DEPARTMENT OF ENVIRONMENTAL PROTECTION
Bureau of Environmental Cleanup and Brownfields

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TITLE: Guidelines for the Evaluation of Underground Storage Tank Cathodic Protection Systems

EFFECTIVE DATE: Upon publication of notice as final in the *Pennsylvania Bulletin.*

AUTHORITY: The Storage Tank and Spill Prevention Act (Tank Act), 35 P.S. §§ 6021.101 *et. seq.*, , and 25 Pa. Code Chapter 245 (Administration of the Storage Tank and Spill Prevention Program).

POLICY: The Department of Environmental Protection (DEP or Department is committed to ensuring compliance with the Storage Tank and Spill Prevention Act and related regulations.

PURPOSE: The purpose of the attached guidance is to establish guidelines regarding the evaluation of cathodic protection systems operating on underground storage tank systems in the Commonwealth of Pennsylvania. Other aspects related to the installation, operation and repair of cathodic protection systems are also addressed in this document where necessary.

APPLICABILITY: This guidance applies to industry professionals who conduct evaluations of cathodic protection systems; owners and operators of underground storage tank systems; and certified companies, installers, and inspectors who install, repair, or inspect underground storage tank cathodic protection systems.

DISCLAIMER: The policies and procedures outlined in this guidance are intended to supplement existing requirements. Nothing in the policies or procedures shall affect regulatory requirements.

The policies and procedures herein are not an adjudication or a regulation. There is no intent on the part of DEP to give the rules in these policies that weight or deference. This document establishes the framework within which DEP will exercise its administrative discretion in the future. DEP reserves the discretion to deviate from this policy statement if circumstances warrant.

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SECTION 1 - INTRODUCTION

The primary purpose of this document is to provide general guidelines regarding the evaluation of cathodic protection systems operating on underground storage tank (UST) systems in the Commonwealth of Pennsylvania. Though conducting structure-to-soil potential surveys is the primary means of testing and evaluating cathodic protection systems, other aspects related to the installation, operation and repair of UST cathodic protection systems are also addressed in this document where necessary. This guidance is also intended to establish what minimum documentation should be generated by a cathodic protection tester in order to conduct a valid cathodic protection evaluation and to reproduce the test results. To this end, the DEP recommends the use of DEP form 2630-FM-BECB0610 "UST Cathodic Protection System Evaluation Form" to document evaluations of UST cathodic protection systems in the Commonwealth of Pennsylvania.

This guidance document is not intended to replace any statute, rule or regulatory requirement concerning the installation, repair, operation or testing of cathodic protection systems. Rather, it is intended to state DEP's interpretation regarding the implementation of those rules and regulations applicable to UST cathodic protection systems.

SECTION 2 - REGULATIONS

The Tank Act requires the Department to adopt regulations that set corrosion protection standards for installation and performance of new and existing underground storage tanks. 35. P.S. § 6021.501(a)(7).

Pennsylvania's storage tank regulations are found in Title 25 of the Pennsylvania Code, Chapter 245 "Administration of the Storage Tank and Spill Prevention Program" (Storage Tank Regulations).

The Storage Tank Regulations require that any component of a UST system that routinely contains a regulated substance (also referred to as product) must be protected from corrosion. 25 Pa. Code §§ 245.421(b)(1)-(2).

There are two general types of cathodic protection that are typically installed on UST systems: galvanic (sacrificial anode) systems and impressed current (rectifier) systems. The Storage Tank Regulations require <u>all</u> cathodic protection systems to be inspected and evaluated for proper operation by a qualified cathodic protection tester within six months of installation/repair and at least once every three years thereafter. 25 Pa. Code § 245.432(a)(2)(i). Documentation of the most recent two cathodic protection system evaluations must be maintained by the UST owner and operator. 25 Pa. Code § 245.435(b)(3)(v).

The Storage Tank Regulations also require impressed current rectifier units to be inspected for proper operation at least every 60 days. 25 Pa. Code § 245.432(a)(3). There are no certification requirements that apply to a person conducting impressed current rectifier unit inspections. However, the tank owner, operator, or other designated rectifier inspector should be familiar enough with the rectifier unit to recognize whether it is powered on or off and whether any of its ammeter or voltmeter gauges (if equipped) indicate the system is operating outside of the output range prescribed by the corrosion expert who designed the system. Documentation of the most recent three rectifier inspections must be maintained by the UST owner and operator.

SECTION 3 - DEFINITIONS[1]

100 mV POLARIZATION – One of the three criteria (see Section 7.2) that are commonly accepted as indicating adequate cathodic protection has been achieved.

850 ON – One of the three criteria (see Section 7.2) that are commonly accepted as indicating adequate cathodic protection has been achieved.

850 OFF - One of the three criteria (see Section 7.2) that are commonly accepted as indicating adequate cathodic protection has been achieved.

ANODE – The electrode of an electrochemical cell where oxidation (corrosion) occurs. With respect to cathodic protection, it can be thought of as the place where electrons leave the surface of a metal.

AMPERAGE – The strength of a current of electricity expressed in amperes. Amperage can be thought of as "gallons per minute" in a water system.

CATHODE – The electrode of an electrochemical cell where reduction (and no corrosion) occurs. With respect to cathodic protection, it can be thought of as the place where current enters the surface of a metal.

CATHODIC PROTECTION – A technique to prevent corrosion of a metal surface by making that surface the cathode of an electrochemical cell.25 Pa. Code § 245.1. This technique causes the entire surface of a metallic structure to become a cathode with respect to its external environment (soil) by supplying an electric current sufficient to overcome the tendency of naturally occurring electrical currents to leave the metallic structure.

CATHODIC PROTECTION EVALUATION – The interpretation of whether or not a cathodic protection system is providing sufficient corrosion protection. An evaluation incorporates all cathodic protection testing, surveys, rectifier operation/output measurements, consideration of voltage drops, condition of dielectric coatings, continuity, bond integrity, circuit integrity and any other factors or site specific conditions that may have an influence on the operation and effectiveness of a cathodic protection system.

CATHODIC PROTECTION SURVEY – The process by which all of the structure-to-soil measurements and tests necessary to contribute to the final evaluation of a cathodic protection system are obtained.

CATHODIC PROTECTION TEST – The process by which a structure-to-soil potential measurement is obtained.

[1] The definitions included in this section, unless otherwise cited, are provided only for application under this guidance.

CATHODIC PROTECTION TESTER – A person who can demonstrate an understanding of the principles and measurements of common types of cathodic protection systems as applied to buried or submerged metal piping and tank systems. At a minimum, the person shall have education and experience in soil resistivity, stray current, structure to soil potential and component electrical isolation measurements of buried metal piping and tank systems. 25 Pa. Code § 245.1.

CONTINUITY – As related to cathodic protection, continuity means that two metallic structures are electrically continuous. With impressed current systems, all protected structures must be continuous. This is normally accomplished using wires referred to as continuity bonds.

CORROSION – The deterioration of a material (usually a metal) caused by an electrochemical reaction with its environment. Corrosion of metal involves the flow of electrons (current) between an anode and a cathode. Corrosion will occur where the electrons leave the surface of a metal.

CORROSION EXPERT – A person who, by reason of thorough knowledge of the physical sciences and the principles of engineering and mathematics acquired by a professional education and related practical experience, is qualified to engage in the practice of corrosion control on buried or submerged metal piping systems and metal tanks. The person shall be accredited or certified as being qualified by the National Association of Corrosion Engineers or be a registered professional engineer who has education and experience in corrosion control of buried or submerged metal piping systems and metal tanks. 25 Pa. Code § 245.1.

CORROSION PROTECTION – The protection of metal from deterioration. The deterioration may be due to a natural electrochemical reaction between the metal and the soil or other electrolyte, or because of stray direct currents. 25 Pa. Code § 245.1.

CURRENT REQUIREMENT TEST – A method of temporarily creating an impressed current cathodic protection system on a metallic structure so that it can be determined how much protective current is necessary in order to achieve adequate cathodic protection. This is normally done by connecting a battery (direct current) to both a temporary anode and the structure being tested.

DIELECTRIC MATERIAL – A material that does not conduct direct electrical current. Dielectric coatings are used to electrically isolate tank systems from the surrounding soils. Dielectric bushings are used to electrically isolate portions of the tank system for example, tank from piping. 25 Pa. Code § 245.1. Various coatings are used, some examples of which are the "fusion-bonded epoxy" found on factory coated steel piping, and coal tar epoxies and other coatings (e.g., aliphatic urethanes) commonly found on sti-P_3® tanks.

ELECTROLYTE – As related to UST cathodic protection systems, electrolyte refers to the soil or water surrounding the metallic structure.

FIELD-INSTALLED – Refers to any impressed current system or galvanic anode system that is installed onsite at a pre-existing UST location, or when sacrificial anodes are installed onsite to new metallic pipe.

GALVANIC (SACRIFICIAL) ANODE – A metal of high electrochemical potential that is used to cathodically protect another metal of lower electrochemical potential. Zinc and magnesium are two metals that are commonly used as galvanic anodes for the protection of UST systems.

INSTANT OFF POTENTIAL (VOLTAGE) – The voltage that is observed momentarily after the protective current supplied by the cathodic protection system is interrupted. It is used when testing a cathodic protection system to determine whether it satisfies the 850 off and/or 100 mV polarization criteria. The second number that appears on a digital voltmeter/multimeter immediately after the protective current is interrupted is considered the proper value to represent the instant off potential.

ISOLATION – As related to cathodic protection, isolation means that two metallic structures are electrically discontinuous. With galvanic systems, a protected structure must be electrically isolated from other metallic structures. This is normally accomplished through the use of nylon bushings and dielectric unions.

LOCAL POTENTIAL (VOLTAGE) – The structure-to-soil potential of a metallic structure that is measured with the reference electrode placed in the soil immediately over the structure.

NATIVE POTENTIAL (VOLTAGE) – The structure-to-soil potential of a metallic structure that is exhibited before any cathodic protection is applied.

ON POTENTIAL (VOLTAGE) – The structure-to-soil potential of a metallic structure that is measured with the protective current applied.

PARALLEL CIRCUIT – A parallel electrical path that can be created by the person conducting the test allowing their person to make contact with a metallic part of the test leads or reference electrode when conducting structure-to-soil potential measurements.

POLARIZATION – The change in the structure-to-soil potential of a metallic structure due to the application of a protective current. In this guidance document, polarization means cathodic polarization – that is, the potential of the metal is shifted in the negative direction.

POLARIZED POTENTIAL – The structure-to-soil potential of a metallic structure that is observed after the protective current is applied and sufficient time has elapsed for the structure to completely polarize.

RAISED EARTH – The high voltage gradient found in the soil around an active impressed current or sacrificial anode. Placement of the reference electrode in proximity to an active anode will cause an abnormally high (more negative) structure-to-soil potential to be measured than would be observed if the anode were not in close proximity.

RECTIFIER – A device used in impressed current systems that transforms AC power to DC power.

REFERENCE ELECTRODE – Also referred to as a reference cell or a half-cell. A device whose electrochemical potential is constant, and that is used to measure the structure-to-soil potential of buried metallic structures. The potential that is observed on the buried metallic structure is relative to the potential of the reference electrode. The observed potential of a buried metallic structure would be zero if it were of the exact same composition as the reference electrode, and if all sources of measurement error were eliminated.

REMOTE POTENTIAL (VOLTAGE) – The structure-to-soil potential of a metallic structure that represents the average potential of the entire surface of the structure, and which is measured with the reference electrode placed in the soil at a point well away (remote earth) from the structure. Remote earth is generally thought of as at least 25 feet away, but not more than 100 feet away. Remote earth is established when the observed structure-to-soil potential does not significantly change as the distance between the reference electrode and the protected structure is increased.

RESISTANCE – A measurement of the tendency of a substance to inhibit the flow of electrical current. Resistance in UST cathodic protection systems is generally meant to refer to the electrical properties of the backfill materials (soil).

SHIELDING – A structure that prevents or diverts an electrical current from reaching the desired location. Normally thought of as something that prevents a reference electrode from being able to "see" the metallic structure for which one is attempting to measure a structure-to-soil potential.

sti-P_3® TANK – A steel tank manufactured to the sti-P_3® standard developed by the Steel Tank Institute. These tanks are fabricated by the tank manufacturer with a "pre-engineered" cathodic protection system. The "P3" means that the steel tank is protected in three ways: 1) A protective dielectric coating that is factory applied to the tank's exterior surface; 2) Galvanic anodes (zinc/magnesium) that are factory installed on the tank; and 3) Dielectric bushings that are installed to facilitate electrical isolation of the tank.

STRAY CURRENT – An electrical current that travels along an unintended path.

STRUCTURE-TO-SOIL POTENTIAL – Also known as "pipe-to-soil potential' or "structure-to-electrolyte potential". It is the difference in the potential of the surface of a buried metallic structure and the electrolyte (soil and water) that surrounds it, measured with respect to a reference electrode in contact with the electrolyte. It can be thought of as the voltage difference between a buried metallic structure and the soil and groundwater in which it is buried.

VOLTAGE – The basic unit of force in an electric circuit. Voltage can be thought of as "pounds per square inch pressure" in a water system.

VOLTAGE (IR) DROP – The change in voltage across a resistance, according to Ohm's law.

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SECTION 4 - TYPES OF CATHODIC PROTECTION

4.1 General

When properly designed and constructed, cathodic protection systems can be used to effectively mitigate corrosion of the external surfaces of metallic UST system components that are in contact with the soil and groundwater present in typical UST installation environments. The two types of cathodic protection systems that are typically installed on UST systems are galvanic (sacrificial anode) and impressed current (rectifier) systems. Both galvanic and impressed current systems can prevent electric current from leaving the protected structure by supplying an electric charge in the form of DC power sufficient to overcome any electric current that would otherwise leave the structure. The difference between galvanic and impressed current systems is the way in which the required electric current is provided.

4.2 Galvanic Systems

Galvanic systems are also known as sacrificial anode systems because the electric current supplied to the protected structure is generated by the corrosion of the anode. In this way, the anode is said to sacrifice itself to protect the structure. For underground applications, galvanic anodes are typically composed of zinc or magnesium because those materials have a greater corrosion potential than steel and other metals typically used for the construction of UST system components. Galvanic anodes are installed in the surrounding soil and connected directly to the structure to be protected by either welding or mechanical connection of lead wires. When installed in this way, a circuit is created in which some of the electric current generated by the corroding anode is directed through the surrounding soil onto the surface of the protected structure. Components of UST systems protected by galvanic cathodic protection should be electrically isolated from other metallic structures.

There are two types of galvanic system installations: factory-installed and field-installed. Factory-installed galvanic anode systems are pre-engineered and installed on the UST system component during its manufacture (e.g., sti-$P_3^{®}$ tanks). Field-installed galvanic systems may be installed on the UST system component at the time of its onsite installation or installed as a retrofit at a later time (e.g., the addition of supplemental galvanic anodes).

4.3 Impressed Current Systems

Impressed current systems use an electric current from an external power source to protect the structure. They are sometimes called rectifier systems because they use a device (a rectifier) to convert an external AC power source to the required DC power source. In this type of system, anodes are installed in the soil around the protected structure and connected to the rectifier’s positive terminal with lead wires. When the system is powered on, the rectifier supplies an electric current to the anodes which is then discharged through the surrounding soil onto the surface of the protected structure. Separate lead wires connect the protected structure to the rectifier’s negative terminal to complete the circuit. Metallic components of UST systems protected by impressed current cathodic protection should be electrically continuous.

It is critical that the anodes are connected to the rectifier’s positive terminal and the protected structure to its negative terminal. Reversal of the lead wire connections will make the tank system components anodic and can cause a rapid failure of the tank system due to corrosion induced by the supplied electric current. In addition, *it is critical that all buried lead wire connections and splices are properly coated and insulated.* Any break in the insulation or dielectric coating will allow current to discharge from the break and cause a rapid corrosion failure of the wire.

SECTION 5 - QUALIFICATIONS TO TEST CATHODIC PROTECTION SYSTEMS

A person must meet certain minimum qualifications in order to test cathodic protection systems in the Commonwealth of Pennsylvania. 25 Pa. Code § 245.1. DEP recommends that a person who meets those minimum qualifications perform cathodic protection system tests in a manner that is consistent with this guidance document. See Section 3 for the definition of "cathodic protection tester" as defined in 25 Pa. Code § 245.1.

Acceptable qualifications for cathodic protection testers include, but are not limited to, Steel Tank Institute Cathodic Protection Tester Certification, International Code Council U-4 UST Cathodic Protection Tester Certification, field training provided by a National Association of Corrosion Engineers (NACE)-Certified Tester with proof of training, and NACE International certification categories of Cathodic Protection Tester, Cathodic Protection Technician, and Cathodic Protection Technologist.

A person who does not possess the knowledge and expertise needed to properly test and evaluate a particular cathodic protection system, as mentioned above, should not attempt to conduct such an evaluation.

SECTION 6 - INSTALLATION AND REPAIR OF CATHODIC PROTECTION SYSTEMS

6.1 General Requirements

Both the installation and repair of UST cathodic protection systems are tank handling activities which must be performed by or under the direct, onsite supervision and control of a DEP certified installer holding the UMX certification category for UST system installation and modification. 25 Pa. Code § 245.21. For additional information on UST system modification requirements, see Storage Tank Program guidance number 263-0900-011 "Storage Tank Modification and Maintenance Issues."

UST cathodic protection systems must be designed, installed, and repaired in accordance with a code of practice developed by a Nationally-recognized association or independent testing laboratory. 25 Pa. Code §§ 245.421(b)(1)-(2), 245.434(2). The most current edition of the codes or standards must be applied at the time of the installation, repair, or upgrade of the cathodic protection system. 25 Pa. Code §§ 245.421(b)(1)-(2), 245.434(2). The Department may request documentation verifying that a cathodic protection system has been installed in accordance with Department regulations and industry standards. *Both field-installed galvanic cathodic protection systems and impressed current systems must be designed by a corrosion expert.* 25 Pa. Code §§ 245.421(b)(1)(B)-(C). As noted in Sections 6.2.1 and 6.2.3 below, this design requirement may be met without the need for a corrosion expert to design the cathodic protection system provided the provisions of an applicable standard or code are followed..

6.2 Galvanic Systems

6.2.1 Factory Coated Steel Tanks

Repairs to the cathodic protection system of a factory coated steel tank must meet all of the requirements of the tank manufacturer and a corrosion expert in order to ensure that the repairs are done correctly and that the cathodic protection system is functionally properly. All repairs must also be properly conducted in accordance with a code of practice developed by a Nationally-recognized association or an independent testing laboratory. 25 Pa. Code § 245.434(2). The Steel Tank Institute's R972 "Recommended Practice for the Addition of Supplemental Anodes to sti-P_3® USTs" is a common example. Procedures and calculations such as the current requirement test should be documented and available for review upon request by the Department.

A factory coated steel tank that cannot be repaired by the addition of supplemental galvanic anodes may be upgraded with an impressed current system if the impressed current system is designed by a corrosion expert and the tank integrity is evaluated in accordance with the tank upgrading requirements found at 25 Pa. Code § 245.422(b)(2).

6.2.2 Non-Factory Coated Steel Tanks (non sti-P_3® Tanks)

Galvanic systems are not recommended for non-factory coated steel tanks (i.e., bare steel, asphalt coated, or poorly coated, etc.). An impressed current system is typically needed to protect such tanks due to the higher amount of current required for adequate cathodic protection. A corrosion expert would be required to evaluate the tank system to determine the best method to protect the tank. 25 Pa. Code § 245.421(b)(1)(ii). Non-factory coated steel tanks that have never had cathodic protection installed, nor been upgraded with an internal lining in accordance with 25 Pa. Code § 245.422(b)(1), cannot be upgraded with cathodic protection and must be permanently closed in accordance with the UST closure requirements in 25 Pa. Code. §§ 245.451-455.

6.2.3 Factory Coated Metallic Piping

Installation of galvanic anodes to factory coated (e.g., extruded polyethylene, fusion bonded epoxy) metallic piping may be accomplished without the design of a corrosion expert if the provisions of the Steel Tank Institute R892, "Recommended Practice for Corrosion Protection of Underground Piping Networks Associated with Liquid Storage and Dispensing Systems", are followed. As an alternative, the practices described in the Petroleum Equipment Institute RP100, "Recommended Practices for Installation of Underground Liquid Storage Systems" may also be followed when installing galvanic anodes on factory coated piping.

6.2.4 Non-Factory Coated Metallic Piping

The installation or repair of a galvanic cathodic protection system installed on metallic piping that is not factory coated with a dielectric material must be completed in accordance with a corrosion expert's design. 25 Pa. Code § 245.421(b)(2)(ii).

6.3 Impressed Current Systems

The installation or repair of an impressed current system must meet the requirements of a corrosion expert's design. 25 Pa. Code § 245.421(b)(1)(ii).

Steel tanks which were upgraded with an internal lining in accordance with 25 Pa. Code § 245.422(b)(1) and have been evaluated in accordance with 25 Pa. Code § 245.432(d) may be upgraded with an impressed current system within 6 months of a passing lining evaluation if the impressed current system is designed by a corrosion expert and the tank integrity is evaluated in accordance with the tank upgrading requirements found at 25 Pa. Code § 245.422(b)(2). For additional information on UST lining evaluation requirements, see Storage Tank Program guidance number 263-3120-001 "Evaluation of Underground Storage Tank (UST) Liners."

SECTION 7 - CATHODIC PROTECTION TESTING

7.1 Equipment

Although the equipment required to test cathodic protection systems is relatively simple, it is very important that the equipment is maintained in good working order and is free of corrosion and contamination. The basic equipment includes a voltmeter/ammeter (multimeter), reference electrode, wires, clips and test probes.

It may be necessary to have a current interrupter for impressed current systems when the power cannot be easily turned on and off at the rectifier. A clamp-on type ammeter can be useful when troubleshooting impressed current systems. Wire locators can help determine the location of buried anode lead wires and header cables. Hand tools to clean corrosion or dielectric coatings from the surface of the structure being tested at the point of contact with lead wires/probes may also be necessary.

Note: Always take safety precautions when working with electrical equipment.

7.1.1 Voltmeters, Ammeters, and Multimeters

A good quality voltmeter, ammeter, and/or multimeter that has an adequate degree of accuracy is essential for testing cathodic protection systems due to the low voltages and electrical currents involved. The batteries in portable meters must also be in good condition. If there is any question about the condition of the batteries, they should be replaced. Battery contacts should be free of corrosion.

Voltmeters – A voltmeter that has a high internal resistance (impedance of 10 megohms (MΩ) or greater) is necessary when testing any cathodic protection system in order to avoid introducing a large error when measuring structure-to-soil potentials. The voltmeter should be properly maintained and periodically calibrated in accordance with the manufacturer's recommendations. The voltmeter should be calibrated at least annually.

The voltmeter must have a high degree of sensitivity and should be placed in the lowest scale possible (normally the 2 volt DC scale works well) to accurately measure the small voltages associated with cathodic protection systems. All voltage (potential) measurements must be recorded as millivolts (mV) when documenting the test results on DEP form 2630-FM-BECB0610 "UST Cathodic Protection System Evaluation Form". For example, a reading of -1.23 volts should be recorded as -1230 mV; a reading of -0.85 volts should be recorded as -850 mV.

Ammeters – An ammeter that has a very low internal resistance is necessary when testing impressed current systems in order to accurately determine the current output of the rectifier and/or individual circuits in the system. Generally, amperage should only be measured where calibrated measurement shunts are present. Alternatively, a clamp-on type ammeter may be used in those cases where shunts are not present.

7.1.2 Reference Electrode

A standard copper/copper sulfate reference electrode (CSE), also known as a half-cell or reference cell, should be used in order to obtain structure-to-soil potentials. The reference electrode must be maintained in good working condition and must be placed in the soil in a vertical position when conducting a test. If an alternative type of standard reference electrode is used to obtain structure-to-soil potentials, the results must be converted to their CSE equivalents when documenting them on DEP form 2630-FM-BECB0610 "UST Cathodic Protection System Evaluation Form".

On sti-P_3® tanks that have a PP4® test station, a reference electrode is permanently buried in the tank field. Since it is generally not possible to determine where the permanent reference electrode was installed on these types of systems, its calibration accuracy, or the degree the reference electrode has been affected by soil chlorides, a cathodic protection tester may have questions about the integrity of a local structure-to-soil potential obtained with a PP4® test station. Additional local potentials and any remote potentials should be obtained in the conventional manner to determine whether adequate cathodic protection has been provided, regardless of what the PP4® test station results indicate.

Maintenance of the copper/copper sulfate reference electrode is important for accurate results. All testing equipment should be maintained and calibrated in accordance with the equipment manufacturer's guidelines and industry standards.

7.1.3 Lead Wires, Test Probes, and Miscellaneous

The insulation material of any lead wires should be in good condition. Any clips or probes used to make contact with the structure being tested must be clean and free of corrosion. A spool of suitable wire of sufficient length is necessary to conduct continuity and/or remote earth testing. It is usually necessary to have a probe that can be attached to the end of a tank gauging stick in order to contact the tank bottom since it is not uncommon for the tank test lead on sti-P_3® tanks to either be missing or discontinuous with the tank shell. A pair of locking pliers may be useful when attempting to get a solid connection by clamping.

7.2 Test Criteria

There are three test criteria that can be used to indicate if adequate cathodic protection is being provided to the structure being evaluated:

850 On – A structure-to-soil potential of -850 mV or more negative with the protective current applied, measured with respect to a CSE. This is commonly referred to as the "850 on" criterion and the structure-to-soil potential obtained with the protective current applied is commonly referred to as the "on potential." This criterion is normally the only one available for factory-installed galvanic anode systems (e.g., sti-$P_3^{®}$ tanks) because the protective current usually cannot be interrupted to conduct the other tests. This criterion may be applied to any galvanic system. *Voltage drops other than those across the structure-to-electrolyte boundary must be taken into consideration whenever this criterion is applied.* Voltage drops may have a significant impact on the potentials observed when testing impressed current systems with the protective current applied. Therefore, the “850 on” criterion is not applicable to impressed current systems.

850 Off – A structure-to-soil potential of -850 mV or more negative with the protective current temporarily interrupted, measured with respect to a CSE. This criterion is often referred to as the “850 off” criterion and the structure-to-soil potential obtained with the protective current temporarily interrupted is commonly referred to as the “instant off potential.” This criterion is applicable to impressed current systems and to galvanic systems where the protective current can be temporarily interrupted. Current interruption is not typical for factory-installed galvanic anode systems (e.g., sti-$P_3^{®}$ tanks) and is generally limited to field-installed or retrofitted galvanic systems. Impressed current systems must have their protective current interrupted in order to obtain structure-to-soil potential measurements free of voltage drops attributed to the protective current flow. Caution must be exercised when testing impressed current systems to ensure that no active galvanic anodes are also installed near the protected structure. If there are active retrofitted or other field-installed galvanic anodes influencing the observed potential, the "850 off" criterion is not applicable unless the output current of these supplementary anodes is interrupted (e.g., use of an isolating test station).

The instant off potential is generally considered to be the second value that is observed on a digital voltmeter the instant the power is interrupted. The first number that appears immediately after power interruption must be disregarded. After the second number appears, a rapid decay of the structure-to-soil potential (depolarization) will normally occur. A current interrupter or a second person is necessary to obtain instant off potentials. If a current interrupter is not available, have the second person turn the rectifier’s power switch off for 3 seconds and then back on for 15 seconds. Repeat this procedure until an accurate instant off reading has been obtained.

100 mV Polarization – A polarization voltage shift of at least 100 mV; commonly referred to as the “100 mV polarization” or “100 mV shift” criterion. This criterion is applicable to impressed current systems and to galvanic systems where the protective current can be temporarily interrupted. The applicability of this criterion to the evaluation of steel UST systems that are electrically continuous to a significant amount of copper (or other metal that is more noble than steel) may need further evaluation by a corrosion expert.

Because instant off potentials are used to demonstrate this criterion, they are typically applied only when the “850 off” criterion is not met. Either the formation or the decay of at least 100 mV polarization may be used to evaluate adequate cathodic protection. Whether testing for polarization formation or decay, the voltage shift is measured by comparing the structure’s instant off potential to its native potential (or depolarized potential) obtained with the reference electrode placed locally to the structure. The reference cell must either be left unmoved during the test or returned to the same location to obtain the second reading.

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Testing for the decay of at least 100 mV polarization can be performed when the cathodic protection system has been energized long enough for the structure potentials to reach polarized values. The base reading from which to begin the measurement of the voltage decay is the structure's instant off potential. Comparison of the instant off potential with a native potential measured in the past is not sufficient to demonstrate that the present level of cathodic protection meets the "100 mV polarization" criterion. A polarization decay of at least 100 mV must be observed by the tester. For example, a structure exhibits an on potential of -835 mV. The instant off potential is -720 mV. In order to meet the 100 mV polarization criterion, the structure-to-soil potential must decay to a final (depolarized) potential of -620 mV or more positive.

The true polarized potential may take a considerable length of time to effectively form on a structure that has had cathodic protection newly applied. Conversely, if the protective current is interrupted on a metallic structure that has been under cathodic protection, the polarization will begin to decay nearly instantaneously. For this reason, it is important that the protective current not be interrupted for any significant length of time. Generally, no more than 24 hours should be allowed for the 100 mV depolarization (decay) to occur.

Testing for the formation of at least 100 mV polarization can be performed when a system is initially energized or is re-energized after a complete depolarization has occurred. The base reading from which to begin the measurement of the voltage formation is the structure's native potential measured just prior to energizing the cathodic protection system. An instant off potential is then measured after the cathodic protection system has been energized long enough for the structure potentials to reach polarized values. Comparison of the instant off and native potentials must demonstrate the formation of at least 100 mV polarization. For example, a structure exhibits a native potential of -590 mV. The cathodic protection system is then energized. In order to meet the 100 mV polarization criterion, an instant off potential of at least -690 mV or more negative must be obtained.

7.3 Other Test Considerations

Various other factors can affect the accuracy of structure-to-soil potential measurements. Some of the more common factors are listed below:

Contact Resistance – A good, low resistivity contact between the reference electrode and the soil must be made in order to obtain an accurate structure-to-soil potential. If the soil at the surface is too dry, the addition of water may lower the resistance between the reference electrode and the soil. In addition, the porous ceramic tip of the reference electrode should be replaced if it becomes clogged or contaminated, since this in itself can cause a high contact resistance.

Contaminated Soil – The reference electrode should be placed in soil that is free of contamination. Hydrocarbon contamination can cause a high resistance between the reference electrode and the soil.

Drought Conditions – On occasion, it has been observed that structure-to-soil potentials can be improved by running water into the backfill material of the tank bed when little to no rainfall has occurred for an extended period. This is commonly done by placing a water hose in one of the tank bed observation wells (or other access points) and allowing the water to run for a period of time. This

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practice serves to lower the resistance of the backfill material. However, keep in mind that the resistivity of the soil is not appreciably lowered if the moisture content is 20% or higher. Even in drought conditions the structure must pass cathodic protection testing.

Electromagnetic Interference – External electrical currents associated with overhead high voltage power lines, railroad crossing signals, airport radar systems and radio frequency transmitters (CB radios, cellular phones, etc.) can all cause an interference that will result in an inaccurate voltage reading.

Galvanized Metals – Buried metals that have a high electrochemical potential can influence the observed voltage if the reference electrode is placed in close proximity to such metals. For instance, the steel skirt of some of the manholes that are installed to provide access to the tank appurtenances may be galvanized. If the reference electrode is placed in the soil within such a manhole, an artificially high (more negative) structure-to-soil potential may be observed. This is actually a raised earth effect (see below), although the galvanized metal is not acting to cathodically protect the buried structure of concern.

Parallel Circuits – Care should be taken to ensure that the person conducting the testing does not allow their person to come into contact with the electrical components of the testing equipment. An error may be introduced due to the creation of a parallel circuit if the person touches the electrical connections.

Pea Gravel – Because pea gravel or crushed stone typically has a very high electrical resistivity, it is necessary to ensure that it is saturated with water when attempting to measure structure-to-soil potentials with the reference electrode placed in the pea gravel. Evaluate any effect high contact resistance may have by changing the input resistance of the voltmeter. Placing the reference electrode in soil remote from the structure is an alternative way to evaluate the effect contact resistance may have. High resistance is indicated when the remote reading is substantially more negative than the local reading. Placement of a saturated sponge on the surface of the pea gravel may help overcome high contact resistance.

Photovoltaic Effect – It is known that sunlight striking the viewing window of a CSE reference electrode can have an effect (as much as 50 mV) on the observed voltage. The viewing window of the reference electrode should be kept out of direct sunlight. Alternatively, the viewing window can be covered with black electrical tape in order to prevent any sunlight from reaching the copper sulfate solution.

Poor Connection – If the observed structure-to-soil potentials are unsteady and the voltmeter will not stabilize, suspect a poor connection somewhere. Ensure that all electrical connections are clean, tight, and good contact is made between the test lead and the structure.

Raised Earth - All active anodes will have a voltage gradient present in the soil around them producing a raised earth effect. An abnormally high (more negative) potential will be observed if the reference electrode is placed within the voltage gradient of an active anode. The magnitude or area of influence of the voltage gradient is dependent predominantly on the voltage output of the anode and the resistance of the soil. Unfortunately, there is no standard guidance that can be given to determine how far away the

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reference electrode must be placed from an anode in order to be outside the voltage gradient. If the potential is suspected to be affected by raised earth, it should be compared to a remote reading.

Because of the raised earth effect, it is necessary to place the reference electrode as far away from any active sacrificial anode and yet still be directly over the structure when obtaining local potentials on galvanic systems. Any effect this type of voltage drop may have can be evaluated by placing the reference electrode in a remote location because the protective current cannot typically be interrupted in galvanic systems (see Section 7.4.4). Remote placement of the reference electrode ensures that it is not within the voltage gradient of an active sacrificial anode. Since it is desirable to eliminate any effect voltage drops may have, it may be helpful to obtain remote structure-to-soil potentials in addition to local structure-to-soil potentials when testing galvanic systems. Any effect raised earth may have when testing impressed current systems is eliminated by temporarily interrupting the protective current.

Shielding – When a metallic structure is buried between the reference electrode and the structure being tested, the reference electrode may not be able to "see" the structure being tested which, in turn, may lower the observed structure-to-soil potential. The various tank risers, pump heads, piping, electrical conduits and manhole skirts that are typically located over the tank may affect the structure-to-soil potentials observed with the reference electrode placed locally above the tank.

7.4 Reference Electrode Placement

7.4.1 General

Where the reference electrode is placed when taking structure-to-soil potential measurements is of critical importance. Soil access must be available for local placement, and for any necessary remote placement, of the reference electrode. Documenting the exact location where the reference electrode was placed is essential so that anyone could return to the site and reasonably duplicate the test. Reference electrode placement must be documented by written description and also depicted on a drawing of the UST system when completing DEP form 2630-FM-BECB0610 "UST Cathodic Protection System Evaluation Form".

7.4.2 Soil Access

All structure-to-soil potentials that are intended to satisfy one of the three acceptable test criteria (see Section 7.2) must be obtained with the reference electrode placed in contact with the soil. Therefore, the person conducting the cathodic protection survey must either confirm that sufficient soil access is available or make prior arrangements with the owner of the UST system to secure soil access.

Under no circumstances is it allowable to place the reference electrode on concrete, asphalt, or any other paving material to achieve satisfactory structure-to-soil potentials. Soil access may be provided by drilling holes through the pavement or the installation of proper cathodic protection test stations. A practical way to provide soil access is to drill a ½ inch diameter hole in the pavement so that a pencil-type reference electrode (a ⅜ inch diameter model) can be inserted through the pavement and into the soil. Upon completion of the survey, the hole should be filled with a fuel resistant caulking material so that easy access can be provided at a later date. As an alternative, a two inch diameter hole could be drilled to accommodate a standard size reference electrode. A short length of PVC pipe could be epoxied in the hole and plugged with a threaded cap.

Various cathodic protection test stations and soil access manholes are available for installation. Provisions for access to the soil should be made so that adequate cathodic protection testing may be accomplished whenever a new tank system is installed or the pavement is reworked around an existing system.

7.4.3 Local Placement

Whether testing a galvanic system or an impressed current system, structure-to-soil potentials must be obtained with the reference electrode placed local to the protected structure. Placement of the reference electrode is considered local when it is contacting the soil directly over the structure that is being tested. Ideally, the tip of the reference electrode should be as close to the structure-to-soil interface as is practical in order to minimize the voltage drop present in the soil due to its resistivity.

Raised earth effects (see Section 7.3) attributed to any active anodes should be considered when selecting the appropriate location for local placement. Other conditions such as shielding or the presence of contaminated soil (see Section 7.3) should also be considered.

7.4.4 Remote Placement

The remote potential represents the average potential of the entire surface of the protected structure. The purpose of remote placement is to eliminate any effect that raised earth (see Section 7.3) may be contributing to the measurement of the structure-to-soil potential, and to overcome any local shielding effects (see Section 7.3).

Placement of the reference electrode is considered remote when it is placed in the soil a certain distance away from the structure that is being tested. There are several factors that determine the distance necessary in order to reach remote earth and a full discussion is beyond the scope of this document. However, a remote condition can normally be achieved when the reference electrode is placed between 25 and 100 feet away from any protected structure.

7.4.5 Galvanic System Test Locations

Tank and piping components protected by galvanic cathodic protection systems must be tested with the reference electrode placed local to the structure being tested. In addition to obtaining one or more local structure-to-soil potentials, the tester may need to obtain one or more remote structure-to-soil potentials. In any case, the tester should obtain enough structure-to-soil potentials to evaluate the adequacy of cathodic protection for the entire structure.

When obtaining local potentials, the reference electrode may be placed in the soil at any point along the centerline of the tank, but not directly over the anodes at each end of the tank. Placement of the reference electrode in the soil within manholes installed for access to submersible turbine pumps or other tank top piping connections should be avoided if galvanic anodes are installed in the surrounding soil to protect any metallic piping components.

For piping, local structure-to-soil potentials should be obtained at both the tank end of the piping run and at each dispenser. A remote structure-to-soil potential may also be obtained. When metallic piping runs are more than 100 feet long, an additional local structure-to-soil potential should be obtained at the approximate midpoint of the piping run. For longer metallic piping runs, enough local structure-to soil potentials should be obtained along the length of the piping run such that no more than 100 feet of piping extends between successive test locations.

7.4.6 Impressed Current System Test Locations

Tank and piping components protected by impressed current cathodic protection systems must be tested with the reference electrode placed local to the structure being tested. The tester should obtain local structure-to-soil potentials from as many soil access points as is practical to evaluate the adequacy of cathodic protection for the entire structure. If there are any active galvanic anodes buried in close proximity to the structure being tested, they must be temporarily disconnected to ensure that the observed local potentials are not influenced by raised earth (see Section 7.3).

For tanks, a sufficient number of local structure-to-soil potentials should be taken to evaluate cathodic protection over the entire structure. When obtaining local potentials, the reference electrode may be placed in the soil at any point along the centerline of the tank.

For piping, local structure-to-soil potentials should be obtained at both the tank end of the piping run and at each dispenser. When metallic piping runs are more than 100 feet long, an additional local structure-to-soil potential should be obtained at the approximate midpoint of the piping run. For longer, metallic piping runs, enough local structure-to-soil potentials should be obtained along the length of the piping run such that no more than 100 feet of piping extends between successive test locations.

SECTION 8 - CATHODIC PROTECTION EVALUATION DOCUMENTATION

8.1 Documentation

When evaluating a cathodic protection system, as with any kind of testing or work that is being performed at a UST facility, it is critical that proper documentation is made of all activities and test procedures. Without proper documentation, the evaluation of a cathodic protection system through the application of a structure-to-soil potential survey is of little value. Various methods of documentation may be necessary in order to clearly convey the procedures and survey results. Some of the more critical aspects of documentation are discussed in more detail in the sections that follow.

8.1.1 Site Drawing

Whenever a cathodic protection survey is conducted, a site drawing should be constructed depicting the UST system, the cathodic protection system, and any related features of the facility. The cathodic protection tester should indicate on the site drawing where the reference electrode was placed for each structure-to-soil potential used to obtain the results used in the evaluation.

DEP recognizes that the cathodic protection tester will not always know where all of the pertinent components of the cathodic protection system may be buried. However, all that is known to the cathodic protection tester should be indicated. It is very important to show where the anodes are located on the site drawing for any impressed current system or field-installed galvanic system.

8.1.2 DEP Cathodic Protection Evaluation Form

Whenever a UST cathodic protection survey is conducted in the Commonwealth of Pennsylvania, DEP form 2630-FM-BECB0610 "UST Cathodic Protection System Evaluation Form" may be used to document the survey and its evaluation. However, use of the prescribed form is not intended to limit other kinds of documentation that may be desirable in order to complete the evaluation. For instance, it may be necessary to provide photographs or a written narrative describing various aspects of the evaluation that are not captured by completion of the form. In addition, any repairs or other modifications made to the cathodic protection system should be documented on DEP form 2630-FM-BECB0575 "Underground Storage Tank Modification Report" by the DEP certified installer (UMX certification) who performed or oversaw completion of the tank handling activity.

8.1.3 Pass / Fail / Inconclusive

In order to assure uniformity in the manner in which UST cathodic protection evaluations are documented, the tester must determine a test result. DEP recommends documenting the test result as prescribed in DEP form 2630-FM-BECB0610 "UST Cathodic Protection System Evaluation Form". The terms "pass", "fail", and "inconclusive" are used for this purpose. Therefore, it is necessary to clarify what these terms mean and their applicability as related to documenting a cathodic protection evaluation using the DEP form.

An evaluation conducted by an individual who is qualified as a cathodic protection tester must result in one of three conclusions: "pass", "fail" or "inconclusive".

Pass – The term "pass", as related to Section III and IV (tester's/expert's evaluation) of the DEP form, means that the cathodic protection survey results indicate that all of the cathodically protected structures at the facility meet at least one of the accepted test criteria.

Fail – The term "fail", as related to Section III and IV (tester's/expert's evaluation) of the DEP form, means that the cathodic protection survey results indicate that one or more of the cathodically protected structures at the facility do not meet any of the accepted test criteria.

Inconclusive – The term "inconclusive", as related to Section III (tester's evaluation) of the DEP form, is taken to mean that a person qualified as a cathodic protection tester is unable to conclusively evaluate the cathodic protection system. *In this instance, a corrosion expert must evaluate the test results and/or conduct additional testing in order to make a "pass" or "fail" determination and complete Section IV (expert's evaluation) of the DEP form.*

8.2 Corrosion Expert's Evaluation

Although the storage tank Regulations allow persons who only have minimal training in the principles of cathodic protection to test and evaluate such systems, some instances may require the expertise of someone who is more qualified and better understands the principles involved.

Some of the more obvious scenarios in which an evaluation by a corrosion expert may be necessary are described below. If any of the conditions described below are met, a corrosion expert should evaluate the survey results obtained by the cathodic protection tester and/or conduct additional testing and complete Section IV (expert's evaluation) of DEP form 2630-FM-BECB0610 "UST Cathodic Protection System Evaluation Form".

A corrosion expert should evaluate or conduct the cathodic protection survey when:

- Supplemental anodes are added or other changes are made to the construction of an impressed current cathodic protection system.
- It is known or suspected that stray current is affecting the protected structure.
- The cathodic protection system evaluation was conducted by a cathodic protection tester and was declared "inconclusive" (see Section 8.1.3) in Section III (tester's evaluation) of DEP form 2630-FM-BECB0610 "UST Cathodic Protection System Evaluation Form".
- Adjustments to the rectifier output are made that are outside the original design specifications.

There may be circumstances, other than those listed above, that could require evaluation of the cathodic protection system by a corrosion expert.

8.3 What if the Evaluation Result is Fail?

It is important for the cathodic protection tester to properly and promptly notify the tank owner of the results of the cathodic protection system evaluation. The tank owner/operator is responsible for ensuring that the cathodic protection system is maintained in a manner that will provide adequate corrosion protection to the tank system.

There may be several different courses of action appropriate to resolve a failed evaluation because there are many factors that may cause a lower than desired structure-to-soil potential to be obtained during a cathodic protection survey. In cases where the results of the cathodic protection system evaluation are "fail" or "inconclusive", the local DEP Regional Office should be contacted for additional guidance.

APPENDIX A – INDUSTRY CODES/STANDARDS AND REFERENCES

Industry Codes/Standards

American Petroleum Institute (API) RP 1632 “Cathodic Protection of Underground Petroleum Storage Tanks and Piping Systems”.

American Petroleum Institute (API) RP 1615 “Installation of Underground Petroleum Storage Systems”.

National Association of Corrosion Engineers (NACE International) SP0169 “Control of External Corrosion on Underground or Submerged Metallic Piping Systems”.

National Association of Corrosion Engineers (NACE International) SP0285 “External Corrosion Control of Underground Storage Tank Systems by Cathodic Protection”.

National Association of Corrosion Engineers (NACE International) Standard TM0101 “Measurement Techniques Related to Criteria for Cathodic Protection of Underground Storage Tank Systems”.

National Association of Corrosion Engineers (NACE International) Standard TM0497 “Measurement Techniques Related to Criteria for Cathodic Protection on Underground or Submerged Metallic Piping Systems”.

Petroleum Equipment Institute (PEI) RP100 “Recommended Practices for Installation of Underground Liquid Storage Systems”.

Steel Tank Institute (STI) R892 “Recommended Practice for Corrosion Protection of Underground Piping Networks Associated with Liquid Storage and Dispensing Systems”.

Steel Tank Institute (STI) R972 “Recommended Practice for the Addition of Supplemental Anodes to sti-P_3® UST's”.

Steel Tank Institute (STI) R051 “Cathodic Protection Testing Procedures for sti-P_3® USTs”.

References

Department of Defense MIL-HDBK-1136 “Maintenance and Operation of Cathodic Protection Systems”.

Department of Defense MIL-HDBK-1136/1 “Cathodic Protection Field Testing”.

Pennsylvania Department of Environmental Protection 263-0900-011 “Storage Tank Modification and Maintenance Issues”.

Pennsylvania Department of Environmental Protection 263-3120-001 “Evaluation of Underground Storage Tank (UST) Liners”.

Pennsylvania Department of Environmental Protection 2630-FM-BECB0610 “UST Cathodic Protection System Evaluation Form”.

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