number of coupon test stations with native coupons should be installed in order to establish a baseline of native potentials throughout the site.

5. 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. According to NACE SP0100-2014 [14], 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.

6. CP System Upgrade

   One plant was in the process of implementing a sizeable CP system upgrade at the time of the assessment. The existing system design consisted of several deep anode beds, which historically had not provided adequate CP throughout the site. As a result, a new approach was being pursued, consisting of supplemental distributed anodes in areas of high congestion and historically low protection.

   As part of the initial design work, the station directed considerable investigative work to be performed regarding subsurface geology. Furthermore, as part of the design, two test anode wells were installed to provide valuable information, such as current requirement test data, soil conditions, depth to bedrock, and anode-to-earth resistance.

   This information and data will improve the chances of meeting with success and properly providing protection as part of the final implementation of the system.

7. Instrumented Test Stations

   One plant had installed several instrumented test stations and more were in the planning stage. These instrumented test stations consisted of a permanently installed reference electrode, a polarized CP coupon, a disconnected (native) coupon, and a polarized and disconnected ER probe. The data from these test stations can be used to provide valuable information regarding corrosion rate, coupon potential and pipe-to-soil potential, and can be used to help support the use of alternate criteria for CP.

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].

8. Installation of Linear Anodes

   One plant had installed a considerable number of linear anode beds as part of a retrofit inside the PA. Linear anodes typically consist of a MMO anode wire, parallel insulated copper bus cable and fabric jacket that is filled with powdered calcined petroleum coke. Some of these anode strings were reportedly installed using the horizontal directional drilling (HDD) method. Linear anodes will typically provide the advantage of more uniform current distribution, lower anode-to-earth resistance, and lower current density for CP compared to other systems, and as such are well suited for the buried piping in plant environments.

9. Galvanic Anode Protection/Zinc Grounding Cells/DC De-couplers

   One plant designed and installed galvanic anodes for CP of select pipelines (post-construction additions). The system consists of pre-packaged high potential magnesium anodes, test stations, and insulating flanges at the supply and receiving ends.

   The insulating flanges were designed with zinc grounding cells. Zinc grounding cells provide low resistance across the insulating joints, without loss of effective cathodic protection current. They act as an open circuit to DC and a low resistance path for AC and lightning surges, thus reducing the danger of shock, arcing and burning of the insulating joints. Installation of these devices will also allow effective use of indirect survey techniques that can be used to locate coating flaws and corrosion activity on buried piping. External connection of the anode lead wires to pipe test leads at the test stations allows for measurement of the anode current and instant-off potential. As an alternative to zinc grounding cells, CP and pipe designers may also wish consider using solid-state de-coupling devices across insulating joints.

   Plants installing new piping systems may wish to consider using galvanic anodes with insulating flanges that are fitted with zinc grounding cells and/or DC de-coupling devices, as this type of design can provide effective CP at a fraction of the total current demand compared to grounded piping systems that use impressed current technology.

10. Programmatic Documents

   One plant had developed detailed and thorough programmatic documents for the CP program. Specifically, a Cathodic Protection Program Manual has been developed which includes the following key elements:

   – List of all rectifiers
   – List of all preventive maintenance tasks associated with CP
   – Description of cathodic protection key concepts and types of systems (e.g., impressed vs galvanic)

– Identification of parameters to be monitored and trended
– Description of types of surveys (annual survey, close-interval survey, area potential earth current, etc.)
– Description of License Renewal implementation guidance
– Description of corrosion rate monitoring devices
– Overview of work control process
– Overview of industry interfaces (e.g., EPRI, NACE, vendors, etc.)
– Definitions of common CP terms

This level of programmatic guidance provides a superior resource to educate new program owners in the event of turnover, as well as for purposes of communicating with management.

A cathodic protection conduct manual for the CP program had also been developed and included the following key elements.

– Extensive list of personnel responsibilities
– List of qualification requirements of various individuals involved in CP (in accordance with EPRI CPUG Position Paper No. 02, "Qualification Guidelines for Personnel Performing Activities Associated with Nuclear Power Plant Cathodic Protection Systems") [11]
– Well-defined listing of various acceptance criteria, including license renewal implications

Recommendations:

1. Improvements to Annual Survey Work Orders

   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.

2. One site was not necessarily interrupting all rectifiers and current sources, and therefore the instant-off potentials that were being measured may not be accurate. Plants should consider performing rectifier influence surveys periodically and using this data to determine which rectifiers or current sources influence a particular area. This would be beneficial to sites where portable GPS current interrupters are being used in annual surveys. The data from rectifier influence surveys will also help facilitate balancing and system adjustment.

3. Training and Certification of Plant Personnel

   As outlined in EPRI CPUG Position Paper No. 02, "Qualification Guidelines for Personnel Performing Activities Associated with Nuclear Power Plant Cathodic Protection Systems" consider having those individuals performing annual surveys of the CP System become trained and certified as NACE CP1 (Cathodic Protection Tester), and those that are reviewing the annual survey data be certified as NACE CP 2 (Cathodic Protection Technician) [11]. Annual surveys should include:

   - Visual inspection of the system components,
   - Recording rectifier DC output values (voltage and current),
   - Recording rectifier tap settings,
   - Measuring individual anode currents in the anode lead junction boxes (using a shunt or clamp-on DC ammeter),
   - Interrupting all influencing rectifiers using GPS synchronized current interrupters,
   - Measuring on and instant-off potentials at test points and other locations as deemed necessary by the corrosion engineer,
   - Adjusting rectifier DC outputs as necessary,
   - Preparing a final report to include a description of the test procedures, rectifier DC output data, interruption cycles, interrupter sites, anode current measurements, anode-to-earth resistance data, structure-to-soil potential measurements at test points and other locations, with recommendations for future monitoring, upgrades and/or improvements to the system performance.

   Additional guidance on performing annual surveys at nuclear power plants can be found in EPRI report 3002000596, *Cathodic Protection Application and Maintenance Guide, Volume 1: Buried Piping* [1].

4. Trending of Data

   Several of the plants did not adequately trend CP data. Trending of data is necessary to observe changes in CP system performance. The system engineer or program engineer should collect, analyze, and manage the data is such a fashion to facilitate predictive modeling and maintenance. Data trending can be accomplished through a variety of means, including spreadsheets and/or computer software (e.g., BPWORKS™) [12]. When the data is presented in a graphical format, observations can be made regarding CP system performance, anode consumption, and changes resulting from seasonal variations or other environmental conditions.

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.
  - Identification of adverse system trends

  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 [12]. However, additional revisions would be required to address many of the CP parameters and trending practices observed at plants that participated in the 2015, 2016, and 2017 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, several of the plant personnel involved in CP at NPPs assessed in 2017 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. Alternatively, a white paper may be effective in documenting the experiences and processes of those plants which have had success in navigating cyber-security concerns and getting these devices installed.
- 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 the 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. 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. *Cathodic Protection Application and Maintenance Guide, Volume 1: Buried Piping and Volume 2: Plant Structures & Equipment.* EPRI, Palo Alto, CA: 2013. 3002000596.
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. *2015 State-of-the-Fleet Assessment of Cathodic Protection Systems.* EPRI, Palo Alto, CA: 2016. 3002007627.
8. *2015 and 2016 State-of-the-Fleet Assessments of Cathodic Protection Systems*. EPRI, Palo Alto, CA: 2017. 3002010678.
9. 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).
10. *Technology Innovation: Corrosion Mitigation of Conventionally Reinforced Concrete Structures*. EPRI, Palo Alto, CA: 2014. 3002003090.
11. 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).
12. *BPWORKS (Data Management and Risk Ranking of Buried Piping Systems Version 2.2.* EPRI, Palo Alto, CA: 2014. 3002003087.
13. *Soil Sampling and Testing Methods to Evaluate the Corrosivity of the Environment for Buried Piping and Tanks at Nuclear Power Plants*. EPRI, Palo Alto, CA: 2015. 3002005294.

14. 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).

15. *Failure of Prestressed Concrete Cylinder Pipe*, AWWA Research Foundation and U.S. Environmental Protection Agency, 2008.

16. *Recommendations for Managing an Effective Cathodic Protection System*. EPRI, Palo Alto, CA: 2014. 3002002949.

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-17-1	NPP-17-2	NPP-17-3
CP System ownership	System Engineer	System Engineer	Program Engineer
Years of CP Experience	3 years	3 years	3 years
CP Qualifications (e.g., EPRI CP101, NACE CP1, CP2, CP3, CP4, etc.)	EPRI CP101 Corporate Training, CP-Specific from 3rd party vendor	NACE CP1	EPRI CP101, NACE CP1, NACE CP2
NACE Member	No	Yes	Yes
Number of Systems/Programs owned	9-10 systems	4 Systems	2 Programs
Estimated % of time normally dedicated to CP	15%	15-25%	40%
Is there a Back-up CP Owner in place?	Yes (no formal training)	Yes	Yes
Number of CP Owners over the last 5 years?	2	2	2
Is corporate support available for CP?	Yes	No	Prior to 2016, Yes. After 2016, No.

Table A-2
Monitoring and Maintenance

	NPP-17-1	NPP-17-2	NPP-17-3
Who takes annual survey readings: Vendor or Site Personnel?	Vendor	Electrical Maintenance Dept.; Vendor is periodically utilized	Vendor
Who checks rectifier operation and obtains readings?	Electrical Maintenance Department	Electrical Maintenance Department	Electrical Maintenance Department
Who maintains the system?	Electrical Maintenance Department	Electrical Maintenance Department	Electrical Maintenance Department
Who reviews annual survey data & prepares report?	Vendor (NACE CP2) obtains data and Corrosion Specialists and Professional Engineer Reviews data.	System Engineer (NACE CP1), or Vendor (NACE CP4) when contracted	Vendor (NACE CP4) prepare report, Program Engineer (NACE CP2) reviews report
Training/qualifications of CP Technician/ Maintenance Electrician?	Electrical Maintenance: Site Standard electrical maintenance training. Vendor: NACE CP1 Minimum	Electrical Maintenance: Site Standard Electrical Maintenance Training Vendor: NACE CP1 Minimum	Electrical Maintenance: Site Standard electrical maintenance training. Vendor: NACE CP2
Frequency of rectifier readings	Monthly	Monthly	Monthly
System performance testing (months)	12-months	12-months	12-months
Has a rectifier influence survey ever been performed?	Yes - 2014	Yes - 2016	Yes-2011
Close interval survey (CIS) performed?	Pseudo CIS performed on buried piping outside of the Protected Area	Pseudo CIS Performed in 2016	Pseudo CIS performed on a recurring basis
CIS frequency?	N/A	N/A	5 -Years

Table A-3
System Design and Operating Details

	NPP-17-1	NPP-17-2	NPP-17-3
Type of CP System:	Impressed Current	Impressed Current	Impressed Current & Galvanic
CP System installed as part of original plant design, or retrofit?	Included in Original Design	Included in Original Design	Included in Original Design
When was system last refurbished?	CP System Upgrade in progress.	New anode beds installed in 2009. Additional rectifier installed in 2015.	Supplemental linear anodes were added in 2016
What structures have dedicated CP by design (e.g., buried pipe, buried tanks, condenser water boxes, intake structures, etc.)	Buried Piping	Buried Piping	Buried Piping
		Buried Tanks	
	Above Ground Storage Tank Bottoms	Above Ground Storage Tank Bottoms	Above Ground Storage Tank Bottoms
		Reactor Building Liner Plate (abandoned)	
Number of rectifiers?	7 for buried piping	9 for buried piping and tanks	21 rectifiers total; 19 active, 2 spares
Number and type of anode beds?	7 Deep Anode Beds, 7 Shallow Anode Beds (2 anodes each)	122 Distributed Anodes, 4 deep anodes	Distributed Anode Beds, Linear Anode Beds and Galvanic (Magnesium) Anodes for select lines
Total DC Amps:	~340 Amps (2016)	~128 Amps (2016)/266 Amp Capacity	~191 Amps (2017)/645 Amp Capacity
Number of test stations?	~230 test points	~140 test stations	~290 test points
Are permanent reference electrodes installed at pipe depth?	Yes, but only at recent excavations.	No	Yes, for ICCP System (but reference electrode values are no longer used). Yes, for Galvanic Anode System.
Are ER probes and/or corrosion coupons installed?	Yes, 11 instrumented test stations with coupons and ER probes	No	Yes, 4 coupon test stations
Remote monitoring installed on rectifiers?	No	No	No
Integral GPS Current Interrupters installed on rectifiers?	Not integral, temporary interrupters installed during testing	No	Not integral, temporary interrupters installed during testing
Have soil samples been taken to assess corrosivity?	Yes	No	Yes
Is the buried piping above, below, or at groundwater elevation?	Above	Above	Above and below

Table A-4
CP Criteria and System Performance

	NPP-17-1	NPP-17-2	NPP-17-3
Rectifier Availability	98% (rolling 12-month)	(Not Reported)	90.5% (March 2017)
Are "instant-off" potentials being measured?	Yes, portable current interrupters are installed in each rectifier during annual surveys	If surveyed by vendor, yes. If survey performed by on-site personnel, Instant Off values are recorded quarterly for a subset of equipment, and only ON potentials recorded annually for majority of piping.	Yes, portable GPS current interrupters are installed during annual surveys
CP acceptance criteria used	-850mV "instant-off" potential	-850mV "On" potential for majority of piping (annually). -850mV I-OFF potential for a subset of test points (quarterly) 100mV polarization for buried piping and aboveground storage tank bottoms (quarterly)	-850mV "instant-off" potential
Over protection guideline used	Corporate Training & Reference Material procedures outline industry accepted guidelines for over protection, however there are no plant specific guidelines for over protection.	None Specified	-1200mV "Instant off" proceduralized, requires entrance into Corrective Action Program
% of Test Points/Test Stations Meeting CP Acceptance Criteria	32% (2016)	44% (2016)	79% (2016) associated with piping within scope of LR 78% (2016) associated with piping not within scope of LR
CP Effectiveness, per CPUG Position Paper #1	Red	Red	Yellow

Table A-5
System/Programmatic Details – Administrative

	NPP-17-1	NPP-17-2	NPP-17-3
System Health Report for CP	No	Yes, Annually	Yes, Quarterly
Do the performance indicators align with EPRI CPUG Position Paper #1?	No	No	No
Which, if any, CP parameters are trended over time? **(monitoring frequency/trending period)**	Rectifier voltage and current outputs (monthly/annually) Rectifier current and circuit resistance (monthly/multi-year basis)	No	Rectifier voltage and current outputs (monthly/annually)
	Rectifier availability (monthly/annually & annually/multi-year basis)		Rectifier availability (monthly/annually & annually/multi-year basis)
	Individual pipe-to-soil potentials (annually/multi-year basis)		Individual pipe-to-soil potentials (annually/multi-year basis)
	System effectiveness [%] (annually/multi-year basis)		Total system current output (monthly/annually)
Is there a CP System Notebook?	Yes - Electronic	Yes - Electronic	Yes
Is there a CP System Design Basis Document?	No	No	Yes
CP factored into Buried Pipe Health Report/Performance Indicator?	No	No	CP is managed as a program with its own health report. CP is not factored into the buried pipe program health report.
Is the CP System Safety-related, have Tech Spec Implications, or within the scope of Maintenance Rule?	No	No	No

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