**SP0169-2013**
**(formerly RP0169)**
**Item No. 21001**

# Standard Practice

# Control of External Corrosion on Underground or Submerged Metallic Piping Systems

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## Foreword

This standard presents methods and practices for achieving effective control of external corrosion on underground or submerged metallic piping systems. These methods and practices are also applicable to many other underground or submerged metallic structures. It is intended for use by corrosion control personnel concerned with the corrosion of underground or submerged piping systems, such as those used for the transport of oil, gas, water, and other fluids. This standard describes the use of electrically insulating coatings, electrical isolation, and cathodic protection (CP) as they relate to external corrosion control. This standard does not include corrosion control methods based on injection of chemicals into the environment, on the use of electrically conductive coatings, or on the use of nonadhered polyethylene encasement (refer to NACE Publication 10A292).[1] The standard contains specific provisions for the application of CP to existing uncoated, existing coated, and new piping systems. Also included are methods for control of stray currents on pipelines.

This standard should be used in conjunction with the practices described in the following NACE standards and publications, when appropriate (use latest revisions):

SP0572[2]

SP0177[3]

SP0285[4]

SP0286[5]

SP0188[6]

TPC 11[7]

TM0497[8]

For accurate and correct application, this standard must be used in its entirety. Using or citing only specific paragraphs or sections can lead to misinterpretation and misapplication of the practices contained in this standard.

This standard does not designate practices for every specific situation because of the complexity of conditions to which underground or submerged piping systems are exposed. This standard is not intended to apply to offshore pipelines and structures. For these facilities, the recommended NACE standards are NACE SP0607/ISO 15589-2[9] for offshore pipelines, and SP0176[10] for offshore structures. Definitions of onshore and offshore vary, and it is the responsibility of the user to determine which of the above standards apply to pipelines across coastal boundaries.

This standard was originally published in 1969, and was revised by NACE Task Group T-10-1 in 1972, 1976, 1983, and 1992. It was reaffirmed in 1996 by NACE Unit Committee T-10A, “Cathodic Protection,” and in 2002 and 2007 by Specific Technology Group (STG) 35, “Pipelines, Tanks, and Well Casings.” It was revised in 2013 by Task Group (TG) 360, “Piping Systems: Review of SP0169-2007 (formerly RP0169), ‘Control of External Corrosion on Underground or Submerged Metallic Piping.’” This standard is issued by NACE International under the auspices of STG 35, which is composed of corrosion control personnel from oil and gas transmission companies, gas distribution companies, power companies, corrosion consultants, and others concerned with external corrosion control of underground or submerged metallic piping systems.

> In NACE standards, the terms *shall*, *must*, *should*, and *may* are used in accordance with the definitions of these terms in the NACE Publications Style Manual. The terms *shall* and *must* are used to state a requirement, and are considered mandatory. The term *should* is used to state something good and is recommended, but is not considered mandatory. The term *may* is used to state something considered optional.

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# Standard Practice

# Control of External Corrosion on Underground or Submerged Metallic Piping Systems

## Contents

FIGURES

TABLES

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## Section 1: General

1.1 This standard presents accepted methods and practices for the control of external corrosion on buried or submerged steel, stainless steel, cast iron, ductile iron, copper, and aluminum piping systems.

1.2 This standard is intended to serve as a guide for establishing requirements for control of external corrosion on the following systems:

1.2.1 New piping systems: A proven method of corrosion control (e.g., coating supplemented with CP) should be provided in the initial design and maintained during the service life of the piping system, unless investigations indicate that corrosion control is not required. Consideration should be given to the construction of piping in a manner that facilitates the use of in-line inspection (ILI) tools.

1.2.2 Existing coated piping systems: CP should be provided and maintained (which includes the maintenance of coating as necessary), unless investigations indicate that CP is not required.

1.2.3 Existing uncoated piping systems: Studies can be made to determine the extent and rate of corrosion on existing uncoated piping systems. When these studies indicate that corrosion affects the safe or economic operation of the system, adequate corrosion control measures shall be taken.

1.3 The provisions of this standard are intended to be applied under the direction of competent persons who, by reason of knowledge of the physical sciences and the principles of engineering and mathematics, acquired by education and related practical experience, are qualified to engage in the practice of corrosion control on underground or submerged metallic piping systems.

Note: Such persons might be, but are not limited to, registered professional engineers or persons recognized as Corrosion Specialists or CP Specialists by NACE, if their professional activities include suitable experience in external corrosion control of underground or submerged metallic piping systems.

1.4 Special conditions in which CP is ineffective or only partially effective sometimes exist (see Paragraph 6.2.1.4 for examples). Deviation from this standard might be warranted in specific situations provided that corrosion control personnel in responsible charge are able to demonstrate that the objectives expressed in this standard have been achieved.

1.5 This standard is not intended for use in the control of internal corrosion.

## Section 2: Definitions,(1) Abbreviations, and Acronyms

**Definitions:**

**Amphoteric Metal:** A metal that is susceptible to corrosion in both acid and alkaline environments.

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

**Anode Bed:** One or more anodes installed—underground or submerged—for the purpose of supplying cathodic protection. It is often called a groundbed.

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

**Beta Curve:** A plot of dynamic (fluctuating) stray current or related proportional voltage (ordinate) versus the corresponding structure-to-electrolyte potentials at a selected location on the affected structure (abscissa). For the purposes of this standard,

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(1) Definitions in this section reflect common usage among practicing corrosion control personnel and apply specifically to how the terms are used in this standard. In many cases, in the interests of brevity and practical usefulness, the scientific definitions are abbreviated or paraphrased.

"Beta Curve" is defined as a correlation between the pipe-to-soil potential of the affected pipeline and the open-circuit potential between the affected pipeline and the stray current source.

**Cable:** One conductor or multiple conductors insulated from one another.

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

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

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

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

**Cathodic Protection:** A technique to reduce the corrosion of a metal surface by making that surface the cathode of an electrochemical cell.

**Cathodic Protection Criterion:** Standard for assessment of the effectiveness of a cathodic protection system.

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

**Coating Disbondment:** The loss of adhesion between a coating and the pipe surface.

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

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

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

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

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

**Corrosion Potential ($E_{corr}$):** The potential of a corroding surface in an electrolyte measured under open-circuit conditions relative to a reference electrode (also known as *electrochemical corrosion potential, free corrosion potential*, *open-circuit potential*).

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

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

**Current Density:** The electric current to or from a unit area of an electrode surface.

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

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

**Distributed-Anode Impressed Current System:** An impressed current anode configuration in which the anodes are "distributed" along the structure at relatively close intervals such that the structure is within each anode's voltage gradient. This anode configuration causes the electrolyte around the structure to become positive with respect to remote earth.

**Electrical Isolation:** The condition of being electrically separated from other metallic structures or the environment.

**Electrical Shielding:** Preventing or diverting the cathodic protection current from its intended path.

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

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

**Electrolytically Contacted Pipeline Casing:** A casing that contains soil or water electrolyte in contact with both the casing and the carrier pipe.

**Electroosmotic Effect:** Passage of a charged particle through a membrane under the influence of a voltage. Soil or coatings can act as the membrane.

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

**Empirical:** Originating in or based on observation or experience.

**Free Corrosion Potential**: See *Corrosion Potential.*

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

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

**Galvanic Series:** A list of metals and alloys arranged according to their corrosion potentials in a given environment.

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

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

**In-Line Inspection:** The inspection of a pipeline using an electronic instrument or tool that travels along the interior of the pipeline.

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

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

**Interference Bond:** An intentional metallic connection, between metallic systems in contact with a common electrolyte, designed to control electrical current interchange between the systems.

**IR Drop:** See *Voltage Drop*.

**Isolation:** See *Electrical Isolation*.

**Line Current:** The direct current flowing in a pipeline.

**Linear Anode Impressed Current System:** An impressed current anode configuration in which a continuous anode is installed parallel to the structure such that the structure is within the anode voltage gradient.

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

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

**Mechanical Damage Protection System:** Consists of multiple processes and products to achieve protection for the piping and coating system.

**Mechanical Shielding:** Protective cover against mechanical damage. See *Mechanical Damage Protection* and *Mechanical Damage Protection System.*

**Microbiologically Influenced Corrosion (MIC):** Corrosion affected by the presence or activity, or both, of microorganisms.

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

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

**Nonshielding Coating System:** A coating system with a failure mode (loss of adhesion, etc.) that does not prevent distribution of cathodic protection current to the metal substrate.

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

**Pipe-to-Electrolyte Potential:** See *Structure-to-Electrolyte Potential*.

**Pipeline Casing:** See *Casing*.

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

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

**Reduction:** Gain of electrons by a constituent of a chemical reaction.

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

**Reverse-Current Switch:** A device that prevents the reversal of direct current through a metallic conductor.

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

**Shorted Pipeline Casing:** A casing that is in direct metallic contact with the carrier pipe.

**Sound Engineering Practices:** Reasoning exhibited or based on thorough knowledge and experience, logically valid, and has technically correct premises that demonstrate good judgment or sense in the application of science.

**Stray Current:** Current through paths other than the intended circuit.

**Stray-Current Corrosion:** Corrosion resulting from stray current.

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

**Telluric Current:** Current in the earth as a result of geomagnetic fluctuations.

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

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

**Voltage Drop:** The voltage across a resistance when the current is applied in accordance with Ohm's Law. This term is also referred to as *IR drop*.

**Weak Acids:** Acids that only partially dissociate to form hydrogen ($H^+$) ions at moderate concentrations.[11]

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

**Abbreviations and Acronyms:**

**AC:** Alternating current

**AGA:**(2) American Gas Association

**ANSI:**(3) American National Standards Institute

**API:**(4) American Petroleum Institute

**ARO:** Abrasion-resistant overcoating

**ASTM:**(5) ASTM International (formerly American Society for Testing and Materials)

**AWG:** American Wire Gauge

**AWWA:**(6) American Water Works Association

**BSI:**(7) British Standards Institute

**CIS:** Close interval (potential) survey

**CP:** Cathodic protection

**CGA:**(8) Canadian Gas Association

**CSA:**(9) Canadian Standards Association International

**CSE:** Saturated copper-copper sulfate reference electrode

**DC:** Direct current

**DCVG:** Direct current voltage gradient

**DIN:**(10) Deutsches Institut fur Normung

**DNV:**(11) Det Norske Veritas

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(2) American Gas Association (AGA), 400 North Capitol St. NW, Suite 400, Washington, DC 20001.
(3) American National Standards Institute (ANSI), 1819 L St. NW, Washington, DC 20036.
(4) American Petroleum Institute (API), 1220 L St. NW, Washington, DC 20005-4070.
(5) ASTM International, 100 Barr Harbor Dr., West Conshohocken, PA 19428-2959.
(6) American Water Works Association (AWWA), 6666 West Quincy Ave., Denver, CO 80235.
(7) British Standards Institution (BSI), British Standards House, 389 Chiswick High Road, London W4 4AL, United Kingdom.
(8) Canadian Gas Association (CGA), 350 Sparks Street, Suite 809, Ottawa, Ontario K1R 7S8, Canada.
(9) CSA International, 178 Rexdale Blvd., Toronto, Ontario, Canada M9W 1R3.
(10) Deutsches Institut fur Normung (DIN), Burggrafenstrasse 6, D-10787 Berlin, Germany.

**ECDA:** External corrosion direct assessment

**EN:** [12] European Standard

**FBE:** Fusion-bonded epoxy

**HDD:** Horizontal directional drilling

**HIC:** Hydrogen-induced cracking

**HPIS:**[13] High Pressure Institute of Japan

**HVAC:** High-voltage alternating current

**HVDC:** High-voltage direct current

**ILI:** In-line inspection

**ISO:**[14] International Organization for Standardization

**JWWA:**[15] Japan Water Works Association

**MIC:** Microbiologically influenced corrosion

**MIG:** Metal inert-gas shielded arc (welding process)

**mV:** Millivolt(s)

**NAPCA:**[16] National Association of Pipe Coating Applicators

**NEC:** National Electrical Code (U.S.)

**NEMA:**[17] National Electrical Manufacturers Association (U.S.)

**NIST:**[18] National Institute of Standards and Technology (U.S.)

**NFPA:**[19] National Fire Protection Association (U.S.)

**NRC:**[20] National Research Council (Canada)

**NSF:**[21] NSF International

**PE:** Polyethylene

**ROW:** Right-of-way

**SA:**[22] Standards Australia

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[11] Det Norske Veritas (DNV), Veritasveien 1, 1322, Høvik, Oslo, Norway.
[12] European Standard; European Committee for Standardisation, Rue de Stassart, 36, B-1050 Brussels. Belgium.
[13] High Pressure Institute of Japan (HPIS), 5th Floor. Sanpo Sakuma Bldg.,1-11, Kanda-Sakuma-cho, Chiyoda-ku 101-0025, Tokyo, Japan.
[14] International Organization for Standardization (ISO), 1 rue de Varembe, Case Postale 56, CH-1121, Geneve 20, Switzerland.
[15] Japan Water Works Association (JWWA), 4-8-9 Kudan Minami, Chiyoda-ku 102-0074, Tokyo, Japan.
[16] National Association of Pipe Coating Applicators (NAPCA), 1000 Louisiana St., Suite 3400, Houston, TX 77002.
[17] National Electrical Manufacturers Association (NEMA), 1300 North 17th St., Suite 1752, Rosslyn, Virginia 22209.
[18] National Institute of Standards and Technology (NIST) (formerly National Bureau of Standards), 100 Bureau Dr., Gaithersburg, MD 20899.
[19] National Fire Protection Association (NFPA), Batterymarch Park, Quincy, MA 02269.
[20] National Research Council Canada (NRC), 1200 Montreal Road, Ottawa, Ontario K1A 0R6, Canada.
[21] NSF International, 789 Dixboro Rd., Ann Arbor, MI 48113.
[22] Standards Australia (SA), P.O. Box 1055, Strathfield, NSW 2135, Australia.

**SCC:** Stress corrosion cracking

**SHE:** Standard hydrogen electrode

**SP:** Standard practice

**SSPC:** Society for Protective Coatings(23)

**STG:** Specific Technology Group (NACE)

**TG:** Task Group (NACE)

**TIG:** Tungsten inert-gas shielded arc (welding process)

**TPC:** Technical Practices Committee (NACE) (now TCC)

**TM:** Test method (NACE)

## Section 3: Determination of Need for External Corrosion Control

### 3.1 Introduction

3.1.1 Metallic structures, underground or submerged, are subject to corrosion. Adequate corrosion control procedures can reduce or eliminate metal loss for safe and economical operation.

3.1.2 This section provides practices for determining when an underground or submerged metallic piping system requires external corrosion control.

3.2 The need for external corrosion control should be based on data obtained from one or more of the following: corrosion surveys, operating records, visual observations, test results from similar systems in similar environments, in-line inspections, engineering and design specifications, risk assessment, environmental exposure, physical operating conditions, safety, and economic considerations. The absence of leaks alone is insufficient evidence that corrosion control is not required; however, such data can be useful to evaluate the effectiveness of existing corrosion control measures.

3.2.1 Environmental and physical factors include the following:

3.2.1.1 Corrosion rate of the particular metallic piping system in a specific environment (see Paragraph 3.2.2.1), pipe wall thickness, pipe material, and method of manufacturing;

3.2.1.2 Nature of the product being transported, the working temperature, temperature differentials within the pipeline causing thermal expansion and contraction, tendency of backfill to produce soil stress, and working pressure of the piping system as related to design specification;

3.2.1.3 Location of the piping system as related to population density and frequency of visits by personnel;

3.2.1.4 Location of the piping system as related to other facilities; and

3.2.1.5 Stray-current sources.

3.2.2 Economic considerations include the following:

3.2.2.1 Costs of maintaining the piping system in service for its expected life. Maintenance of a piping system may include repairing corrosion leaks and reconditioning or replacing all or portions of the system. To make estimates of the costs involved, the user should determine the probability of corrosion or the rate at which corrosion is proceeding. The usual methods of predicting the probability or rate of corrosion are as follows:

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(23) Society for Protective Coatings (SSPC), 40 24th St., Pittsburgh, PA 15222.

(a) Study of corrosion history on the piping system in question or on other systems of the same material in the same general area or in similar environments. Cumulative leak-frequency curves are valuable in this respect.

(b) Study of the environment (electrolyte) surrounding a piping system: resistivity, pH, and chemical and microbial composition of the soil. Redox potential tests may also be used to a limited extent. Once the nature of the environment has been determined, the probable corrosiveness is estimated by reference to actual corrosion experience on similar metallic structures, when environmental conditions are similar. Consideration of possible environmental changes such as those that might result from irrigation, spillage of corrosive substances, pollution, and seasonal changes in water table and soil moisture content should be included in such a study.

(c) Investigation for corrosion on a piping system by visual inspection of the pipe or by instruments that mechanically or electrically inspect the condition of the pipe. Condition of the piping system should be carefully determined and recorded each time a portion of the line is excavated for any reason.

(d) Maintenance records detailing leak locations, pipe inspection reports, soil studies, structure-to-electrolyte potential surveys, surface potential surveys, line current studies, and wall thickness surveys used as a guide for locating areas of maximum corrosion.

(e) Statistical treatment of available data.

(f) Results of pressure testing. Under certain conditions, this can help to determine the existence of corrosion.

(g) Coating, if present, should be evaluated for consideration of its effectiveness in corrosion control.

3.2.2.2 Contingent costs of corrosion (risk assessment, etc.). In addition to the direct costs that result from corrosion, contingent costs include:

(a) Public liability claims;

(b) Property damage claims;

(c) Damage to natural facilities, such as municipal or irrigation water supplies, forests, parks, and scenic areas;

(d) Cleanup of product lost to surroundings;

(e) Plant shutdown and startup costs;

(f) Cost of lost product;

(g) Loss of revenue through interruption of service;

(h) Loss of contract or goodwill through interruption of service; and

(i) Loss of reclaim or salvage value of piping system.

3.2.2.3 Costs of corrosion control. The usual costs for protecting buried or submerged metallic structures are for coating and CP, which may each be applied to part or all of the structure as needed to provide adequate corrosion control. Other corrosion control costs include:

(a) Relocation of piping to avoid known corrosive conditions (this may include installing lines above ground);

(b) Relocation because of public road or transit construction that results in adverse conditions;

(c) Reconditioning and externally coating the piping system, especially a coating upgrade;

(d) Use of corrosion-resistant materials;

(e) Use of selected or inhibited backfill;

(f) Electrical isolation to limit possible galvanic action; and

(g) Correction of conditions in or on the pipe that might accelerate corrosion.

3.2.2.4 Replacement cost of the asset under protection.

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## Section 4: Piping System Design

### 4.1 Introduction

This section provides accepted corrosion control practices in the design of an underground or submerged piping system. A person qualified to engage in the practice of corrosion control should be consulted during all phases of pipeline design and construction (see Paragraph 1.3). These practices should not be construed as taking precedence over recognized safety practices.

### 4.2 External Corrosion Control

4.2.1 External corrosion control must be a primary consideration during the design of a piping system. Materials selection and coatings are primary methods of external corrosion control. Because perfect coatings are not feasible, CP should be used in conjunction with coatings for extended corrosion protection. For additional information, see Sections 5 and 6.

4.2.2 External coatings are commonly utilized in conjunction with CP. When specified, they should be properly selected, specified, and applied. Desirable characteristics of external coatings are given in Paragraph 5.1.2.1.

4.2.3 Piping systems should be constructed in such a manner to avoid electrical shielding of CP.

### 4.3 Electrical Isolation

4.3.1 Isolation devices such as flange assemblies, prefabricated joints, unions, couplings, or, where permissible, sections of nonconductive piping should be installed within piping systems in which electrical isolation of portions of the system is required to facilitate the application of external corrosion control. These devices must be properly selected for temperature, pressure, chemical resistance, dielectric resistance, and mechanical strength. Safety measures must be considered if isolating devices are installed in areas in which combustible atmospheres are likely to be present. Locations at which electrical isolating devices may be considered include, but are not limited to, the following:

4.3.1.1 Points at which facilities change ownership, such as meter stations, delivery facilities, and well heads;

4.3.1.2 Connections to mainline piping systems, such as gathering or distribution system laterals;

4.3.1.3 Inlet and outlet piping of in-line measuring and pressure-regulating stations;

4.3.1.4 Compressor or pumping stations, either in the suction and discharge piping or in the main line immediately upstream and downstream from the station;

4.3.1.5 Stray-current areas;

4.3.1.6 The junction of dissimilar metals;

4.3.1.7 The termination of service line connections and entrance piping;

4.3.1.8 The junction of a coated pipe and an uncoated pipe;

4.3.1.9 Locations at which electrical grounding is used, such as motorized valves and instrumentation; and

4.3.1.10 Water pipeline~~s~~, connections to water hydrants, existing pipelines, or pipelines of different materials, such as steel and ductile or cast iron.

4.3.2 Casings should be avoided. However, when metallic casings are required as part of the underground piping system, the pipeline should be electrically isolated from such casings. Casing isolators must be properly sized and spaced and be tightened securely on the pipeline to withstand insertion stresses without sliding on the pipe. Inspection should be made to verify that the leading isolator has remained in position. Concrete coatings on the carrier pipe could preclude the use of casing isolators. Consideration shall be given to the use of support under the pipeline at each end of the casing to minimize settlement. The type of support selected should not cause damage to the pipe coating. Casing seals may be installed to resist the entry of foreign matter into the casing (refer to NACE SP0200).[12]

4.3.3 Piping systems should be electrically isolated from supporting pipe stanchions, bridge structures, tunnel enclosures, pilings, grounded structures, reinforcing steel in concrete, and metal tiedowns used for restraining purposes when electrical contact would adversely affect CP.

4.3.4 When an isolating joint is required, a device manufactured to perform this function should be used, or, if permissible, a section of nonconductive pipe, such as plastic pipe, may be installed. In either case, these should be properly rated and installed in accordance with the manufacturer’s instructions. In addition, consideration must be given to possible detrimental effects of stray current around the joint, both inside (if containing an electrically conductive material ) and outside the pipe.

4.3.5 River weights, pipeline anchors, and metallic reinforcement in weight coatings should be electrically isolated from the carrier pipe. Weighting and anchors should be designed and installed so that coating damage does not occur and the carrier pipe is not electrically shielded.

4.3.6 Metallic curb boxes and valve enclosures should be designed, fabricated, and installed in such a manner that electrical isolation from the piping system is maintained.

4.3.7 Isolating spacing materials should be used when the intent is to maintain electrical isolation between a metallic wall sleeve and the pipe.

4.3.8 Underground piping systems should be installed so that they are physically separated from all foreign underground metallic structures at crossings and parallel installations and in such a way that electrical isolation could be maintained if desired.

4.3.9 Based on load rating of alternating current (AC) transmission lines, adequate separation should be maintained between pipelines and electric transmission tower footings, ground cables, and counterpoise. Consideration must always be given to induced AC voltages, lightning, fault current protection of pipeline(s), and to personnel safety (see NACE SP0177). The need for lightning and fault current protection at isolating devices must be considered. Cable connections from isolating devices to arresters should be short, direct, and of a size suitable for short-term high current loading.

### 4.4 Electrical Continuity

Electrical continuity of piping systems that are constructed with nonwelded pipe joints is not reliable. Electrical continuity can be ensured by bonding across bell- and spigot-type joints and to the metallic components of the mechanical joints in an effective manner (see Paragraph 4.5.3).

### 4.5 Corrosion Control Test Stations

4.5.1 Test stations for potential, current, or resistance measurements shall be provided at sufficient locations to facilitate CP testing. Such locations may include, but are not limited to, the following:

4.5.1.1 Pipe casing installations;

4.5.1.2 Metallic structure crossings;

4.5.1.3 Isolating joints;

4.5.1.4 Waterway crossings;

4.5.1.5 Bridge crossings;

4.5.1.6 Valve stations;

4.5.1.7 Galvanic anode installations;

4.5.1.8 Road crossings;

4.5.1.9 Stray-current areas; and

4.5.1.10 Impressed current installations.

4.5.2 A span of pipe used for current flow measurement test stations should exclude:

4.5.2.1 Foreign metallic structure crossings;

4.5.2.2 Lateral connections;

4.5.2.3 Mechanical couplings such as screwed joints, transition pieces, valves, flanges, or electrical connections, such as anode or rectifier attachments, or metallic bonds; and

4.5.2.4 Changes in pipe wall thickness and diameter, unless span resistance is measured.

4.5.3 Attachment of Copper Test Lead and Bonding Wires to Steel and Other Ferrous Pipes

4.5.3.1 Test lead wires may be used both for periodic testing and for current-carrying purposes. As such, the wire/pipe attachment should be mechanically strong and electrically conductive.

4.5.3.2 Methods of attaching wires to the pipe include (a) exothermic welding, (b) soldering, (c) brazing, (d) mechanical means, and (e) high-strength permanent magnetic connections.

4.5.3.3 Particular attention must be given to the attachment method to avoid (a) damaging or penetrating the pipe, (b) sensitizing or altering of pipe properties, (c) weakening the test lead wire, (d) damaging internal or external pipe coatings, and (e) creating hazardous conditions in explosive or combustible environments. Refer to ASME B31.8,[13] Section 862.115 or ASME B31.4,[14] Section 461.1.5 for additional recommendations when attaching a test lead wire on gas or liquid pipeline systems.

4.5.3.4 Mechanical connections that remain secure and electrically conductive may be used. Attachment by mechanical means is the least desirable method. Such a connection can loosen, become highly resistant, or lose electrical continuity.

4.5.3.5 The connection must be tested for mechanical strength and electrical continuity. All exposed portions of the pipe and connection should be thoroughly cleaned of all welding slag, dirt, oils, etc.; primed, if needed; and coated with materials compatible with the cable insulation, pipe coating, and environment.

4.5.4 Attachment of Aluminum Test Lead Wire to Aluminum Pipes

4.5.4.1 Aluminum test lead wire, or aluminum tabs attached to aluminum wire, may be welded to aluminum pipe using the tungsten inert-gas shielded arc (TIG) or metal inert-gas shielded arc (MIG) process. Welded attachments should be made to flanges or at butt weld joints. Attachment at other sites can adversely affect the mechanical properties of the pipe because of the heat of welding.

4.5.4.2 Test lead wire may be attached to aluminum pipe by soldering. If low-melting-point soft solders are used, a flux is required. Flux residues can cause corrosion unless removed. Particular attention must be given to the attachment method to avoid (a) damaging or penetrating the pipe, (b) sensitizing or altering of pipe properties, (c) weakening the test lead wire, and (d) creating hazardous conditions in explosive or combustible environments.

Note: The use of copper test lead wire can cause preferential galvanic attack on the aluminum pipe. When copper wire or flux is used, care must be taken to seal the attachment areas against moisture. In the presence of moisture, the connection can disbond and be damaged by corrosion.

4.5.4.3 Aluminum tabs to which test lead wires have been TIG welded can be attached by an explosive bonding technique called high-energy joining.

4.5.4.4 Mechanical connections that remain secure and electrically conductive may be used. Attachment by mechanical means is the least desirable method. Such a connection can loosen, become highly resistant, or lose electrical continuity.

4.5.5 Attachment of Copper Test Lead Wire to Copper Pipe

4.5.5.1 Copper test lead wire, or copper tabs attached to copper wire, may be attached to copper pipe by one of the following methods. Mechanical connections that remain secure and electrically conductive may be used. Attachment by mechanical means is the least desirable method. Such a connection can loosen, become highly resistant, or lose electrical continuity. Particular attention must be given to the attachment method to avoid (a) damaging or penetrating the pipe, (b) sensitizing or altering of pipe properties, (c) weakening the test lead wire, and (d) creating hazardous conditions in explosive or combustible environments. The relative thickness of the wire and the pipe wall dictates, in part, which of the methods can be used:

4.5.5.1.1 Arc welding (TIG, MIG, or shielded metal);

4.5.5.1.2 Electrical resistance (spot) welding;

4.5.5.1.3 Brazing;

4.5.5.1.4 Soldering; or

4.5.5.1.5 Mechanical connection.

4.5.5.2 Attention shall be given to proper joining procedures to avoid possible embrittlement or loss of mechanical properties of the metals from the heat of welding or brazing.

4.5.5.3 A flux might be required, or self-produced, when brazing with some filler metals or soldering with some low-melting-point soft solders. Because flux residues can cause corrosion, they must be removed.

4.5.5.4 The connection must be tested for mechanical strength and electrical continuity. All exposed portions of the pipe and connection should be thoroughly cleaned of all welding slag, flux, dirt, oils, etc.; primed, if needed; and coated with materials compatible with the cable insulation, pipe coating, and environment.

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## Section 5: External Coatings

5.1 Introduction

5.1.1 This section provides an overview of practices to provide guidance for selecting, testing, evaluating, handling, storing, inspecting, installing, and protecting coating systems for external corrosion control on piping systems.

5.1.2 The functions of external coatings are to control corrosion by isolating the external surface of the underground or submerged piping from the environment, to reduce CP current requirements, and to improve current distribution.

5.1.3 Mechanical Damage Protection System

5.1.3.1 Mechanical damage protection systems such as rock shield, abrasion-resistant overcoatings, etc., may be installed if required by owner specifications, and should be designed to eliminate or minimize damage to the pipe and its coating without inhibiting or interfering with CP requirements (see *Electrical shielding* in Section 2.)

5.1.3.2 Considerations for Determining Whether a Mechanical Damage Protection System Might Be Beneficial or Necessary

5.1.3.2.1 Type of bedding and backfill; and

5.1.3.2.2 Method of installation—horizontal directional drilling, submerging, etc.

5.1.3.3 Considerations for Selecting a Mechanical Damage Protection System

5.1.3.3.1 Must be nontoxic to the environment, does not break down and release toxic chemicals or gases;

5.1.3.3.2 Must not break down during storage, handling, and installation;

5.1.3.3.3 Must be chemically and physically compatible with pipe coating;

5.1.3.3.4 Must be resistant to degradation caused by acidic or caustic electrolyte; and

5.1.3.3.5 Must retain physical characteristics when installed and during anticipated life of the pipe.

5.1.4 Information in this section is primarily by reference to other documents (see Tables 1a, 1b, and Tables A1 through A4). It is important that the latest revision of the pertinent reference be used, and these tables are not intended to be all inclusive.

5.1.4.1 Tables 1a and 1b are example listings of types of external coating systems, showing the more common references for material specifications and recommended practices for application. This standard does not necessarily recommend the listed coating systems for any particular application. The user must determine the appropriate coating system based on the specific installation. There are currently no known specific coating standards for aluminum, copper, or stainless steel. Note that Tables A1 through A4 are found in Appendix A (nonmandatory).

5.1.4.2 Table A1 lists groupings of references for general use during installation and inspection, regardless of coating type.

5.1.4.3 Table A2 includes lists of external coating system characteristics related to environmental conditions containing suggested laboratory test references for various properties.

5.1.4.4 Tables A3(a) and A3(b) are lists of external coating system characteristics related to design and construction, with recommended laboratory tests for evaluating these properties.

5.1.4.5 Table A4 lists the references that are useful in field evaluation of external coating systems after the pipeline has been installed.

### Table 1a
### Generic External Coating Systems for Carbon Steel Pipe with Material Requirements and Recommended Practices for Application(A) for Underground and Submerged Pipe (Field- and Shop-Applied)

| Generic External Coating System | Reference |
|---|---|
| Asphalt/Coal Tar Enamel + Concrete | DNV-RP-F102[15]<br>NACE Standard RP0602[16]<br>DNV-RP-F106[17]<br>NACE Standard RP0399[18] |
| Coal Tar Enamel | ANSI/AWWA C 203[19]<br>NACE Standard RP0602<br>NAPCA Bulletin 13-79-94[20]<br>NACE Standard RP0399 |
| Cold-Applied and Hot-Applied Tape | ANSI/AWWA C 214[21]<br>ANSI/AWWA C 209[22]<br>NAPCA Bulletin 15-83-94[23]<br>NACE SP0109[24] |
| Concrete | ISO 21809-5[25] |
| Elastomeric Materials (Polychloroprene or Equivalent) | DNV-RP-F102<br>DNV-RP-F106 |
| Field-Applied Coatings for Repairs and Rehabilitation | DNV-RP-F102<br>NACE Standard RP0602<br>NACE SP0109 |
| Field Joint Coatings | ISO 21809-3<br>AWWA C 216[26]<br>AWWA C209<br>DIN 30672[27]<br>NACE Standard RP0402[28]<br>NACE SP0109<br>NACE Standard RP0303[29] |

| | |
|---|---|
| Fusion-Bonded Epoxy Coatings | ANSI/AWWA C 213[30]<br>API RP 5L9[31]<br>CSA Z245.20[32]<br>DNV-RP-F106<br>NACE Standard RP0394[33]<br>NACE Standard RP0402<br>NAPCA Bulletin 12-78-04[34]<br>NAPCA Bulletin 17-98[35]<br>ISO 21809-2 |
| Fusion-Bonded Epoxy + Concrete | DNV-RP-F106, used in conjunction with DNV-OS-F101[36] |
| Liquid-Epoxy | ANSI/AWWA C 210[37]<br>NACE Standard RP0105[38]<br>CSA Z245.20 |
| Mastic Coating | SSPC Paint 33[39] |
| Multilayer Epoxy Polyethylene | CSA Z245.21[40]<br>NF A49-710[41]<br>DIN 30670 |
| Multilayer (Including FBE Primer) Polyethylene (PE) and Polypropylene (PP) Anticorrosion | CSA Z245.21<br>DNV RP-F102<br>DNV RP-F106<br>DIN 30670 |
| Polyolefin Coatings | NACE SP0185[42]<br>DIN 30670<br>ANSI/AWWA C 215[43]<br>ANSI/AWWA C 216<br>ANSI/AWWA C 225[44]<br>DNV-RP-F102<br>DNV-RP-F106<br>NAPCA Bulletin 14-83-94[45]<br>ISO 21809-4 |
| Polyurethane | ANSI/AWWA C 222[46]<br>CSA Z245.20<br>Work in progress by TG 281[47] |
| Prefabricated Films | ANSI/AWWA C 214<br>ANSI/AWWA C 216<br>ANSI/AWWA C 209 |
| Wax | NACE Standard RP0375[48]<br>AWWA C 217[49] |

(A)Note: Many other references are available, and this table is not comprehensive. Listing does not constitute endorsement of any external coating system in preference to another. Omission of a system might be a result of unavailability of reference standards or lack of data.

### Table 1b
### Generic External Coating Systems for Ductile Iron Pipe with Material Requirements and Recommended Practices for Application(A)

| Generic External Coating System | Reference |
|---|---|
| Adhesive Tape | BS EN 545[50]<br>DIN 30672 |
| Extruded Polyethylene | BS EN 545<br>BS EN 14628[51] |
| Reinforced Cement Mortar Coating | BS EN 545<br>DIN 15542[52] |
| Field Joint Coating | BS EN 545 |
| Mastic Coating | SSPC Paint 33 |
| Polyurethane Coating | BS EN 545 |

| | |
|---|---|
| Polyethylene Sleeving (as a Supplement to the Zinc Coating with Finishing Layer) | BS EN 545 |
| Wax | NACE Standard RP0375 |
| Zinc—All Variations, Including Zinc-Rich Paint and Zinc-Aluminum with Finishing Layer | BS EN 545<br>DIN 30674-3[53]<br>ISO 8179-1[54]<br>ISO 8179-2 |

(A) Note: Many other references are available, and this table is not comprehensive. Listing does not constitute endorsement of any external coating system in preference to another. Omission of a system might be a result of unavailability of reference standards or lack of data.

## 5.2 Transport, Storage, Handling, Inspection, and Installation of Coated Pipe

### 5.2.1 Storage and Handling

5.2.1.1 When coated pipe is stored for later use, the user should evaluate the need to protect the coating from damage and environmental degradation. Consideration should be given to detrimental effects such as mechanical damage, severity of environmental conditions, anticipated length of storage, and ultraviolet (UV) degradation.

5.2.1.2 Damage to coating can be minimized by careful handling and using proper pads and slings placed at appropriate lifting points.

5.2.1.3 For additional guidance on the transport, storage, and handling of coated pipe, refer to API RP 5L1[55] (rail transport), API 5LW[56] (water transport), PRCI PR-218-064505[57] (highway transport), and sections in AWWA standards that discuss shipping, handling, and storage of pipe. There might be additional standards that apply to the specific pipe that is being installed.

### 5.2.2 Inspection

5.2.2.1 All inspection requirements and acceptance criteria should be noted in owner coating specifications and documented in a manner acceptable to the owner.

5.2.2.2 Only personnel trained and qualified in coating inspection should perform inspections. Inspectors shall be familiar with the characteristics of the mill- and field-applied coatings.

5.2.2.3 Surface preparation, primer application (if required), coating thickness, environmental conditions, temperature, bonding, and other specific requirements should be checked periodically, using appropriate or specified test procedures, for conformance to specifications and documented in accordance with owner requirements.

5.2.2.4 For dielectric coatings, holiday detectors are used to detect coating flaws that would not be observed visually. The holiday detector must be operated in accordance with the manufacturer's instructions and at a voltage level appropriate to the electrical characteristics of the coating system.[6,58]

### 5.2.3 Installation

5.2.3.1 Joints, fittings, and tie-ins must be coated with materials compatible with the existing coatings.

5.2.3.2 Coating defects identified during testing/inspection shall be repaired and the coating repair inspected in accordance with Paragraph 5.2.2.

5.2.3.3 Materials used to repair coatings shall be compatible with the pipe coating to be repaired and have equivalent properties.

5.2.3.4 The ditch bottom should be graded and free of rock or other foreign matter that could damage the external coating or cause electrical shielding. Under difficult conditions, consideration shall be given to importing select bedding material, padding the pipe or ditch bottom, or using a mechanical damage protection system.[59]

5.2.3.5 Pipe shall be lowered carefully into the ditch to avoid external coating damage. If the pipe is installed by boring (HDD) or other trenchless techniques, external coating damage should be avoided.[60,61] When possible, the pipe that passes through the bore should be inspected for coating damage and repaired as necessary.

5.2.3.6 During backfilling:

5.2.3.6.1 Caution should be exercised to prevent rocks or other debris from striking the pipe and damaging the coating.

5.2.3.6.2 No rock or other foreign material that could damage the external coating or cause electrical shielding should be placed in a trench or closer than 100 mm (4 in, nominal) to the pipe/pipeline.

5.2.3.7 When a pipeline is exposed to atmospheric conditions as a result of operational requirements, it must be coated with a material suitable for the atmosphere to which it is exposed. Coatings shall be applied in accordance with manufacturer's specifications. Special attention should be given to air-to-soil interfaces, splash zones, and pipe exposed to UV radiation.

5.2.4 External coatings must be properly selected and applied. The coated pipe must be carefully handled and installed to fulfill these functions. Various types of external coatings can accomplish the desired functions.

5.2.4.1 Desirable characteristics of external coatings include the following:

5.2.4.1.1 Effective electrical isolator;

5.2.4.1.2 Effective moisture barrier;

5.2.4.1.3 Application to pipe by a method that does not adversely affect the properties of the pipe;

5.2.4.1.4 Application to pipe with a minimum of defects;

5.2.4.1.5 Good adhesion to pipe surface;

5.2.4.1.6 Resistance to development of holidays with time;

5.2.4.1.7 Resistance to damage during handling, storage, and installation;

5.2.4.1.8 Ability to maintain substantially constant electrical resistivity with time;

5.2.4.1.9 Resistance to cathodic disbondment and disbonding from other factors such as soil stress and other environmental stresses;

5.2.4.1.10 Resistance to chemical and thermal degradation;

5.2.4.1.11 Ease of repair;

5.2.4.1.12 Retention of physical characteristics;

5.2.4.1.13 Nontoxic to the environment;

5.2.4.1.14 Resistance to changes and deterioration during aboveground storage and long-distance transportation;

5.2.4.1.15 Resistance to abrasion and mechanical stress;

5.2.4.1.16 Compatible with cathodic protection; and

5.2.4.1.17 Resistance to microorganisms.

5.2.4.2 Typical factors to consider during selection of an external pipe coating include:

5.2.4.2.1 Type of environment and design life expectations;

5.2.4.2.2 Accessibility of piping system;

5.2.4.2.3 Operating temperature of piping system;

5.2.4.2.4 Ambient temperatures during application, shipping, storage, construction, installation, and pressure testing;

5.2.4.2.5 Geographical and physical location;

5.2.4.2.6 Type of external coating on existing pipe in the system;

5.2.4.2.7 Handling and storage;

5.2.4.2.8 Pipeline installation methods;

5.2.4.2.9 Pipe surface preparation requirement;

5.2.4.2.10 Possible soil stresses, including thermal cycles; and

5.2.4.2.11 With submerged piping, susceptibility to mechanical damage by impact from debris.

5.2.4.3 Pipeline external coating systems shall be properly selected and applied to ensure that adequate bonding is obtained. Nonadhered (disbonded or unbonded) coatings can create electrical shielding of the pipeline that is detrimental to the effectiveness of the CP system.

5.2.4.4 Coatings may be periodically reformulated, but this might not be declared and the revised coatings can retain the same name. Regular laboratory batch testing can be beneficial to evaluate the quality of coatings and to detect the effects of any reformulation.

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## Section 6: Criteria and Other Considerations for Cathodic Protection

6.1 Introduction

6.1.1 This section lists criteria for CP that indicate whether adequate CP of a metallic piping system has been achieved (see also Section 1, Paragraphs 1.2 and 1.4). Adequate CP can be achieved at various levels of cathodic polarization depending on the environmental conditions. As such, a single criterion for evaluating the effectiveness of CP might not be satisfactory for all conditions or at all locations along a structure. The use of any approach, including a combination of methods or criteria to achieve adequate corrosion control, is the responsibility of the user, and should be based on the experience of the user and the unique conditions influencing the piping system(s). In determining whether adequate corrosion control has been achieved, the conditions and factors listed in Paragraph 6.2.1.3.1.2, Special Conditions (6.2.1.4), and Relevant Considerations (6.3) should be considered regardless of what methods or criteria are used. A commonly used benchmark for effective external corrosion control is (a reduction in the corrosion rate to) 0.025 mm per year (1 mil per year) or less.

6.1.2 In selecting the methods or criteria for a specific pipeline, the following are the responsibilities of the user:

6.1.2.1 To determine the level of corrosion control that is necessary and sufficient to address the specific conditions.

6.1.2.2 To include a means to evaluate the effectiveness of that method or criterion, whether used separately or in combination.

6.1.2.3 To document the effectiveness of CP or other external corrosion control measures (see Section 11). In the absence of such documentation, at least one of the criteria in Paragraph 6.2 shall apply.

6.2 Criteria

6.2.1 Criteria for Steel and Gray or Ductile Cast-Iron Piping

6.2.1.1 Criteria that have been documented through empirical evidence to indicate corrosion control effectiveness on specific piping systems may be used on those piping systems or others with the same characteristics.

6.2.1.2 A minimum of 100 mV of cathodic polarization. Either the formation or the decay of polarization must be measured to satisfy this criterion.[8,62]

6.2.1.3 A structure-to-electrolyte potential of –850 mV or more negative as measured with respect to a saturated copper/copper sulfate (CSE) reference electrode. This potential may be either a direct measurement of the polarized potential or a current-applied potential. Interpretation of a current-applied measurement requires consideration of the significance of voltage drops in the earth and metallic paths.

6.2.1.3.1 Consideration is understood to mean the application of sound engineering practice by either of the following:

6.2.1.3.1.1 Measuring or calculating the voltage drop(s) to establish whether a potential of –850 mV or more negative across the structure-to-electrolyte boundary has been achieved, or

6.2.1.3.1.2 Performing a technical evaluation of the system, including data or information such as the following, used either separately or in combination, which the user deems necessary and sufficient for the situation:

6.2.1.3.1.2.1 Reviewing the historical performance of the CP system, such as type of CP, consistency with time of the potentials at individual test points along the line, consistency of CP current over time, number of years with CP, remedial CP activities, consistency of CIS over time, and external corrosion-related leak history. (Note: Leak history should not be used as the sole means of determining adequate levels of CP). When reviewing the historical performance of the CP system, physical characteristics and results of direct examinations and the environment should also be considered.

6.2.1.3.1.2.2 Determining whether there is physical evidence of corrosion, such as by direct examination to determine evidence of active corrosion and correlation of direct examination data with other data such as CIS, DCVG surveys, and ILI results. When direct examinations are used, the number and extent of the examinations performed as well as a comparison of the environments and their relevance should be considered.

6.2.1.3.1.2.3 Evaluating the physical and electrical characteristics of the pipe and its environment, such as type of electrolyte, electrolyte resistivity, pH, dissolved oxygen content, moisture content, degree of aeration, differences in pipe metallurgy and installation dates, and variations in coating types and condition.

6.2.1.3.1.2.4 Physical characteristics and operational data, such as coated or bare, type of coating and possibility to shield CP, proximity to other lines, especially other lines in the right-of-way, temperature of the pipe, depth of the pipe, proximity to potential stray current sources such as light rail systems, HVAC and HVDC systems, foreign structures with CP, proximity and electrical isolation with structures of varying metals where mixed-metal potentials are a concern, locations where concrete weights and anchors are installed, and changes in operating conditions over time. Construction-related information alone might not provide sufficient information to adequately evaluate the effectiveness of CP, but should be considered during direct examinations and reviewing historical performances.

6.2.1.3.1.2.5 Evaluation of indirect inspection data, such as above-grade electrical surveys, ILI, and direct assessment.

6.2.1.3.1.2.6 Use of coupons to establish levels of current density, free corrosion potential, levels of polarization, corrosion rates, and comparisons between coupon and pipe potentials.

6.2.1.3.1.2.7 Other methods that confirm that sufficient polarization has been achieved to control corrosion.

6.2.1.4 Special Conditions Applicable to Steel and Gray or Ductile Cast-Iron Piping Systems

6.2.1.4.1 When active MIC has been identified or is probable, (e.g., caused by acid-producing or sulfate-reducing bacteria), the criteria listed in Paragraphs 6.2.1.2 and 6.2.1.3 might not be sufficient. Under some conditions, a polarized potential of –950 mV CSE or more negative[63-65] or as much as 300 mV of cathodic polarization might be required.[66]

6.2.1.4.2 At elevated temperatures (> 40 °C [104 °F]), the criteria listed in Paragraphs 6.2.1.2 and 6.2.1.3 may not be sufficient. At temperatures greater than 60 °C (140 °F), the polarized potential of –950 mV CSE or more negative might be required.[63,66-68]

6.2.1.4.3 On mill-scaled steel, cathodic polarization greater than 100 mV might be required.[66]

6.2.1.4.4 In uniformly high-resistivity well-aerated and well-drained soil, polarized potentials less negative than –850 mV CSE might be sufficient. Note: ISO 15589-1 offers the following for consideration: –750 mV CSE where soil resistivity is between 10,000 Ω·cm and 100,000 Ω·cm, and –650 mV CSE where soil resistivity is greater than 100,000 Ω·cm.

6.2.1.4.5 Under certain circumstances, when well-coated pipelines are installed in close proximity to HVAC power lines, electromagnetically induced AC can cause external corrosion. AC densities in excess of 30 A/m$^2$ (2.8 A/ft$^2$) can be sufficient to cause significant external corrosion of ferrous metals, and at AC densities greater than 100 A/m$^2$ (9.3 A/ft$^2$), AC corrosion is to be expected even if a CP criterion is satisfied.[69] Furthermore, under some soil conditions, increasing the cathodic polarization can increase AC corrosion as shown in Figure 1.

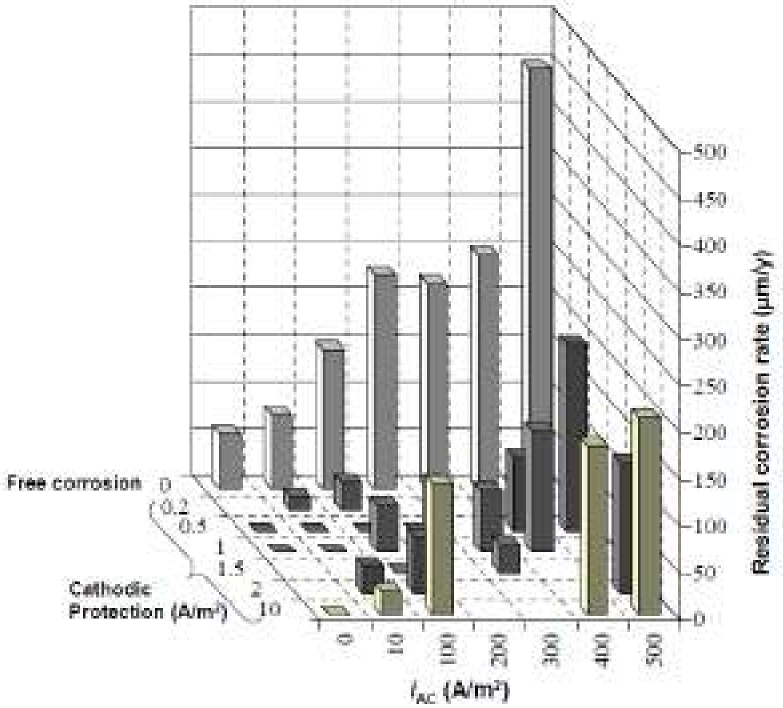

**Figure 1: Residual Corrosion Rate of Carbon Steel Specimens as a Function of AC and CP Current Density. Laboratory Tests Performed in Simulated Soil Conditions.[70]**

6.2.1.4.6 In weak acid environments, a polarized potential of –950 mV CSE or more negative might be required.[11,71]

6.2.1.4.7 When operating pressure and conditions are conducive to high pH stress corrosion cracking, polarized potentials in the cracking range relative to the temperature indicated in Figure 2 should be avoided.[71]

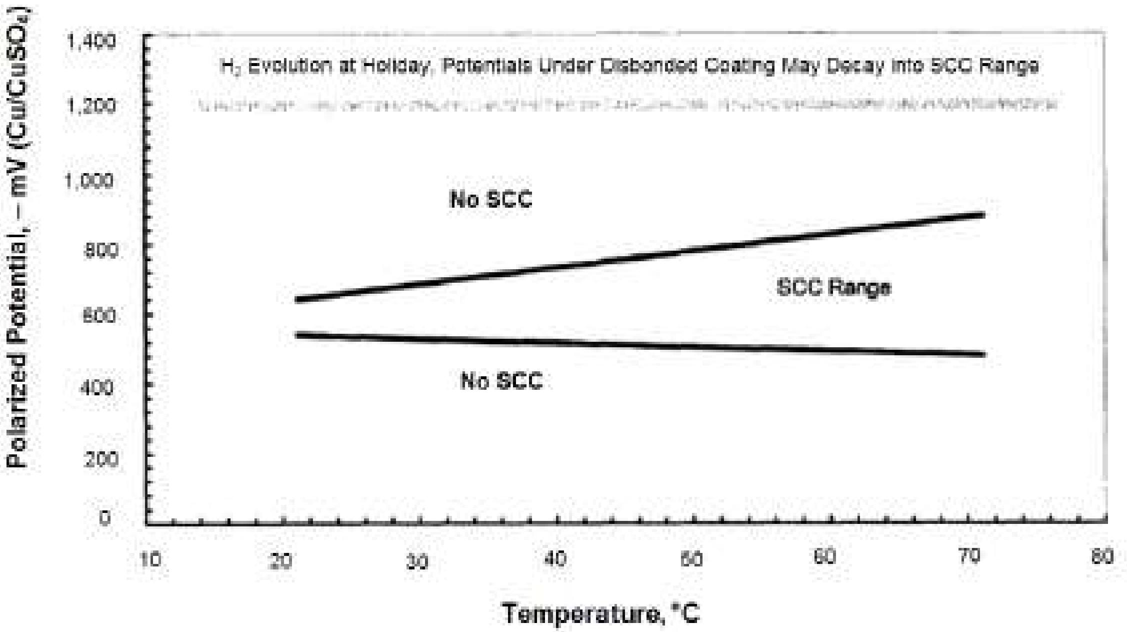

**Figure 2: SCC Range of Pipe Steel in Carbonate/Bicarbonate Environments.[72] Note: This figure is not applicable to all grades of steel and in all electrolytes. (For conversion, °F = 9/5 °C + 32).**

6.2.2 Criteria for Aluminum Piping

6.2.2.1 Criteria that have been documented through empirical evidence to indicate corrosion control effectiveness on specific piping systems may be used on those piping systems or others with the same characteristics.

6.2.2.2 A minimum of 100 mV of cathodic polarization between the structure surface and a stable reference electrode containing two electrolytes. Either the formation or the decay of this polarization must be measured to satisfy this criterion.[8,62]

6.2.2.3 Precautionary Notes

6.2.2.3.1 Excessive Voltages: Notwithstanding the minimum criterion in Paragraph 6.2.2.2, a polarized potential more negative than –1,200 mV with respect to a CSE reference electrode shall not be used unless previous test results indicate that no appreciable corrosion has occurred in the particular environment. Specific attention shall be given to possible corrosion as a result of the buildup of alkali on the metal surface, as outlined in Paragraph 6.2.2.3.2.

6.2.2.3.2 Alkaline Conditions: Aluminum can suffer from corrosion under high-pH conditions, and application of CP tends to increase the pH at the metal surface. Therefore, investigations or testing should be completed prior to the application of CP to determine whether the anticipated level of polarization of the aluminum can create a corrosive condition in the specific electrolyte adjacent to the aluminum alloy under consideration. Aluminum can experience corrosion in alkaline or acidic environments ($8.5 < pH < 4$) according to the Pourbaix diagrams.[73] The specific ranges depend on the specific electrolyte and alloy being tested.

6.2.3 Criteria for Copper Piping

6.2.3.1 Criteria that have been documented through empirical evidence to indicate corrosion control effectiveness on specific piping systems may be used on those piping systems or others with the same characteristics.

6.2.3.2 A minimum of 100 mV of cathodic polarization. Either the formation or the decay of this polarization must be measured to satisfy this criterion.

6.2.4 Criteria for Stainless Steel Piping

6.2.4.1 Criteria that have been documented through empirical evidence to indicate corrosion control effectiveness on specific piping systems may be used on those piping systems or others with the same characteristics.

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

6.2.4.3 A polarized potential of –450 mV or more negative with respect to a CSE in neutral or alkaline conditions. In acid conditions, the protection potential should be determined by testing.

6.2.4.4 Cautionary note: When operating pressure and conditions are conducive to high pH stress corrosion cracking, polarized potentials in the cracking range relative to the temperature should be avoided. For austenitic stainless steels in acid conditions, the safe negative potential limit shall be determined by testing. For ferritic, martensitic, and duplex stainless steels, the safe potential limit shall be determined by testing.[74]

6.3 Relevant Considerations

6.3.1 Potential measurements related to criteria are intended to be made with respect to reference electrodes at 25 °C (77 °F). Common practice does not require a temperature correction within 10 °C (18 °F) of this temperature. For temperature correction factors, see Table 2.

6.3.2 When feasible and practicable, ILI of pipelines can be an effective method for determining the presence or absence of corrosion damage. Absence of external corrosion damage or the halting of its growth can indicate adequate external corrosion control. The appropriate use of ILI must be carefully considered. The ILI technique, however, might not be capable of detecting all types of external corrosion damage, has limitations in its accuracy, and might report as anomalies items that are not external corrosion. For example, longitudinal seam corrosion and general corrosion might not be readily detected by in-line inspection when magnetic tools are used. Also, possible thickness variations, dents, gouges, and external ferrous objects might be detected as corrosion.

6.3.3 The amount of cathodic polarization maintained on a metallic surface can be affected by changes in electrolyte conditions, CP system or structure configuration changes, and changes in influencing sources of AC or DC. These factors should be considered when tests are performed to satisfy the CP criteria.

6.3.4 In mixed-metal piping systems, CP can typically be achieved at a polarized potential that is 100 mV more negative than the open-circuit potential of the most active metal in the system. Amphoteric materials, such as aluminum or lead, which could be damaged by high alkalinity created by CP, might need to be electrically isolated and separately protected.

6.3.5 Cathodic polarization levels that result in excessive generation of atomic hydrogen should be avoided on all metals susceptible to hydrogen embrittlement.

6.3.6 On externally coated pipelines, as the level of cathodic polarization increases, the pH at the structure-to-electrolyte interface increases, which can increase the risk of blistering or disbondment of the coating.

6.3.7 Reliable measurement of potentials and therefore interpretation of CP criteria can be significantly affected by the presence of electrical shielding. Electrical shielding can be caused by disbonded coatings, thermal insulation, loose wrappers, high-resistivity rock or soils, metal structures or pipelines that are close to the structure being protected, and other man-made materials partially or completely surrounding the pipeline.[75]

6.4 Alternative Reference Electrodes

6.4.1 Other standard reference electrodes may be substituted for the CSE. Three commonly used reference electrodes are listed below. Refer to Table 2 for their voltage equivalents.

6.4.1.1 Saturated KCl calomel reference electrode.

6.4.1.2 Saturated silver/silver chloride reference electrode.

6.4.1.3 Zinc reference electrode.

In addition to these standard reference electrodes, an alternative metallic element in an electrolyte of fixed concentration may be used in place of the CSE, if the stability of its electrode potential is ensured and if its voltage equivalent referred to a CSE is established.

## Table 2
## Common Reference Electrodes and Their Potentials and Temperature Coefficients

| Reference Electrode | Electrolyte Solution | Potential at 25 °C [77 °F] (V/SHE) | Potential at 25 °C [77 °F] (V/CSE) | Temperature Coefficient mV/°C (mV/°F) | Typical Usage |
|---|---|---|---|---|---|
| $Cu/CuSO_4$ (CSE) | Sat. $CuSO_4$ | +0.316[76] | 0 | 0.9 (0.5)[76] | soils, fresh water |
| Ag/AgCl(A) (SSC) | 0.6 M NaCl<br>(3 ½%) | +0.256[77] | –0.06 | – 0.33 (0.18)[77] | seawater, brackish(B) |
| Ag/AgCl(C) (SSC) | Sat. KCl | +0.222[78] | –0.094 | – 0.70 (0.39)[78] | --- |
| Ag/AgCl(C) (SSC) | 0.1 N KCl | +0.288[79] | –0.028 | – 0.43 (0.24)[79] | --- |
| Sat. Calomel (SCE) | Sat. KCl | +0.244[10] | –0.072 | – 0.70 (0.39)[10] | water, laboratory |
| Zn (ZRE) | Saline Solution | –0.79 ± 0.1[65] | –1.1 ± 0.1[65] | --- | seawater |
| Zn (ZRE) | Soil | –0.80 ± 0.1[65] | –1.1 ± 0.1[65] | --- | underground |

(A) Solid junction.
(B) Potential becomes more electropositive with increasing resistivity. See nomograph for correction in waters of varying resistivity in NACE SP0176,[10] or see reference 77.
(C) Liquid junction.

Examples: –850 mV CSE measured at 100 °F (37.8 °C) would be corrected to –838.5 mV at 25 °C (the actual potential is 11.5 mV less negative than the reading), while –850 mV measured at 40 °F (4.4 °C) would be corrected to –868.5 mV at 25 °C (18.5 mV more negative than the reading). (Note: 1 mV/ºC = 0.55 mV/ºF.)

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## Section 7: Design of Cathodic Protection Systems

7.1 Introduction

7.1.1 This section provides guidelines for designing effective and reliable CP systems.

7.1.2 In the design of a CP system, the following should be considered:

7.1.2.1 Recognition of hazardous conditions prevailing at the proposed installation site(s) and the selection and specification of materials and installation practices that ensure safe installation and operation.

7.1.2.2 Specification of materials and installation practices to conform to the latest editions of applicable codes and national, international, and NACE standards.

7.1.2.3 Selection and specification of materials and installation practices that ensure dependable and economical operation throughout the intended operating life.

7.1.2.4 Selection of locations for proposed installations to minimize currents or earth potential gradients that can cause detrimental effects on foreign underground or submerged metallic structures.

7.1.2.5 Cooperative investigations to determine mutually satisfactory solution(s) for interference problems (see Section 9).

7.1.2.6 Consideration must be given to the special conditions listed in Paragraph 6.2.1.4.

7.2 Major objectives of CP system design include the following:

7.2.1 To provide sufficient current to the structure to be protected and distribute this current so that the selected criteria for CP are effectively attained;

7.2.2 To minimize the stray currents on neighboring underground structures (see Section 9);

7.2.3 To provide a design life of the system commensurate with the required life of the protected structure, or to provide for periodic rehabilitation of the system;

7.2.4 To provide adequate allowance for anticipated changes in current requirements with time over the design life of the CP system;

7.2.5 To locate anodes, cable, test stations, and other equipment where the possibility of disturbance or damage is minimal; and

7.2.6 To provide sufficient monitoring facilities to test and evaluate the effectiveness of the CP system performance.

7.3 Information Useful for Design

7.3.1 Useful piping system specifications and information include the following:

7.3.1.1 Route maps and atlas sheets;

7.3.1.2 Construction dates;

7.3.1.3 Pipe material, fittings, and other appurtenances;

7.3.1.4 Line pipe and field joint external coatings;

7.3.1.5 Casings;

7.3.1.6 Corrosion control test stations;

7.3.1.7 Electrically isolating devices;

7.3.1.8 Electrical bonds; and

7.3.1.9 Aerial, bridge, and underwater crossings.

7.3.2 Useful information on piping system site conditions includes the following:

7.3.2.1 Existing and proposed CP systems;

7.3.2.2 Possible interference sources (see Section 9);

7.3.2.3 Special environmental conditions such as operating temperatures, SCC susceptibility, MIC;

7.3.2.4 Neighboring buried metallic structures (including location, ownership, and corrosion control practices);

7.3.2.5 Structure accessibility;

7.3.2.6 Power availability;

7.3.2.7 Feasibility of electrical isolation from foreign structures; and

7.3.2.8 Possibility of lightning/voltage surge effects that might require mitigation considerations.

7.3.3 Useful information from field surveys, corrosion test data, and operating experience includes the following:

7.3.3.1 Protective current requirements to meet applicable criteria;

7.3.3.2 Electrical resistivity of the electrolyte;

7.3.3.3 Electrical continuity;

7.3.3.4 Electrical isolation;

7.3.3.5 External coating integrity;

7.3.3.6 Cumulative leak history or results of inspections;

7.3.3.7 Stray currents;

7.3.3.8 Deviation from construction specifications;

7.3.3.9 Natural pH of the environment; and

7.3.3.10 Other maintenance and operating data.

7.3.4 Field survey work before actual application of CP is not always required if prior experience or test data are available to estimate current requirements, electrical resistivity of the electrolyte, and other design factors.

7.4 Types of CP Systems

7.4.1 Galvanic Anode Systems

Galvanic anodes may be made of materials such as alloys of magnesium, zinc, or aluminum. The anodes are cast, extruded, or continuously cast and hot rolled onto steel cores that support the alloy and, for pipelines, to which cables are normally connected. The anodes are connected to the pipe by these cables, either individually or in groups. Galvanic anodes are limited in current output by the anode-to-pipe driving voltage, the electrolyte resistivity, and the total circuit resistance.

7.4.2 Impressed Current Anode Systems

Impressed current anodes may be of materials such as graphite, high-silicon cast iron, lead-silver alloy, precious metals, mixed-metal oxides, conductive polymers, or steel. They are connected with an insulated cable, either individually or in groups, to the positive terminal of a DC source, such as a rectifier, solar power array, wind generator, closed cycle vapor turbine (CCVT), thermoelectric generator, motor generator, or DC-DC converter. The pipeline (structure) is connected to the negative terminal of the DC source.[80]

7.5 Considerations influencing selection of the type of CP system include the following:

7.5.1 Magnitude of protective current required;

7.5.2 Stray currents causing significant potential fluctuations between the pipeline and earth that can preclude the use of galvanic anodes;

7.5.3 Effects of CP stray currents on adjacent structures that can limit the use of impressed current CP systems;

7.5.4 Availability of electrical power;

7.5.5 Physical space available, proximity of foreign structures, easement procurement, surface conditions, presence of streets and buildings, river crossings, and other construction and maintenance concerns;

7.5.6 Future development of the right-of-way area and future extensions to the pipeline system;

7.5.7 Costs of installation, operation, and maintenance;

7.5.8 Electrical resistivity of the environment; and

7.5.9 Location of remote earth.

7.6 Factors Influencing Design of CP Systems

7.6.1 Anode materials have different rates of deterioration or consumption when discharging a given current density from the anode surface in a specific environment. Therefore, for a given current output, the anode life is determined by the environment and anode material, which determine the capacity (often expressed in A·h/kg for galvanic anodes or as a consumption rate in kg or µg/A·h for impressed current materials), and the anode weight and the number of anodes in the CP system. Established anode performance data should be used to calculate the probable deterioration rate. Design of galvanic anode systems must consider both current requirement and design life. The shape of the anode determines its resistance to earth in a given environment, and for galvanic anodes, determines their current output. For impressed current anodes, their shape and resistance determine the relationship between driving voltage and current output.

7.6.2 Data on the dimensions, depth, and configuration of the anodes and the electrolyte resistivity can be used to calculate the resultant resistance to electrolyte of the anode system. Formulas and graphs relating to these factors are available in the bibliography literature and from most anode manufacturers.

7.6.3 Design of galvanic anode systems considers anode-to-pipe potential, electrolyte resisivity, current output, and in special cases, anode lead wire resistance. A separate design for each anode or anode system might not be necessary.

7.6.4 Galvanic anode performance and service life in most soils can be improved by using special backfill material. Mixtures of gypsum, bentonite, and anhydrous sodium sulfate are most commonly used. The backfill is designed to provide a uniform environment, ensure electrolyte contact with the anode, and prevent passivation.

7.6.5 For impressed current systems, the number of anodes required can be reduced and their useful life lengthened by the use of special backfill around the anodes. The most common materials are coal coke, calcined petroleum coke, or natural or manufactured graphite.

7.6.6 In the design of an extensive distributed-anode or linear-anode impressed current system, the voltage and current attenuation along the anode-connecting (header) cable should be considered. In such cases, the design objective is to optimize anode system length, anode spacing and size, and cable size to achieve efficient external corrosion control at the extremities of the protected structure.

7.6.7 When it is anticipated that entrapment of gas generated by anodic reactions could impair the ability of the impressed current anode bed to deliver the required current, suitable provisions shall be made for venting the anodes. For the same current output of the system, an increase in the surface area of the special backfill material or an increase in the number of anodes may reduce gas blockage.

7.6.8 When it is anticipated that electroosmotic effects could impair the ability of the impressed current anode bed to deliver the required current output, suitable provisions shall be made to ensure adequate soil moisture around the anodes. Increasing the number of impressed current anodes or increasing the surface area of the special backfill materials can further reduce the electroosmotic effect.

### 7.7 Design Drawings and Specifications

7.7.1 Suitable drawings shall be prepared to designate the overall layout of the piping to be protected and the location of significant items of structure hardware, corrosion control test stations, electrical bonds, electrical isolation devices, and neighboring underground or submerged metallic structures.

7.7.2 Layout drawings shall be prepared for each impressed current CP installation, showing the details and location of the components of the CP system with respect to the protected structure(s) and to major physical landmarks. These drawings should include right-of-way information.

7.7.3 The locations of galvanic anode installations should be recorded on drawings or in tabular form, with appropriate notes on anode type, weight, spacing, depth, and backfill.

7.7.4 Specifications should be prepared for all materials and installation practices that are to be incorporated in construction of the CP system.

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## Section 8: Installation of CP Systems

### 8.1 Introduction

This section provides procedures for installation of CP systems.

### 8.2 Construction Specifications

All construction work on CP systems should be performed in accordance with construction drawings and specifications. The construction specifications should be in accordance with Sections 4 and 7.

### 8.3 Construction Supervision

8.3.1 All construction work on CP systems should be performed under the surveillance of trained and qualified personnel to verify that the installation is in strict accordance with the drawings and specifications. Exceptions may be made only with the approval of qualified personnel responsible for external corrosion control.

8.3.2 All deviations from construction specifications should be documented and when appropriate, documented on as-built drawings.

### 8.4 Galvanic Anodes

#### 8.4.1 Inspection, Handling, and Storage

8.4.1.1 Packaged anodes should be inspected and steps taken to ensure that backfill material completely surrounds the anode. The individual container for the backfill material and anode should be intact. If individually packaged anodes are supplied in waterproof containers, the containers must be removed before installation. Packaged anodes should be kept dry during storage.

8.4.1.2 Lead wire must be securely connected to the anode. Lead wire should be inspected to ensure that it is not damaged.

8.4.1.3 Other galvanic anodes, such as the unpackaged bracelet or ribbon type, should be inspected to ensure that dimensions conform to design specifications and that any damage during handling does not affect application. If a coating is used on bands and the inner side of bracelet anode segments, it must be inspected and, if damaged, repaired before the anodes are installed.

#### 8.4.2 Installation

8.4.2.1 Anodes should be installed according to construction drawings and specifications. As-built documentation of installation should be maintained for use in follow-up maintenance, repairs, and replacements.

8.4.2.2 Packaged galvanic anodes shall be backfilled with appropriately compacted material. When anodes and special chemical backfill are provided separately, anodes should be centered in special backfill, which should be compacted before backfilling. Care should be exercised during all operations so that lead wires and connections are not damaged. Sufficient slack should exist in lead wires to avoid strain.

8.4.2.3 When anodes in bracelet form are used, external pipe coating beneath the anode should be inspected prior to bracelet installation to ensure that it is free of holidays. Care should be taken to prevent damage to the external coating when bracelet anodes are installed. After application of concrete (if used) to pipe, all concrete should be removed from the anode surface. If reinforced concrete is used, there must be no metallic contact between the anode and the reinforcing mesh or between the reinforcing mesh and the pipe.

8.4.2.4 When a ribbon-type anode is used, it can be trenched or plowed in, with or without special chemical backfill as required, generally parallel to the section of pipeline to be protected.

### 8.5 Impressed Current Systems

#### 8.5.1 Inspection, Handling, and Storage

8.5.1.1 The rectifier or other DC power source should be inspected by qualified personnel to ensure that internal connections are mechanically secure and that the unit is free of damage and conforms to specifications. Rating of the power source shall comply with the construction specification. Care shall be exercised in handling the power source. The CP power source must be inspected for conformance to specifications.

8.5.1.2 Impressed current anodes are inspected for conformance to specifications concerning anode material, size, length of lead cable, anode lead connection, and integrity of seal. Care shall be exercised to avoid cracking or damaging anodes during handling.

8.5.1.3 All cables must be carefully inspected to detect defects in insulation. Care shall be taken to avoid damage to cable insulation. Defects in the cable insulation must be repaired using an approved material and technique.

8.5.1.4 Anode backfill material must conform to specifications.

8.5.1.5 When storage is necessary, all materials must be properly stored. The environmental effects of UV damage or weather damage (e.g., freezing, etc.) must be considered.

8.5.2 Installation

8.5.2.1 A rectifier or other DC power source should be located and installed to minimize the possibility of damage and vandalism.

8.5.2.2 Wiring to rectifiers shall comply with applicable codes, standards, and requirements. For safety reasons, an external disconnect switch shall be provided in the AC circuit, and the disconnect switch and rectifier case shall be properly grounded.

8.5.2.3 On thermoelectric generators, a reverse current device shall be installed to prevent galvanic action between the anode bed and the pipe if the flame is extinguished.

8.5.2.4 Impressed current anodes can be installed vertically, horizontally, or in deep holes (see NACE SP0572) as indicated in construction specifications. Backfill material should be installed to ensure that there are no voids around anodes. Care shall be exercised during backfilling to avoid damage to the anode and cable.

8.5.2.5 The cable from the rectifier negative terminal to the pipe is connected to the pipe as described in Paragraph 8.6. Cable connections to the rectifier must be mechanically secure and electrically conductive. Before the power source is energized, it must be verified that the negative cable is connected to the structure to be protected and that the positive cable is connected to the anodes. Measurements shall be made to verify that these connections are correct, such as determining that a negative potential shift has occurred on the structure being protected as a result of energizing the DC power source.

8.5.2.6 Underground splices on the header (positive) cable to the anode bed should be kept to a minimum. Connections between the header and anode cables must be mechanically secure and electrically conductive. If underground or submerged, these connections must be sealed to prevent moisture penetration so that electrical isolation from the environment is ensured.

8.5.2.7 Care must be taken during installation of direct-burial cable to the anodes (positive cable) to avoid damage to insulation. Sufficient slack should be left to avoid strain on all cables. Backfill material around the cable should be free of rocks and foreign matter that might cause damage to the insulation when the cable is installed in a trench. Cable can be installed by plowing if proper precautions are taken.

8.5.2.8 If insulation integrity on the underground or submerged header cable, including splices, is not maintained, this cable can fail because of corrosion.

8.6 Corrosion Control Test Stations, Connections, and Bonds

8.6.1 Pipe and test lead wires shall be clean, dry, and free of foreign materials at points of connection when the connections are made. Connections of cables and test lead wires to the pipe must be installed so they remain mechanically secure and electrically conductive.

8.6.2 All underground or submerged cables and lead wire attachments shall be coated with an electrically isolating material that is compatible with the pipe surface, external pipe coating, copper wire, weld material, and wire insulation.

8.6.3 Suitably sized test lead wires shall be color coded or otherwise permanently identified. Wires should be installed with slack. Damage to insulation shall be avoided and repairs made if damage occurs. Test leads should not be exposed to excessive heat and sunlight. Aboveground or flush-to-ground test stations may be used as applicable. If test stations are flush with the ground, adequate slack should be provided within the test station to facilitate test connections.

8.6.4 Cable connections at bonds to other structures or across isolating joints shall be mechanically secure, electrically conductive, and suitably coated. Where possible, bonds between structures or across isolation fittings should be made in above-ground test stations to facilitate monitoring and maintenance.

8.6.5 Refer to NACE Standard RP0104[81] for guidelines on installing CP coupon test stations.

### 8.7 Electrical Isolation

Inspection and electrical measurements are made to ensure that electrical isolation is adequate (see NACE SP0286[5]).

## Section 9: Control of Stray Currents

### 9.1 Introduction

This section provides practices for the detection and control of stray currents. Stray currents can be static or dynamic in nature. Static stray current is characterized by a consistent magnitude and electrolytic path. Dynamic stray current is characterized by varying magnitude and/or electrolytic path. The stray current mechanism and its detrimental effects are described.

### 9.2 Mechanism of Interference-Current Corrosion (Stray-Current Corrosion)

9.2.1 Interference-current corrosion on underground or submerged metallic structures differs from other causes of corrosion damage in that the current, which causes the corrosion, has a source foreign to the affected structure. Usually the interfering current is collected from the electrolyte by the affected structure from a DC source not metallically bonded to the affected structure. Stray currents can occur as a result of potential differences (gradients) in the earth. The potential difference causes current to flow along parallel paths in the earth. The amount of current flow is determined by the magnitude of the potential difference and the resistance of the parallel paths. A structure that is positive with respect to the surrounding earth discharges current into the earth. A structure that is negative with respect to the surrounding earth picks up current from the earth. In general, the lower the electrolyte resistivity, the more severe the damage from stray-current corrosion can be.

9.2.1.1 Detrimental effects of stray current usually occur at locations where the current is exchanged between the affected structure~~s~~ and the electrolyte.

9.2.1.2 Affected structures made of amphoteric metals such as aluminum and lead can be subject to corrosion damage from a buildup of alkalinity at or near the metal surface collecting stray currents.

9.2.1.3 Coatings can experience cathodic disbondment at areas where voltage gradients in the electrolyte force current onto the affected structure. In addition, as the external coating becomes disbonded, a larger area of metal can be exposed, which would increase the demand for CP current. The coating disbondment can also create electrical shielding problems.

9.2.2 The severity of external corrosion resulting from stray currents depends on several factors:

9.2.2.1 Separation and routing of the interfering and affected structures and location of the interfering current source;

9.2.2.2 Magnitude, duration, and density of the current exchange;

9.2.2.3 Quality of the external coating or absence of an external coating on the structures involved; and

9.2.2.4 Presence and location of mechanical joints having high electrical resistance.

9.2.3 Typical sources of stray currents include the following:

9.2.3.1 Direct current: CP rectifiers, thermoelectric generators, DC electrified railway and transit systems, coal mine haulage systems and pumps, welding machines, facilities that utilize grounded DC induction equipment, HVDC power systems, and other DC power systems;

9.2.3.2 Alternating current: AC power systems and AC electrified railway systems (refer to NACE SP0177); and

9.2.3.3 Telluric current.

### 9.3 Detection of Stray Currents

9.3.1 During external corrosion control surveys, personnel should be alert for electrical or physical observations that could indicate interference from a foreign source such as the following:

9.3.1.1 Pipe-to-electrolyte potential changes or fluctuations on the affected structure caused by a foreign source;

9.3.1.2 Changes or fluctuations in the line current magnitude or direction caused by a foreign source;

9.3.1.3 Localized pitting in areas near or immediately adjacent to a foreign structure or where a diversion occurs between the structure and an AC power corridor; and

9.3.1.4 Damage to external coatings in a localized area near an anode bed or near any other source of stray current.

9.3.2 For new construction, efforts should be made to identify and plan for the mitigation of anticipated stray currents prior to construction. As soon as practicable after construction of the pipeline is completed, monitoring, testing, and mitigation plans to control the effects of stray currents should be implemented.

9.3.3 In areas where stray currents are suspected, appropriate tests should be conducted. All affected parties should be notified before tests are conducted. Notification should be channeled through local corrosion control coordinating committees, when they exist (see NACE Publication TPC 11). In many cases, especially with dynamic stray current interference, there is more than one source of stray current. Any one or a combination of the following typical test methods can be used to evaluate each possible source of stray current.

9.3.3.1 Measurement or correlations of structure-to-electrolyte potentials with recording or indicating instruments to determine the source(s) and extent of stray current pickup and discharge;

9.3.3.2 Measurement or correlations of current flowing on the structure with recording or indicating instruments to determine the source(s) and extent of stray current pickup and discharge;

9.3.3.3 Development of beta curves from correlation testing data to locate the area of maximum current discharge from the affected structure; and

9.3.3.4 Measurement of the variations in current output of the suspected source(s) of stray current and correlations with measurements obtained in Paragraph 9.3.2.

### 9.4 Methods for Mitigating Interference Corrosion Problems

9.4.1 Interference problems are individual in nature, and the solution should be mutually satisfactory to the parties involved. The typical methods of mitigation described below may be used individually or in combination.

9.4.2 CP current can be applied to the affected structure at those locations where the interfering current is being discharged. The source of CP current may be from galvanic anodes or impressed current. The driving voltage of the CP current source must be greater than the driving voltage of the stray current for this method to be effective.

9.4.3 A common industry best practice is to install a grounding cell (an interference cell). An alternative is to install a dual galvanic anode cell. This consists of two magnesium or zinc anodes within a close proximity to one another (but isolated to ensure no metallic contact) near the interference location. Each anode is electrically connected to one single pipeline through a junction box or foreign test station. The advantage of this arrangement is that it allows the stray current to flow safely between the anodes through the soil and thus prevents or minimizes interaction effects without installing a direct bond between the two pipelines.

9.4.4 Relocation of the impressed current anode beds can reduce or eliminate the pickup of stray currents on nearby structures.

9.4.5 Rerouting of proposed pipelines can avoid sources of stray current.

9.4.6 Properly located isolating fittings in the affected structure can reduce or resolve interference problems. Caution must be exercised to ensure stray current does not discharge across an isolation device.

9.4.7 Application of external coating to current pickup area(s) on the affected structure can reduce or resolve interference problems. Current discharge areas should not be recoated, as this can move the discharge point or concentrate stray current at coating holidays.

9.4.8 Reduction of the stray earth current, e.g., by maximizing the resistance-to-earth and controlling track-to-earth voltage of an ungrounded DC-powered transit system.

9.4.9 Design and installation of electrical bonds of proper resistance between the affected and interfering structures. The purpose of a mitigation bond is to eliminate current flow from the affected structure into the electrolyte by providing a metallic return path for the current. Mitigation bonds should be installed as close as practical to the point of maximum discharge from the affected structure. In general, the feasibility of the mitigation methods described above should be evaluated before an electrical bonding solution is pursued.

9.4.9.1 Unidirectional control devices, such as diodes or reverse current switches, might be required in conjunction with electrical bonds if bidirectional currents are present or could possibly occur. These devices prevent reversal of current flow.

9.4.9.2 A resistor might be necessary in the bond circuit to control the magnitude of electrical current flow from the affected structure to the interfering structure. The resistor(s) must be of the proper wattage rating to safely conduct the bond current.

9.4.9.3 The attachment of electrical bonds can reduce the level of CP on the interfering structure. Supplementary CP might be required on the interfering structure to compensate for this effect.

9.4.9.4 A bond might not effectively mitigate the interference problem in the case of a cathodically protected uncoated or poorly coated pipeline that is causing interference on a coated pipeline. In this situation, consideration should be given to coating/recoating the interfering pipeline in the vicinity of the interference problem.

9.4.9.5 In certain instances, such as rail transit with ungrounded DC traction power distribution systems, bonds can lower the transit system's resistance to earth substantially, often with a notable increase in overall stray earth current levels. In these circumstances, it is important to assess the overall impact of the bond versus its value in mitigating stray current on a particular structure.[82]

9.5 Indications of Resolved Interference Problems

9.5.1 Restoration of the structure-to-electrolyte potentials on the affected structure to those values that existed before the interference or to mutually accepted values between the parties involved.

9.5.2 Measured line currents on the affected structure that show that the stray current is not being discharged to the electrolyte.

9.5.3 Adjustment of the slope of the beta curve to show that current discharge has been adequately mitigated at the location of maximum exposure. Some approaches to the mitigation of stray current effects can redistribute/relocate current discharges rather than eliminate them. Testing must verify that conditions remain within acceptable limits at locations other than the previous site of maximum exposure.

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## Section 10: Operation and Maintenance of CP Systems

10.1 Introduction

10.1.1 This section provides procedures and practices for energizing and maintaining continuous, effective, and efficient operation of CP systems.

10.1.1.1 Electrical measurements and inspection are necessary to determine that protection has been established according to applicable criteria (see TM0497 for measurement techniques) and that each part of the CP system is operating properly. Conditions that affect protection are subject to change. Correspondingly, changes might be required in the CP system to maintain protection. Periodic measurements and inspections are necessary to detect changes in the CP system. Conditions may exist in which operating experience indicates that testing and inspections need to be made at different intervals.

10.1.1.2 Care should be exercised in selecting the location, number, and type of electrical measurements used to determine the adequacy of CP.

10.1.1.3 When practicable and determined necessary by sound engineering practice, CIS may be conducted to:

(a) assess the effectiveness of the CP system;

(b) provide baseline operating data;

(c) locate areas of inadequate protection levels;

(d) locate areas of possible coating deterioration;

(e) identify locations likely to be adversely affected by construction, stray currents, or other environmental conditions; or

(f) select areas to be monitored periodically.

Additional reasons for performing close-interval potential surveys are listed in NACE SP0207.[83]

10.1.1.4 Adjustments to a CP system shall be accompanied by sufficient testing to assure the criteria remain satisfied and to reassess interference with other structures or isolation points.

10.2 Representative potential measurements shall be obtained after each CP system is initially energized to determine whether the applicable criteria have been satisfied.

10.2.1 Representative potential measurements should be considered after each CP system adjustment.

10.3 The effectiveness of the CP system should be monitored annually. Longer or shorter intervals for monitoring might be appropriate, depending on the variability of CP factors, safety considerations, and economics of monitoring.

10.3.1 A minimum voltage drop considered target on-potential (required minimum [RM]) can be developed for individual test points for either polarization criterion by adding the measured voltage drop at each location to –850 mV or to the free corrosion potential plus 100 mV. Voltage drop measurement may be collected during CIS or annual CP surveys. Once developed, the target potential may continue to be used until CP polarization conditions change enough to alter the corrosion control requirements or new voltage drop measurements are obtained. Refer to NACE Standard TM0497 for additional information.

10.4 Inspection and tests of CP facilities should be performed and documented to verify their proper operation and maintenance as follows:

10.4.1 All impressed current systems should be checked at intervals of two months. Longer or shorter intervals for monitoring might be appropriate. Evidence of proper functioning can be current output, normal power consumption, a signal indicating normal operation, or satisfactory CP levels on the pipe.

10.4.2 All impressed current systems should be inspected annually as part of a preventive maintenance program to minimize in-service failure. Longer or shorter intervals for monitoring might be appropriate. Inspections may include a check for electrical malfunctions, safety ground connections, meter accuracy, efficiency, and circuit resistance.

10.4.3 Reverse current switches, diodes, interference bonds, and other protective devices whose failures would jeopardize structure protection should be inspected for proper functioning at intervals of two months. Longer or shorter intervals for monitoring might be appropriate.

10.4.4 The effectiveness of isolating fittings, continuity bonds, and casing isolation should be evaluated during the external corrosion control surveys. This can be accomplished by electrical measurements.

10.5 When pipe has been uncovered, it should be examined for evidence of external corrosion and, if externally coated, for condition of the external coating, including, but not limited to, any disbonded coating, noting whether corrosion is under the disbonded coating and pH of environment under the disbonded coating.

10.6 The test equipment used for obtaining each electrical value should be of an appropriate type. Instruments and related equipment should be maintained in good operating condition and checked for accuracy.

10.7 Remedial measures should be taken when periodic tests and inspections indicate that CP is no longer adequate. These measures may include the following:

10.7.1 Repair, replace, or adjust components of CP systems;

10.7.2 Provide supplementary facilities in which additional CP is necessary;

10.7.3 Thoroughly clean and properly coat bare or poorly coated structures if required to attain CP;

10.7.4 Repair, replace, or adjust continuity and interference bonds;

10.7.5 Remove unintentional metallic contacts; and

10.7.6 Repair defective isolating devices.

10.8 An electrical short circuit between a casing and carrier pipe can result in inadequate CP of the pipeline outside the casing because of reduction of protective current to the pipeline.[12]

10.8.1 When a short results in inadequate CP of the pipeline outside the casing, steps must be taken to restore CP to a level required to meet the CP criterion. These steps may include eliminating the short between the casing and carrier pipe, supplementing CP, or improving the quality of the external coating on the pipeline outside the casing. None of these steps will ensure that external corrosion will not occur on the carrier pipe inside the casing; however, a shorted casing does not necessarily result in external corrosion of the carrier pipe inside the casing.[12]

10.8.2 NACE SP0200 contains useful information on the design, fabrication, installation, and maintenance of steel-cased metallic pipelines.

10.9 When the effects of electrical shielding of CP current are detected, the situation should be evaluated and appropriate action taken.

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## Section 11: External Corrosion Control Records

11.1 Introduction

11.1.1 This section describes external corrosion control records that will document in a clear, concise, workable manner data that are pertinent to the design, installation, operation, maintenance, and effectiveness of external corrosion control measures.

11.2 Relative to the determination of the need for external corrosion control, the following should be recorded (see Paragraph 7.3.3):

11.2.1 Corrosion leaks, breaks, and pipe replacements; and

11.2.2 Pipe and external coating condition observed when a buried structure is exposed.

11.3 Relative to structure design, the following should be recorded:

11.3.1 Line pipe and joint coating material and application specifications; and

11.3.2 Design and location of isolating devices, test leads and other test facilities, and details of other special external corrosion control measures taken.

11.4 Relative to the design of external corrosion control facilities, the following should be recorded:

11.4.1 Results of current requirement tests;

11.4.2 Results of soil resistivity surveys;

11.4.3 Location of foreign structures; and

11.4.4 Interference tests and design of interference bonds and reverse current switch installations.

11.4.4.1 Scheduling of interference tests, correspondence with corrosion control coordinating committees, and direct communication with the concerned companies.

11.4.4.2 Record of interference tests conducted, including location of tests, name of company involved, and results.

11.5 Relative to the installation of external corrosion control facilities, the following should be recorded:

11.5.1 Installation of CP facilities:

11.5.1.1 Impressed current systems:

11.5.1.1.1 Location and date placed in service;

11.5.1.1.2 Number, type, size, depth, backfill, and spacing of anodes;

11.5.1.1.3 Nameplate data of rectifier or other energy source; and

11.5.1.1.4 Cable size and type of insulation.

11.5.1.2 Galvanic anode systems:

11.5.1.2.1 Location and date placed in service;

11.5.1.2.2 Number, type, size, backfill, and spacing of anodes; and

11.5.1.2.3 Wire size and type of insulation.

11.5.2 Installation of interference mitigation facilities:

11.5.2.1 Details of interference bond installation:

11.5.2.1.1 Location and name of company involved;

11.5.2.1.2 Resistance value or other pertinent information; and

11.5.2.1.3 Magnitude and polarity of drainage current.

11.5.2.2 Details of reverse current switch:

11.5.2.2.1 Location and name of companies;

11.5.2.2.2 Type of switch or equivalent device; and

11.5.2.2.3 Data showing effective operating adjustment.

11.5.2.3 Details of other remedial measures.

11.6 Records of surveys, inspections, and tests should be maintained to demonstrate that applicable criteria for interference control and CP have been satisfied.

11.7 Relative to the maintenance of external corrosion control facilities, the following information should be recorded:

11.7.1 Maintenance of CP facilities:

11.7.1.1 Repair of rectifiers and other DC power sources; and

11.7.1.2 Repair or replacement of anodes, connections, wires, and cables.

11.7.2 Maintenance of interference bonds and reverse current switches:

11.7.2.1 Repair of interference bonds; and

11.7.2.2 Repair of reverse current switches or equivalent devices.

11.7.3 Maintenance, repair, and replacement of external coating, isolating devices, test leads, and other test facilities.

11.8 Records sufficient to demonstrate the effectiveness of external corrosion control measures should be maintained as long as the facility involved remains in service. Other related external corrosion control records should be retained for such a period that satisfies individual company needs.

11.9 Records sufficient to demonstrate adequate criteria used under Paragraph 6.2 must be maintained as long as the criteria are used to determine adequate CP.

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# Appendix A
# External Coatings Tables
# (Nonmandatory)

This appendix is considered nonmandatory, although it may contain mandatory language. It is intended only to provide supplementary information or guidance. The user of this standard is not required to follow, but may choose to follow, any or all of the provisions herein.

## Table A1
## References for General Use in the Installation and Inspection of External Coating Systems for Underground or Submerged Piping

| Subject | Reference |
|---|---|
| Application of Organic Pipeline Coatings | ANSI/AWWA C 203[84]<br>ANSI/AWWA C 209<br>ANSI/AWWA C 210<br>ANSI/AWWA C 214<br>ANSI/AWWA C 215<br>ANSI/AWWA C 216<br>ANSI/AWWA C 222<br>NACE Standard RP0375<br>ANSI/AWWA C 213<br>API RP 5L9<br>CSA Z245.20<br>AWWA C 225<br>EN 12068[85] |
| Film Thickness of Pipeline Coatings | ASTM D4138[86]<br>ASTM G12[87]<br>NACE Standard RP0394<br>NACE Standard RP0399<br>DNV RP-F103[88]<br>SSPC PA 2[89] |
| Inspection of Pipeline Coatings | NACE SP0274[90]<br>ISO 21809-3 |
| Installation | DNV-OS-F101<br>ISO 21809-3 |

## Table A2
## External Coating System Characteristics Relative to Environmental Conditions(A)

| Environmental Factor | Recommended Test Methods(B) |
|---|---|
| General Underground Exposure with or Without CP | ANSI/AWWA C 203<br>ANSI/AWWA C 209<br>ANSI/AWWA C 210<br>ANSI/AWWA C 214<br>ANSI/AWWA C 215<br>ANSI/AWWA C 216<br>ANSI/AWWA C 222<br>ANSI/AWWA C 213<br>API RP 5L9<br>CSA Z245.20<br>ASTM G8[91]<br>ASTM G19[92]<br>ASTM G42[93]<br>ASTM G95[94]<br>API RP 5L9<br>AWWA C 225<br>DNV RP-F103 |
| Resistance to Water Penetration and Its Effect on Choice of Coating Thickness | ASTM G9[95] |
| Resistance to Penetration by Stones in Backfill | ASTM G17[96]<br>ASTM D2240[97]<br>ASTM G14[98] |
| Soil Stress | ASTM D427[99]<br>Note: ASTM has withdrawn this standard, and it has not yet been replaced. |
| Resistance to Specific Liquid Not Normally Encountered in Virgin Soil | ASTM D543[100]<br>ASTM G20[101] |
| Resistance to Thermal Effects | ASTM D2304[102]<br>ASTM D2454[103]<br>ASTM D2485[104]<br>ASTM G42 |
| Suitability of Supplementary Materials for Joint Coating and Field Repairs | ASTM G8<br>ASTM G19<br>ASTM G42<br>ASTM G95<br>ASTM G9<br>ASTM G18[105]<br>ASTM G55[106]<br>NACE Standard RP0394<br>NACE Standard RP0375<br>DNV RP-F103<br>DNV RP-F102 |
| Resistance to Microorganisms | ASTM G21[107]<br>Federal Test Standard No. 406A, Method 6091[108]<br>EN 12068 |

(A) Note: Apply only those factors pertinent to the installation.
(B) No specific criteria are available. Comparative tests are recommended for use and evaluation as supplementary information only.

## Table A3(a)
## External Coating System Characteristics Related to Design and Construction

| Design and Construction Factor | Recommended Test Methods[(A)] |
|---|---|
| Backfill Resistance | ASTM G14 |
| Driving Ability (Resistance to Sliding Abrasion) | ASTM G6[109]<br>ASTM D2197[110] |
| Field Bending Ability | ASTM G10[111]<br>NACE Standard RP0394 |
| Handling Resistance, Abrasion | ASTM G6 |
| Handling Resistance, Impact | ASTM G14 |
| Resistance to Thermal Effects | ASTM G8<br>ASTM G19<br>ASTM G42<br>ASTM G95<br>ASTM D2304<br>ASTM D2454<br>ASTM D2485 |
| Special Requirements for Application of Coating Over the Ditch | ANSI/AWWA C 203<br>NACE Standard RP0375<br>ANSI/AWWA C 214<br>ANSI/AWWA C 209<br>ANSI/AWWA C 213<br>API RP 5L9<br>CSA Z245.20<br>NACE SP0185 |
| Special Requirements for Mill-Applied Coating | ANSI/AWWA C 210<br>ANSI/AWWA C 216<br>ANSI/AWWA C 222<br>ANSI/AWWA C 203<br>NACE Standard RP0375<br>ANSI/AWWA C 214<br>ANSI/AWWA C 209<br>ANSI/AWWA C 213<br>API RP 5L9<br>CSA Z245.20<br>NACE SP0185<br>DIN 30670<br>ANSI/AWWA C 215<br>DNV RP-F106<br>NACE Standard RP0394<br>NACE Standard RP0399<br>AWWA C 225 |
| Suitability of Joint Coatings and Field Repairs | ANSI/AWWA C 213<br>API RP 5L9<br>CSA Z245.20<br>ASTM G8<br>ASTM G19<br>ASTM G42<br>ASTM G95<br>ASTM G9<br>ASTM G18<br>ASTM G55<br>NACE SP0185<br>AWWA C 216 |
| Yard Storage, Penetration Under Load | ASTM G17<br>ASTM D2240 |
| Yard Storage, Weathering | ASTM G11[112] |

[(A)] No specific criteria are available. Comparative tests are recommended for use and evaluation as supplementary information only.

### Table A3(b)
### External Coating System Characteristics Related to Design and Construction
### Design and Construction Factor Recommended Test Methods

| **Design and Construction Factor** | **Recommended Test Methods**(A) |
|---|---|
| Corrosion Control | DNV-OS-F101 |
| Current Effects | ISO 15589-1 |
| Field Bending Ability | DNV RP-F102<br>NACE Standard RP0394 |
| Handling Resistance, Impact | EN 12068<br>DNV RP-F107[113] |
| Resistance to Thermal Effects | ASTM G8 |
| Special Requirements for Mill-Applied Coating | ANSI/AWWA C 203<br>NACE Standard RP0375<br>ANSI/AWWA C 214<br>ANSI/AWWA C 209<br>ANSI/AWWA C 213<br>API RP 5L9<br>CSA Z245.20<br>NACE SP0185<br>DNV-OS-F101<br>DNV RP-F102<br>DNV RP-F103<br>NACE Standard RP0394<br>NACE Standard RP0399<br>AWWA C 210<br>AWWA C 215<br>AWWA C 216<br>AWWA C 222<br>AWWA C 225 |
| Suitability of Joint Coatings and Field Repairs | ANSI/AWWA C 213<br>CSA Z245.20<br>ASTM G55<br>NACE SP0185 |

(A) No specific criteria are available. Comparative tests are recommended for use and evaluation as supplementary information only.

### Table A4
### Methods for Evaluating Field Performance of External Coatings

| Title or Subject of Method | Reference | Basis for Rating |
|---|---|---|
| (1) Cathodic Disbondment | ASTM G8<br>ASTM G19<br>ASTM G42<br>ASTM G95 | Purpose is to obtain data relative to specific conditions for comparison with laboratory data |
| (2) Change in Current Required for CP | ISO 15589-1 | Comparison of initial current requirement with subsequent periodic determination of current requirement |
| (3) Coating Conductance | NACE Standard TM0102 | Specific coating conductance normalized to 1,000 Ω·cm soil |
| (4) High-Voltage Electrical Inspection of Pipeline Coating | NACE SP0274<br>DNV-OSS-301[114] | Detection of holidays using high-voltage electrical inspection |
| (5) Aboveground Survey Techniques for the Evaluation of Underground Pipeline Coating Condition | NACE Standard TM0109[115] | Measuring alternating current attenuation or identifying, locating (and for some techniques) determining a relative magnitude of coating defects. |
| (6) In Situ Evaluation of Directional Drill/Bore Coating Quality | PRCI PR-262-9738[116] | Combination of current requirements and coating conductance applied to directionally drilled pipe installations. |

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## Appendix B
## Review of International Standards
## (Nonmandatory)

This appendix is considered nonmandatory, although it may contain mandatory language. It is intended only to provide supplementary information or guidance. The user of this standard is not required to follow, but may choose to follow, any or all of the provisions herein.

The following are summaries and direct copies (published with permission) of some international and country standards and regulations on cathodic protection criteria that TG 360 has reviewed which could be of benefit to the corrosion control practitioner. The TG is attempting to receive permission from the various document owners to include criteria excerpts to replace the summaries and as these are received the summaries will be replaced. Permission to publish received after the standard has been approved will be retained for the next SP0169 revision/review. The corrosion control practitioner should be aware of all local applicable standards and regulations for the facilities of concern.

### AUSTRALIAN

There is an Australian Standard, AS/NZS 2832.1,[117] which is titled “Cathodic Protection of Metals Part 1: Pipes and Cables.” The following is a summary of Section 2, Criteria for Cathodic Protection:

- When operators use cathodic protection criteria, they should seek the advice of a cathodic protection specialist to make sure that the criteria are applied correctly.

- For ferrous structures, the criterion for protection is equal to or more negative than –850 mV CSE measured by an instant-off (for clarification: near IR free) method.

- For copper/copper alloy structures, the criterion for protection is equal to or more negative than –300 mV CSE.

- For lead structures, the criterion for protection is equal to or more negative than –650 mV CSE, if the structure is in aerated soils. When conditions are anaerobic, the criterion for protection is equal to or more negative than –800 mV CSE.

- For mixed-metal structures, the criterion for protection requires that the potential be maintained on all parts of the structure based on the protection requirements for the most anodic metal.

- AS/NZS 2832.1 describes the requirements for structures that are subject to traction or telluric current.

- The 100 mV criterion maintains that an instant off-potential on all parts of the structure must be 100 mV or more negative than the depolarized potential.

- Coupons may be used as an alternate criterion. The instant-off potential must be equal to or greater than –850 mV CSE or 100 mV or more negative than the depolarized potential.

- Resistance probes may be used as an alternate criterion, given that the corrosion rate of the resistance probe is less than 5 µm/y (0.2 mpy), and the instant-off potential must be equal to or greater than –850 mV CSE or 100 mV or more negative than the depolarized potential.

- Other criteria may be used if the user can demonstrate their validity.

- Overprotection can occur if the instant-off potential for ferrous, lead, copper, and copper-alloy structures exceeds –1.2 V.

- AS/NZS 4352[118] describes testing to determine the coating resistance to cathodic disbonding.

## BRITISH

The 1991 edition of British Standard BS 7361,[119] “Cathodic protection, Part 1. Code of practice for land and marine applications,” presents CP in Section 2.3.2, Cathodic protection criteria. A summary of this standard is as follows:

- Cathodic protection is achieved by bringing metals to certain protection potentials. The protection potentials are listed in Table 1, and corrosion can occur in values more positive than these. These values are, for iron and steel, –850 mV CSE in aerobic conditions and –950 mV CSE in anaerobic conditions.

- Potentials can vary considerably over the surface of a metal, so it is important to ensure that the least negative metal soil potential is located when measurements are taken.

- Measurement of the potential difference between the metal surface and electrolyte can be affected by the potential drop that is produced by the protection current (IR drop). The values given in Table 1 might not provide full protection against corrosion, unless measurement methods to eliminate or reduce the effects of IR drop are undertaken. The instant-off potential method has gained acceptance as a method of minimizing IR drop error, although any technique that can be shown to reduce IR drop error may be used.

- Special considerations are discussed in Paragraphs 2.3.2.2 and 2.3.2.6 of BS 7361.

- A more negative potential is recommended for irons and steels that are installed in anaerobic conditions in which sulfate-reducing bacteria (SRB)s might be present.

- Hydrogen blistering and a loss of mechanical strength can occur in stainless steels that are polarized to excessively negative potentials. Stainless steels typically do not need protection in many environments, but in some cases, anodic protection is used.

- Crevice corrosion is common in stainless steel. Cathodic protection significantly reduces the occurrence or severity of crevice corrosion. It is important to note that stainless steel can become more susceptible to crevice corrosion if cathodic protection is administered for some time, and then is disconnected.

- Concrete-encased steel that is free from chlorides normally does not require cathodic protection, but if the steel is only partially encased, the protection potential depends on the part that is exposed to the soil or water.

- Aluminum is not normally included in cathodic protection systems, because it is susceptible to corrosion if the potential is too negative.

- Lead occasionally corrodes at very negative potentials in alkaline environments.

This standard is was withdrawn as of August 2, 2013, and replaced by BS EN 13635:2004 and BS EN 15112:2006 according to the BSI Web site. It is accepted that the criteria in ISO 15589-1/EN 14919-1[120] and EN 12954 are more precise, up to date, and more appropriate than those in BS 7361. The European standards are known as BS EN in Britain and are published as such by BSI.

## CANADIAN

The applicable Canadian standard is Recommended Practice for the Control of External Corrosion on Buried or Submerged Metallic Piping Systems, OCC-1,[121] published by the Canadian Gas Association. Appendix B addresses the criteria for CP. A summary of this appendix is as follows:

- For steel and cast or ductile iron piping, the negative polarized (instant off) potential shall be at least 850 mV CSE. The on-potential should be at least negative 850 mV CSE, but should account for voltage (IR) drop and a number of factors to consider are listed. The other criterion is a minimum of 100 mV of cathodic polarization between the structure and a reference electrode that contains the electrolyte as it is measured by the formation or decay of polarization.

- For copper and aluminum piping, the 100 mV cathodic polarization criterion applies. However, polarized potentials that are more negative than –1,200 mV can result in corrosion for aluminum piping.

- Dissimilar metal piping requires that the polarized potential be maintained on all surfaces of the structure based on the protection requirements for the most anodic metal.

- The presence of SRBs, elevated temperatures, acidic environments, and dissimilar metals can cause the first criterion (the polarized [instant off] potential shall be at least negative 850 mV CSE) and second criterion (the on-potential should be at least negative 850 mV CSE, but should account for voltage [IR] drop) to be insufficiently electronegative.
- Concrete, dry, or aerated soils are environmental conditions in which it might be acceptable for the values to be more electropositive.

- Stray current and stray electrical gradient situations require that different criteria be used than those mentioned in Appendix B of OCC-1.

- Operators should account for voltage (IR) drop between the structure and reference electrode, IR drop in the pipe steel and the lead wire (during close-interval potential surveys), presence of dissimilar metals, influence of risers, stray and telluric current, and proximity to anodes when they interpret potential measurements in relation to the criteria mentioned in Appendix B of OCC-1.

- Aluminum and other amphoteric materials can be damaged by high alkalinity created by cathodic protection. They should be electrically isolated and separately protected.

- Saturated copper-copper sulfate reference electrodes can be substituted by other saturated reference electrodes, provided that the voltage equivalent can be established and its stability can be ensured.

## EUROPEAN

ISO 15589-1, titled “Petroleum and natural gas industries - Cathodic protection for pipeline transportation systems—Part 1: On-land pipelines,” is now also EN 14919-1 (with minor modifications that do not affect the summary of criteria given under the “International” heading). It is applicable to petroleum and natural gas pipelines in all European countries. There is an initiative within CEN and ISO to consolidate EN 14919-1 and EN 12954 into a single common document for all pipelines.

EN 12954: 2001 was prepared by CEN TC 219 WG1 and is applicable to all pipeline categories (including petroleum and natural gas) in all European countries. A summary of this standard is as follows:

- The criterion for cathodic protection is $E \le E_p$, where $E_p$ is the metal-to-electrolyte potential at which the corrosion rate is < 0.001 mm/y (0.04 mpy).

- In the case of metals that are subject to corrosion damage at very negative potentials, the criterion for cathodic protection is $E_l \le E \le E_p$, in which the potential shall not be more negative than a limiting critical potential ($E_l$).

- Table 1 of EN 12954 lists the protection potentials of the most common metals.

- The protection criteria are identical to those in ISO 15589-1/EN 14919-1 and all potential criteria are defined as IR free.

## GERMAN

A translation of the German Standard DIN 30 676[122] of October 1985, titled "Design and application of cathodic protection of external surfaces," discusses CP criteria in Sections 3 and 4. A summary of these sections is as follows:

- The criterion for cathodic protection is $U \le U_s$, where $U$ is the potential of the material, and $U_s$ is the protective potential.

- In some cases, corrosion damage occurs in materials at very negative potentials. In these cases, the potential range is limited by a threshold potential, $U'_s$, and the criterion for protection is as follows: $U'_s \le U \le U_s$.

- The protective potentials for the most commonly used materials are shown in Table 1 of DIN 30 676.

- More criteria related to relative potential changes is available in the Handbuch des kathodischen Korrosionsschutzes (Cathodic Protection Handbook).[123]

- It is difficult to distinguish between anaerobic and aerobic soils, and because of this, the standard recommends trying to use a protective potential of –0.95 V when laying new pipelines.

- Thin coatings can be affected by blistering. In order to minimize this problem, DIN 50 928[124] states that the protective potential range should be limited as the function of the coating.

- DIN 50 918[125] describes prerequisites for applying potential criterion. Voltage drop can affect potential measurements. Voltage drop can be caused by cathodic protection currents, cell currents, stray currents (from DC systems), or equalizing currents that flow between different parts of the surface that have different polarities after the current has been switched off.

- Additional protection potentials can be found in DIN 50 927.[126]

- DIN VDE 0150[127] describes the methods of measurement of a structure-to-electrolyte potential.

It is understood that all of these DIN standards have now been withdrawn and replaced with the ENs discussed in the European section.

## INTERNATIONAL ORGANIZATION FOR STANDARDIZATION (ISO)

An International Standard, ISO 15589-1, titled "Petroleum and natural gas industries - Cathodic protection for pipeline transportation systems—Part 1: On-land pipelines," was first published in 2003. It has been prepared by ISO/TC 67/SC 2/WG 11, which is the working group devoted to CP for pipelines used in the oil and gas industry. The following is a summary of Sections 5.3.2, Protection criteria, and 5.3.3, Measurements of protection potentials. Although it is only specifically stated in the standard that reference potentials are in respect of the –850 mV CSE protection criterion, it is clear that the intent of the ISO standard is that all referenced potentials are IR free.

- In CP systems, all parts of buried pipelines should have polarized potentials more negative than –850 mV CSE. These potentials exist at the metal-to-electrolyte interface, such as the polarized potentials. Polarized potentials are defined in 3.15 and are synonymous with IR-free potential, as well as being structure-to-electrolyte potentials measured without the voltage error caused by IR drop from protection current or any other current.

- The critical potential should not be more negative than –1,200 mV CSE to avoid detrimental effects at the metal surface.

- Stainless steel and other corrosion-resistant alloys typically need to have a potential value that is more positive than –850 mV CSE, but for most practical applications, –850 mV CSE can be used.

- For pipelines in anaerobic soils in which there are significant quantities of SRBs, the potential should be more negative than –950 mV CSE.

- For pipelines in high-resistivity soils, a protection potential that is more positive than –850 mV CSE may be considered.

- A minimum of 100 mV cathodic polarization between the surface of a pipeline and the reference electrode in contact with the electrolyte may be considered as an alternative to the protection potentials mentioned above. The method of determination is defined.

- Use of the 100 mV criterion shall be avoided on pipelines that operate at high temperatures, consist of or are connected to mixed-metal components, are in soils that contain SRBs, or with interference, equalizing, and telluric currents.

- In some cases, pipelines can be afflicted with high pH SCC in the IR free potential range –650 mV to –750 mV. When protective potentials more positive than –850 mV CSE are used, this shall be taken into consideration.

- When the pipeline is electrically continuous and contains components from metals more noble than carbon steel, care should be exercised in the consideration of the protection criteria.

- Pipelines that operate above 40 °C (104 °F) might not be adequately protected by the above values. In these cases, alterative criteria may be used.

- Other reference electrodes may be used for the various criteria, provided that they have reliable properties and can be documented.

- The measurement techniques are defined.

## JAPANESE

Three documents from Japan were reviewed, and the information regarding CP criteria was translated:

(1) Japan Water Pipeline Association, WSP 050-95,[128] Section 5-1 (1), states that cathodic protection potential shall be at least –850 mV CSE.

(2) High Pressure Institute of Japan, HPIS G105-1989,[129] Section 4.5.2, states that cathodic protection potential shall be at least –850 mV CSE. The criterion for using a saturated calomel electrode is –0.77 V, and the potential for using a zinc electrode is –0.25 V.

(3) Japan Fire Bureau Regulations, Detailed Technical Criteria for Hazardous Materials, dated May 31, 2000,[130] states that cathodic protection potential shall be at least –850 mV CSE. –0.77 V is the criterion for using a saturated calomel electrode, and the piping may be affected by stray current, so that current drainage points shall be established.

## RUSSIAN

The National Standard of the Russian Federation, GOST 51164-98,[131] is titled “Main Steel Pipelines, General Requirements for Protection Against Corrosion.” CP criteria are addressed in Section 5, Requirements for Electrolytic Protection. A summary of this section is as follows:

- For soils with (a) specific resistance ≥ 10 Ω•m, (b) water soluble salts content ≤ 1 g for 1 kg soil, or (c) if the transported product is < 293 K (20 °C [68 °F]), the minimal protective potential relative to saturated Cu/$CuSO_4$ reference electrode is –0.85 V (polarization only), or –0.90 V (with ohmic component).

- Tables 4 and 5 in GOST 51164 show the minimal protective potential relative to saturated Cu/$CuSO_4$ reference electrode for pipelines in other conditions.

- Polarization potentials with no ohmic components shall only be provided for new pipelines and rehabilitated pipelines.

Russia is an active member of ISO, and ISO 15589-1 may be increasingly used.

## UNITED STATES OF AMERICA

Cathodic protection requirements for natural gas pipelines are contained in 49 CFR Part 192,[132] Appendix D, as follows:

- Criteria for cathodic protection of steel, cast-iron, and ductile-iron structures:

  (a) a negative (cathodic) voltage of at least –0.85 volt with reference to a saturated copper-copper sulfate half-cell. Protective current is applied in accordance with the sections on “Interpretation of Voltage Measurement” and “Reference Half Cells” of Appendix D of 49 CFR Part 192, which are summarized below:

  (b) a negative (cathodic) polarization voltage shift of 100 mV, which is determined in accordance with the sections on “Determination of Polarization Voltage Shift” and “Reference Half Cells” of Appendix D of 49 CFR Part 192, which are summarized below;

  (c) a voltage that is at least as negative (cathodic) as that which was established at the beginning of the Tafel segment of the E-log-I curve, and this voltage shall be measured in accordance with the sections on “Determination of Polarization Voltage Shift” and “Reference Half Cells” of Appendix D of 49 CFR Part 192, which are summarized below;

  (d) a minimum negative (cathodic) voltage shift of 300 mV, which is produced by the application of protective current, and the voltage shift must be determined in accordance with the sections on “Interpretation of Voltage Measurement” and “Reference Half Cells” of Appendix D of 49 CFR Part 192, which are summarized below. This criterion of voltage shift applies to structures that are not in contact with metals that have different anodic potentials;

  (e) a net protective current from the electrolyte into the structure that is measured by an earth current technique. This is applied at predetermined current discharge points (anodic) of the structure.

- Criteria for cathodic protection of aluminum structures:

  (a) A minimum negative (cathodic) voltage shift of 150 mV, which is produced by the application of protective current, and the voltage shift must be determined in accordance with the sections on “Interpretation of Voltage Measurement” and “Reference Half Cells” of Appendix D of 49 CFR Part 192, which are summarized below. The exceptions to (a) are provided in subpoints (c) and (d);

  (b) A minimum negative (cathodic) voltage shift of 100 mV, which must be determined in accordance with Sections III and IV of Appendix D of 49 CFR Part 192. The exceptions to (b) are provided in subpoints (c) and (d);

  (c) Notwithstanding the alternative minimum criteria listed in subpoints (a) and (b), if aluminum is cathodically protected at voltages greater than 1.20 V as measured with reference to a copper-copper sulfate half-cell (in accordance the section on “Reference Half Cells” of Appendix D of 49 CFR Part 192, which is summarized below) and is compensated for voltage drops other than those across the structure-to-electrolyte boundary, it may experience corrosion that results from the build-up of alkali on the metal surface. Unless previous test results indicate that no appreciable corrosion will occur in the particular environment, voltage greater than 1.20 V may not be used;

  (d) Careful investigation/testing must be made before CP is applied to stop pitting attacks on aluminum structures in environments with a natural pH greater than 8 because aluminum may suffer from corrosion under high-pH conditions and because application of CP has a tendency to increase the pH at the metal surface.

- Criteria for cathodic protection of copper structures:

  (a) a minimum negative (cathodic) polarization voltage shift of 100 mV, which is determined in accordance with the sections on “Determination of Polarization Voltage Shift” and “Reference Half Cells” of Appendix D of 49 CFR Part 192, which are summarized below;

- Criteria for cathodic protection of metals with different anodic potentials:

(a) A negative (cathodic) voltage that is equal to that which is required for the most anodic metal in the system must be maintained. The negative (cathodic) voltage must be measured in accordance with the section on "Reference Half Cells" of Appendix D of 49 CFR Part 192, which is summarized below;

(b) Amphoteric structures that could be damaged by high alkalinity (see subpoints (b) and (c) under the section "Criteria for Cathodic Protection of Aluminum Structures") must be electrically isolated with insulating flanges or the equivalent.

- Interpretation of voltage measurement in 49 CFR Part 192, Appendix D is as follows:

(a) Voltage (IR) drops other than those across the structure electrolyte boundary must be considered for valid interpretation of the voltage measurement, according to subpoints (a) and (b) of the section on "Criteria for Cathodic Protection of Steel, Cast-Iron, and Ductile-Iron Structures," and subpoint (a) of the section on "Criteria for Cathodic Protection of Aluminum Structures."

- Determination of polarization voltage shift in 49 CFR Part 192, Appendix D is as follows:

(a) The polarization voltage shift must be determined by interrupting the protective current and measuring the polarization decay. When the current is initially interrupted, an immediate voltage shift occurs, and the voltage reading after the immediate shift must be used as the base reading from which to measure polarization decay, as specified in subpoint (c) of the section on "Criteria for Cathodic Protection of Steel, Cast-Iron, and Ductile-Iron Structures," subpoint (b) of the section on "Criteria for Cathodic Protection of Aluminum Structures," and the section on "Criteria for the Cathodic Protection of Copper Structures."

- The following section covers reference half-cells:

(a) Except as provided in the section on "Criteria for Cathodic Protection of Aluminum Structures," and the section on "Criteria for the Cathodic Protection of Copper Structures," negative (cathodic) voltage must be measured between the structure surface and a saturated copper-copper sulfate half-cell that are in contact with the electrolyte;

(b) Other standard reference half-cells can be substituted for the saturated copper-copper sulfate half-cell, and two commonly used reference half-cells are as follow, as well as their voltage equivalents:

(i) Saturated KC1 calomel half-cell: –0.78 V;

(ii) Silver-silver chloride half-cell used in seawater: –0.80 V.

(c) An alternate metallic material or structure may be used, in addition to the standard reference half-cells. The alternate metallic material or structure may be used if its potential stability is assured as well as if its voltage equivalent referred to a saturated copper-copper sulfate half-cell is established.

- Cathodic protection requirements for hazardous liquid pipelines are contained in 49 CFR Part 195,[133] Subpart H, as follows:

(a) Cathodic protection must comply with one or more applicable criteria and other considerations for CP that are contained in NACE Standard RP0169 (2002 edition), "Control of External Corrosion on Underground or Submerged Metallic Piping Systems," Paragraphs 6.2 and 6.3.

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